Geology and Coal Resources of the Cedar Mountain Quadrangle, Iron County Utah

GEOLOGICAL SURVEY PROFESSIONAL PAPER 389

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By PAUL AVERITT

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A study of the Hurricane Cliffs and the Kolob Terrace in the southern part of the historic Cedar City coal field

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GEOLOGY AND COAL RESOURCES OF THE CEDAR MOUNTAIN QUADRANGLE, IRON COUNTY, UTAH

By Paul Averitt

ABSTRACT

The Cedar Mountain quadrangle lies in southeastern Iron County, Utah, a few miles south of Cedar City. It covers the southern half of the Cedar City coal field, which lies on the western edge of the much larger Kolob coal field. The Hurricane fault zone, one of the most pronounced structural features of southwestern Utah, crosses the northwest corner of the quadrangle, and is responsible for the 3,000-foot Hurricane Cliffs, which divide the quadrangle into three physiographic units: the topographically low Great Basin to the northwest, the precipitous Hurricane Cliffs, and the topographically high Kolob Terrace to the southeast.

The rocks exposed in the Hurricane Cliffs range from the Moenkopi formation of Early and Middle(?) Triassic age to the Straight Cliffs and Wahweap sandstones of Late Cretaceous age. These beds dip generally eastward at angles ranging from vertical to overturned near the base of the Hurricane Cliffs, to about 6° a few miles east of the Cliffs. This structure represents the east half of an ancestral anticline, termed the "Kanarra fold," which was broken and displaced longitudinally near the fold axis by the younger Hurricane fault.

The coal in the Cedar Mountain quadrangle is exposed near the crest of the Hurricane Cliffs in the Tropic formation and Straight Cliffs sandstone. The thickest and best beds are at the top of the Tropic formation in a coal and shale sequence termed the "Upper Culver coal zone." Minable beds containing as much as 7 feet of coal occur in this zone. The estimated remaining reserves in the quadrangle in beds containing 72 inches or more of coal total 229 million tons. Additional reserves are present in thinner beds. The rank of the coal lies near the boundary between high volatile C bituminous and subbituminous A. The ash content ranges from about 5 to 17 percent, and the sulfur content from 4.4 to 7.3 percent.

The Kolob Terrace, which extends over the southeastern half of the quadrangle, is a broad rolling dissected upland, 9,000 to 10,000 feet above sea level, developed on gently dipping beds of Cretaceous age. The terrace is covered locally by basalt flows of Quaternary age, which, in turn, are surmounted by several cinder cones.

The terrace is now being dissected by headward-working tributaries of the North Fork of the Virgin River, which drain southward to the Colorado River, and by many small streams, which drain westward into the Great Basin. As a consequence of lying on a major divide between the Colorado River and Great Basin drainage, the part of the Kolob Terrace in the Cedar Mountain quadrangle, and the region just to the east, contain preserved remnants of an ancient gravel-covered pediment and abandoned stream-channel deposits on ridges as evidence of earlier erosion cycles.

INTRODUCTION

LOCATION OF AREA

The Cedar Mountain quadrangle lies on the west edge of the Kolob coal field in southern Iron County, Utah (figs. 1, 2). The quadrangle covers an area of 58 square miles between lat 37°30′00″ and 37°37′30″ N., and long 113°00′00″ and 113°07′30″ W. Cedar City, a town of about 6,000 inhabitants and the largest in Iron County, is 5 miles north of the quadrangle. Kanarraville, a small settlement of 300 inhabitants, is about 5 miles west of the quadrangle.

PURPOSE AND SCOPE OF PRESENT WORK

The Cedar City coal field is about 250 miles by railroad from Hoover Dam and 575 miles from Los Angeles. As the nearest coal field to these major power-producing and power-consuming centers, the Cedar City field has been the subject of persistent interest for many years. The fieldwork on which this report is based was undertaken primarily to obtain data on the coal resources as they relate to the future development of the Pacific Southwest, and secondarily to contribute to a study of Utah coal reserves being undertaken by the Geological Survey as part of a program to estimate the coal reserves of the United States. The greater part of the fieldwork was done in 3 periods, ranging from 2 to 3 months each during the summers of 1952, 1954, and 1955.

PREVIOUS WORK

Systematic investigations of the geology and mineral resources of southwestern Utah began in 1872, results of which are recorded in the classic reports of Howell (1875), Gilbert (1875), and Dutton (1880, 1882). The first attempt to appraise the thickness, distribution, and quality of the coal in the Cedar City field was started by Lee (1907) and amplified by Richardson (1909). The structure and geologic history of the Hurricane fault zone have been studied and described by Huntington and Goldthwait (1903, 1904) and later by Gardner (1941). The geology and water

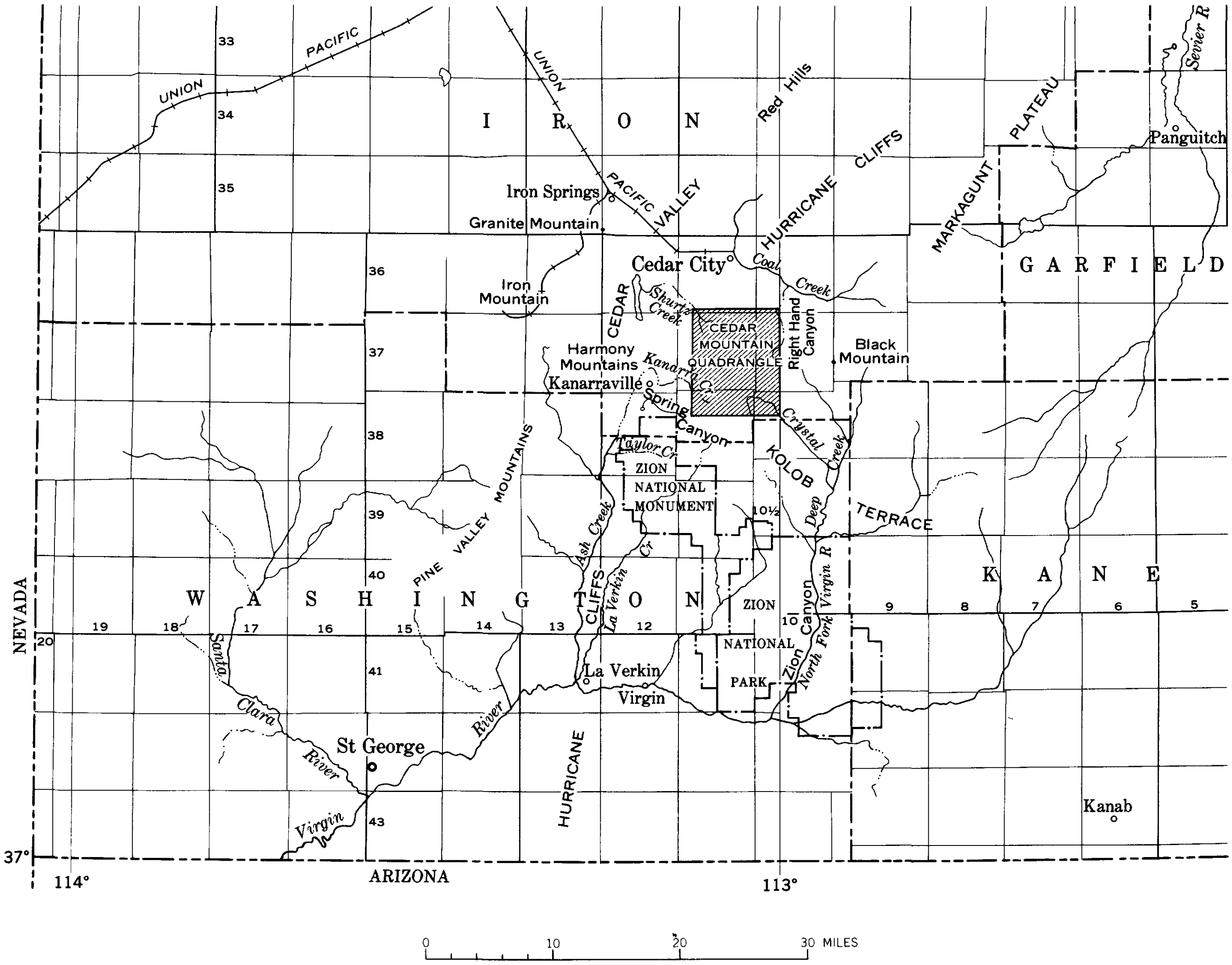

FIGURE 1.—Map of southwestern Utah showing location of southern Iron County and Washington County and the Cedar Mountain quadrangle.

resources of the Cedar City Valley, including the northwest corner of the Cedar Mountain quadrangle, have been described by Thomas and Taylor (1946). A reconnaissance map and report on the geology of eastern Iron County by Gregory (1950a) include the area covered by the present paper; his report presents a few additional details about the coal not contained in the earlier reports of Lee and Richardson. Studies of the stratigraphy and geology of surrounding areas are contained in reports by Gregory and Williams (1947), Mackin (1954), Pillmore (1956), Threet,[1] and others as listed in the bibliography.

[1] R. L. Threet, 1952, Geology of the Red Hills area, Iron County, Utah: Unpublished doctor of philosophy dissertion, Washington Univ. [Seattle].

ACKNOWLEDGMENTS

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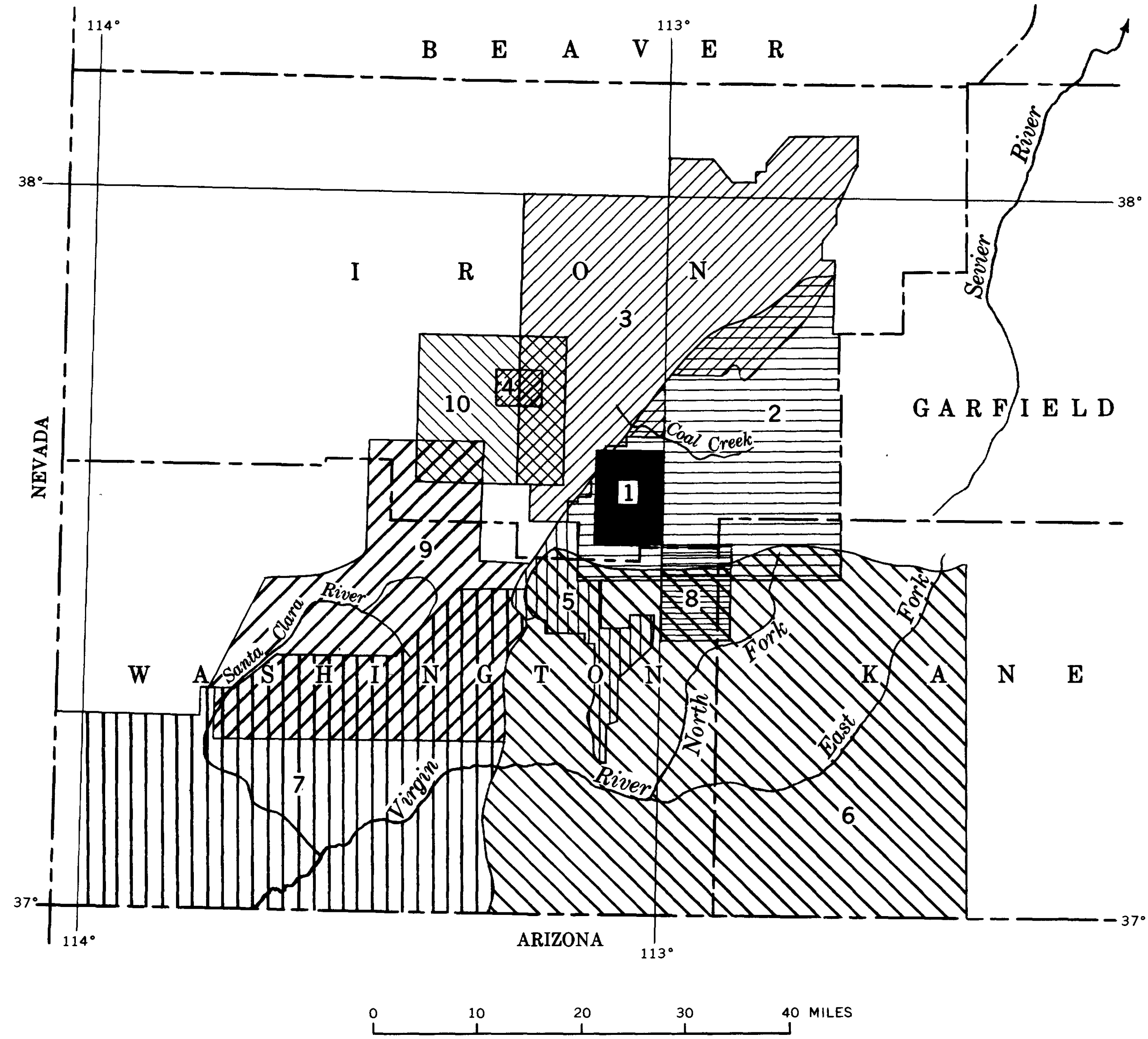
GEOGRAPHY

TOPOGRAPHY

The Hurricane Cliffs, a prominent escarpment 3,000 feet high, extends across the northwest corner of the Cedar Mountain quadrangle and divides it into two unequal parts. (See pl. 1.) The smaller area northwest of the Hurricane Cliffs is part of the relatively low Basin and Range province, which covers most of



EXPLANATION

1. This report
2. Utah Geol. Mineralog. Survey Bull. 37
3. U. S. Geol. Survey Water-Supply Paper 993
4. U.S. Geol. Survey Field Studies Map MF-14
5. Geol. Soc. America Bull., v. 58, no. 3
6. U.S. Geol. Survey Prof. Paper 220
7. Am. Assoc. Petroleum Geologists Bull., v. 23, no. 2
8. U. S. Geol. Survey Misc. Geol. Inv. Map I-188
9. Utah Geol. Mineralog. Survey Bull. 58
10. U.S. Geol. Survey Bull. 339

FIGURE 2.—Index map of southwestern Utah showing location of the Cedar Mountain quadrangle and adjoining areas covered by geologic reports.

western Utah and areas to the west and south. The larger upland area southeast of the Cliffs, known generally as Cedar Mountain, is part of the Kolob Terrace, which, in turn, is part of the High Plateaus of central Utah.

The land surface at the base of the Hurricane Cliffs is between 5,800 and 6,200 feet above sea level, whereas the upland surface on Cedar Mountain is 9,000 to 10,000 feet above sea level. The maximum relief in the quadrangle is 4,415 feet as measured between the low point of 5,720 feet in the northwest corner of the quadrangle and the high point of 10,135 feet on top of the knoll in sec. 26, T. 37 S., R. 11 W.

DRAINAGE AND WATER SUPPLY

The upland areas in the Cedar Mountain quadrangle form part of the major divide between the Great Basin and Colorado River drainage. Urie Creek, which flows north along the west edge of the quadrangle through Right Hand Canyon, and Shurtz Creek, which flows west from the center of the quadrangle, both discharge into the Cedar City Valley, a closed basin without exterior drainage. Crystal Creek, which heads in the southeast corner of the quadrangle and flows to the southeast, joins the North Fork of the Virgin River above Zion Canyon. Kanarra Creek and Willow Creek, which head in the southwest corner of the quadrangle, flow generally southwest and south into Ash Creek and La Verkin Creek, respectively, and join the Virgin River near the town of La Verkin, about 20 miles west of Zion Canyon.

Except in the uppermost reaches, all these streams are perennial, but they are both narrow and shallow, particularly during the late summer months when the winter accumulation of snow has melted.

The water impounded in the small reservoir in Meadow Hollow, sec. 16, T. 38 S., R. 11 W., is diverted from its normal course down Willow Creek by way of a ditch just south of the quadrangle to the head of Spring Canyon, and thus ultimately reaches the Kanarraville area.

The town of Cedar City depends in part on springs in Shurtz Creek and in Right Hand Canyon for its domestic water supply, and an extensive network of pipes lead from gathering points in these canyons to storage tanks on the outskirts of town. The trunkline of this collecting system in Shurtz Creek is shown on plate 1.

ACCESSIBILITY AND ROUTES OF TRAVEL

U.S. Highway 91, a main route of travel between Salt Lake City, Las Vegas, and Los Angeles, passes through Cedar City and Kanarraville, only a few miles west of the Cedar Mountain quadrangle. State Highway 14, a modern surfaced road that connects U.S. 91 at Cedar City with U.S. 89 at Long Valley Junction, follows the valley of Coal Creek about 3 miles north of the quadrangle. From these highways several good graded dirt roads lead into the quadrangle.

The most frequently traveled of these roads leaves State Highway 14 about 4 miles east of Cedar City and extends up the valley of Right Hand Canyon. One fork from this road winds up the west slopes of Right Hand Canyon and the north and west slopes of Lone Tree Mountain and enters the Cedar Mountain quadrangle from the north. This is the preferred route to the top of Cedar Mountain. Another fork extends up the valley of Right Hand Canyon to the Tucker coal mine in the extreme northeast corner of the quadrangle.

An older road leaves U.S. 91 about 1 mile south of Cedar City, follows a steep winding course in Green Hollow, and joins the above-mentioned road from Right Hand Canyon just before it enters the quadrangle.

Another frequently traveled road turns off U.S. 91 about 4 miles south of Cedar City and enters the quadrangle in the northwest corner.

These roads and their extensions and connections on Cedar and Kanarra Mountains, as shown on plate 1, provide access to most of the upland areas in the quadrangle and to other points to the east and south on the Kolob Terrace. The road leading south from sec. 18, T. 38 S., R. 10 W., continues through Zion National Monument to Virgin, Utah, but is used very little for through travel.

The main line of the Union Pacific Railroad passes about 30 miles west of Cedar City, and a spur line from Lund, Utah, to Cedar City provides a direct rail connection to Salt Lake City and to Los Angeles. Cedar City also supports a modern airport, and is a regularly scheduled stop on a route served by Bonanza Air Lines.

STRATIGRAPHY

The sedimentary rocks exposed in the Cedar Mountain quadrangle form a 7,000- to 9,000-foot sequence ranging from the Moenkopi formation of Early and Middle(?) Triassic age, to the Straight Cliffs and Wahweap sandstones of Late Cretaceous age. The beds of Cretaceous age are overlain in turn by basalt flows and volcanic ash of late Tertiary and Quaternary ages. The older beds, which are exposed near the base of the Hurricane Cliffs, crop out as conspicuous ledges and slopes in various characteristic shades of red and brown. The younger beds of Cretaceous age, which are exposed near the top of the Hurricane Cliffs and form the broad eastward-sloping upper surface of Cedar Mountain, are a more uniform olive drab, and stand in marked contrast to the brightly colored underlying beds.

Viewed as a whole, the sequence consists largely of alternating beds of sandstone, siltstone, and shale, intercalated with a few conspicuous beds of limestone and gypsum. The limestone beds, in particular, are continuous over wide areas in southwestern Utah and are important stratigraphic markers.

In general, the beds form an uninterrupted sedimentary sequence, but several minor disconformities are present, one of which at the base of the Moenave formation has stratigraphic significance throughout southwestern Utah and northern Arizona. The lithologic characteristics, succession, and thickness of the several formations exposed in the quadrangle are summarized in table 1 and discussed in greater detail in subsequent paragraphs.

TABLE 1.—*Generalized section of rocks exposed in the Cedar Mountain quadrangle, Iron County, Utah.*

System	Series	Group	Formation and member		Thickness (feet)	Lithologic characteristics
Cretaceous	Upper Cretaceous		Straight Cliffs and Wahweap sandstones		1,590±	Sandstone, fine-grained, massive; in beds 5 to 40 ft thick; and siltstone. Contains 4 or 5 layers of oyster shells. Forms cliffs. Grades upward to nonresistant shale and siltstone, which form upper surface of Kolob Terrace.
			Tropic formation		1,070±	Shale, light- to dark-gray, 80 percent; and 20 percent pale yellowish-orange, fine- to medium-grained sandstone in beds 1 to 5 ft thick. Contains several coal beds. Local conglomerate at base. Top is marked by the Upper Culver coal zone. Forms slope.
			Disconformity			
Jurassic	Upper Jurassic	San Rafael	Winsor formation		300–320	Sandstone, fine-grained, and mudstone; in beds typically 1 to 2 ft thick. Characterized by strong color banding in shades ranging from light gray to red brown. Forms slope.
			Curtis formation		130–140	Massive gypsum 100 ft thick at base overlain by 30 ft of limestone resembling the Carmel formation. Forms break in slope.
			Slight disconformity			
			Entrada formation		150–200	Sandstone, siltstone, and mudstone, red-brown; and conspicuous amounts of gypsum in thin beds as cement. Forms slope.
			Carmel formation		540–650	Limestone, light-gray, shaly, very thin bedded. Fossiliferous in central part. Crops out as two conspicuous ledges above slopes covered with small angular talus fragments.
			Disconformity			
Jurassic and Jurassic(?)		Glen Canyon	Navajo sandstone		1,700±	Sandstone, moderate reddish-orange, medium-grained. Crossbedded on massive scale. Crops out conspicuously as isolated blunt points.
Jurassic(?)			Kayenta formation	Cedar City tongue	425–800	Mudstone and silty mudstone, reddish-brown; and light-gray to moderate reddish-orange siltstone, in beds 1 to 5 ft thick. Forms strike valley.
				Shurtz sandstone tongue of Navajo sandstone	62–345	Sandstone, fine- to medium-grained, reddish-orange; like overlying Navajo sandstone, but somewhat more even bedded. Forms prominent ridge.
				Lower member	275–420	Mudstone and silty mudstone, reddish-brown; and light-gray to light-brown siltstone; in beds 1 to 5 ft thick. Forms slope.
Triassic(?)			Moenave formation	Springdale sandstone member	110±	Sandstone, pale reddish-brown to purplish, fine- to medium-grained, massive; some crossbedding. Forms ledge.
				Dinosaur Canyon sandstone member	400±	Siltstone and mudstone, red-brown. Base includes a 40-ft bed of red-brown siltstone. Uppermost beds are thinner bedded and include a few beds of light-gray siltstone.
			Disconformity			
Triassic	Upper Triassic		Chinle formation, restricted		255–360	Mudstone and siltstone, reddish-brown to grayish-red. Upper beds are characteristic purplish mudstone. Disconformity at top marked by 6-ft limy bed containing shale fragments.
				Shinarump member	40–60	Sandstone, greenish-gray, fine- to coarse-grained, crossbedded; locally conglomeratic. Forms ridge.
			Disconformity			
	Lower and Middle(?) Triassic		Moenkopi formation	Upper red member	515±	Siltstone and mudstone, red-brown, with beds of gray-white gypsum and resistant light-brown siltstone. Forms strike valley with Shnabkaib and middle red members.
				Shnabkaib member	320±	Siltstone and mudstone, light- to olive-gray; intercalated with beds of red-brown mudstone. Gradational with underlying and overlying units.
				Middle red member	370±	Siltstone and mudstone, red-brown, and a few beds of gray-white gypsum.
				Virgin limestone member	133±	Limestone, fine-grained to aphanitic, and silty shale. Fossiliferous. Less calcareous, more gypsiferous towards top. Forms conspicuous ridge.
				Disconformity		
				Lower red member	454±	Siltstone and mudstone, red-brown, with intercalated gypsum in wafer-thin layers.
				Timpoweap member	102±	Limestone and shaly limestone, yellowish, fossiliferous, resistant. Crops out at base of Hurricane Cliffs south of Shurtz Creek.

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TRIASSIC SYSTEM

MOENKOPI FORMATION

The Moenkopi formation of Early and Middle(?) Triassic age includes the oldest rocks exposed in the Cedar Mountain quadrangle. It crops out in a belt ½ to 1 mile wide along the base of the Hurricane Cliffs where the beds are folded and faulted, or steeply dipping.

The formation is made up of six distinctive members, which differ markedly in lithology, color, and resistance to erosion. These differences, which are summarized in table 1, give rise to the ridges and variegated slopes that characterize outcrops of the formation in the Cedar Mountain quadrangle.

A detailed account of the regional stratigraphy and history of the Moenkopi formation is contained in a report by McKee (1954).

As noted by McKee, the Moenkopi thickens from east to west across northern Arizona and southern Utah. The sediments were derived from the east and deposited in shallow waters on a westward-sloping flood plain. The Moenkopi formation is thus thicker and more diversified in southwestern Utah than it is in areas to the east. In the Cedar Mountain quadrangle it includes both marine units, represented by the Timpoweap and Virgin limestone members, and nonmarine units, represented by the mudstone and siltstone members.

The three lower members of the Moenkopi, which are based on pronounced lithologic differences, are shown separately on the geologic map (pl. 1), but the three upper members, which are based on color differences, are shown as a single unit because of the difficulty of establishing in the disturbed rocks mappable boundaries at the base and top of the dominantly white Shnabkaib member. The six members are discussed in greater detail under separate headings below.

TIMPOWEAP MEMBER

The Timpoweap member was first defined by Reeside and Bassler (1922, p. 60) and given the name "Rock Canyon" member. Gregory (1948, p. 225–226; 1950b, p. 54–60) later redefined the unit and assigned the name Timpoweap, which has now become firmly fixed in the geologic literature. In areas south of the Cedar Mountain quadrangle, where the full thickness of the Timpoweap is exposed, it consists of a variable and erratic sequence of conglomerate, limestone, and shale that is 0 to 450 feet thick (Gregory, 1950a, p. 31–33; Gregory and Williams, 1947, p. 224–226). In the Cedar Mountain quadrangle the upper part of the member crops out in valley bottoms at the base of the Hurricane Cliffs, but the lower part is below drainage.

The best exposure of the member is about 0.3 of a mile southwest of Shurtz Creek where the visible upper part of the member is 102 feet thick. At this locality the Timpoweap dips uniformly eastward toward the Hurricane Cliffs, whereas farther south the member is folded and broken by minor faults subsidiary to the Hurricane fault zone. At the locality south of Shurtz Creek the Timpoweap member consists of a basal fossiliferous limestone unit 15 feet thick, overlain by a sequence of yellowish calcareous shale and thin fossiliferous limestone beds 87 feet thick. A section measured at this locality is given below:

Section of Timpoweap member in SW¼ sec. 9, T. 37 S., R. 11 W., 0.3 of a mile southwest of Shurtz Creek

	Feet
Triassic:	
Lower red member of Moenkopi formation.	
Timpoweap member of Moenkopi formation:	
1. Limestone, fossiliferous; in beds 2 to 6 in. thick; and gray shale. Forms bench. Weathered slopes have a brown tinge, derived by commingling of shale fragments from beds in overlying lower red member	16
2. Shale, calcareous, thin-bedded, gray. Contains a few 2- to 3-in. beds of dark-gray fossilferous limestone. Has superficial brown color on weathered slopes like unit 1	11
3. Mostly concealed, presumably gray shale. Has superficial brown color like units 1 and 2. Radioactivity 1½ times background	16
4. Limestone, thin-bedded, shaly, fossiliferous. Weathers yellow. Forms cliff	22
5. Concealed. Yellowish weathered slopes covered with rubble of thin-bedded shaly limestone. Basal part radioactive, 1½ times background	22
6. Limestone, fossiliferous, finely crystalline, yellowish-gray; in beds 1 to 3 ft thick. Conspicuously veined with calcite. Weathers to irregular rubble	15
Total, exposed thickness	102
Base concealed by fault.	

The limestone at the base of the member resembles the underlying Kaibab limestone in appearance, and the distinction between the two is based on differences in age as determined by fossils. Fossils in the Kaibab limestone, which is exposed a few miles south of the Cedar Mountain quadrangle, are clearly of Permian age, whereas those in the Timpoweap are clearly of Triassic age. Lists of representative species in the two units are given in a report by Gregory (1950b, p. 54, 63).

LOWER RED MEMBER

The lower red member of the Moenkopi formation is a sequence of soft, reddish-brown silty shale and mudstone containing considerable gypsum in closely spaced wafer-thin layers, and a few beds of harder siltstone, ranging in thickness from a few inches to 5 feet. The siltstone beds are thicker and more numerous toward the top.

The member is soft and easily eroded. It crops out in a belt about 2 miles long in the northwest corner of the Cedar Mountain quadrangle, where it forms a conspicuous red slope beneath a protective cap of the resistant Virgin limestone member. Elsewhere in the quadrangle it is less readily observed.

Some of the layers are well bedded, particularly those near the base; others are structureless and crumbly; others are lumpy. Some beds show asymmetrical ripple marks, cross-laminations, sun cracks, and worm trails, indicative of the shallow-water origin of the member. Minor unconformities are present, both within the member, and at its upper contact with the Virgin member. At a point 0.3 of a mile southwest of Shurtz Creek the member is 454 feet thick, which is thicker than the maximum figure of 350 feet given in a previous report on the area (Gregory, 1950a, p. 31). A generalized measured section at this locality is given below:

Section of lower red member in the SW$\frac{1}{4}$ sec. 9, T. 37 S., R. 11 W., 0.3 of a mile southwest of Shurtz Creek

	Feet
Triassic:	
Virgin limestone member of Moenkopi formation.	
Lower red member of Moenkopi formation:	
1. Silty shale and mudstone, reddish-brown. Contains a few thin beds of siltstone and some gypsum in closely spaced, $\frac{1}{10}$- to $\frac{1}{4}$-in. layers	152
2. Silty shale and mudstone, reddish-brown. Contains siltstone in beds 1 to 2 ft thick, making up about 25 percent of unit. Some siltstone layers contorted. Gypsum not conspicuous	35
3. Silty shale and mudstone, reddish-brown. Contains a few thin beds of siltstone and much gypsum in closely spaced, $\frac{1}{10}$- to $\frac{1}{4}$-in. layers	83
4. Siltstone, reddish-brown, very thinly bedded; mud lump and cross-laminations in upper part	4
5. Silty shale and mudstone, reddish-brown. Like unit 3	125
6. Silty shale and mudstone, reddish-brown. Like unit 3	24
7. Shale, pale-brown (5*YR* 5/2).[1] Forms weathered slope	8
8. Siltstone, yellowish-orange (10*YR* 7/6), wavy-bedded; in layers $\frac{1}{4}$- to 3-in. thick	5
9. Shale, pale yellowish-brown on fresh surfaces (10*YR* 6/2), darker on weathered surfaces. Radioactivity $1\frac{1}{2}$ times background	18
Total, lower red member of Moenkopi formation	454
Timpoweap member of Moenkopi formation.	

[1] Goddard and others, 1948.

VIRGIN LIMESTONE MEMBER

The Virgin limestone member has received more study than other members of the Moenkopi formation, in part because of its conspicuous position throughout southern Utah as a resistant unit between the two markedly nonresistant lower and middle red members of the Moenkopi, and in part because of the abundant invertebrate fossils it contains (Poborski, 1954). The name comes from the town of Virgin in Washington County, Utah, where the unit was first described (Reeside and Bassler, 1922, p. 60).

In the Cedar Mountain quadrangle the Virgin member crops out in a belt parallel to the Hurricane fault zone for a distance of about 4 miles. North of Shurtz Creek it forms the unbroken caprock of a low anticline. South of Shurtz Creek this anticline is broken by a strike fault, and the Virgin member on the southeast flank has been uplifted to form a hogback ridge. Farther south the Virgin is in a tightly compressed zone of deformation and is vertical to overturned.

The Virgin limestone member consists of several resistant, ridge-forming units of very fine grained to aphanitic silty limestone that are interbedded with nonresistant silty shale or mudstone. The resistant units make up about half the total thickness of the member. At most outcrops two or three of the resistant units are visible, but the intervening softer beds are covered by talus. The best exposure of the full thickness of the Virgin member in the Cedar Mountain quadrangle is in the NW$\frac{1}{4}$ sec. 20, T. 37 S., R. 11 W., in a small gulch just below a sharp turn in the Kanarra Mountain road, where the member is 133 feet thick. The characteristic appearance of the formation is well displayed at this locality. (See fig. 3.)

A section measured at the locality is given below:

Section of the Virgin limestone member in NW$\frac{1}{4}$ sec. 20, T. 37 S., R. 11 W.

	Feet
Triassic:	
Middle red member of Moenkopi formation.	
Virgin limestone member of Moenkopi formation:	
1. Siltstone, very slightly calcareous; in beds 1 to 6 in. thick. Has 5 or 6 thin $\frac{1}{4}$-in. stringers of gypsum in upper part	8
2. Shale, silty, largely concealed	6
3. Siltstone, slightly calcareous	2
4. Shale and siltstone in $\frac{1}{4}$- to 2-in. layers. Upper surfaces of some beds ripple marked	16
5. Siltstone, thin-bedded, calcareous. Upper surface undulating	2
6. Shale, light brownish-gray (5*YR* 6/1) to brownish-gray (5*YR* 4/1). Contains 1- to 2-in. beds of siltstone. Partly concealed	9
7. Limestone, silty, thin-bedded	2
8. Shale, silty, light olive-gray (5*Y* 6/1)	2
9. Limestone, silty. More massive than unit 7	5

Triassic—Continued	
Virgin limestone member of Moenkopi formation—Con.	
10. Shale, light olive-gray (5*Y* 6/1)	2
11. Limestone, silty, resistant. With unit 9, forms pronounced outcrop	2
12. Shale, like unit 6; with 1- to 2-in. beds of siltstone and limestone, partly concealed	30
13. Limestone, silty, massive, grayish-yellow (5*Y* 7/3); in beds 1 to 3 ft thick	10
14. Limestone, massive, fossiliferous, fine-grained to aphanitic, blue-gray (5*B* 6/1); in beds 1 to 2 ft thick. Markedly more calcareous and less silty than unit 13. With unit 13, forms ridge	15
15. Limestone, generally thin-bedded; of intermediate resistance; in beds 6 in. to 1 ft thick	11
16. Silty shale and siltstone, gray	5
17. Limestone, finely crystalline to aphanitic; in beds 6 in. to 1 ft thick	6
Total, Virgin limestone member	133
Disconformity.	
Lower red member of Moenkopi formation.	

The Virgin limestone member rests disconformably on the lower red member and grades without break in sedimentation into the overlying middle red member. The disconformity at the base is best displayed in the east-central part of sec. 4, T. 37 S., R. 11 W., on a sharp bend in the North Fork of Shurtz Creek. Although somewhat disturbed by faulting, the exposures at this locality are excellent, and show a transition in the lower red member from the normal reddish-brown shale and mudstone to gray-green and pale-brown shale, on which there are minor undulations and local relief of about 6 inches.

FIGURE 3.—Virgin limestone member of the Moenkopi formation showing typical development of thin parallel resistant ledges. View looking north on the Kanarra Mountain road in NW¼ sec. 20, T. 37 S., R 11 W.

A feature of the Virgin member is the gradual decrease upward in calcium carbonate content. The lowermost resistant layers are fairly pure limestone; succeeding resistant layers become more silty and less calcareous, and the uppermost layer is only slightly calcareous and exhibits stringers of gypsum. The suggestion is strong that, following the deposition of the lowermost calcareous and fossiliferous layers, the seas gradually became shallower and more alkaline throughout deposition of the remaining layers.

In a recent detailed report on the Virgin member in the St. George area, Poborski (1954) recommends that it be changed in classification from a member of the Moenkopi formation to an independent formation. Although the Virgin is sufficiently distinctive and persistent to merit classification as a formation, the other members of the Moenkopi formation, except possibly the lower red member, are less well defined, and would not merit reclassification. As removal of the Virgin limestone member from the Moenkopi formation would require extensive changes in classification and nomenclature throughout the remainder of the Moenkopi—for which there is little justification or immediate need—it seems best to retain, in this report, the older familiar classification and unity.

MIDDLE RED, SHNABKAIB, AND UPPER RED MEMBERS

The three upper members of the Moenkopi formation are soft and readily eroded. Throughout most of the area of their occurrence in the Cedar Mountain quadrangle they form a strike valley between the underlying steeply dipping Virgin limestone member and the overlying Shinarump member of the Chinle formation. In the southern part of the quadrangle, particularly along the Kanarra Mountain road, the three upper members of the Moenkopi are overturned and contorted as a result of subsequent movements on the Hurricane fault zone. The folding at this locality is shown in figure 4. It is likely that in this area the upper members are also broken by several small strike faults. A few miles farther north where the beds cross Shurtz Creek they are largely concealed by outwash material. As the three members are contorted and poorly exposed, and as their boundaries are based primarily on a change in color, which is entirely

FIGURE 4.—Folded and contorted beds in upper part of the Moenkopi formation. View looking north on the Kanarra Mountain road in NW¼ sec. 20, T. 37 S., R. 11 W.

gradational, it was not practicable to show them separately on the geologic map (pl. 1). The three members are relatively undisturbed and partly exposed at one locality in the quadrangle, in sec. 3, T. 37 S., R. 11 W. Measurements made at this locality, supplemented by partial measurements in Shurtz Creek, show the following thicknesses:

Member	*Thickness* (feet)
Upper red	515
Shnabkaib	320
Middle red	370
Total	1, 205

The figure of 320 feet for the Shnabkaib checks closely with the thickness of 310 feet in Coal Creek, 4 miles to the north, as recorded by Gregory (1950a, p. 81); but the figures of 370 and 515 feet, respectively, for the middle and upper red members are significantly higher than the figures of 125 and 300 feet, also recorded in Coal Creek by Gregory. When this difference was noted, the section in Coal Creek was examined to see if a reason were apparent. Although the section in Coal Creek is somewhat faulted and distorted, there is no question but that the middle and upper red members are relatively thin in Coal Creek as compared to the section in the Cedar Mountain quadrangle. The difference is fairly well distributed throughout the middle and upper red members, and certainly cannot be attributed in any large part to pre-Shinarump erosion.

The middle and upper red members of the Moenkopi closely resemble the lower red member in lithology and color. Both are composed largely of reddish-brown mudstone and siltstone with thin stringers of gypsum. The middle red member differs from the lower red member in containing a few grayish-white beds of gypsum, 1 to 8 feet thick, particularly near the base and top; the upper red member differs from the lower and middle red members in containing both grayish-white beds of gypsum and several beds of light-brown (5*YR* 6/4) siltstone. Locally the siltstone beds are very resistant.

The Shnabkaib member is largely light gray or white in general appearance, and forms a conspicuous band between the middle and upper red members. It is composed of light-gray to olive-gray gypsiferous mudstone and siltstone, and a few beds and stringers of relatively pure gypsum. It also contains a few beds of reddish-brown mudstone, which may be as much as 30 feet thick. The Shnabkaib is gradational with the two enclosing red members, and its boundaries usually are drawn at places where the color change seems most pronounced. It is unlikely that the same boundaries would be chosen at all localities because light- and dark-colored beds are fairly evenly distributed in the zones where the boundaries must be placed.

A stratigraphic section of the three upper members of the Moenkopi is given below:

Section of the middle red, Shnabkaib, and upper red members of the Moenkopi formation in sec. 3, T. 37 S., R. 11 W.

	Feet
Triassic:	
Shinarump member of the Chinle formation.	
Disconformity.	
Upper red member of the Moenkopi formation:	
1. Mudstone, alternating grayish-red (10*R* 4/2) and medium light-gray (*N* 6); in thin to medium beds	75
2. Siltstone and mudstone in about equal proportions; reddish-brown; in beds 2 to 6 ft thick	180
3. Sandstone, fine-grained, massive; in beds 5 to 10 ft thick. Lower 20 ft white, upper 20 ft reddish-brown. Forms cliff. Thickness estimated	40
4. Mudstone and siltstone, gypsiferous; largely reddish-brown, but light-gray beds common	220
Total, upper red member	515
Shnabkaib member of the Moenkopi formation:	
5. Mudstone and siltstone, very gypsiferous, light-gray to olive-gray	32
6. Mudstone and siltstone, gypsiferous, reddish-brown	30
7. Mudstone and siltstone, very gypsiferous; all light gray to olive gray except for 1 or 2 reddish-brown layers 2 ft thick	138
8. Mudstone and siltstone, reddish-brown, gypsiferous	18
9. Mudstone and siltstone, very gypsiferous; all light gray to olive gray except for several reddish-brown layers 1 to 5 ft thick	102
Total, Shnabkaib member	320

Moenkopi formation—Continued

	Feet
Middle red member of the Moenkopi formation:	
10. Mudstone and siltstone, gypsiferous, reddish-brown. Contains a few 1-in. to 4-ft layers of light-gray mudstone and gypsum	332
11. Very gypsiferous layer, light-gray. Forms bench	8
12. Mudstone, reddish-brown; heavily interbedded with wafer-thin gypsum; also gypsum in diagonal joints	11
13. Siltstone, light-gray, slightly gypsiferous; in beds 1 to 4 in. thick	7
14. Silty mudstone, reddish-brown. Radioactivity 1½ times background, locally 2 times background	12
Total, middle red member	370
Virgin limestone member of the Moenkopi formation.	

CHINLE FORMATION OF PREVIOUS REPORTS

As originally mapped by Thomas and Taylor (1946, p. 22) and by Gregory (1950a, p. 34–36), the Chinle formation in eastern Iron County included the sequence of rocks between the top of the Shinarump conglomerate and the base of the Navajo sandstone. This sequence, about 1,900 feet thick in the Cedar Mountain quadrangle, is composed of siltstone, sandstone, and mudstone in alternating layers, ranging from reddish-brown to white, but with the overall striking reddish-brown color so typical of rocks of Late Triassic age throughout the Colorado Plateau. The most conspicuous bed in the sequence is the Springdale sandstone member (Gregory, 1950b, p. 67). During the period 1951-55, Harshbarger, Repenning, and Irwin (1957), working in the Navajo Indian Reservation of northern Arizona, R. F. Wilson, working in the Kanab area, Utah, and the writer, working in the Cedar City area, were able to demonstrate the continuity of the Springdale and a lower key disconformity between the three areas, and thus throw new light on the correlation and age assignment of various parts of the sequence. A discussion of the findings of the group and the revised nomenclature applicable to this sequence throughout southwestern Utah and northern Arizona are contained in a separate paper (Averitt and others, 1955).

In the Cedar Mountain quadrangle the beds formerly assigned to the Chinle formation are now divided into three formations—the Chinle formation, restricted, at the base, the Moenave formation in the middle, and the Kayenta formation at the top—as shown in the table below and as discussed under separate headings in subsequent paragraphs:

Classification of sequence between base of the Chinle formation and base of the Navajo sandstone according to past and present reports

Thomas and Taylor (1946) and Gregory (1950a)	Present report
Navajo sandstone (youngest)	Navajo sandstone (youngest)
Chinle formation	Kayenta formation: Cedar City tongue Shurtz sandstone tongue of Navajo sandstone Unnamed lower member Moenave formation: Springdale sandstone member Dinosaur Canyon sandstone member
Shinarump conglomerate (oldest)	Chinle formation, restricted: Shinarump member (oldest)

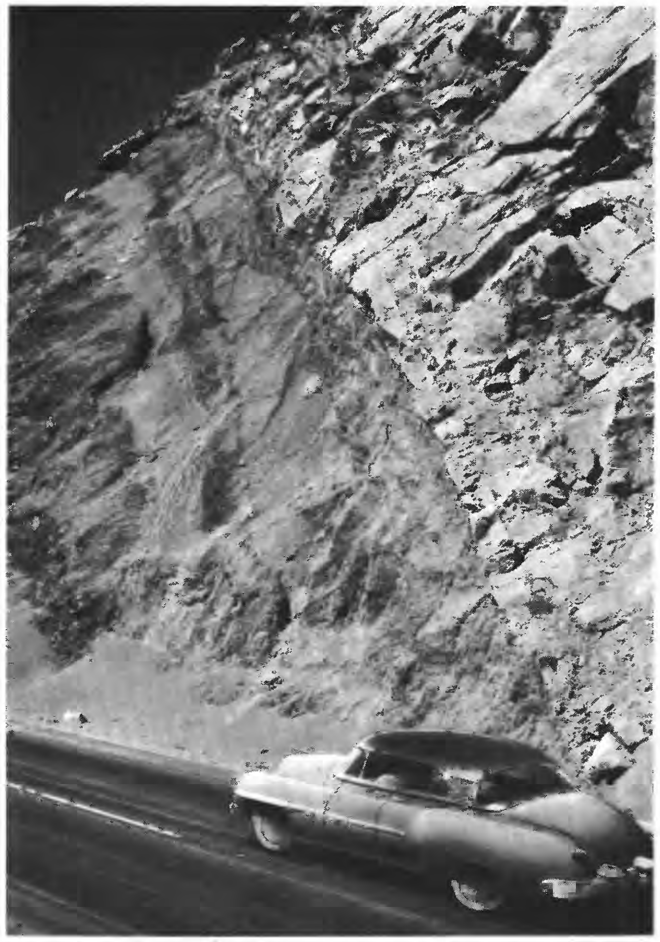

FIGURE 5.—Base of the Shinarump member of the Chinle formation showing disconformable contact with upper red member of the Moenkopi formation. State Highway 14 in NW¼ sec. 13, T. 36 S., R. 11 W.

CHINLE FORMATION, RESTRICTED, OF PRESENT REPORT

As redefined to include only the lower part of the Chinle as originally mapped by Thomas and Taylor (1946, p. 22) and by Gregory (1950a, p. 34–36), the Chinle formation, restricted, is 295 to 420 feet thick in the Cedar Mountain area. This thickness includes the Shinarump, now considered a member of the Chinle.

SHINARUMP MEMBER

The Shinarump member, which overlies the Moenkopi formation disconformably, is a persistent and conspicuous unit throughout southern Utah and northern Arizona; it also extends into southern Nevada, southwestern Colorado, and northwestern New Mexico. It is typically 50 to 100 feet thick in most parts of this broad area. The member consists predominantly of light-gray to yellowish-gray sandstone and of small amounts of conglomerate and siltstone. This material was deposited on a surface of very low relief cut on the Moenkopi formation, and thus fills in shallow channels and surrounds and blankets the higher places. (See fig. 5.) The Shinarump is conformable with the overlying part of the Chinle formation, and may be regarded as the basal conglomerate of a continuous sedimentary cycle.

The Shinarump is conspicuously crossbedded, and at most localities exhibits two main types of crossbedding: a planar type, representing foreset beds on the advancing fronts of small-scale, deltalike deposits, and a trough-shaped type, representing deposition in scoured-out channels. In a study of the sedimentology of the Shinarump of northeastern Arizona by McKee and others (1953), the major features of the Shinarump were reproduced in water-tank experiments by minor changes or fluctuations in the depth of water, and minor features were reproduced by changes in the velocity of the water and in the amount and grain size of the sediments. As stated by McKee (p. 44),

> Experimental work in a laboratory delta tank demonstrates clearly the nature of the process of local base-level control and by-passing of sediments. With constant base-level, the foreset beds build forward indefinitely, and virtually no accumulation can take place on top. With slowly rising base-level, new topset beds form above. With a series of rises of base-level, entire new sets of cross-strata form on top of the old, and the resulting structure pattern resembles that seen in many sections of the Shinarump conglomerate.

The sheet- or blanket-like form of the Shinarump conglomerate [thus] finds explanation as a regressive sand, in which deposits built forward from the basin margin toward its center. The thickness of the formation was determined by local base-level which apparently had little total change over a long time, thus requiring most of the sediment to be deposited forward rather than upward. At times when local base-level fluctuated up and down, scouring and reworking of sediments took place, developing trough-type cross-strata over large areas. At other times when local base-level gradually rose through a series of stages, the planar type was formed by deposits of sheet flood. In general, each set of cross-strata in a vertical section represents a rise in water level, and the plane formed between the development of any two results from an unknown but probably a considerable time during which by-passing of sediments occurred.

The pebbles in the Shinarump member are composed primarily of quartzite, quartz, chert, and flint. In the Cedar Mountain quadrangle most of the pebbles are one-quarter inch or less in diameter, and only a few attain a maximum size of about 1 inch. As the formation is traced southward into Arizona the pebbles increase in size and number, and it is likely that a considerable part of the material in the Shinarump was derived from the south and west (Gregory, 1950b, p. 65).

Perhaps the most characteristic minor constituent of the Shinarump is petrified wood, which accumulates typically as numerous small fragments in the rubble at the base of ledges of the Shinarump. In the Cedar Mountain quadrangle most of this wood has been bleached to a light yellowish-gray color and is very brittle. Thus, it has little attraction for ornamental purposes.

At many places in the Colorado Plateau to the east the Shinarump member contains deposits of radioactive minerals, concentrated either in the petrified wood, or in zones of coarser grained sandstone, particularly in the sandstone-filled channels cut into the underlying Moenkopi formation. In the course of mapping in the Cedar Mountain quadrangle, the more conspicuous and accessible outcrops of the Shinarump were tested with a scintillation counter with only negative results.

In the Cedar Mountain quadrangle the Shinarump is 40 to 60 feet thick, and forms a distinctive light-gray sandstone ridge that rises above the softer reddish-brown slopes of the underlying Moenkopi formation and the overlying part of the Chinle formation. It is notable, however, that the Shinarump crops out much more conspicuously at some places than at others. Where the Shinarump is conspicuous it consists primarily of massive coarse-grained locally conglomeratic sandstone, representing deposition in scoured-out channels; where it is inconspicuous it consists primarily of thin-bedded finer grained sandstone and a larger percentage of siltstone and shale, representing deposition in intervening areas. The resistant facies of the formation is the one most often stressed in generalized descriptions.

The best exposure of the Shinarump member in the Cedar Mountain quadrangle is in the SW¼ sec. 10, T. 37 S., R. 11 W., on a prominent point that rises between forks of Shurtz Creek. At this locality the formation ranges in thickness from about 40 to 60 feet and exhibits features of both the resistant and nonresistant facies. The section below, which was measured along the Shurtz Creek road near the drainage level of the creek, is typical of the nonresistant facies of the formation:

Section of the Shinarump member in SW¼ sec. 10, T. 37 S., R. 11 W.

	Feet
Triassic:	
Chinle formation, Shinarump member:	
1. Sandstone, fine-grained, greenish-gray, 1 bed; tends to break into wafer-thin laminations	1
2. Concealed	4
3. Sandstone, fine-grained, greenish-gray; like unit 1	1
4. Concealed	5
5. Sandstone fine-grained, greenish-gray; beds 6 in to 1 ft thick; tends to break into wafer-thin laminations. Forms dip slope	8
6. Concealed	7
7. Sandstone, fine-grained, 1 bed	1
8. Concealed; presumbly medium light-gray siltstone	4
9. Sandstone, fine-grained, in beds 4 in to 1 ft thick, and medium light-gray mudstone. Sandstone is 50 percent of unit. Petrified wood comon. All nonradioactive	6½
10. Sandstone, medium-grained, with ¼- to 1-in. pebbles. (This unit thickens and thins rapidly northward along strike. About 100 ft north it is 6 ft thick, and 200 ft north it is only 2 ft thick. A short distance farther north it is 15 ft thick and is composed of very pale orange (10*YR* 8/2) coarse-grained crossbedded arkosic sandstone with conspicuous feldspar and biotite, which is typical of most outcrops of the formation.)	1½
Total, Shinarump member	39

Disconformity: Shows 8 in of relief, with blebs of shale in sandstone and concentrations of pebbles in low places.
Upper red member of the Moenkopi formation.

About 500 feet north of the above-measured section near the high point on the ridge, the Shinarump is somewhat thicker and contains a much higher percentage of coarse-grained sandstone, as the following section shows:

Section of the Shinarump member in SW¼ sec. 10, T. 37 S., R. 11 W., about 500 feet north of previous section

Triassic:

Chinle formation, Shinarump member:	Feet
1. Sandstone, coarse-grained, crossbedded, arkosic; in beds 1 to 4 ft thick. Forms dip slope	8
2. Concealed	4
3. Sandstone, like unit 1	3
4. Concealed	17
5. Sandstone, coarse-grained, crossbedded, arkosic; in massive beds 1 to 6 ft thick. Forms prominent point	20
Total, Shinarump member	52

Disconformity.

Upper red member of Moenkopi formation.

The Shinarump grades without break in sedimentation into beds of the overlying part of the Chinle formation, and locally in the Cedar Mountain quadrangle in a zone 10 to 100 feet above the Shinarump the lithology of the Shinarump is repeated in several thin discontinuous beds. One of these beds crops out conspicuously in the SW¼ sec. 16, T. 37 S., R. 11 W., on the divide between Hicks Creek and the next creek to the south, where, except for its stratigraphic and topographic position, it could easily be mistaken for the Shinarump proper.

UPPER PART OF THE CHINLE FORMATION, RESTRICTED

The upper part of the Chinle formation, restricted, is composed largely of nonresistant mudstone and siltstone, intercalated with a few thin beds of soft sandstone. The mudstone and siltstone beds are variegated in pastel shades ranging from light gray to grayish red, but on weathered slopes display the overall purplish cast typical of the Petrified Forest member of the Chinle to the south and east. It is likely that the upper part of the Chinle formation, restricted, of this report is equivalent to the Petrified Forest member of the Chinle of other areas.

At the time the upper part of the Chinle was deposited the main clastic constituents were admixed with an appreciable amount of volcanic ash, which is responsible, in part, for some of the colorful tones of the formation. This ash has since been altered to a variety of clay minerals of the montmorillonite family, which have been studied in considerable detail by Allen (1930) and by Waters and Granger (1953). Montmorillonite expands on becoming wet, and in so doing produces the fluffy surface that is characteristic of weathered slopes of the Chinle. Other beds in the sequence of rocks of Triassic and Jurassic ages display the distinctive fluffy weathered surface, but the feature is particularly well displayed in the Chinle and is helpful in distinguishing between the Chinle and the overlying beds of the Dinosaur Canyon sandstone member of the Moenave formation, which do not display the fluffy weathered surfaces.

The top of the Chinle formation in the Cedar Mountain quadrangle is marked by a calcareous layer, 3 to 6 feet thick, containing scattered shale fragments, which exhibits on its upper surface a 2- to 4-inch disconformity. The overlying beds of the Dinosaur Canyon sandstone member of the Moenave formation are characteristically reddish brown and are markedly more sandy and thicker bedded than the Chinle. The disconformity is thus clearly marked by a pronounced change in both color and texture, though a few thin beds similar to the Chinle may be present locally in the base of the Dinosaur Canyon sandstone member. In areas to the south and east the base of the Dinosaur Canyon sandstone member is marked locally by a pebble conglomerate zone, which aids greatly in determining its position in the field.

In the Cedar Mountain quadrangle the Chinle formation and the Dinosaur Canyon sandstone member of the Moenave formation form a strike valley between the steeply dipping ridge composed of the Shinarump on the west and the ridge of the Springdale member and Shurtz tongue of the Navajo sandstone on the east, and, as a result, the Chinle is very poorly exposed. The best exposure in the quadrangle is along the Shurtz Creek road, in the SW¼ sec. 10, T. 37 S., R. 11 W., and on the slopes below and above the road. A section measured at this locality is given below:

Section of the Chinle formation, restricted, on Shurtz Creek road in SW¼ sec. 10, T. 37 S., R. 11 W.

Triassic(?):

Dinosaur Canyon sandstone member of the Moenave formation.

Disconformity showing 4 in. of relief.

Triassic:

Chinle formation, restricted:	Fee
1. Calcareous layer containing fragments of shale	3
2. Mudstone, grayish-red; with purplish cast on weathered surface; partly concealed	111
3. Sandstone, coarse-grained, arkosic, like Shinarump	3
4. Sandstone, coarse-grained, arkosic, crossbedded, grayish-red. Fairly well consolidated, but only moderately resistant	15
5. Siltstone, grayish-red (5*R* 4/2)	1
6. Sandstone, coarse-grained, arkosic, poorly consolidated, purplish-gray to light-purple. Slight unconformity at base	9
7. Concealed. Upper part is mottled light- and dark-gray shale with purplish cast. Radioactivity about 2 times background	26

	Feet
Triassic—Continued	
Chinle formation, restricted—Continued	
8. Sandstone, coarse-grained, arkosic. Like Shinarump, but thins and disappears along strike	3
9. Concealed	54
10. Sandstone, medium- to fine-grained, arkosic, pinkish-red (5*YR* 7/1). Weathers into ½-in. plates	3
11. Concealed. Probably gray shale or mudstone	12
12. Sandstone, medium-grained, grayish-red (5*R* 4/2)	6
13. Concealed	20
14. Sandstone, medium-grained, medium-gray	2
15. Concealed	28
16. Siltstone, pale reddish-brown; largely concealed. Weathers to ½-in. plates. Thickness estimated from distribution of float. Forms ridge	18
17. Concealed	20
18. Sandstone, coarse-grained, somewhat arkosic; like Shinarump, but discontinuous	4
19. Concealed	23
Shinarump member	52
Total, Chinle formation, restricted	413
Moenkopi formation.	

The Chinle formation, restricted, is also well exposed along State Highway 14 in Coal Creek. In the section measured at this locality by Thomas and Taylor (1946, p. 20) it includes units 15–18, which total 285 feet. In the same section as republished by Gregory (1950a, p. 81) it includes units 10–13. Figure 6 shows the Chinle formation, restricted, and the overlying beds in the basal part of the Dinosaur Canyon member of the Moenave formation as they appear a few hundred yards north of this locality.

TRIASSIC(?) SYSTEM

MOENAVE FORMATION

The Moenave formation was defined and named by Harshbarger, Repenning, and Irwin (1957) from exposures in the Navajo Indian Reservation of northern Arizona. In the Navajo Reservation the formation includes a lower, 300-foot sequence of sandstone and siltstone termed the Dinosaur Canyon sandstone member (Colbert and Mook, 1951) and an upper unit termed the Springdale sandstone member (Gregory, 1950b, p. 67). The formation underlies the Kayenta formation in the southern and western parts of the reservation and overlies the Wingate sandstone as that term is used in Utah (Baker, Dane, and Reeside, 1947) in the southern and southwestern parts. The Wingate sandstone intertongues with the basal part of the Dinosaur Canyon sandstone member near Cameron, Ariz., and is not present farther north or west. The Moenave formation has been traced in reconnaissance from the Navajo Indian Reservation in northern Arizona, to the Cedar City area, and because of its age, which is demonstrably younger than the Wingate sandstone and older than the Kayenta formation, it has been a most important factor in

FIGURE 6.—Contact between the Chinle formation, restricted, and the Dinosaur Canyon sandstone member of the Moenave formation as exposed on the north side of Coal Creek. View looking north in NW¼ sec. 13, T. 36 S., R. W. Ꞧcs, Shinarump member of the Chinle formation, restricted; Ꞧcu, upper part of the Chinle formation, restricted; Ꞧmd, Dinosaur Canyon sandstone member of the Moenave formation.

determining the present correlation and age assignment of overlying and underlying beds that were formerly included in the Chinle formation.

DINOSAUR CANYON SANDSTONE MEMBER

Although originally named the Dinosaur Canyon sandstone by Colbert and Mook (1951), the unit contains predominantly siltstone in the Cedar Mountain quadrangle. The Dinosaur Canyon sandstone member forms a weathered brush-covered slope at all outcrops in the Cedar Mountain quadrangle and is very poorly exposed. Fortunately, a very good section crops out along State Highway 14 in Coal Creek several miles north of the quadrangle at a point very convenient for examination. In a section measured at this locality by Thomas and Taylor (1946, p. 20) the Dinosaur Canyon sandstone member is described as units 19, 20, 21, and most of unit 22. In the same section as republished by Gregory (1950a, p. 81) it is described as units 14, 15, 16, and most of unit 17. The basal part of the member includes a massive 40-foot bed of reddish-brown siltstone that is incorrectly identified as the Springdale sandstone member in the republished section. This siltstone bed, which is visible in figure 6, forms a prominent ledge at this exposure and gives every indication of being a resistant, ledge-forming, but not a ridge-forming, unit. It is very soft and nonresistant at most places, however, and generally forms a weathered slope like the overlying and underlying beds. Locally at the base of this bed, and above the disconformity at the top of the Chinle formation, are several 1- to 5-foot beds of reddish-brown mudstone and grayish-red mudstone similar to that in the Chinle, in alternating layers.

The upper part of the Dinosaur Canyon sandstone member consists of siltstone and mudstone in alternating layers 1 to 5 feet thick. The beds are mostly reddish brown like the underlying massive siltstone bed, but exhibit a few layers of light-gray siltstone and a few thin stringers of light-colored chert. The siltstone layers seem to be thicker and more numerous toward the top of the unit.

The Dinosaur Canyon sandstone member is 350 to 400 feet thick in the section on Coal Creek measured by Thomas and Taylor. In Shurtz Creek, where the member is partly concealed on a weathered slope below outcrops of the Springdale sandstone member, it is about 400 feet thick.

SPRINGDALE SANDSTONE MEMBER

The Springdale sandstone member of Triassic(?) age was defined and named by Gregory (1950b, p. 66–68) from exposures near the town of Springdale, Utah, near the mouth of Zion Canyon. The Springdale crops out continuously, but not always prominently, from Springdale southward and eastward to the Navajo Indian Reservation of northern Arizona, and westward and northward through Zion National Monument and the Cedar Mountain quadrangle to a point several miles north of Cedar City. In the Cedar Mountain quadrangle, the Springdale is a fine-grained massive sandstone sequence about 110 feet thick. The individual beds range in thickness from 1 to 10 feet; they are, however, lenticular and tend to pinch out along the strike, typically within distances of several hundred feet. The bedding planes throughout the sequence are thus subparallel and somewhat irregular. Locally the contacts between beds are marked by thin zones containing clay pellets or mud lumps, which suggest temporary erosion surfaces such as would be found in stream-channel deposits. Some of the lenses are even bedded; others are crossbedded at very low angles. In general, however, crossbedding is not a conspicuous feature.

From a distance the weathered surfaces of the Springdale sandstone member appear to be pale purple, but fresh surfaces are pale reddish brown. The member also includes a few thin reddish or greenish shale layers, which render it less resistant to weathering than sandstones in the Shinarump or in the Shurtz sandstone tongue of the Navajo sandstone. In outcrops in the Cedar Mountain quadrangle the Springdale has a less resistant zone through the center. At some localities only the upper part of the member is exposed, and at others only the lower part is exposed. A section of the Springdale sandstone member measured in the SW¼ sec. 10, T. 37 S., R. 11 W., on the high point between the forks of Shurtz Creek is given below:

Section of the Springdale sandstone member in SW¼ sec. 10, T. 37 S., R. 11 W.

	Feet
Jurassic(?): Lower member of the Kayenta formation.	
Triassic(?):	
Springdale sandstone member of the Moenave formation:	
1. Sandstone, fine-grained, pale reddish-brown, massive; beds 1 to 10 ft thick, lenticular; some low angle crossbedding	22
2. Concealed; probably soft sandstone with some shale	28
3. Sandstone, like unit 1	60
Total, Springdale sandstone member	110

Dinosaur Canyon sandstone member of the Moenave formation.

The Springdale sandstone member does not form a ridge, but crops out fairly prominently on the slopes below the ridge formed by the more resistant Shurtz sandstone tongue of the Navajo sandstone. The best and most accessible exposure of the Springdale in Iron County is in Coal Creek Canyon, a few miles north of the Cedar Mountain quadrangle, where it has been blasted back as a high wall to smooth out a turn in State Highway 14. (See fig. 7.) A section of the rocks exposed in Coal Creek Canyon measured by H. E. Thomas has been published in a report by Thomas and Taylor (1946, p. 20) and republished by Gregory (1950a, p. 81). In the Thomas and Taylor report, the Springdale is composed of the beds described as units 24, 23, and possibly the upper part of unit 22. In the Gregory report, the Springdale is composed of the beds described as units 19, 18, and possibly the upper part of unit 17, not unit 14 as incorrectly stated on the republished section.

In the Cedar Mountain quadrangle, the basal part of the Springdale consists of several sandstone layers alternating with reddish-brown mudstone layers like those in the underlying Chinle formation. Slight unconformities could be said to show on these basal layers, but the break in sedimentation, if any, is insignificant. In general, the contact between the Springdale sandstone member and the underlying Dinosaur Canyon sandstone member is gradational, accompanied by intertonguing on a small scale. In areas to the east, however, the base of the Springdale is marked by an unconformity. At the type locality near the town of Springdale, Gregory (1950b, p. 67) reports that this unconformity is marked at most places by "angular gravel, sunbaked surfaces and cracks, and balls and slabs of blue-green shale." In the Vermilion Cliffs near Kanab he reports it to be "a surface of erosion above and below which the bedding is discordant."

The contact between the Springdale sandstone member and the overlying beds was not observed in the Cedar Mountain quadrangle.

JURASSIC(?) SYSTEM

KAYENTA FORMATION

The Kayenta formation of Jurassic(?) age includes the sequence of beds between the top of the Springdale sandstone member of the Moenave formation and the base of the Navajo sandstone. In the Cedar Mountain quadrangle it includes two distinct mappable members, each consisting of nonresistant siltstone and mudstone, separated by a highly resistant, ridge-

FIGURE 7.—The Red Hill, a prominent landmark on the north side of Coal Creek, 2 miles east of Cedar City. The massive ledge forming back and crest of hill is the Shurtz sandstone tongue of the Navajo sandstone. The top of the hill is 900 feet above Utah State Highway 14 at base. View looking north in secs. 12 and 13, T. 36 S., R. 11 W. R̄mu, upper part of the Moenkopi formation; R̄cs, Shinarump member of the Chinle formation, restricted; R̄cu, upper part of the Chinle formation, restricted; R̄md, Dinosaur Canyon sandstone member of the Moenave formation; R̄ms, Springdale sandstone member of the Moenave formation; Jkl, lower member of the Kayenta formation; Jns, Shurtz sandstone tongue of the Navajo sandstone; Jkc, Cedar City tongue of the Kayenta formation; Jn, Navajo sandstone.

forming sandstone tongue of the Navajo sandstone, termed the Shurtz sandstone tongue. The three units are discussed below.

UNNAMED LOWER MEMBER

The lower member of the Kayenta formation, which includes the sequence of beds between the top of the Springdale sandstone member of the Moenave formation and the base of the Shurtz sandstone tongue of the Navajo sandstone, is 275 to 420 feet thick in the Cedar Mountain quadrangle. It consists of light-gray to light-brown (5*YR* 6/4) siltstone, pale reddish-brown (10*R* 5/4) silty mudstone, and dark reddish-brown (10*R* 4/4) mudstone, with siltstone in beds 1 to 5 feet thick making up about a third of the total. The dark beds are mottled and spotted with light gray. Some beds have undulating or ripple-marked surfaces, and many layers are composed of mudstone pellets, all indicative of shallow-water origin. The lower member normally forms the upper slope below a ridge formed by the markedly more resistant Shurtz sandstone tongue.

SHURTZ SANDSTONE TONGUE OF THE NAVAJO SANDSTONE

The Shurtz sandstone tongue of the Navajo sandstone is the prominent sandstone sequence that forms the crest of The Red Hill north of Coal Creek and the prominent ridge below the base of the Navajo in Shurtz Creek, which has been designated as the type locality (Averitt and others, 1955, p. 2520). It lies 410 to 720 feet below the base of the Navajo sandstone as mapped by Thomas and Taylor (1946, p. 20) and as accepted in this report. In the measured section along Coal Creek published by Thomas and Taylor the Shurtz sandstone tongue comprises units 26 and 27, and is described as being "quite similar in lithology to the typical Navajo sandstone." In the section as republished by Gregory (1950a, p. 81) the tongue comprises units 21 and 22. Figure 7 shows the Shurtz tongue and underlying and overlying beds in the prominent exposure on the north side of Coal Creek.

Although the Thomas and Taylor section shows the Shurtz sandstone tongue as a separate unit lying below the base of the Navajo, Gregory mapped the base of the Shurtz tongue as the base of the Navajo, but he did not note the change on the republished section. The revised interpretation of the Shurtz sandstone as a tongue of the Navajo sandstone is based on observations of a pronounced southward thinning of the unit from 345 feet in Coal Creek to 110 feet in Shurtz Creek, and to 62 feet in Murie Creek. A photograph of the Shurtz tongue at the latter locality is shown in figure 8. The north to south thinning of the Shurtz tongue can be observed by comparing figures 7 and 8. The Shurtz tongue is not visible in Taylor Creek nor in other creeks to the south in Zion National Monument, and it presumably thins and disappears between Murie and Taylor Creeks. The pronounced thinning from 345 to 62 feet takes place in a distance of 8 miles. The Shurtz sandstone tongue cannot be observed to join the base of the Navajo sandstone in a northward direction because the units are cut off by faulting along the mountain front about 2 miles north of Coal Creek. However, the pronounced southward thinning and the fact that the Shurtz sandstone tongue closely resembles the Navajo sandstone, but is separated from it through its entire length of exposure by the overlying thick sequence of strata similar to the Kayenta, give credence to the interpretation.

The Shurtz sandstone in Shurtz Creek is fine to medium grained, moderate reddish orange (10*R* 6/6), and massive, and the beds range in thickness from 2 to 5 feet. Through the middle part it seems to be somewhat coarser grained than at the top or bottom, and displays many 1-grain laminae of coarser and heavier material. It is conspicuously even bedded, but crossbedding is present. Except for the more even bedding, it is like the basal part of the Navajo in color, texture, and resistance to erosion, and obviously represents material of the same origin.

FIGURE 8.—Shurtz sandstone tongue of the Navajo sandstone (left) and basal part of the Navajo sandstone (right); Cedar City tongue of the Kayenta formation in between. View looking north on Kanarra Mountain road in sec. 20, T. 37 S., R. 11 W. Beds are overturned. Valley of Murie Creek in foreground. Knoll on near skyline left of center is capped by basalt, presumably extruded in older and higher channel of Murie Creek.

CEDAR CITY TONGUE OF THE KAYENTA FORMATION

The name Cedar City tongue of the Kayenta formation has been applied to the sequence of beds between the top of the Shurtz sandstone tongue and the base of the Navajo sandstone. These beds form a strike valley everywhere in the Cedar Mountain quadrangle. A good exposure of the Cedar City tongue just east of The Red Hill, about 2 miles east of Cedar City along State Highway 14 (fig. 7), has been designated as the type locality (Averitt and others, 1955, p. 2521–2522). The Cedar City powerplant of the California-Pacific Utilities Co. is only a few hundred feet upstream from the top of the unit. In the section along Coal Creek published by Thomas and Taylor (1946, p. 20) and republished by Gregory (1950a, p. 81) the rocks assigned to the Cedar City tongue are designated as units 28, 29, and 30, and as units 23, 24, and 25, respectively. The Cedar City tongue is 425 feet thick in the section along Coal Creek, but about 800 feet thick in Shurtz Creek, 5 miles to the south. This increase in thickness accompanies a decrease in the thickness of the underlying Shurtz sandstone tongue of the Navajo sandstone.

The Cedar City tongue is composed largely of nonresistant mudstone and siltstone. The mudstone and silty mudstone, which make up a large part of the total thickness, are reddish brown (10*R* 4/4), locally streaked and spotted with light gray. The siltstone, which forms beds 1 to 5 feet thick, is moderate reddish orange (10*R* 5/6) to light gray and is mottled with white in some places. Like the lower member of the Kayenta formation, the Cedar City tongue contains ripple marks, mudstone-pellet layers, and other features characteristic of shallow-water deposition.

The contact between the Cedar City tongue and the overlying Navajo sandstone is completely gradational with alternating layers of the two rock types being repeated several times in the sequence between beds of obvious Kayenta and obvious Navajo. These intercalated layers probably represent intertonguing on a small scale comparable to that exhibited on a large scale by the Shurtz and Cedar City tongues.

JURASSIC AND JURASSIC(?) SYSTEM

NAVAJO SANDSTONE

The Navajo sandstone of Jurassic and Jurassic(?) age, which forms Sugarloaf Mountain and other prominent points that rise above Shurtz, Hicks, and Murie Creeks, is the most conspicuous and best known formation in the Cedar Mountain quadrangle. (See figs. 7, 17.) Because it has been jointed and fractured by movements on the Hurricane fault zone and dips 45° to 90° in the belt of outcrop, it does not exhibit the massive vertical cliffs so characteristic of outcrops in the Zion Canyon region to the south, but rather erodes into isolated blunt points with slopes near the angle of repose. Sugarloaf Mountain, the most prominent of the points formed by the Navajo sandstone, rises less than 1,000 feet above the floor of Shurtz Creek, but the Navajo sandstone in Sugarloaf Mountain is 1,700 feet thick and dips 45° to 47° E.

The Navajo sandstone is composed largely of well-sorted loosely cemented fine- to medium-grained rounded to subangular quartz sand and contains only small amounts of the common accessory feldspar, mica, and magnetite. It shows some evidence of regular bedding at the base, but throughout most of its thickness it is elaborately crossbedded on a massive scale. All outcrops in the Cedar Mountain quadrangle are moderate reddish orange (10*R* 6/6), which results from a thin coating of iron oxide on the individual grains. This color contrasts strikingly with the reddish-brown slopes of the underlying Triassic rocks and the light-gray slopes of the overlying Carmel formation.

TEMPLE CAP MEMBER

In the Zion Canyon region to the south, Gregory (1950b, p. 89) has recognized an uppermost member of the Navajo sandstone, which he has termed the Temple Cap member. This member consists of an upper cliff-forming sandstone like the Navajo sandstone and an underlying sequence of "irregularly bedded shaly calcareous sandstones, siliceous limestones, and limestone conglomerates colored red, gray, or brown." In the Zion Canyon region the Temple Cap member is a discontinuous unit ranging in thickness from a few feet to as much as 200 feet. It is not recognizable as a discrete unit in the Cedar Mountain quadrangle, but may be represented in the 40- to 60-foot sequence of red mudstone and siltstone interbedded with gypsum, which forms the basal part of the Carmel formation of this report.

JURASSIC SYSTEM

CARMEL FORMATION

The Carmel formation of early Late Jurassic age was defined and named by Gregory and Moore (Gilluly and Reeside;[2] Gregory and Moore, 1931, p. 72) from exposures near the town of Mount Carmel in Kane County, Utah. At the type locality, and else-

[2] Cited *in* U.S. Department of Interior, 1926, Possibility of finding oil in southeastern Utah and southwestern Colorado: Mem. for Press 6064, Mar. 30, 1926.

where in southwestern Utah, the Carmel consists primarily of thin-bedded fossiliferous gray limestone. On the basis of the contained fossils the Carmel formation and its equivalents are known to crop out over a wide area in southern and southeastern Utah, eastern Colorado, northern Arizona, and southwestern Wyoming. In the Iron Springs district, about 10 miles west of the Cedar Mountain quadrangle, beds known formerly as the Homestake limestone were redefined as a member of the Carmel (Mackin, 1954). In southwestern Wyoming, beds equivalent to the Carmel are known as the Twin Creek formation.

Viewed as a whole, the Carmel exhibits a marked east-west change in thickness and facies. In the Cedar Mountain quadrangle and areas just to the south, where it consists primarily of limestone, it attains a maximum thickness of at least 540 feet, and perhaps as much as 650 feet, which is near the maximum known thickness. It thins and becomes progressively more argillaceous across central and southeastern Utah, and in the southeastern part of the State, near the line where it pinches out, it consists only of nonfossiliferous red, earthy sediments (Baker, Dane, and Reeside, 1936, p. 45, 48).

With continuity of the Carmel formation well established over a wide area on the basis of fossil evidence, Gregory assigned to the mappable nonfossiliferous units overlying the thick Carmel at the type locality, and elsewhere in southwestern Utah, the names Entrada and Curtis formations, which had been assigned by Gilluly and Reeside[3] (1928) to units overlying the thinner Carmel in the San Rafael Swell of central Utah, though there are certain conspicuous differences between the two formations in the two localities. The Entrada and Curtis formations, as these terms have been used in southwestern Utah and as they are used in this report, are described on page 21.

Extensive stratigraphic work in the Colorado Plateau and southern Utah during and after the Second World War has revealed that the thin Carmel formation as mapped in central and eastern Utah probably is equivalent to the combined Carmel, Entrada, Curtis, and Winsor formations of southwestern Utah, and that the Entrada and Curtis formations of the type locality in central and eastern Utah probably do not extend into southwestern Utah.

Nevertheless, the distinctive Carmel, Entrada, Curtis, and Winsor formations of southwestern Utah need to be considered separately, and as local usage of these terms is well defined and understood, they are retained for this report. However, in describing the thick limestone of the Carmel of the Cedar Mountain quadrangle, it is pertinent to remember that it probably is equivalent only to the lower part of the much thinner Carmel of central and eastern Utah.

In the Cedar Mountain quadrangle, as in areas to the south, the Carmel formation forms a thick resistant cap immediately overlying the Navajo sandstone, and is more resistant to weathering and in a few places more conspicuous topographically than the Navajo. Where the Navajo sandstone is flat lying, as in the Zion Canyon region, the Carmel cap may be inconspicuous or absent, but it still has been an important factor in producing and preserving the boldly sculptured cliffs of the Navajo sandstone. Where the beds are steeply dipping, as in the Hurricane Cliffs, the Carmel crops out characteristically as a series of white or light-gray points rising 2,000 feet above the lowlands to the west. In the Shurtz Creek amphitheater, several of these points stand out against the sky like miniature alpine peaks, dwarfing outcrops of the Navajo.

In typical outcrops in the Cedar Mountain quadrangle the Carmel weathers differentially into two prominent cliffs, each of which rises above a scree-covered slope. (See fig. 9.) The beds in the cliffs are somewhat thicker bedded and less argillaceous than beds in the slope, but the entire formation is uniformly thin bedded and tends to weather into thin hard angular chips. These chips are ideal for road construction. At several places in Coal and Shurtz Creeks chips of the Carmel formation are scraped from the slopes and loaded directly into trucks without further processing.

A section of the Carmel formation measured on the point just north of the Shurtz Creek road in secs. 11 and 14, T. 37 S., R. 11 W., is given below:

Section of Carmel formation on point north of Shurtz Creek road in secs. 11 and 14, T. 37 S., R. 11 W.

	Feet
Jurassic:	
Entrada sandstone.	
Carmel formation:	
Unit 4 (Homestake limestone member of Mackin):	
1. Limestone, thin-bedded, light-gray. Contains a few beds 6 in. to 2 ft thick. Forms cliff	127
2. Limestone, very thin bedded, argillaceous, light-gray. Forms slope covered with hard angular chips	107
Unit 3 (siltstone member of Mackin):	
3. Limestone, thin-bedded; oolitic in part; contains a few 6-in. layers; and siltstone containing a few thin sandy layers; yellowish-gray; fossiliferous; contains a few pebbles. Forms saddle	71

[3] See footnote 2, on page 18.

Jurassic—Continued
Carmel formation—Continued

	Feet
Unit 2:	
4. Limestone, thin-bedded, light-gray. Contains a few beds 2 to 6 in. thick. Forms cliff	96
5. Limestone, very thin bedded, argillaceous, yellowish-gray. Forms slope covered with hard, angular chips	77
6. Siltstone, calcareous, yellowish-gray, soft, nonresistant; rarely exposed because of rubble from above	5
Unit 1:	
7. Gypsum, massive, resistant	9
8. Sandstone, fine-grained, and mudstone; reddish-brown; veined with gypsum. Very poorly exposed	30
9. Gypsum	11
10. Mudstone and sandstone, fine-grained, reddish-brown	7
Total, Carmel formation	540

Disconformity.
Navajo sandstone.

As noted in the section, the Carmel may be divided for discussion into four lithologic units. Unit 1 at the base of the Carmel is a 40- to 60-foot sequence of red mudstone and siltstone interbedded with gypsum, which rests disconformably on the Navajo sandstone. It is well exposed in Coal Creek, just north of the Cedar Mountain quadrangle, and on the point in secs. 11 and 14, T. 37 S., R. 11 W., in Shurtz Creek, but at most places in the quadrangle it is concealed under weathered slopes. These lower beds of the Carmel are identical in composition, texture, and color to beds in the Entrada and Curtis formations, and in small isolated outcrops could easily be mistaken for the higher beds.

Unit 2 consists of a lower sequence of very thin bedded argillaceous yellowish-gray slope-forming limestone, 82 feet thick; and an upper sequence of somewhat thicker bedded light-gray cliff-forming limestone, 96 feet thick. This cliff-forming limestone is the lower of the two main ledges shown in figure 9.

FIGURE 9.—Outcrop of Carmel formation in Shurtz Creek, showing typical development of light-colored twin ledges and complementary, scree-covered slopes. Steeply dipping darker ledges of Navajo sandstone on left. Gently dipping beds of Cretaceous age on skyline right of center. View looking north in sec. 14, T. 37 S., R. 11 W.

Unit 3 is a thin-bedded fossiliferous limestone and siltstone sequence, about 70 feet thick, which is markedly less resistant than other units in the Carmel. It forms the base of the slope above the lowermost cliff-forming ledge of the Carmel, and is responsible for a saddle on the point in secs. 11 and 14, T. 37 S., R. 11 W., north of Shurtz Creek. A collection of mollusks taken from unit 3 at this locality by Ralph W. Imlay and the writer (USGS Mesozoic locs. 25672, 26309) is said by Imlay (written communication, October 3, 1955) to be the same as the assemblage occurring in the lower 1/3 to 1/4 of the Carmel in the San Rafael Swell. The species making up this collection are listed below:

Astrocoenia cf. *A. hyatti* Wells (worn fragments)
Pentacrinus asteriscus Meek and Hayden
Ostrea sp.
Plicatula sp.
Nucula sp.
Trigonia conradi Meek and Hayden
americana Meek
Lima (*Plagiostoma*) *occidentalis* Hall and Whitfield
Camptonectes platessiformis White
Ctenostreon sp.

In the Iron Springs district to the west unit 3 has been termed the siltstone member of the Carmel by Mackin (1954).

Unit 4 consists of a lower sequence of very thin-bedded argillaceous light-gray slope-forming limestone 107 feet thick, and an upper sequence of somewhat thicker bedded light-gray cliff-forming limestone 127 feet thick. This cliff-forming limestone is the uppermost of the two main ledges shown in figure 9. Unit 4, which in the accompanying section is 234 feet thick, has been recognized in the Iron Springs district to the west, and is there termed the Homestake limestone member of the Carmel.

The contact between units 1 and 2 is sharp and distinct; it has little value in geologic mapping, however, for it is generally concealed in a weathered slope and is, in any event, too near the top of the Navajo sandstone to have structural significance. The contacts between the upper units are gradational and cannot be traced precisely in all parts of the quadrangle, though the individual units can be recognized.

Like most of the rocks in the Cedar Mountain quadrangle, the Carmel formation was deposited in fairly shallow water as evidenced by the very thin bedding, which suggests rhythmic seasonal deposition, and by local ripple and current marks. The Carmel is overlain conformably by the Entrada sandstone.

ENTRADA SANDSTONE

The Entrada sandstone of Late Jurassic age is nowhere exposed in the Cedar Mountain quadrangle. Its position in the stratigraphic sequence is well marked, however, by weathered red-brown slopes, which separate the gray cliffs of the underlying Carmel formation from the white cliffs of the overlying Curtis formation. Its probable relation to the Carmel formation and to the Entrada of the Colorado Plateau has been discussed previously in the section on the Carmel formation.

Although the Entrada sandstone is not visible for study in the Cedar Mountain quadrangle, it is well exposed in the canyon of Coal Creek, about 3 miles north of the quadrangle, and in the cliffs at the head of Squaw Creek, 2 miles north of the quadrangle in sec. 24, T. 36 S., R. 11 W. Sections measured at these localities by Williams (Gregory, 1950a, p. 80, 83) show the formation to be 157 and 155 feet thick, respectively.

South of the Cedar Mountain quadrangle, the Entrada is reported to be somewhat thicker. On the divide between Deep and Crystal Creeks, sec. 2 and 11, T. 39 S., R. 10 W., it is 224 feet thick, and in Taylor Creek, T. 38 S., R. 12 W., it is more than 200 feet thick (Gregory, 1950a, p. 89, 93). The Entrada is at least 150 feet thick in the Cedar Mountain quadrangle, and it may well be 170 to 200 feet thick.

Where exposed in Coal Creek, the Entrada consists of very fine grained reddish-brown sandstone and siltstone, intercalated with red-brown mudstone. The beds of sandstone and siltstone, which make up the greater part of the total thickness, are typically about 1 foot thick, but locally may be as much as 5 feet thick. The sandstone is loosely cemented with gypsum, and contains a few white beds. The mudstone contains thin layers and veinlets of gypsum. The sandstone beds disintegrate almost as readily as the mudstone beds, and even in good exposures many of the features of the formation are obscured by the disintegration products.

The Entrada sandstone is conformable with the underlying Carmel formation, but shows a slight disconformity at the contact with the overlying Curtis formation.

CURTIS FORMATION

The Curtis formation of Late Jurassic age is composed largely of massive gypsum, a hydrous calcium sulfate ($CaSO_4 \cdot 2H_2O$), which crops out locally as a sparkling white cliff or erodes to form a slope covered with white gypsum boulders. In detail, it consists of a lower gypsiferous unit 100 to 110 feet thick, and an upper unit about 30 feet thick, composed of thin-bedded hard shaly limestone, similar to that in the Carmel formation. Some of the limestone beds show ripple marks. The probable relation of the Curtis formation of southwestern Utah to the Carmel formation and to the Curtis formation of the Colorado Plateau has been discussed in the section on the Carmel formation.

At the base, the gypsum tends to be bedded and contains thin beds of limestone and gypsiferous shale, but, in general, the gypsum is highly contorted and seems to be a single incoherent mass. In other parts of Iron County a central unit of red and brown sandstone 6 to 30 feet thick lies between the gypsum and the limestone (Gregory, 1950a, p. 41), but this was not observed in the Cedar Mountain quadrangle.

The formation is about 140 feet thick in the Cedar Mountain quadrangle, which compares closely with measurements of 128 feet in Coal Creek 3 miles north of the north boundary of the quadrangle, and 137 feet in Spring Canyon 1 mile west of the southwest corner of the quadrangle (Gregory, 1950a, p. 80, 85).

The Curtis lies with a slight disconformity on the underlying Entrada sandstone, but is conformable with the overlying Winsor formation.

Data on the possible commercial use of gypsum from the Curtis formation are given on page 64.

WINSOR FORMATION

The Winsor formation, which is assigned provisionally to the Upper Jurassic System, was defined and named by Gregory (1950b, p. 96–98) from outcrops near Winsor Cove 3 miles southwest of Mount Carmel in Kane County. It is very poorly exposed in the Cedar Mountain quadrangle, but its position in the stratigraphic sequence is clearly marked by sporadic outcrops of grayish-orange to red-brown sandstone and by persistent reddish-brown slopes overlying the Curtis formation.

The Winsor formation probably is equivalent to the uppermost part of the Carmel formation of the Colorado Plateau (p. 19). If this correlation becomes firmly established, the Carmel, Entrada, Curtis, and Winsor formations of the Cedar Mountain quadrangle and southwestern Utah will have to be regarded as a single thick formation that is equivalent in age to the thin Carmel formation of the Colorado Plateau.

The best exposures of the Winsor formation are just south and west of the southwest corner of the quadrangle, in sec. 18, T. 38 S., R. 11. This area is best shown on the topographic map of Zion National Park. At this locality the Winsor is 300 to 320 feet thick and consists of a sequence of alternating fine-grained even-bedded sandstone and mudstone in beds ranging in thickness from a few inches to more than 40 feet, but typically ranging from 1 to 3 feet. About two-thirds of the total thickness, including most of the thicker beds, is sandstone, and about one-third is mudstone. In addition, the sequence includes a few thin stringers of gypsiferous mudstone and a few layers of very coarse sandstone and pebble conglomerate.

The formation is typically reddish brown in overall appearance, but the sandstone beds range in color from light gray through various shades of pale orange and red to reddish brown, and the mudstone beds range from pale green to red brown. In general, the lower half of the formation is lighter than the upper half. In fresh exposures the formation appears strongly layered, with individual layers, typically 1 or 2 feet thick, set apart by differences in texture and by color. (See fig. 10.)

The Winsor formation is conformable with the underlying Curtis formation and is overlain unconformably by sandstone and shale of the Tropic formation of Late Cretaceous age. The contact with the Tropic formation is marked in some places by a resistant 10-foot conglomerate bed with 4-inch cobbles, at others by thinner uncemented conglomerate with smaller pebbles, and at others by little more than a weathered zone. In Green Hollow just north of the north boundary of the quadrangle and in Coal Creek Canyon about 3 miles north of the north boundary, the contact is characterized by a zone of light-gray and purplish mudstone several feet thick resembling sedimentary material from the Winsor formation that was reworked by the advancing Cretaceous sea.

A section of the Winsor formation measured at the head of Pine Hollow is given below:

Section of the Winsor formation at head of Pine Hollow, a tributary of La Verkin Creek, NE. cor. sec. 18, T. 38 S., R. 11 W.

Cretaceous: Tropic formation.

Unconformity marked by 6-in. layer of yellow sandstone, which grades laterally within about 20 ft into a 6-in. pebble conglomerate layer.

Jurassic:

	Feet
Winsor formation:	
1. Concealed. Largely sandstone like unit 3	22
2. Mudstone, pale green	1
3. Sandstone, fine-grained, reddish-brown	9
4. Mudstone, reddish-brown and pale-green; in alternating layers 6 in. to 1 ft thick	19
5. Sandstone. fine- to medium-grained, reddish-brown; in beds 2 to 5 ft thick, separated by 1- to 3-in. stringers of mudstone	25
6. Mudstone, reddish-brown	½
7. Sandstone, fine-grained, pale-red (10*R* 6/2)	6

Jurassic—Continued

Winsor formation—Continued

	Feet
8. Sandstone, fine-grained; in beds 1 to 2 ft thick, alternating with mudstone; largely concealed	64
9. Mudstone, reddish-brown and pale-green	½
10. Sandstone, fine-grained, pale-red (10*R* 6/2)	16
11. Mudstone and sandstone in alternating layers 1 to 2 ft thick and alternating gray green to reddish brown	17
12. Sandstone; fine- to medium-grained at base, coarse-grained at top; even bedded; banded in all shades between light gray and reddish brown, in alternating layers 1 to 2 ft thick. Contains several stringers of mudstone	32
13. Mudstone, reddish-brown and light-green	1
14. Sandstone, fine- to medium-grained, light-gray and light reddish-brown	2
15. Mudstone, reddish-brown and pale-green	½
16. Sandstone, fine-grained, pale-gray	1
17. Mudstone, silty, reddish-brown and pale-green in alternating layers 6 in. to 1 ft thick	6
18. Sandstone, fine- to medium-grained, pale-red (10*R* 6/2)	4
19. Mudstone, reddish-brown and pale-green, with one 3-in. layer of reddish-brown siltstone	3
20. Sandstone, fine- to medium-grained, grayish-orange (10*YR* 7/4) mottled with reddish brown. Contains several 3-in. stringers of reddish-brown mudstone near top. Very soft and friable, but most distinctive and resistant bed in sequence	47
21. Concealed	43
Total, Winsor formation	319

Curtis formation.

CRETACEOUS SYSTEM

Rocks of Late Cretaceous age crop out boldly along the crest of the Hurricane Cliffs and form the upland surface of most of the eastern half of the Cedar Mountain quadrangle. These younger rocks are characterized by the typical drab grayish-yellow color of Cretaceous rocks and by gentle dips, which differ markedly from the vivid colors and steep dips of the older rocks of Triassic and Jurassic ages.

The Cretaceous sediments were deposited in a great inland sea, the central axis of which lay east of the Rocky Mountains and the western shore of which lay only a few miles west of the Cedar Mountain quadrangle. As a result of the erratic and heterogeneous nature of deposition along this former seashore, the Cretaceous rocks in the Cedar Mountain quadrangle show many marked variations in composition and texture—from coal, representing onshore deposition; to sandstone and conglomerate, representing near-shore deposition; and to shale, representing nearshore and offshore deposition. These changes in lithology may take place in very short distances both vertically and horizontally, and greatly complicate the work of mapping and describing the Cretaceous rocks. The previous workers, Lee (1907), Richardson (1909), and Gregory (1950a), have also remarked upon the heterogeneous nature of the Cretaceous rocks in this area and the difficulty of establishing valid mappable subdivisions in the thick sequence of beds.

Viewed as a whole, the rocks of Cretaceous age in the Cedar Mountain quadrangle consist of a lower nonresistant shale and sandstone unit, a middle highly resistant cliff-forming sandstone unit, and an upper nonresistant sandstone and shale unit. Gregory (1950a, p. 43–50) recognized this threefold division and assigned the name Tropic formation to the lower nonresistant unit, but designated a thin discontinuous sandstone or conglomerate unit at the base as the Dakota(?) sandstone. To the middle resistant unit he assigned the name Straight Cliffs sandstone, and to the upper nonresistant unit he assigned the name Wahweap sandstone. These subdivisions of the Cretaceous are described in greater detail below.

DAKOTA(?) SANDSTONE

The contact between Cretaceous rocks and the underlying Winsor formation is marked everywhere in the Cedar Mountain quadrangle by a pronounced disconformity, but the basal Cretaceous beds differ greatly from place to place. Locally, in the southwest corner of the mapped area, a 10-foot conglomerate sequence with 4-inch cobbles overlies the Winsor. (See fig. 11.) A few miles away, however, the contact is marked by a few inches of yellow sand with shale above and below. Elsewhere, and most characteristically, the basal part of the Cretaceous consists merely of sandstone beds typically less than 10 feet thick but locally as much as 70 feet thick.

Gregory (1950a, p. 45) assigned these heterogeneous basal beds of the Cretaceous to the Dakota(?) sandstone, but grouped them with the overlying Tropic formation on his map. Because the basal beds of the Cretaceous have no persistent lithologic continuity in the Cedar Mountain quadrangle, it seems best to regard them as local manifestations of the unconformity at the base of the Tropic formation and not as a separate but unmappable formation. Accordingly, in this report the basal beds of the Cretaceous are included in the Tropic formation, and use of the term Dakota(?) sandstone is abandoned for the Cedar Mountain area.

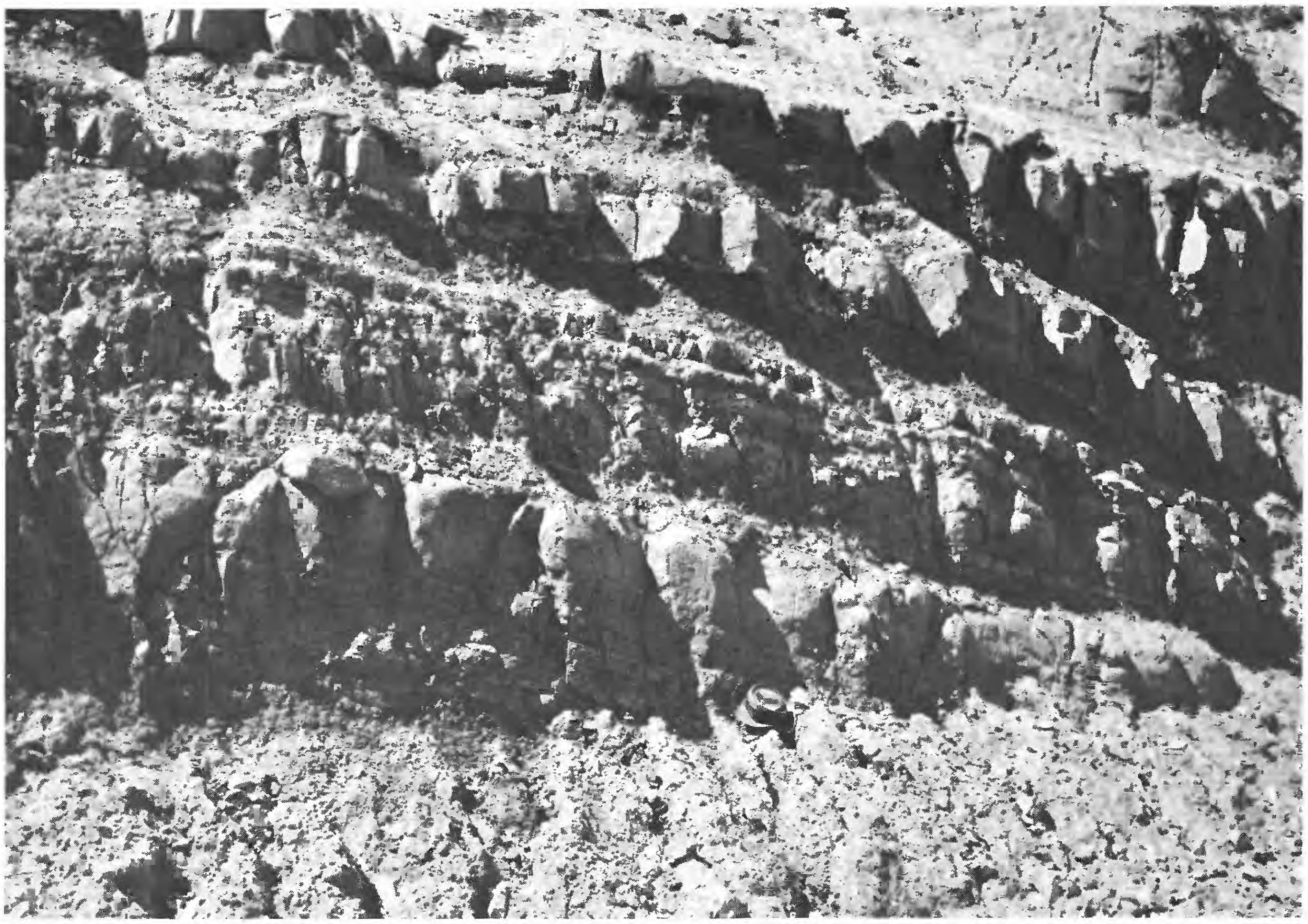

FIGURE 10.—Upper part of the Winsor formation at head of Pine Hollow in the northeast corner of sec. 18, T. 38 S., R. 11 W.

TROPIC FORMATION

The Tropic formation was defined and named by Gregory and Moore (1931, p. 98–100) from exposures near the town of Tropic in Garfield County, Utah. Gregory (1948, 1950b, 1951) subsequently traced the formation from the type locality through the Paunsaugunt region, central Kane County, and Zion National Park to eastern Iron County. The formation is of early Colorado (Greenhorn and Carlile) age and is thus equivalent to the Tununk shale and the Ferron sandstone members of the Mancos shale in the Henry Mountains region (Cobban and Reeside, 1952).

In mapping the Tropic formation in eastern Iron County, Gregory (1950a, p. 45–46) drew the upper boundary at the base of the lowest cliff-forming sandstone bed in the overlying Straight Cliffs sandstone. Gregory noted that the basal sandstone beds in the Straight Cliffs sandstone were intertongued with beds of Tropic lithology, and that the contact could not be drawn at the same horizon at all localities. Nevertheless, the division was desirable as a means of emphasizing the difference in lithology and topographic expression between the two formations.

In the Cedar Mountain quadrangle the most distinctive and persistent stratigraphic change between rocks of dominantly Tropic lithology and rocks of dominantly Straight Cliffs lithology takes place at the top of the Upper Culver coal zone. (See p. 26 and section on coal.) Throughout the entire area of the quadrangle the Upper Culver coal zone is overlain by a distinctive gray fossiliferous marine calcareous shale, or marl, 5 to 10 feet thick. The most conspicuous fossil in the marl is the spiral gastropod *Admetopsis*, known popularly as a "screw shell." This marl records a minor but pronounced westward advance of the Upper Cretaceous sea over the preexisting coastal-plain type of coal swamp.

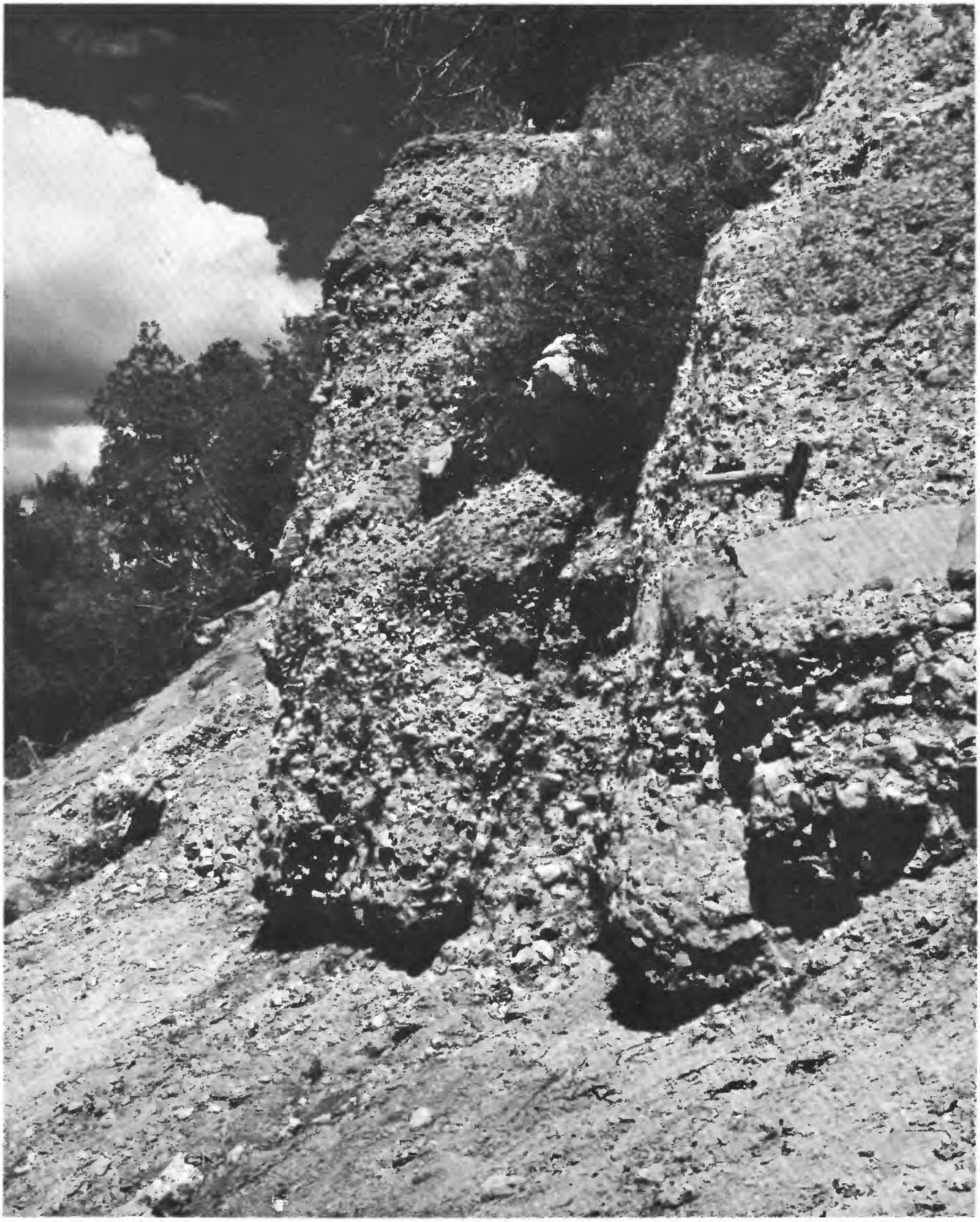

FIGURE 11.—Local conglomerate zone at base of the Tropic formation (Dakota(?) sandstone of Gregory). In NW¼NW¼ sec. 7, T. 38 S., R. 11 W.

Although this contact involves soft and nonresistant rocks both above and below, it is easily located in the field by sporadic coal prospect pits, by shows of coal bloom, or by washed-out fragments of the overlying gray marl. Thinner beds of gray marl and coal occur lower in the immediate sequence, but the marl overlying the Upper Culver coal zone is the thickest and best exposed, and the underlying coal is the thickest and most generally prospected.

About 20 feet above the top of the Upper Culver coal zone are the first resistant ledges of the Straight Cliffs sandstone as here defined, and at many places in the quadrangle these ledges provide a readily visible marker for the Upper Culver coal zone and the upper boundary of the Tropic. Unfortunately, the beginning of resistant sandstone ledges in the stratigraphic sequence is not everywhere a reliable marker for the coal. About 40 feet below the top of the Upper Culver coal zone, and just below the base of the Lower Culver coal zone, is the top of a sequence of thin- to medium-bedded sandstone. At several places in the quadrangle, particularly on the Kanarra Mountain road and on the south side of the Shurtz Creek amphitheater, the upper part of this sequence crops out as a conspicuous ledge, and, as the lowest resistant sandstone ledge in the sequence, closely resembles the ledge overlying the Upper Culver coal zone. In the southeast corner of the quadrangle this lower ledge crops out in the lower part of Crystal Creek canyon, and in that area is a distinct mappable unit. In mapping the Orderville NW quadrangle to the southeast, Pillmore (1956) used the base of this lower ledge as the top of the Tropic formation. Neglecting expectable stratigraphic changes between the two areas, the base of the Straight Cliffs sandstone in the Orderville NW quadrangle is about 150 feet lower than the base selected for the Cedar Mountain quadrangle.

Because the top of the Upper Culver coal zone is demonstrably a more persistent and reliable stratigraphic boundary in the Cedar Mountain quadrangle than the base of any of the associated sandstone ledges, it is hereby adopted as the upper boundary of the Tropic formation as used in this report. This choice also permits the use of a single line on the geologic map (pl. 1) to represent both the boundary between the Tropic formation and the Straight Cliffs sandstone and the outcrop of the Upper Culver coal zone, which contains the thickest coal in the quadrangle.

Cobban and Reeside (1952) have mentioned that fossils of latest Carlile age have not been found in the Tropic formation of the Hurricane Cliffs region, and they suggest, tentatively, that a hiatus exists between the Tropic formation of Carlile age and the overlying Straight Cliffs sandstone of Niobrara age. Although the contact between the Tropic formation and the Straight Cliffs sandstone as described above marks a pronounced stratigraphic change in a sequence of intercalated marine and continental beds, it provides no evidence of significant erosion between deposition of the coal and deposition of the overlying marl. On the other hand, the sequence of marine and continental beds at the top of the Tropic provides conclusive evidence of several abrupt changes in environment in which a minor hiatus in the fossil record could occur.

As here defined, the Tropic formation is about 1,075 feet thick in the Cedar Mountain quadrangle. In Coal Creek, north of the Cedar Mountain quadrangle, Gregory (1950a, p. 80, 84) reported the Tropic formation to be 206 feet thick, and at the head of Spring Canyon, south of the Cedar Mountain quadrangle, he reported it to be 868 feet thick.

Of the total thickness of the Tropic formation, 80 to 85 percent is nonfissile blocky shale, and the remainder is fine- to medium-grained sandstone in beds typically 1 to 5 feet thick, but reaching a maximum of 70 feet thick. The sandstone beds are thickest and most numerous near the base of the formation. Most of the sandstone beds are lenticular, and rarely persist more than a few hundred yards. A few beds contain thin coarse-grained or conglomeratic layers or exhibit minor crossbedding.

The upper part of the Tropic formation and the lower part of the Straight Cliffs sandstone of the Cedar Mountain quadrangle contain several coal-bearing zones as follows:

Straight Cliffs coal zone.—Coal and shale 4 ft thick about 75 ft above base of Straight Cliffs sandstone.

Upper Culver coal zone.—Coal and shale 10 to 14 ft thick at top of Tropic formation as here defined. Contains thickest and best coal in the quadrangle.

Lower Culver coal zone.—Coal and shale 7 to 13 ft thick. Lies 11 to 34 ft below base of Upper Culver coal zone. Contains thin beds of minor economic importance.

Willow Creek coal zone.—Coal and shale about 9 ft thick. Lies 145 ft below top of Tropic formation. Coal too thin to be of economic importance.

These zones are described in greater detail in the section on coal.

Gregory (1950a, p. 80, 84) has mentioned that thin impure coal beds occur in the basal 100 feet of the Tropic formation in eastern Iron County, but in the Cedar Mountain quadrangle only a few thin layers of carbonaceous shale were observed at this stratigraphic position.

Fossils of marine, brackish-, and fresh-water origin have been collected at various places both vertically and horizontally throughout the Tropic formation. (See Richardson, 1927; Gregory, 1950a, p. 55, and 1950b, p. 104). These fossils and the enclosing sediments provide evidence of many changes in sea level and position of the shoreline in Tropic time (Spieker and Reeside, 1926; Gregory, 1950b, p. 102–105). In general, the lower part of the formation was deposited in brackish water very near shore, as evidenced not only by fossils of brackish-water origin, but also by local conglomerate beds and crossbedded sandstone. Higher in the formation the fossils are dominantly of marine origin, and the characteristic sedimentary material is shale, representing deposition farther from shore.

The maximum westward advance of the Upper Cretaceous sea probably took place during the middle or upper middle part of Tropic deposition. The major eastward retreat of the sea began in late Tropic time, and continued throughout deposition of the Straight Cliffs sandstone, which represents a major return to near-shore type of deposits. However, the major advance and retreat of the sea was greatly complicated by many minor short-term oscillations of sea level, which are primarily responsible for the heterogeneous nature of the formation.

Each of the several coal zones in the Tropic formation, for example, records a minor eastward retreat of the sea, which created for a short time the near-shore swampy environment necessary for plant accumulation. The marine marl or shale overlying each coal zone records a relatively rapid westward advance of the sea, terminating plant accumulation.

Because of the high percentage of shale in the Tropic formation it weathers to relatively smooth slopes below the cliffs of the more resistant Straight Cliffs sandstone. These weathered slopes are remarkably unstable and have given rise to numerous landslides. The largest and most conspicuous slide in the area is the mile-long tongue of debris from the Tropic formation in Green Hollow just north of the Cedar Mountain quadrangle, which extends from near the top to the base of the Hurricane Cliffs, obscuring all the older formations. Elsewhere, most of the outcrop of the Tropic formation is largely concealed by slump and landslide material, which ranges in thickness from 10 to about 50 feet, measured normal to the slope, and by a thick growth of scrub oak, which is more abundant on the Tropic formation than on other formations in the stratigraphic sequence.

The Tropic formation is partly exposed in an undisturbed condition at only three places in the Cedar Mountain quadrangle: (1) on the ridge between the forks of Shurtz Creek in secs. 13 and 14, T. 37 S., R. 11 W.; (2) on the ridge below Graff Point in the center of sec. 29, T. 37 S., R. 11 W.; and (3) on the northwest and southwest slopes of Bean Hill in sec. 8, T. 38 S., R. 11 W. It is best exposed at the second locality where the following section was measured:

Section of Tropic formation on point in the center of sec. 29, T. 37 S., R. 11 W., just above the Kanarra Mountain road

Cretaceous:	
Straight Cliffs sandstone.	
Tropic formation:	*Feet*
1. Upper Culver coal zone. Not exposed; thickness includes shale partings	12
2. Largely concealed. Mostly shale with a few 2- to 10-ft beds of sandstone	373
3. Sandstone, fine-grained	6
4. Largely concealed. Contains several 5-ft beds of sandstone, but shale is at least two-thirds of total	140
5. Sandstone, fine-grained, thin-bedded. Top bed 1 ft thick, others 2 to 4 in.	6
6. Shale, dark-gray to light olive-gray (5*Y* 5/2); some red brown. Contains 2 or 3 thin beds of fine-grained sandstone	35
7. Sandstone, fine- to medium-grained, arkosic, pale yellowish-orange (10*YR* 8/6); in beds 1 to 3 ft thick. Thins in both directions along strike	16
8. Shale, light- to dark-gray, with carbonaceous shale zone 1 ft thick near top	22
9. Sandstone, fine- to medium-grained. Layers 2 in. thick	7
10. Concealed	9
11. Sandstone, fine- to medium-grained, thinly laminated. No outcrop, but strong line of slumped blocks	2
12. Concealed slope. Largely shale, but may contain a few beds of sandstone 1 ft or less thick	75
13. Shale, light- to medium-gray	6
14. Shale, carbonaceous	2
15. Shale, light-gray to olive. Sandy at base	15
16. Sandstone, fine- to medium-grained, pale yellowish-orange (10*YR* 8/4); in beds 1 to 2 ft thick	7
17. Concealed	40
18. Sandstone, fine-grained, pale yellowish-orange (10*YR* 8/4)	2
19. Shale, light- to dark-gray, with 2-ft zone of carbonaceous shale in middle	13
20. Sandstone. Like unit 18	2
21. Concealed	17
22. Sandstone. Like unit 18	2
23. Shale, light olive-gray (5*Y* 5/2) to dark-gray, with some carbonaceous shale in float	18

	Feet
Cretaceous—Continued	
Tropic formation—Continued	
24. Sandstone, fine- to medium-grained; with few thin coarse-grained layers; arkosic; minor small-scale crossbedding; grayish-yellow (5*Y* 8/4) to pale yellowish-orange (10*YR* 8/6). Beds 5 to 10 ft thick, separated by thin shale beds	80
25. Concealed slope. Largely shale, but exposures elsewhere show thick sandstone at base. The section in Shurtz Creek contains two 40-ft sandstone beds at base, overlain by a shale and mudstone sequence in which red mudstone is conspicuous	160
26. Conglomerate, mostly chert and quartzite in pebbles typically 1 to 2 in. across, but with cobbles as much as 4 in. across	5
Total, Tropic formation	1, 072
Winsor formation.	

STRAIGHT CLIFFS AND WAHWEAP SANDSTONES

The Straight Cliffs and Wahweap sandstones, which overlie the Tropic formation, were defined and named by Gregory and Moore (1931, p. 100–104) from exposures in the Kaiparowits region. In mapping areas to the west, Gregory (1948, 1950a, 1951) treated the two sandstone sequences as one undifferentiated unit because persistent regional changes in lithology obscured the original boundary. On the geologic map (pl. 1) the two formations are also undifferentiated for reasons explained in the description of the Straight Cliffs sandstone below. However, the absence of a boundary between the two formations is of little consequence in the Cedar Mountain area because the Straight Cliffs sandstone crops out on a very steep slope, and the upper boundary would lie very near and parallel to the lower boundary. Nevertheless, the two units exhibit differences in lithology and topographic expression that merit individual description.

STRAIGHT CLIFFS SANDSTONE

As here interpreted, the Straight Cliffs sandstone of the Cedar Mountain quadrangle is about 600 feet thick. It forms the uppermost ledges at the top of the Hurricane Cliffs and the inner canyon walls of Crystal Creek.

The Straight Cliffs sandstone consists of a sequence of fine-grained massive marine sandstone beds intercalated with perhaps an equal amount of siltstone. The sandstone beds, which form the conspicuous outcrops, range in thickness from 5 to as much as 40 feet, but are highly lenticular. The amount of sandstone in the Straight Cliffs sequence seems to be greatest in the Hurricane Cliffs and at the head of Crystal Creek. East of these points the sandstone seems to decrease, and the bedding seems to become more uniform. Most of the sandstone beds are friable, and the formation is particularly difficult to core drill.

The Straight Cliffs sandstone also contains 4 or 5 layers of oyster shells, individually 1 to 6 feet thick, distributed throughout the total thickness. Near the base it contains a 20-foot sequence of shale and carbonaceous shale overlying the basal marine marl, which was discussed above.

The Straight Cliffs sandstone is of late Colorado (Niobrara) age and is roughly equivalent to the Blue Gate shale of the Henry Mountains region and to the middle part of the Mancos shale of Colorado (Cobban and Reeside, 1952). Lists of representative fossils from the Straight Cliffs sandstone are contained in reports by Richardson (1927) and Gregory (1950a, p. 55–56; 1950b, p. 107).

In areas to the east Pillmore (1956) and Cashion (1961) selected the top of the highest resistant sandstone bed in the sequence as the top of the Straight Cliffs sandstone. This line has been traced from Pillmore's area westward about 2 miles into the Cedar Mountain quadrangle, and is shown on the geologic map (pl. 1) in secs. 6 and 7, T. 38 S., R. 10 W., on the north side of Crystal Creek. This boundary cannot be traced with certainty west of this general area.

Taking into account the different basal boundaries selected for the Straight Cliffs sandstone in the Cedar Mountain quadrangle and in the Orderville NW quadrangle to the southeast (Pillmore, 1956), and the uncertainty as to the upper boundary in the Cedar Mountain quadrangle, the Straight Cliffs sandstone in its gross aspects seems to maintain a fairly uniform thickness of about 600 feet across the two quadrangles.

WAHWEAP SANDSTONE

Sandstone beds like those in the Straight Cliffs continue without interruption into the overlying sequence considered to be equivalent to the basal part of the Wahweap sandstone; but the beds gradually decrease in thickness, number, and resistance to erosion, and a few hundred feet above the base the Wahweap consists primarily of shale and siltstone.

In the section of the Straight Cliffs and Wahweap sandstones the boundary between the two units was selected at the top of the highest conspicuous resistant sandstone bed in the sequence, and on this basis conforms, at least roughly, with the boundary selected by Pillmore (1956) and Cashion (1961), which is shown on plate 1 in secs. 6 and 7, T. 38 S., R. 10 W., on the east side of the quadrangle. Using this boundary, the part of the Wahweap sandstone exposed in the Cedar Mountain quadrangle is 987 feet thick. The contact between the Wahweap sandstone and the overlying Kaiparowits formation lies several miles east of the Cedar Mountain quadrangle and across a wide expanse of deeply eroded canyons at the head of the Virgin River drainage.

The Wahweap probably is of latest Colorado (Niobrara) age (Cobban and Reeside, 1952).

A section of the Straight Cliffs and Wahweap sandstones measured from a point on the east edge of the quadrangle in sec. 20, T. 37 S., R. 10 W., up the west fork of Urie Creek and down the divide north of the road in Shurtz Creek is given below:

Partial section of Straight Cliffs and Wahweap sandstones from east edge of quadrangle in sec. 20, T. 37 S., R. 10 W., up west fork of Urie Creek and down divide north of road in Shurtz Creek

	Feet
Cretaceous:	
Wahweap sandstone:	
1. Concealed. Mostly gray shale with a few 4- to 6-in. beds of sandstone	182
2. Sandstone, fine- to medium-grained, soft, friable, pale yellowish-orange (10*YR* 8/6). Contains a few hard beds. Forms small dunes here but not elsewhere	15
3. Concealed	64
4. Sandstone, fine-grained, arkosic, yellowish-orange (10*YR* 7/6)	½
5. Concealed	8
6. Sandstone, like unit 4	1¼
7. Shale, gray	1
8. Sandstone, like unit 4	1¼
9. Shale, gray	1
10. Ledge containing abundant oyster shells	1
11. Concealed; largely shale	11
12. Shale, medium light-gray	6
13. Shale, carbonaceous	1
14. Concealed; mostly gray shale	21
15. Marly clay, dark yellowish-brown (10*YR* 4/2). Contains fossil fragments plus oyster shells	2
16. Shale, carbonaceous	2
17. Shale, light brownish-gray (5*YR* 6/2)	7
18. Limestone, argillaceous, yellowish; no fossils	1
19. Shale, gray	6
20. Shale, carbonaceous. Radioactivity 2.2 times background	2
21. Coal. Radioactivity 2.2 times background	¼
22. Shale, carbonaceous, with coaly streaks. Radioactivity 2.2 times background	2½
23. Clay, orange-yellow	½
24. Coal. Radioactivity 2.9 times background	⅔
25. Shale, carbonaceous. Radioactivity 2.2 times background	2
26. Shale, light olive-gray (5*Y* 6/1). Radioactivity 1.9 times background	4
27. Sandstone, thin-bedded, fine- to medium-grained, arkosic, grayish-yellow (5*Y* 8/4) to pale yellowish-orange (10*YR* 8/6). Radioactivity 1.6 times background	1
28. Shale, light olive-gray (5*Y* 6/1). Radioactivity 2.0 times background	3
Cretaceous—Continued	
Wahweap sandstone—Continued	
29. Clay, marly, dark yellowish-brown (10*YR* 4/2). Contains white fossil fragments. Radioactivity 1.7 times background	2
30. Shale, carbonaceous, with coaly streaks. Radioactivity 2.2 times background	½
31. Shale, brown, clayey. Radioactivity 2.2 times background	1
32. Concealed. Radioactivity 1.7 times background	4
33. Sandstone, fine- to medium-grained, arkosic, grayish-yellow (5*Y* 8/4) to pale yellowish-orange (10*YR* 8/6). Radioactivity 1.4 times background	2
34. Concealed. Probably gray shale. Contains few oyster shells in float. Radioactivity 1.4 times background	5
35. Ledge containing abundant oyster shells. Radioactivity 1.4 times background	1
36. Concealed. Probably gray shale. Radioactivity 1.4 times background	2
37. Ledge containing abundant oyster shells Radioactivity 1.4 times background	3
38. Concealed. Mostly soft gray shale with few thin beds of fine-grained sandstone and ledges of oyster shells. Thickness calculated from width of outcrop versus dip	570
39. Sandstone, fine-grained, very pale orange (10*YR* 8/2); in beds 1 in. to 1 ft thick; outcrop inconspicuous; some oyster shells	12
40. Concealed, dark soil. Probably carbonaceous shale and gray shale with a few thin, 2- to 4-in. beds, of sandstone	37
Total, Wahweap sandstone, measured	987
Straight Cliffs sandstone:	
41. Ledge containing abundant oyster shells	3
42. Sandstone, fine-grained, thin-bedded, very pale orange (10*YR* 8/2), laminated at top, massive at base. Contains a few medium- to coarse-grained layers in upper part of massive beds	43
43. Concealed	75
44. Sandstone, fine-grained	2
45. Concealed	3
46. Ledge containing abundant oyster shells	5
47. Sandstone, fine-grained, very pale orange (10*YR* 8/2); in beds 1 to 5 ft thick. Contains a few oyster shells. Forms conspicuous outcrop	59
48. Concealed	90
49. Sandstone containing oyster shells. Forms ledge	6
50. Sandstone, fine-grained; in beds 1 to 2 ft thick, and shale; partly concealed	33
51. Sandstone, fine-grained, dense, very pale orange (10*YR* 8/2); in beds a few inches to 5 ft thick. Contains many oyster shells	27
52. Concealed	48
53. Ledge containing abundant oyster shells	1
54. Sandstone, fine-grained, very pale orange (10*YR* 8/2); in beds 4 in. to 1 ft thick; partly concealed	13

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Cretaceous—Continued

Straight Cliffs sandstone—Continued	Feet
55. Concealed	11
56. Sandstone, fine-grained, dense, very pale orange (10*YR* 8/2); in massive beds 5 to 10 ft thick. Forms conspicuous outcrop	40
57. Concealed	65
58. Concealed. Heavy float of oyster shells	8
59. Sandstone, fine-grained, very friable, very pale orange (10*YR* 8/2); some crossbedding; in beds 6 in. to 5 ft thick. Does not form ledge	18
60. Concealed	7
61. Sandstone, very fine grained, very pale yellowish orange (10*YR* 8/4); in beds 2 in. to 1 ft thick	6
62. Concealed. Probably soft marl and siltstone	40
Total, Straight Cliffs sandstone	603

Tropic formation.

IGNEOUS ROCKS

About one-fifth of the area of the Cedar Mountain quadrangle is covered by thick olivine basalt flows and associated cinder cones, which are conspicuous features of the landscape. Three small obscure outcrops of several varieties of older volcanic rocks of intermediate to acid composition are also present. The basalt is very resistant to erosion, and has produced many sheer cliffs and an equal number of large talus slopes. Boulders and cobbles of basalt and older volcanic rocks form a considerable part of the material in pediment, fanglomerate, and stream-channel deposits, and thus are to be found in all parts of the quadrangle.

OLDER VOLCANIC ROCKS

Outcrops of older volcanic rocks of early Tertiary age, and of intermediate to acid composition, are present at three small exposures in the Cedar Mountain quadrangle. Two of these exposures lie very close together on the North Hills at the base of the Hurricane Cliffs, and the third lies about 6 miles to the east and about 3,000 feet higher on the Kolob Terrace. The igneous rocks at the two localities are different in type and origin, and must be described separately.

WELDED TUFF DEPOSITS ON THE NORTH HILLS

Two small outcrops of welded tuff are partly exposed below gravel of the fanglomerate on the North Hills in the SW¼ sec. 5, T. 37 S., R. 11 W. The tuff in the northern outcrop is apparently the same as Member D of the tuff sequence described by Mackin (1954) in the Granite Mountain area of the Iron Springs district to the west. The tuff in the southern outcrop is apparently the same as Member E, which overlies Member D in the Granite Mountain area.

KOLOB LATITE

The third occurrence of older volcanic rock in the Cedar Mountain quadrangle is a small outcrop of porphyritic quartz latite that is exposed on the Kolob Terrace on the west side of Urie Creek near the center of sec. 17, T. 37 S., R. 10 W. At this point the quartz latite lies below a thick flow of younger basalt, which forms an extensive lava plateau on the west side of Urie Creek.

The latite, here named the Kolob latite, is evidently the lower part of an early and once more extensive lava flow, or series of flows, that originated east of and higher than the present outcrop, as evidenced by many boulders of this rock in surficial deposits east of the Cedar Mountain quadrangle.

The shape of the outcrops of both the quartz latite and the overlying basalt suggest that they occupy a former stream channel that drained either to the north or west.

The Kolob latite exhibits many conspicuous phenocrysts of plagioclase and small amounts of ferromagnesian minerals in a fine-grained matrix. The plagioclase phenocrysts, which comprise 40 to 45 percent of the rock, are light gray and of intermediate lime-soda (Ab_5–An_5) composition. A few of the crystals are zoned. The individual crystals range typically from 2 to 5 mm in the long dimension, but a few are as much as 1.5 cm long.

The ferromagnesian minerals consist of euhedral crystals of augite and biotite. Both of these minerals show partial alteration to magnetite, hematite, and chlorite. The biotite is the more highly altered of the two, and exhibits pronounced reaction rims. Accessory minerals are magnetite and apatite.

The matrix is a microgranular intergrowth of quartz and orthoclase.

The percentage distribution of each of the several major components of the rock is about as follows:

	Percent
Matrix (quartz and orthoclase)	45–50
Plagioclase (Ab_5–An_5)	40–45
Augite	4– 6
Biotite	2– 4

The weathered surface of the rock is light gray or pinkish gray, and exhibits a rough granitelike texture. The porphyritic character is not readily apparent because of the preponderance of phenochrysts. A few of the large crystals of plagioclase, which are conspicuous and diagnostic features of the rock, are visible on most large surfaces.

As determined by the distribution of residual boulders in surficial deposits, the Kolob latite was restricted in its former area of occurrence to the area generally east of the Cedar Mountain quadrangle and on a surface generally higher than the present surface of the Kolob Terrace. As far as known, it is not present in the Tertiary volcanic sequence of nearby surrounding areas. Nevertheless, the Kolob latite is certainly the same general age as other volcanic rocks of acid to intermediate composition, which are present throughout southwestern Utah. Gardner (1941, p. 251) has assigned a Miocene(?) age to latite flows in the area south and west of the Cedar Mountain quadrangle, and Thomas and Taylor (1946, p. 30–31) have assigned the same age to the older "extrusive acidic rocks" in the nearby Cedar City Valley. Mackin (1954) has assigned an Eocene(?) age to the older volcanic rocks in the Granite Mountain area of the Iron Springs district because they are conformable with the underlying Wasatch formation. It seems likely, therefore, that the Kolob latite is of early Tertiary age—certainly no older than Eocene and no younger than Miocene.

In common with most volcanic rocks of acid to intermediate composition, the Kolob latite is slightly radioactive. Data on the radioactivity of the outcrop described above are contained in the section on uranium.

BASALT FLOWS, DIKES, AND RELATED CINDER CONES

Much of the upland surface of the Cedar Mountain quadrangle is covered by layers of hard dark-gray to black olivine basalt that has provided the most recent, and perhaps the most conspicuous, modification to the topography. The basalt exhibits many characteristic variations in texture, from hard, dense material in the centers of the flows, to scoriaceous material on the surfaces. It is composed fairly uniformly of labradorite, with numerous and conspicuous phenocrysts of olivine and successively smaller amounts of augite and magnetite.

The flows appear to have issued from openings below the six cinder cones—from north to south: Lone Tree Mountain; Pryor Knoll; The Three Knolls,[4] including Pine Spring Knoll at the south; and Co-op Knoll, which lie in a line along the crest of the Hurricane Cliffs. At the time of the lava outpouring the Hurricane Cliffs had attained part of their present elevation, but the broad eastward-sloping upland surface of Cedar Mountain was less dissected than at present.

BASALT FLOWS

The visible basalt flows emanated in several periods of eruption, of diminishing intensity and quantity so that, in general, the older flows are the most widespread. The successive flow layers stand out fairly clearly in a few localities, as in sec. 3, T. 38 S., R. 11 W., where two distinct flows are clearly visible; or as in the open meadow in sec. 1, T. 37 S., R. 11 W., and sec. 6, T. 37 S., R. 10 W., where the topographic relief on the weathered basalt suggests four periods of flow. Similarly, two steeply dipping flows, each 10 to 12 feet thick, separated by a soil zone are exposed on the south side of the Lone Tree Mountain cinder cone just north of the Cedar Mountain road in sec. 36, T. 36 S., R. 11 W. Over most of the Cedar Mountain area, however, the basalt surfaces have weathered to a fair soil zone, and now support a profuse growth of aspen.

In marked contrast with the relatively large quantities of basalt that characterize the upland surfaces at the top of the Hurricane Cliffs, only small quantities are present at the base of the Hurricane Cliffs—notably in association with the fanglomerate deposits on the North Hills. Here the basalt has been broken by several faults in the Hurricane fault zone, and, for the most part, now dips toward the Hurricane Cliffs.

BASALT FILLING OF ANCIENT STREAM CHANNELS

As the first flows poured out upon the upland surface of Cedar Mountain, the lava must have followed the shallow channels of the then-existing streams. The most conspicuous of these channels underlies the two-pronged mass in secs. 1, 2, and 12, T. 38 S., R. 11 W. (pl. 1), that clearly marks a right-angle turn in a former course of Shiver Creek. This older channel, now preserved in basalt, is about 600 feet above the present channel, and provides a measure of the low relief of the topography before the outpouring of the lava as well as the depth of erosion after the lava was deposited. (See fig. 12.)

The upper surface of the southward-pointing prong dips 2° south (upstream), and the base presumably rises at about the same rate to the point where the prong tapers out. The upper surface, and presumably also the base, of the eastward-pointing prong dips about 3° E. (downstream), and the whole prong thins in this direction also.

For a time after the initial filling of the ancestral Shiver Creek channel the water continued to flow over the basalt. With rapid headward and downward erosion, however, the stream soon worked southward

[4] The name, "The Three Knolls," was assigned by Gregory (1950a, p. 97; pl. 2) to the three closely spaced cinder cones in secs. 26 and 35, T. 37 S., R. 11 W., shown roughly in the center of plate 1. The northernmost of the three is marked by a triangulation station, altitude 10,135 feet, and the southernmost is Pine Spring Knoll. The two northern knolls are unnamed.

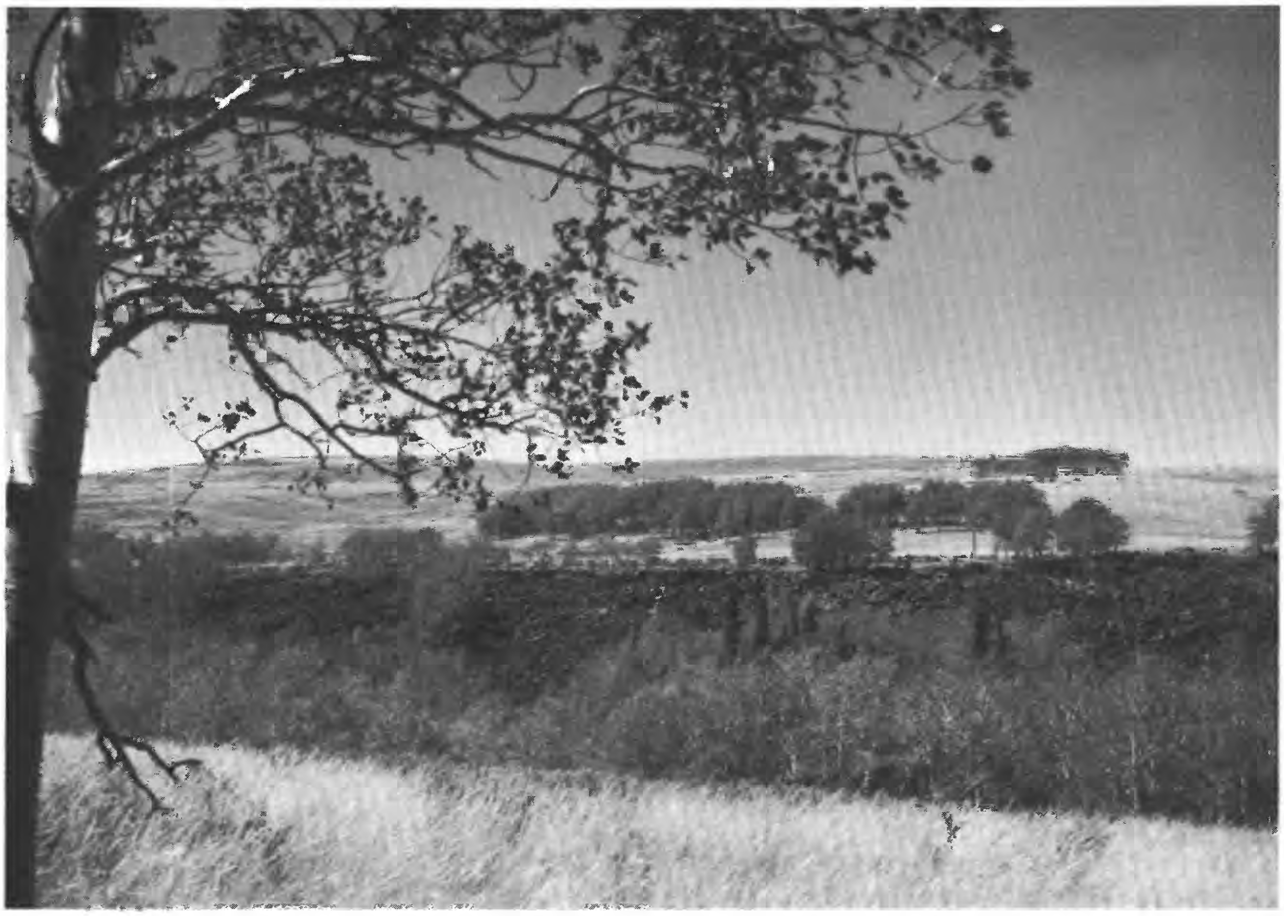

FIGURE 12.—Basalt flow in older and higher channel of Shiver Creek. View looking west across modern channel of Shiver Creek in sec. 12, T. 38 S., R. 11 W.

and eastward and cut a new parallel channel in the softer sedimentary rock. The top of the basalt is still covered with pebbles and cobbles remaining from this earlier period of stream history. The shift of the channel also forced the eastward-flowing tributaries of Shiver Creek to join in a new direction of flow along the west edge and around the south end of the southward-pointing prong. This indirect course is now in process of being shortened by erosion of the lava prong.

The west edge of the large sheet of basalt in secs. 5, 6, 7, 8, 17, 18, and 19, T. 37 S., R. 10 W., also terminated in an ancestral channel of Urie Creek ¼ to ½ mile west of the present channel, as evidenced by the southward-pointing prong in sec. 19 and by the northward-pointing prong in secs. 5 and 8. These two prongs, and locally the edge of the basalt between the prongs, are covered by deposits of gravel and cobbles that are relics of the period when the ancestral Urie Creek flowed over the basalt filling. The central part of the northern prong is completely concealed by the mass of gravel on top. Subsequent rapid erosion in the soft sedimentary rocks along the east edge of the basalt filling has produced the present stream channel.

The westward-projecting point of basalt in the W½ sec. 21, T. 37 S., R. 11 W., and the small isolated outcrops of basalt in sec. 20 mark the former steep course of a stream ancestral to the present Murie Creek.

THICKNESS OF FLOWS

The basalt flows range in thickness from 20 to about 200 feet, but thicker sheets are more common. The large sheet on Square Mountain in sec. 35, T. 36 S., R. 11 W., is about 200 feet thick over a considerable part of its area, as is also the sheet on the south side of the Shurtz Creek amphitheater. The large sheet in secs. 5, 6, 7, 8, 17, 18, and 19, T. 37 S., R. 10 W., is about 40 feet thick on the east edge, though this may be a local linear thickening in the former Urie Creek channel. The flows in Shiver Creek are 20 to 30 feet thick where they join, but they taper both up and down stream. The flow at the north end of the North Hills is at least 15 feet thick.

BASALT DIKES

In the NW¼ sec. 10, T. 38 S., R. 11 W., is a small 2- by 6-foot dike of basalt, enclosed in Cretaceous rocks. Other dikes in the quadrangle are directly associated with cinder cones and are discussed under that heading.

SURFACE STRUCTURES ON BASALT

Most of the surface structures on basalt in the Cedar Mountain quadrangle are obscured by the covering of soil and attendant meadowlands and timber. Locally, however, a few of the more pronounced structures typical of basalt rise above the weathered surfaces.

SPATTER CONES

At several places in the quadrangle are small spatter cones 6 to 10 feet high, which were formed by the ejection of liquid basalt from small vents on the surface of the flows. One such spatter cone occurs on the small knoll in the NW¼ sec. 18, T. 37 S., R. 10 W.

PRESSURE RIDGE

An excellent example of a pressure ridge extends longitudinally down the center of the flow in secs. 1 and 2, T. 38 S., R. 11 W. This ridge is very sharp and distinct in the east half of sec. 2, where it shows both in the topography and in the curve in the north-south section-line road. The ridge is best developed about one-quarter mile west of the road. The characteristic features of the ridge at this locality are high steep outer walls and a medial crack or depression, which extends longitudinally down the center of the ridge.

From the outside, the ridge rises 60 to 75 feet above the surrounding countryside and exhibits either a steep talus slope or a series of tree-covered slump terraces with an overall slope near the angle of repose. The medial crack or depression at the crest of the ridge is only 2 to 12 feet below the top of the enclosing walls, which from the inside are seen to be composed of basalt dipping 20° to 40° away from the center. The linear depression, which is irregular and discontinuous, ranges in width from 10 to 75 feet, and at places is a smooth grass- or timber-covered meadow. Figure 13 is a view across the widest and flattest part of the central depression at a place where the walls are about 8 feet high on the inside. Not shown in the photograph is the 60- to 75-foot drop, which occurs just beyond the walls.

FIGURE 13.—Crest of pressure ridge in sec. 2, T. 38 S., R. 11 W. Meadow is about 75 feet wide. Walls are composed of basalt dipping 20° to 40° away from center. Visible inward-facing walls are about 8 feet high. Outer walls, not visible in photograph, rise 60 to 75 feet above surrounding countryside.

The pressure ridge was formed by uplift and rupture of the lava crust along the medial line of the flow at a time when the interior of the flow was still a hot liquid. Inasmuch as the flow follows an old drainage line, the center of the flow is thicker than the edges and therefore was slowest to cool. For this reason the crust was thinnest and weakest along the medial line. If the liquid lava below the crust were part of a closed system, the uplift could be the result of hydrostatic pressure produced by newly extruded lava higher up the slope. According to this hypothesis, which has been proposed for some pressure ridges by Wentworth and Macdonald (1953), the sides of the gaping crack along the top of the ridge are edges of the broken crust that have been pushed aside and held apart by upwelling lava from below. Evidence supporting this view may be found in the wide flat meadows, presumably formed by a column of liquid lava, and by the fact that the bottom of the central depression is everywhere higher than the normal top of the flow, indicating addition of lava.

AGE OF BASALT

The basalt flows in the Cedar Mountain quadrangle are considered to be of Quaternary age, ranging from Pleistocene to Recent. The evidence for this assignment includes: (a) the flows overlie fanglomerate material, itself of late Tertiary age, (b) the flows and associated deposits of ash constitute the most recent addition to the topography on Cedar Mountain, and (c) only a nominal amount of erosion has taken place since the flows were formed.

CINDER CONES

The last manifestation of volcanic activity in the Cedar Mountain quadrangle was the formation of the six cinder cones, from north to south: Lone Tree Mountain; Pryor Knoll; The Three Knolls, including Pine Spring Knoll at the south; and Co-op Knoll. These cones rise with very steep slopes several hundred feet above the lava plateaus on which they accumulated and form the highest points in the quadrangle. Two of the cones, Pryor Knoll and the northernmost of The Three Knolls, are more than 10,000 feet above sea level and more than 4,000 feet above Cedar City Valley. The cones are now grass- and tree-covered, and their origin is not immediately apparent from a distance. (See fig. 14.)

The individual pellets making up the cones are dark red and generally are less than 1 inch in diameter. The chemical composition of the pellets is the same as that of the underlying and surrounding basalt.

The cones have been quiescent for a long time, and with the gradual wasting away of the rims the central craters have disappeared, leaving gently rounded or flattened tops. In the central areas of each of the cinder cones are one or more conspicuous dikelike masses of basalt. On Pine Spring Knoll, in particular, the basalt outcrops form a ring that must have been the throat of the cone during the period of activity.

The conspicuous alinement of the cones on the brink of the precipitous Hurricane Cliffs is most puzzling. Considering that the Hurricane fault zone has been a zone of persistent movement since early Tertiary time, one would expect a concentration of lava flows and an alinement of cinder cones along the base of the Cliffs. This is true to a limited degree, for a number of small basalt flows are clearly alined along the base of the Cliffs south of Cedar City, and there are several cones in the Red Hills area north of Cedar City. Nevertheless, the conspicuous bulk of basalt on Cedar Mountain and elsewhere on the Kolob Terrace, and, more particularly, the alinement of the six cinder cones on the brink of the Hurricane Cliffs, merit speculation and comment.

FIGURE 14.—Pryor Knoll, a weathered cinder cone on west edge of Kolob Terrace. Foreground is typical mature topography developed on gently dipping beds of Cretaceous age.

In his classic report on the High Plateaus of Utah, Dutton (1880, p. 203) observed and commented on this relation as follows:

> . . . basaltic vents occur very often upon the brink of cliffs of erosion, and never (within my own observation) at the base of one; often upon the top of the wall of a cañon and never within the cañon itself, though the stream of lava often runs into the cañon. So numerous, indeed, are the instances of cones upon the verge of a cliff of erosion or cañon-wall, that I was at one time led to suspect that it was a favorite locality. This is very conspicuous in the large basaltic field near the Grand Cañon in the vicinity of Mount Trumbull, where 10 large cones stand upon the very brink of the great abyss and have sent their lavas down into it. Away from the cañon a considerable number of craters are seen upon the various cliffs near the Hurricane Ledge, and far to the northeastward half a dozen are found upon the crests of the White Cliffs. Out of rather more than 300 basaltic cones of this region, I have noted 33, or nearly 11 percent, occupying such positions. Whether this is accidental it is difficult to say, but when it is remembered that they do not occur at the bases of such cliffs, nor in the cañons (so far as I have observed), the fact is certainly a remarkable one.

In his report on the Tertiary history of the Grand Canyon district, Dutton (1882, p. 105) commented further on this anomalous relation and concluded as follows:

> If there be any specially favored locus of eruption, with reference to a great fault, I should say that it may be found along the upthrow of the fault, and from a mile and a half to four or five miles from the plane or line of dislocation.

This relation is true to a remarkable degree in the Cedar Mountain quadrangle; it suggests that the upward movement of basalt was triggered by release of pressure at depth over a broad area on the upthrown side of the Hurricane fault.

ASH

On the geologic map (pl. 1) volcanic ash is shown only in areas near the cinder cones where the concentrations are thick enough to be expressed in the topography. However, the ash extends farther out around the bases of the cones in a veneer of gradually decreasing thickness. This covering locally obscures the underlying rock, but generally is cut through by the stronger gullies.

An interesting, isolated extrusion of ash occurs in Spanish Hollow in the SE$\frac{1}{4}$ sec. 32, T. 37 S., R. 10 W., on the extreme east edge of the quadrangle. This small outcrop is noteworthy, both because it is remote from other areas of volcanic activity and because it is near the bottom of a deeply incised valley where erosion is most vigorous. Considering its exposed location and small size, it is likely that this is the most recent manifestation of volcanic activity in the quadrangle.

SURFICIAL DEPOSITS

The Hurricane Cliffs and the Kolob Terrace have been subjected to intermittent uplift and continued erosion since early Tertiary time. The erosion has progressed at a very rapid rate as a consequence of the pronounced elevation of the upthrown block, which is 9,000 feet or more above sea level over most of the area of the Kolob Terrace. One of the more interesting products of the downcutting, other than the conspicuous cliffs and canyons, is the vast quantity of clastic material, including silt, sand, gravel, cobbles, and boulders, that has been transported and redeposited in various parts of the quadrangle.

This material occurs as isolated and abandoned stream-channel deposits and as ancient pediment deposits on the highest parts of the Kolob Terrace; as a gravel covering of a pedimentlike surface in the Shurtz Creek valley; as bolson and fanglomerate deposits in the Cedar City Valley; and as talus, landslide debris, and Recent alluvium in various parts of the quadrangle.

ABANDONED STREAM-CHANNEL DEPOSITS ON KOLOB TERRACE

Lying generally east of the Cedar Mountain quadrangle, but extending a short distance into the eastern part of the quadrangle, is a system of long, narrow ridges capped with gravel that are interpreted as abandoned stream channels. The largest abandoned stream channel within the boundaries of the Cedar Mountain quadrangle crops out in the south half of sec. 17, T. 37 S., R. 10 W. (See pl. 1.)

The material in this deposit ranges in size from small pebbles to boulders 10 to 12 feet in diameter. The pebbles and cobbles are well rounded, the small boulders are subrounded, and the large boulders are subangular to angular. The material was derived from the Kaiparowits formation of latest Cretaceous age, the Wasatch formation of early Eocene age, and the Kolob latite of early Tertiary age. Basalt is not present. The deposit disappears beneath basalt in the SW¼ sec. 17 and is therefore older than basalt. It is considered to be of middle to late Tertiary age. The channel was undoubtedly formed at or near the base of the Wasatch Cliffs at a time when they stood about 5 miles west of their present position.

Other channel deposits shown on plate 1 are much younger. They all contain basalt, and are related to the present erosion cycle.

ABANDONED GRAVEL-COVERED PEDIMENT ON KOLOB TERRACE

In secs. 2, 3, 4, and 10 of T. 37 S., R. 10 W., less than a mile east of the Cedar Mountain quadrangle, is the lower west end of a high gently sloping gravel-covered pediment. Like the abandoned stream-channel deposit in sec. 17, the pediment is a relic of an earlier erosion cycle, and is also of middle to late Tertiary age. The pediment formerly extended westward into the east edge of the Cedar Mountain quadrangle as evidenced by the unusual concentration of quartzite cobbles along the road in sec. 8, T. 37 S., R. 10 W.

FANGLOMERATE DEPOSIT AT NORTH HILLS

The fanglomerate deposit at North Hills caps a low hill at the base of the Hurricane Cliffs in the northwest corner of the Cedar Mountain quadrangle (pl. 1). The deposit covers an area of about 1 square mile in the quadrangle and several square miles west of the quadrangle. The fanglomerate material ranges in size from small pebbles to boulders as much as 10 feet in diameter and ranges in composition from the Navajo sandstone to the Kolob latite. Particularly abundant and conspicuous in the fanglomerate are cobbles and boulders of limestone of the Wasatch formation and Kolob latite and cobbles of quartzite from conglomerate beds in the Kaiparowits formation. Except for small amounts of material from the Navajo sandstone and the Carmel formation, the fanglomerate material closely resembles in both composition and texture material in the abandoned stream-channel deposit in sec. 17, T. 37 S., R. 10 W., which was described in preceding paragraphs. Like the stream-channel deposit, the fanglomerate deposit does not contain basalt.

Material from the Hurricane Cliffs is no longer being deposited on the North Hills deposit. As shown on plate 1, the deposit is faulted on the east side and is separated from the Hurricane Cliffs by a down-faulted alluvial valley ½ to 1 mile wide. The deposit is now being actively eroded by minor intermittent streams. Murie Creek, which issues from the Hurricane Cliffs near the head of the deposit and which is an obvious source for the constituent fragments of the Carmel formation and the Navajo sandstone, now skirts the deposit on the south side.

It is immediately apparent that the major part of the gravel deposit was not transported by the present

Murie Creek because it heads in areas of basalt and in rocks of Cretaceous age and does not have access to the Kaiparowits or Wasatch formation or to the Kolob latite. However, evidence for the existence of an older stream ancestral to the present Murie Creek is well preserved in the geology and topography of the quadrangle.

ANCESTRAL MURIE CREEK

The headwaters of ancestral Murie Creek are defined by the barbed drainage at the head of Crystal Creek. As shown clearly by the detailed topography in the southeastern part of the quadrangle, several of the headward tributaries of Crystal Creek flow first to the west or north, then turn abruptly about 90° and flow to the south or east. These tributaries formerly flowed westward, but were captured by the headward erosion of the more vigorous Crystal Creek. This act of stream piracy must have taken place in late Tertiary time because after being diverted the new tributaries of Crystal Creek cut down many hundreds of feet and were later filled by basalt of Quaternary age.

A second line of evidence is found in the branchlike pattern of the basalt flows emanating from Coop and Pine Spring Knolls. These flows bifurcate first in secs. 21 and 28, T. 37 S., R. 11 W., and again in sec. 2, T. 38 S., R. 11 W., and can easily be visualized as filling the branches of a westward-flowing stream of considerable proportions. The flow in secs. 1, 2, and 12, T. 38 S., R. 11 W., slopes eastward, conforming to the reversal of drainage resulting from the capture by Crystal Creek of the headwaters of ancestral Murie Creek, but it has preserved the ground plan of the ancestral creek.

Basalt filling the channel of ancestral Murie Creek extends from sec. 12, T. 38 S., R. 11 W., to outliers on the north side of the present Murie Creek in sec. 20, T. 37 S., R. 11 W. The filling took place in Quaternary time. The present Murie Creek developed later by erosion of beds on the south side of the basalt filling the older channel. This interruption and southward diversion of Murie Creek resulted in its developing the new course on the south side of the North Hills deposit.

A final, less conclusive, line of evidence of an ancestral Murie Creek is found in the small scattered occurrences of boulders and cobbles in sec. 7, T. 38 S., R. 10 W., and in secs. 1, 2, and 12, T. 38 S., R. 11 W., which are similar in composition to the abandoned stream-channel deposits to the east and northeast, and to the fanglomerate at North Hills as previously described. These scattered boulders are now much lower topographically than the former headwaters of ancestral Murie Creek. Presumably they have been reworked and lowered as the topography has been lowered by the headward erosion of Crystal Creek. However, the presence of material similar in composition to the fanglomerate at North Hills in the headwaters area of ancestral Murie Creek is in harmony with the concept as developed by the stronger lines of evidence.

In total, the three lines of evidence strongly suggest that in late Tertiary time the ancestral Murie Creek headed eastward to within a mile or so of the east boundary of the quadrangle, and in the process of growing to that length transported and deposited the material in the North Hills fanglomerate. The capture of the headwaters of ancestral Murie Creek by the headwaters of Crystal Creek in late Tertiary time slowed deposition of the fanglomerate at North Hills, and subsequent filling of the channel of ancestral Murie Creek by basalt terminated deposition of the fanglomerate.

RELATION OF BASALT FLOWS TO FANGLOMERATE DEPOSIT

As shown on plate 1, the fanglomerate material at North Hills is largely interspersed with many small isolated masses of basalt. Most of these masses dip eastward at angles ranging from 10° to 20°, but a few dip westward at comparable angles. The evidence is clear that these many small masses of basalt were part of a larger flow or flows that were faulted. Most of the dipping masses are buried in gravel, but this relation is most readily explained by assuming that the basalt was deposited on top of the fanglomerate and later broken by faulting, which disturbed both the basalt and the underlying gravel.

At no place in the small area studied could it be said with confidence that gravel lay in normal stratigraphic succession upon basalt. On the other hand, the nearly horizontal mass of basalt in the northeast corner of the North Hills and others are clearly on top of the gravel. Similarly, no cobbles or boulders of basalt were observed in the gravel. On the basis of this inconclusive evidence, it seems most likely that the basalt was deposited on top of the fanglomerate and is correspondingly younger.

Thomas and Taylor (1946, p. 34) have reported that "just southwest of Cedar City, in sec. 15, T. 36 S., R. 11 W., the fanglomerate lies beneath, beyond, and above the end of a basalt flow some 50 feet thick." On the basis of this evidence they conclude that the fanglomerate is "roughly contemporaneous with the basalt, the deposition having perhaps been initiated before the beginning of volcanic activity and having continued throughout the activity, and perhaps for some time thereafter."

AGE OF FANGLOMERATE DEPOSIT

As the basalt flows in the Cedar Mountain area are considered to be of Quaternary age, the available direct evidence suggests that the fanglomerate deposit at North Hills is either of very late Tertiary or very early Quaternary age. Other, indirect evidence suggests that the fanglomerate deposit is largely of late Tertiary age. The growth of the North Hills deposit, for example, was largely terminated in late Tertiary time by stream piracy at the head of ancestral Murie Creek. Subsequently, the residual channel of Murie Creek was filled by basalt. Recognizing that deposition of gravel and outpourings of basalt may have overlapped considerably, the assignment of a late Tertiary age to the fanglomerate deposit is a reasonable and meaningful reconciliation of the information available.

PEDIMENT DEPOSITS IN SHURTZ CREEK AMPHITHEATER

The Shurtz Creek amphitheater, which stands out prominently in the center of plate 1, contains in its lower part a dissected gravel-covered surface that is here termed the "Shurtz Creek pediment." This surface is continuous between the tributaries of Shurtz Creek at the lower end of the amphitheater, but extends as individual prongs up the individual valleys at the upper end. The surface rises from an altitude of about 6,200 feet at the lower end to about 7,200 feet at the upper end. The angle of slope increases gradually upward from an average of about 430 feet per mile at the base to about 600 feet per mile at the top.

The gravel covering, which is about 20 feet thick, includes pebbles, cobbles, and boulders representative of all the resistant formations above the Triassic. Boulders of olivine basalt from flows on top of the Hurricane Cliffs and of sandstone from resistant ledges in the Straight Cliffs sandstone are particularly conspicuous. The largest boulder observed was a subrounded mass of basalt 9 by 10 by 11 feet in diameter.

The gravel on the Shurtz Creek pediment is much younger than any of the deposits previously described. It was formed long after the several outpourings of basalt at a time when the Hurricane Cliffs were very near their present height. Since the formation of the Shurtz Creek pediment, the Cliffs have been uplifted at least 40 feet, and perhaps more. (See fig. 15.) As a result, Shurtz Creek and its tributaries have been entrenched about 40 feet below the surface of the pediment. With no new material being added to the pediment it is slowly being eroded, and the debris is being deposited as a series of low fans at the base of the Hurricane Cliffs.

FIGURE 15.—Faulted surficial gravel of Quaternary age at mouth of Shurtz Creek, W½ sec. 9, T. 37 S., R. 11 W. Abrupt change in slope records uplift of at least 40 feet.

BOLSON DEPOSITS IN CEDAR VALLEY

The broad, open valley beginning at the base of the Hurricane Cliffs and extending to the west is known locally by the residents as Cedar Valley, or Cedar City Valley. It is a typical bolson, or intermontane valley, that has been filled with bedded deposits of silt, sand, gravel, and even cobbles and boulders, washed in primarily from the Hurricane Cliffs. The full thickness of this material is not known, but it is certainly in excess of 960 feet in the Cedar Valley, for a well drilled to that depth in sec. 20, T. 34 S., R. 11 W., failed to find solid rock (Thomas and Taylor, 1946, p. 39).

TALUS AND ROCK STREAMS

Most of the outcrops of basalt in the Cedar Mountain quadrangle are surrounded by steep talus slopes composed of angular blocks of basalt ranging in size from 5 or 10 feet in diameter at the tops of the slopes to 1 or 2 feet in diameter at the bases. These areas of rough and barren rock cover about 3 square miles in the quadrangle, and locally are much more conspicuous than the parent basalt. The appearance of the middle part of a typical talus slope is well shown in figure 16.

All the large talus slopes are underlain by relatively nonresistant beds of Cretaceous age. The talus is formed initially by erosion of the underlying beds and sapping of the edges of the basalt. This process yields

FIGURE 16.—Basalt talus, largely the result of frost action. Cedar Mountain road, SE¼ sec. 36, T. 36 S., R. 11 W.

large "slices" of basalt typically 3 to 5 feet wide and 20 to 30 feet long that separate from the parent flow and fall on the slopes below. These slices break into successively smaller blocks as they work slowly down hill. The rate of formation of the slices and of the talus blocks is greatly increased by frost action, which is operative at least 8 months a year in the relatively severe climate that prevails on Cedar Mountain.

Most of the talus piles form slopes ranging from 10° to a maximum of about 30°, but seem to be steeper than they actually are because of the gradual upward increase in slope.

At the widest places the talus belts are about ½ to ¾ of a mile wide, but typically are only a few hundred yards wide. Locally, as in the east half of sec. 23, T. 37 S., R. 11 W., and in the northeast corner of sec. 17, T. 37 S., R. 10 W., the lower ends of the talus slopes continue as rock streams. The rock stream in the northeast corner of sec. 17 has a terminal gradient not vastly different from that of a normal mountain stream.

A feature of the steeper slopes is the presence locally of an irregular trough or line of depressions in the lower part of the slope. The mass of talus on the downhill side of a trough probably is the upper part of a landslide that originated in the soft rock underlying the talus. Many of the troughs also mark areas of maximum winter snow accumulation or areas where snow lies longest in the spring, and they are generally filled with snow 7 or 8 months a year. The troughs are probably maintained, in spite of the steady creep of talus material from above, because the talus blocks tend to migrate across the snow.

LANDSLIDES

The steep escarpment of the Hurricane Cliffs has given rise to several large landslides both in and near the Cedar Mountain quadrangle. Most of the slides originate in the shaly beds of the Tropic formation, which crops out near the top of the cliffs.

The largest slide in the Cedar Mountain quadrangle is in secs. 33 and 34, T. 36 S., R. 11 W. This slide is about 2 miles long and extends from well up on the Hurricane Cliffs out into the valley at the base of the cliffs. The slide is partly covered with blocks and fragments of basalt derived from the thick flow on Square Mountain.

Several other areas are covered by indefinite slides and slumped material from the Tropic formation. The largest of these areas are in the head of Shurtz Creek around the common corner of secs. 13, 14, 23, and 24,

T. 37 S., R. 11 W.; in the head of Kanarra Creek in secs. 4 and 5, T. 38 S., R. 11 W.; and on the west side of Right Hand Canyon. Except for the small arcuate slumped area in the southwest corner of sec. 13, T. 37 S., R. 11 W., this slumped material does not have the distinctive topographic expression of the slide described above, and for this reason has not been shown as landslide breccia on the geologic map (pl. 1). However, most of the area of outcrop of the Tropic formation is concealed by such featureless slump material, which may be 10 to 50 feet thick measured normal to the slope. All the slumped areas in the Tropic formation are covered with a dense growth of vegetation, which attests to the more abundant supplies of water held in the slumped material.

Two other slumped areas are perhaps worthy of mention. One in the SE¼ sec. 9 and NE¼ sec. 16, T. 38 S., R. 11 W., involves blocks of basal Straight Cliffs sandstone, which have separated along joints and have slumped southeastward as a result of movement in the underlying Tropic formation.

Another slumped area is the slope southeast of The Three Knolls in parts of secs. 25, 26, and 35, T. 37 S., R. 11 W. This area is about ½ mile wide and about 1 mile long and involves beds of the Wahweap sandstone and volcanic ash from The Three Knolls. The slumped material is largely overgrown with aspen, and the boundaries are obscured by weathering.

ALLUVIUM

An area of several square miles between the base of the Hurricane Cliffs and the east edge of the North Hills is floored with alluvium. The alluvium is red brown in color because Shurtz Creek and other smaller creeks, which have supplied the material making up the alluvium, have relatively large drainage areas in the dominantly red-brown rock of Triassic age. At the base of the Hurricane Cliffs the alluvium merges imperceptibly with surface wash from the beds of Triassic age, with the result that the line on plate 1 delimiting the edge of the alluvium is placed rather arbitrarily at the break in slope.

The alluvium is composed largely of well-bedded silt, but contains layers of sand, and, locally, gravel that was deposited during periods of flood.

RECENT GULLYING

In common with most areas in the semiarid southwest, the alluvium in the Cedar Mountain quadrangle has been cut extensively by gullies during the last 50 to 70 years. The severity of such gullying is well illustrated in sec. 5, T. 37 S., R. 11 W., at points where the main road into the Cedar Mountain quadrangle crosses the gully system of lower Shurtz Creek. In this area, the main channel of Shurtz Creek is in a narrow gully with vertical walls nearly 20 feet high, which clearly reveal the sedimentary sequence in the alluvium.

STRUCTURE

The Cedar Mountain quadrangle is divided structurally into three parts: (a) the Hurricane fault zone in the extreme northwest corner of the quadrangle, which is part of the huge Basin and Range province extending to the west and south; (b) the zone of deformed rocks in the Hurricane Cliffs, which merits special description because most of the deformation in the cliffs occurred before movement on the Hurricane fault zone; and (c) the upland area at the top of the Hurricane Cliffs, which is part of the Kolob Terrace of the High Plateaus of Utah to the east.

HURRICANE FAULT ZONE

The Hurricane fault zone, which extends across the northeast corner of the Cedar Mountain quadrangle, is the most pronounced structural feature in southern Utah. As described by Gardner (1941) it is a major zone of rock dislocation, 170 to 200 miles long and locally several miles wide, that extends in a generally north-south direction from a point on the Colorado River in Arizona to a point a few miles north of Cedar City. The rocks on the east side of the fault zone have been uplifted relative to those on the west by amounts ranging from 1,500 feet at the south end of the zone to at least 8,000 feet at the north end. The east edge of the fault zone lies at the base of the Hurricane Cliffs, which constitute the deformed and eroded edge of the uplifted block.

In the Cedar Mountain quadrangle the Hurricane fault zone is about 3 miles wide, extending from the base of the Hurricane Cliffs westward beyond the northwest corner of the quadrangle. On the basis of mapping by Thomas and Taylor (1946, pl. 3; p. 51–57) the zone includes about four major faults and about three separate fault blocks, which have been downfaulted differentially.

Three of the major faults in the Hurricane fault zone cross the northwest corner of the Cedar Mountain quadrangle. The Hurricane fault proper, along which most of the displacement has occurred, lies at the base of the Hurricane Cliffs and marks the eastern margin of the zone. This fault is in line with, and presumably continuous with, the East Enoch fault of Thomas and Taylor (1946, pl. 3).

The next fault to the west, here termed the "North Hills fault," marks the east edge of the North Hills.

This fault is not exposed in the quadrangle, but its presence is clearly indicated by the eastern dip of the basalt on the west side of the fault and by the wide alluviated valley between the North Hills and the Hurricane Cliffs. The North Hills fault is in line with the West Enoch fault of Thomas and Taylor and, like it, is downthrown on the east side. The North Hills fault must die out or join the Hurricane fault a mile or so beyond the west edge of the quadrangle. The downfaulted block between the Hurricane fault and the North Hills fault, here termed the "North Hills graben," is comparable to, and may be continuous with, the Enoch graben of Thomas and Taylor.

The next fault to the west, the Bulldog fault of Thomas and Taylor (1946, pl. 3), crosses the extreme northwest corner of the Cedar Mountain quadrangle, but throughout this short distance lies below the North Hills fanglomerate. Its presence and position have been established by a zone of steeply dipping fanglomerate material in a small gravel pit in the NW¼ sec. 5, T. 37 S., R. 11 W., which is in line with the trace of the fault as established by Thomas and Taylor from evidence to the north and south.

The numerous broken and tilted masses of basalt on the North Hills fanglomerate suggest that other faults are present in the older rocks concealed beneath the gravel. Similarly, other faults may be concealed beneath the alluvium in the North Hills graben.

A suggestion of the complex structures that may be below the alluvium in the North Hills graben is found in the presence of two anomalous outcrops of the Shinarump member of the Chinle formation at the base of the Hurricane Cliffs, which seem to have been faulted into position. One such exposure occurs in the SW¼ sec. 9 and the other in the NE¼ sec. 19, T. 37 S., R. 11 W. At both localities the Shinarump exposures are near the zone of maximum structural disturbance on the edge of the Hurricane fault zone, and they lie just above the level of alluviation at the base of the Cliffs where geologic relations are obscure.

At the first locality in the SW¼ sec. 9 the Shinarump mass strikes N. 65° E. and dips 50° W., which is parallel to the strike and dip of nearby beds in the middle red member of the Moenkopi formation, but which is en echelon to the general trend of the Hurricane fault zone. Between the Shinarump exposure and the alluviated valley to the west is a small area of transported gravel containing boulders as large as 2 feet in diameter. This gravel and nearby occurrences of similar gravel are considered to be fanglomerate material of Quaternary age, which has been uplifted a few feet by Recent movements on the Hurricane fault zone.

The Shinarump cannot be interpreted as part of the transported surficial material because of its comparatively large size and definite strike. Therefore, it has been interpreted as part of a block brought into position by movements on the Hurricane fault zone. Accordingly, a short hypothetical cross fault has been drawn at this locality to conform with this interpretation.

At the second Shinarump exposure in the NE¼ sec. 19 the beds strike nearly east-west and dip 40° N. Here again the strike of the Shinarump is en echelon to the trend of the Hurricane fault zone, and the dip is in general accord with the dip of the nearby beds in the lower red member of the Moenkopi formation. This exposure of the Shinarump is much larger than the first exposure and is clearly underlain by beds in the upper part of the Moenkopi formation and overlain by other beds in the basal part of the Chinle formation, which establishes that the block is not overturned. It is to all appearances an exotic block, or horse, on the edge of the Hurricane fault zone.

AMOUNT OF DISPLACEMENT

As the several downfaulted blocks in the Hurricane fault zone are largely concealed beneath alluvium and fanglomerate material, the age and amount of displacement on the zone can be ascertained only from a few widely scattered exposures. About 2 miles west of the Cedar Mountain quadrangle Thomas and Taylor (1946, pl. 3) have mapped blocks of Navajo sandstone, limestone of the Wasatch formation, and Tertiary volcanic rocks in the Hamilton Fort horst, which constitutes one of the major downfaulted blocks in the fault zone. About 10 miles north of the quadrangle Thomas and Taylor (1946) and Threet[5] have mapped large areas of Wasatch and Cretaceous beds in the Red Hills, which in a broad general sense constitute part of the downfaulted zone. The Wasatch formation of early Eocene age is thus the youngest sedimentary formation exposed on the downfaulted side of the Hurricane fault zone. As discussed in the section on igneous rocks, the still younger volcanic rocks of early Tertiary age also extended across the fault zone and were broken by the first movements on the zone.

These downfaulted blocks in the Hurricane fault zone are at the same elevation as the base of the nearby Hurricane Cliffs. The oldest rock exposed in the base of the Hurricane Cliffs is the Timpoweap member of the Moenkopi formation, which is roughly 8,000 feet stratigraphically below the Wasatch forma-

[5] R. L. Threet, 1952, Geology of the Red Hills area, Iron County, Utah: Unpublished doctor of philosophy dissertation, Washington Univ. [Seattle].

tion. Although the total stratigraphic interval is not a precise measure of total displacement because the beds were folded into an anticline before faulting, it is indicative of the order of magnitude of the displacement.

A partial check on this figure is found in the displacement of some of the younger volcanic rocks. Mackin, who has mapped in the Iron Springs district about 10 miles west of the Hurricane Cliffs, states (oral communication, 1956) that certain sequences of volcanic rocks exposed in the district at an altitude of about 6,000 feet are identical to sequences on Brian Head about 12 miles east of the Cliffs at an altitude of about 11,000 feet. The apparent displacement of 5,000 feet is an assured minimum because the beds on Brian Head dip about 3° eastward, and beds near the fault zone dip eastward even more steeply. If an average dip of 3° is projected west across the 12-mile interval from Brian Head to the Hurricane fault zone, an additional 3,300 feet would be added to the apparent displacement. The figure of 8,000 feet thus seems to be fairly well substantiated as the minimum displacement on opposite sides of the Hurricane fault zone in the Cedar Mountain quadrangle. Gardner (1941, p. 248) has suggested that the maximum displacement is 10,000 feet near Kanarraville, which is very near the mapped area. All factors considered, the displacement in the Cedar Mountain quadrangle probably is between 8,000 and 10,000 feet.

DIP OF FAULT PLANES

The easternmost fault of the Hurricane fault zone is parallel to, and very near the base of, the Hurricane Cliffs, and locally, both north and south of the Cedar Mountain quadrangle, the plane of movement is exposed in the rocks at the base of the Cliffs. Near the mouth of Camp Creek, 6 miles south of the southernmost exposure of the fault zone in the Cedar Mountain quadrangle, slickensided surfaces on beds on the upthrown side of the fault dip 65° W. In areas farther south, Gardner (1941, p. 247) reports that dips on the planes of movement range from 70° W. to vertical. In areas north of Cedar City, Thomas and Taylor (1946, p. 52) report that the dip on the fault "appears in rather poor exposures to dip about 70 degrees westward." As the three measurements are in good general agreement, it may be assumed that in the Cedar Mountain quadrangle the easternmost major fault in the Hurricane fault zone, and probably most of the faults in the zone, dip steeply westward at angles ranging from 65° to vertical.

The westward dip of the planes of movement and the relative direction of movements on opposite sides of the Hurricane fault establish it as a normal fault. The grooves on the slickensided surface near the mouth of Camp Creek are normal to the strike of the fault, which substantiates the belief that there is no appreciable horizontal component in the motion.

AGE AND NATURE OF MOVEMENT

Upward movement of the block on the east side of the Hurricane fault zone has been in progress intermittently since early Tertiary time. A part of the movement has taken place in Pleistocene and Recent time, and movement is continuing at the present time. The evidence used to date this movement and to prove its intermittent nature may be summed up as follows:

1. The Wasatch formation of Eocene age and overlying volcanic rocks of distinctive intermediate to acid composition, considered to be of Eocene to Miocene(?) age, exhibit maximum displacement on opposite sides of the fault zone and establish the first strong movement as being in post-Eocene to post-Miocene(?) time.
2. Older fanglomerate deposits, such as those on the North Hills, contain cobbles and boulders of older volcanic rocks, but none of basalt, thus establishing their age as being between the two periods of volcanic activity. The fanglomerate deposits were originally laid down against the Hurricane Cliffs, but are now separated from it by a low alluviated valley. The deposits accumulated in late Tertiary time, and were later isolated from the base of the cliff because of downfaulting of a block between the present North Hills and the cliff.
3. Basalt lava flows of Quaternary age are present on both sides of the fault zone. Locally, as on the north side of Murie Creek, these lavas poured down a steep valley in the Hurricane Cliffs. Elsewhere, as on Square Mountain, the basalt terminates abruptly at the edge of the cliff as if cut off by faulting. Basalt flows on the older fanglomerate deposits of the North Hills have themselves been extensively broken by minor faults, and most outcrops now dip toward the Hurricane Cliffs. This phenomenon of basalt on the downthrown side of the Hurricane fault dipping toward the fault has also been observed by Gardner (1941, p. 254) in Ash Creek, and is considered by him to indicate a sag in rocks on the downthrown side of the fault, perhaps induced by the outpouring of lava. Gardner presents a list of six or eight other such occurrences in southwestern Utah and northern Arizona. The faulted basalt flows thus present evidence of

several periods of quiet and several intervening periods of movement.

4. The sloping gravel-covered pedimentlike surface in Shurtz Creek valley could have been developed only during a period of stability of the upthrown block. This period occurred after most of the basalt outpourings because the basalt flows have been cut by the headward erosion of Shurtz Creek and have contributed to the gravel on the pediment.
5. The sloping gravel-covered surface in the Shurtz Creek valley is cut off abruptly at the base of the Hurricane Cliffs. The movement has been so recent that the gravel still stands in a steep slope on the uplifted side of the fault. (See fig. 15.) At the same time, the main stream and tributaries of Shurtz Creek are now entrenched below the gravel-covered surface. This entrenchment obviously took place after, and because of, the renewed uplift.
6. Locally, the steepest part of the Hurricane Cliffs is imposed on relatively nonresistant beds in the lower red member of the Moenkopi formation at the base of the Cliffs. Normally, the gentlest upward slope would be at the base, and the present steepness can only be the result of comparatively recent upward movement.
7. The alluvial material in the Coal Creek fan is broken locally by small faults (Thomas and Taylor, 1946, p. 54).
8. Fifteen minor earthquake tremors attributed to movement on the Hurricane fault zone have been recorded during the last 75 years. These are discussed in greater detail below.

EARTHQUAKE ACTIVITY

The most recent evidence of movement along the Hurricane fault zone is found in the record of earthquake activity in southwestern Utah as reported by Townley and Allen (1939), Heck (1928, 1947), and by the U.S. Coast and Geodetic Survey (1928–51). Of 31 tremors recorded in Iron and Washington Counties between 1881 and 1949, 14 were reported from Cedar City on the trace of the fault zone, and 1 covered a large area in southwestern Utah on both sides of the zone, and may be attributed to movement along the zone.

The observed concentration of 15 out of 31 tremors on the Hurricane fault zone is more or less expectable in view of the strong geologic evidence of Recent movement. On the other hand, the concentration of 14 out of 15 tremors at Cedar City, as compared to only 1 tremor throughout the remaining 170-mile length of the fault to the south, merits some speculation. The town of Cedar City is located on the unconsolidated alluvial fan of Coal Creek, where the effects of an earthquake shock would be most noticeable. The displacement on the Hurricane fault zone is also greatest in the Cedar City area; hence, evidence of tectonic disturbance should be greatest. In spite of these facts, the comparative absence of reports of shocks from the towns of Kanarraville, Pintura, Toquerville, and Hurricane, all of which are located on the fault zone south of Cedar City, seems to suggest that the present movement on the fault zone is concentrated at the north end.

HURRICANE CLIFFS

The Hurricane Cliffs constitute the eroded edge of the uplifted block on the east side of the Hurricane fault zone. The exposed beds in the base of the Cliffs are the oldest in the quadrangle and exhibit deformation that is older than, and clearly not related to, motion on the Hurricane fault zone. The most conspicuous manifestation of this deformation is the pronounced eastward dip of the beds in the lower half of the Cliffs. (See fig. 17.) The general impression gained in driving along the roads at the base of the Cliffs is that all the lower beds dip 20° to 60° eastward, and this is true for many miles along the face of the Cliffs. Locally, however, for a distance of 4 or 5 miles between Spring Canyon, near Kanarraville, and Murie Creek, on the east edge of the Cedar Mountain quadrangle, the lower beds are overturned to the east and dip steeply westward. The north end of this zone of overturned beds extends a short distance north of Murie Creek into the Cedar Mountain quadrangle. Farther north the beds again dip eastward at angles ranging from vertical just north of Murie Creek to about 25° E. just south of Shurtz Creek. North of Shurtz Creek the beds in the base of the Hurricane Cliffs form a low northward-plunging anticline, here named the Shurtz Creek anticline. This small fold is the clue to the nature and origin of the older structure displayed in the Hurricane Cliffs.

KANARRA FOLD

The structures preserved in the Hurricane Cliffs represent the east half of a former sharply folded north trending anticline, or welt, called the Kanarra fold by Gregory and Williams (1947, p. 240). This older anticline was broken by the Hurricane fault zone along a line approximately parallel to, and very near, the axis of folding. The west half of the fold, including most of the fold axis, is now concealed beneath alluvial material in the downthrown block

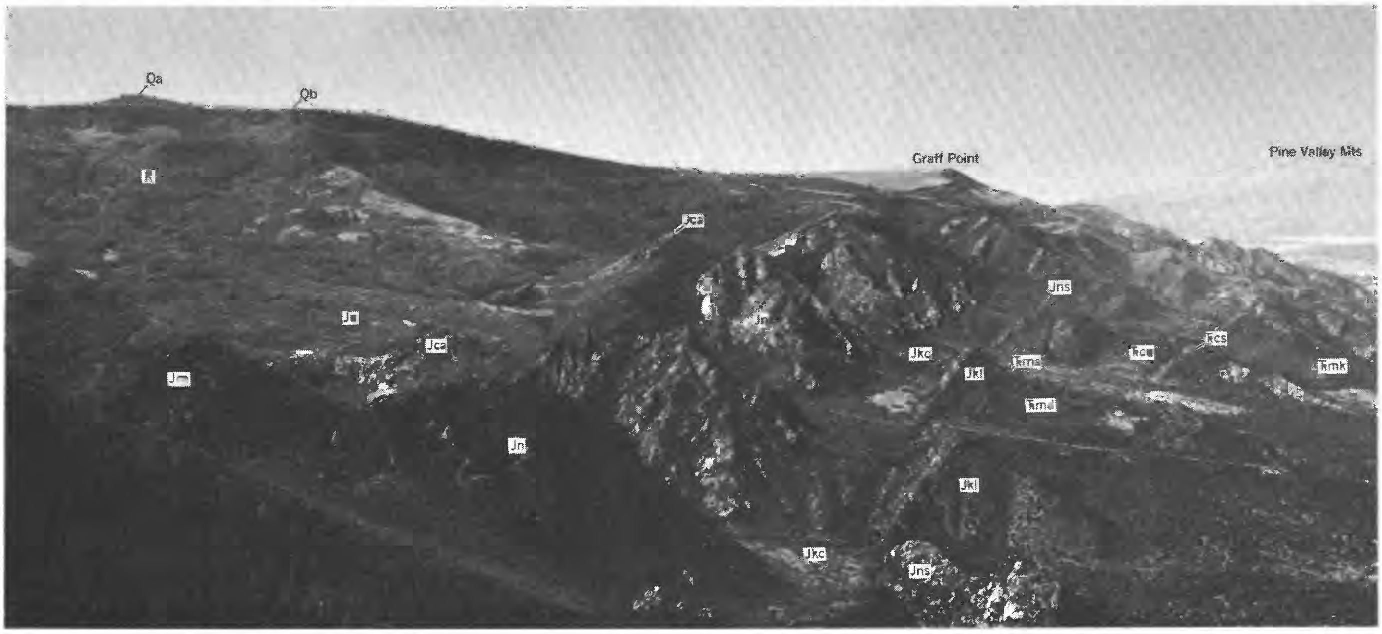

FIGURE 17.—Hurricane Cliffs as seen from Square Mountain. View looking south across the amphitheaterlike valley of Shurtz Creek. Steeply dipping beds are the east flank of the ancestral Kanarra fold. Ŧmk, Moenkopi formation; Ŧcs, Shinarump member of the Chinle formation, restricted; Ŧcu, upper part of the Chinle formation, restricted; Ŧmd, Dinosaur Canyon sandstone member of the Moenave formation; Ŧms, Springdale sandstone member of the Moenave formation; Jkl, lower member of the Kayenta formation; Jns, Shurtz sandstone tongue of the Navajo sandstone; Jkc, Cedar City tongue of the Kayenta formation; Jn, Navajo sandstone; Jca, Carmel formation; Ju, Entrada, Curtis and Winsor formations; K, Cretaceous deposits; Qb, basalt; Qa, volcanic cinders and ash in northernmost of The Three Knolls. Area shown covers approximately 16 square miles.

just west of the Hurricane Cliffs. The Shurtz Creek anticline is the only place where the axis of the former fold is clearly exposed.

The attitude of the exposed beds on the east flank of the Kanarra fold suggests that the fold axis was virtually horizontal from a point about 25 miles south of Cedar City to Shurtz Creek. From Shurtz Creek northward to a point a mile or so north of Cedar City the axis plunges northward. The beginning of this plunge is very gentle, as noted in the closure of the Virgin limestone member around the north end of the Shurtz Creek anticline. Farther north, at Cedar City, all the beds to the base of the Cretaceous curve sharply westward, which suggests that at this point the axis of the Kanarra fold plunges very steeply northward. (See Thomas and Taylor, 1946, pl. 3.)

The older beds at the base of the Hurricane Cliffs were tightly compressed in the heart of the fold, and thus dip more steeply than the younger beds at the top of the Cliffs, which were farther eastward on the more gently dipping east flank of the fold. The beds of Cretaceous age at the top of the Cliffs thus dip only about 6° eastward as contrasted with the steeply dipping to overturned beds of Triassic and Jurassic ages at the base of the Cliffs. The transition from steeply dipping to gently dipping beds is very gradual and uniform, but local views of steeply dipping ledges of Navajo sandstone in the foreground against gently dipping ledges of the Straight Cliffs sandstone in the background may give the erroneous impression of angular discordance.

DIRECTION OF COMPRESSION

The Kanarra fold was the result of compressive forces acting in an east-west direction. The fact that beds on the east side of the fold are overturned to the east proves that the dominant compressive force came from the west. It is interesting to note that although the older Kanarra fold was the result of compression, the younger Hurricane fault was the result of tension acting along almost exactly the same line, but in the opposite direction.

A different interpretation of the nature of the Hurricane fault and the Hurricane Cliffs has been presented by Lovejoy (1959). According to this interpretation the Hurricane fault is a Laramide reverse fault dipping steeply to the east, and the Kanarra fold is slightly younger than the fault.

The writer believes that the accumulated weight of evidence as previously presented provides much stronger support for the opposite view that the Kanarra fold is a Laramide fold overturned to the east, and that the Hurricane fault is a younger normal fault dipping steeply to the west.

AGE OF FOLDING

In the Cedar Mountain quadrangle, the Straight Cliffs and Wahweap sandstones of Late Cretaceous (latest Colorado) age are the youngest formations clearly involved in the compressive forces that formed the Kanarra fold, and it is likely that the folding started at the end of Cretaceous time as part of the more widespread Laramide orogeny that characterized the close of the Cretaceous.

CONTORTION AND MINOR REVERSE FAULTING ASSOCIATED WITH FOLDING

The tight compression that produced the Kanarra fold also produced considerable contortion, with associated minor steeply dipping reverse faults. The contortion is particularly noticeable in the softer beds of the Moenkopi formation, particularly in the NW¼ sec. 20, T. 37 S., R. 11 W., in the vicinity of Murie Creek where the beds have been overturned. (See fig. 4.) For about a mile north of Murie Creek the outcrops of the middle red and Shnabkaib members of the Moenkopi formation are somewhat thinned as a result of this contortion, which is accompanied by numerous minor unmappable reverse faults parallel to the strike of the bedding.

South of Murie Creek, the overturned beds are broken by two small steeply dipping reverse faults. The westernmost, which causes a pronounced thinning of the outcrop of the Navajo sandstone, continues southwestward beyond the edge of the quadrangle for several miles. The easternmost, which causes a thinning of the outcrops of the Entrada and Curtis formations, dies out at the west edge of the quadrangle. Both faults are upthrown on the east side, both fault planes probably dip steeply eastward, and both faults have relatively small displacements.

POSSIBLE LARGE-SCALE THRUST FAULTING

Although the rocks in the Hurricane Cliffs give no evidence of having been subjected to large-scale thrust faulting, the formation of the ancestral Kanarra fold may have been accompanied by a significant amount of thrusting that is no longer visible. If thrust faulting from west to east did take place at that time, the rocks now exposed in the Hurricane Cliffs were on the lower plate of the thrust. The rocks on the upper plate, if such existed, have been eroded on the upthrown side of the more recent Hurricane fault, and are concealed below surficial deposits on the downthrown side.

NORMAL FAULTS

In addition to the contortion and the two small reverse faults mentioned above, the rocks in the Hurricane Cliffs are broken by 11 normal faults. These faults occurred either during the period of adjustment immediately following compression or with the later movement on the Hurricane fault zone. Of the 11 faults, 3 have special features that merit separate discussion.

MURIE CREEK FAULT

The Murie Creek fault is a conspicuous eastward-trending cross fault roughly parallel to Murie Creek on the west edge of the quadrangle. As shown on the geologic map (pl. 1), the beds on the north side of the fault are offset consistently to the east, with a larger offset at the east end where the beds are dipping steeply eastward than at the west end where the beds are dipping steeply westward. These anomalous relations can best be reconciled by assuming that the rocks on the north side of the fault have moved up and to the east in relation to those on the south side.

The concept of a strong horizontal component in the motion on the fault is supported by the pronounced eastward drag on the Shurtz sandstone tongue on the south side of the fault and by the fact that the fault occurs at a slight eastward bend in the Hurricane fault zone.

The displacement on the Murie Creek fault increases from west to east, and at the east end where it disappears under a basalt flow it has a stratigraphic displacement of about 1,200 feet. The fault is believed to extend about 2 miles farther eastward under the basalt because in this area the top of the Tropic formation is displaced vertically about 1,400 feet between exposures in the SE¼ sec. 22, T. 37 S., R. 11 W., on the north or upthrown side of the fault extended, and exposures in the NW¼ sec. 28 on the south or downthrown side of the fault extended.

BEAR TRAP FAULT

Trending north-northeast across sec. 10 and continuing northward into sec. 4, T. 38 S., R. 11 W., is a northward extension of the Bear Trap fault of Zion National Monument as mapped by Gregory and Williams (1947) and by Gregory (1950a, b). In the Cedar Mountain quadrangle the Bear Trap fault breaks beds of Cretaceous age, which are poorly exposed and which are similar in appearance on both sides of the fault. The best exposure of the fault is on a spur ridge in the NW¼NW¼ sec. 10 where the drag zone on both sides of the fault is expressed as a narrow belt of disturbed beds with local dips as steep as 68° W. As observed at this locality, the plane of movement of the Bear Trap fault is either vertical or steeply dipping to the west, and the upthrown side is to the east. Throughout sec. 10 the vertical displacement on the fault is roughly 600 feet.

The Bear Trap fault is obscured on a slumped and overgrown slope throughout its extent in sec. 4, but the displacement is believed to decrease in this direction. Depending on the amount of displacement, the Upper Culver coal zone should be either at, or just below, the surface on the north side of the fault. A dotted line in this area on plate 1 shows the approximate position of the coal, assuming maximum displacement on the fault. It must be emphasized that coal was not observed in this position, and that the line has only diagrammatic value. Exploration by trenching or drilling, preferably the latter, would be required to establish the exact position of the coal zone at this locality.

Similarly, in the SW¼ sec. 10 the Upper Culver coal zone should come back against the Bear Trap fault on the downthrown side, somewhat as shown by the dotted line on plate 1. Again, the dotted line has only diagrammatic value, and drilling would be required to establish the exact position of the coal. In this locality the coal should be very near the surface over a considerable area.

Although all evidence of the Bear Trap fault in and north of sec. 4 is concealed beneath slumped material, talus, and basalt flows, a small fault in the NE¼ sec. 28, T. 37 S., R. 11 W., could be the northward termination of the Bear Trap fault.

About 2,000 feet east of the Bear Trap fault is a very minor parallel fault that breaks beds of the Straight Cliffs sandstone. This fault is conspicuous both on aerial photographs and in the topography, but the vertical displacement is only a few feet.

RELATION BETWEEN THE MURIE CREEK AND BEAR TRAP FAULTS

The displacement on top of the Tropic formation between secs. 22 and 28, T. 37 S., R. 11 W., which has been interpreted by the writer as evidence of an eastward extension of the Murie Creek fault under a basalt flow, was observed by Richardson (1909, p. 392; pl. 25), who interpreted it as evidence of a northward extension of the Bear Trap fault along the boundary between secs. 21 and 22. Although this was a most reasonable interpretation, restudy of the area did not reveal evidence of offset in the sedimentary rocks north of the basalt covering. In part for this reason and in part for reasons stated in the discussion of the Murie Creek and Bear Trap faults, the Richardson interpretation has been abandoned.

HICKS CREEK FAULT

The Hicks Creek fault is a strike fault about 1 mile long in the area between Murie and Hicks Creeks, secs. 16 and 17, T. 37 S., R. 11 W. This fault has only a moderate vertical displacement, but it is responsible for a repetition of the conspicuous conglomerate of the Shinarump member of the Chinle. The beds involved in the faulting dip steeply eastward, and the stratigraphic sequence is normal, both above the easternmost Shinarump ridge and below the westernmost Shinarump ridge. Between the two ridges is an isolated outcrop of sandstone in the Shinarump dipping 80° W., which is interpreted as being a small block, or horse, in the fault plane. The relations suggest that the fault plane dips west, and that the Hicks Creek fault is a normal fault with the upthrown side to the east.

About 2½ miles to the north is another short fault of moderate displacement that also is responsible for a repetition of the Shinarump. At this locality the beds dip gently eastward, and the fault can be interpreted only as a steeply dipping normal fault with the upthrown side to the east.

These two faults are believed to join under the gravel-covered pediment in the Shurtz Creek valley as shown on the geologic map (pl. 1) and accompanying cross section. Although direct evidence for such connection could not be found in the few available exposures between the two localities, the indirect evidence for the connection is very convincing. Both faults dip to the west and are upthrown on the east sides. Both are strike faults of moderate displacement. Both cause repetition of the Shinarump. Furthermore, the belt of outcrop of beds in the upper part of the Moenkopi formation (middle red, Shnabkaib, and upper red members), which underlies the broad gravel-covered area where connection between the two faults has been made, is too wide in relation to the visible dips and the known thickness of the units, and can be explained only by assuming repetition of part of the sequence.

KOLOB TERRACE

The Kolob Terrace, the third and largest of the three major parts of the quadrangle, is a lower terracelike southern extension of the High Plateaus of Utah. It is bounded on the north by the Pink Cliffs ramparts of the Markagunt section of the High Plateaus and on the west by the Hurricane Cliffs. Unlike the High Plateaus proper, which are developed largely on beds of Tertiary age, the Kolob Terrace is developed entirely on the Straight Cliffs and Wahweap sandstones and overlying beds of Cretaceous age. These beds dip gently and uniformly eastward away from the Hurricane Cliffs at angles of 6° or less. Faults are conspicuously absent. All the upland area in the Cedar Mountain quadrangle above an altitude of 9,000 feet is part of the Kolob Terrace.

In the Cedar Mountain quadrangle the Kolob Terrace is characterized by a gently rolling subdued topography, by a fairly good soil and vegetation cover, and by the deeply incised canyons of Crystal Creek and other tributaries of the North Fork of the Virgin River, which head in the area due east of the quadrangle. This subdued topography (fig. 14) is a relic of a former erosion cycle before the last major uplifts on the Hurricane fault. At this earlier stage—which must have been in late Tertiary time—stream gradients were less, and downcutting was much less rapid than at present. With the last great uplift on the Hurricane fault in early Quaternary time, the period of rapid downcutting and canyon development began, and has continued to the present.

The open country on the east side of the quadrangle north of Crystal Creek is typical of the undissected relic topography of the former erosion cycle. The canyon of Crystal Creek, which heads in the southeast corner of the quadrangle, is a typical canyon developed in the present cycle of canyon cutting.

Outside the Cedar Mountain quadrangle, the Kolob Terrace consists of two distinct levels. The description above applies to the upper level, which is developed on the softer rocks of the Wahweap sandstone, and which exhibits the subdued topography inherited from an earlier erosion cycle. East and south of the quadrangle, however, the upper level of the Kolob Terrace drops off steeply to a lower level developed on the more resistant sandstone beds in the Straight Cliffs sandstone. This lower level, known as the lower Kolob by the residents, is a graded platform, or stripped plain, formed by gradual removal of the overlying softer beds during both the past and present cycles of erosion. The flat surface of the lower Kolob is cut into numerous isolated peninsulas by the dendritic pattern of the deeply incised canyons, which add to its distinctive appearance.

DRAINAGE CHANGES

The three major streams that head in the Cedar Mountain quadrangle—Shurtz, Crystal, and Urie Creeks—have different gradients and erosive power, and the divides between them are gradually shifting in response to these differences.

SHURTZ CREEK

The Shurtz Creek amphitheater has been formed largely in Quaternary time since the last major uplift on the Hurricane fault. Headward erosion has progressed rapidly because the stream is developed on relatively nonresistant sedimentary rocks between two great basalt flow sheets—one emanating from Pryor Knoll and the other from The Three Knolls. Because of its steep gradient and favorable location, Shurtz Creek is rapidly enlarging its drainage area headward at the expense of Urie Creek, which has a longer route and a lower gradient to the Cedar City Valley by way of Right Hand Canyon and Coal Creek.

CRYSTAL CREEK

As a tributary of the North Fork of the Virgin River, and thus of the Colorado River, Crystal Creek has a much lower ultimate base level than Urie Creek and thus is working headward at the expense of Urie Creek.

URIE CREEK

The headward drainage area of Urie Creek is gradually being captured by headward erosion of Shurtz Creek from the west and Crystal Creek from the south.

MINOR FEATURES OF INTEREST

During work in the Cedar Mountain quadrangle, the writer noted several minor features of geologic and general interest that should be recorded for the information of subsequent visitors to the area. The locations of these features are shown on the geologic map (pl. 1).

NATURAL BRIDGE IN SHIVER CREEK

A small but very beautiful natural bridge spans the lower course of a tributary of Shiver Creek near its junction with Crystal Creek in the NE¼SW¼ sec. 1, T. 38 S., R. 11 W. (See fig. 18.) The rocks at this locality dip uniformly 2° to 3° eastward, and are composed of sandstone and shale in alternating layers. The bridge is formed from a single 2-foot bed of hard sandstone, which is the uppermost layer in a thicker sandstone sequence. The bridge originated near the lip of a waterfall at the present position of the span by the diversion of the stream downward through a joint crack back of the span and by the subsequent upstream migration of the waterfall.

Because the bridge crosses the channel of an active and precipitous stream, it has a relatively short life expectancy. On the other hand, erosion of the stream

FIGURE 18.—Natural bridge in Shiver Creek. View looking downstream from base of parent waterfall in NE¼SW¼ sec. 1, T. 38 S., R. 11 W.

channel under the bridge and of the parent waterfall upstream is proceeding very rapidly, and as long as the bridge stands, it can be used as a convenient datum to measure the rate of erosion. In the hope that the information may be of future value for this purpose, following are measurements of the bridge as recorded in August 1954:

	Feet
Bottom of span to bed of creek	7. 8
Circumference of span at narrowest place in center	5. 7
Circumference of span at narrowest place at north end	5. 2
(NOTE.—Measurements of circumference were made with steel tape, which did not hug span as closely as a cloth tape would.)	
Upstream side of span to lip of parent waterfall; measured in line of creek between points that would give greatest airline distance at elevation of top of bridge-forming ledge; 6-in. sag in steel tape	41. 5

PETRIFIED STUMP IN SHURTZ CREEK

A fairly complete petrified stump, 2 to 3 feet long, of a quality suitable for public display occurs on the ridge just north of the Shurtz Creek road near the center of the NE¼ sec. 14, T. 37 S., R. 11 W. The stump has weathered out of the enclosing sediments and rests on top of the second strong sandstone ledge about 80 feet above the base of the Tropic formation. It is easily reached by a sheep trail that takes off from a switchback in the Shurtz Creek road, 2,000 feet south and east of the stump.

COAL DEPOSITS

Most of the coal in the Cedar Mountain quadrangle occurs in four well-defined zones, which are here named, from oldest to youngest, the Willow Creek, Lower Culver, Upper Culver, and Straight Cliffs coal zones. Each of these zones consists of coal intercalated with shale or clay in varying amounts. In general, the zones are more distinctive and persistent than any of the contained layers of coal, and thus merit prior description.

As shown in figure 19, the four zones occur within a stratigraphic interval of about 300 feet. Three of the zones, the Willow Creek and the Lower and Upper Culver zones, are in the Tropic formation; and one, the Straight Cliffs zone, is in the lower part of the Straight Cliffs sandstone. The contact between the Tropic formation and the Straight Cliffs sandstone, which has been established at the top of the Upper Culver coal zone, is shown in figure 19, on the geologic map (pl. 1), and in figure 20, and thus serves to integrate the information on the three illustrations. The localities at which the sections shown in figure 19 were measured are indicated by corresponding numbers on plate 1.

UPPER CULVER COAL ZONE

The Upper Culver coal zone is the most distinctive and thickest of the four zones, and is the only one that contains coal of current economic interest. The zone ranges in thickness from 10 to 14 feet, and is characterized by a 6- to 8-foot sequence of coal at the top, and by an overlying bed of gray fossiliferous marine marl, which has been described in the section on stratigraphy. This marl represents a minor invasion of the sea from the east that terminated deposition of plant debris in the Upper Culver coal swamp. The contact between the coal and the marl, which has been selected as the boundary between the Tropic formation and the Straight Cliffs sandstone, is probably the most distinctive contact in the local sequence of Cretaceous rocks, though it is not visible at many localities because the beds above and below are soft and easily weathered.

Most of the mines and prospects in the Cedar Mountain quadrangle are in the upper part of the Upper Culver zone. Exposures in these openings and elsewhere along stream courses and in cliffs make it possible to trace and correlate this zone from the northeast to the southeast corners of the quadrangle. It is also exposed locally in coal openings along Coal Creek northeast of the quadrangle.

Sections of coal and associated rock in the Upper Culver coal zone at 33 localities in and near the Cedar Mountain quadrangle are shown on plate 2. The numbers on the sections correspond to those on plate 1 and figures 19 and 20. The sections are arranged in a rough north to south order, with section 1 at the north and east and section 39 at the south. The sections are also bracketed to show the drainage basins in which they lie.

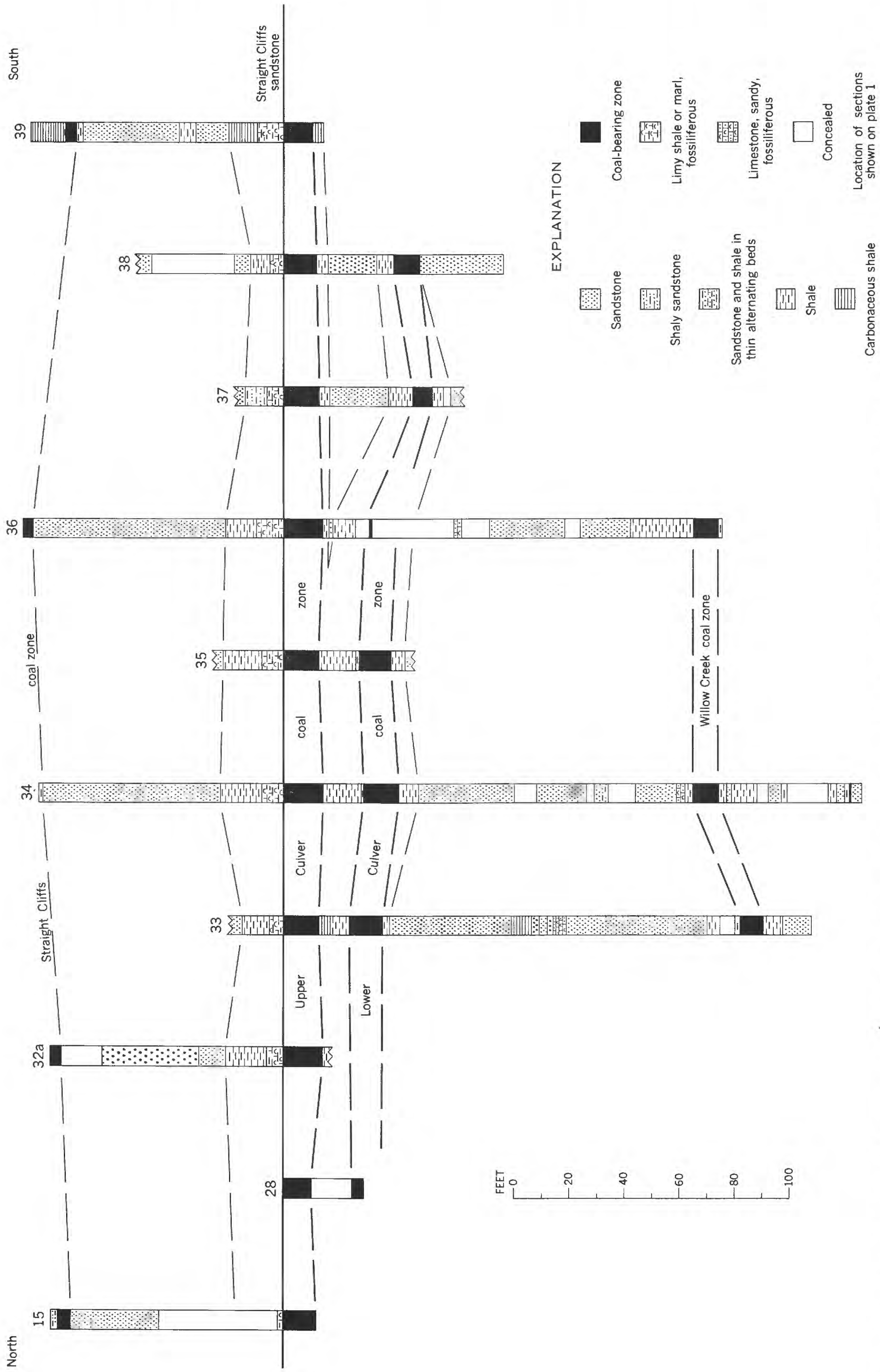

FIGURE 19.—Sections through the upper part of the Tropic formation and lower part of the Straight Cliffs sandstone showing stratigraphic relations of the four major coal-bearing zones in the Cedar Mountain quadrangle, Iron County, Utah.

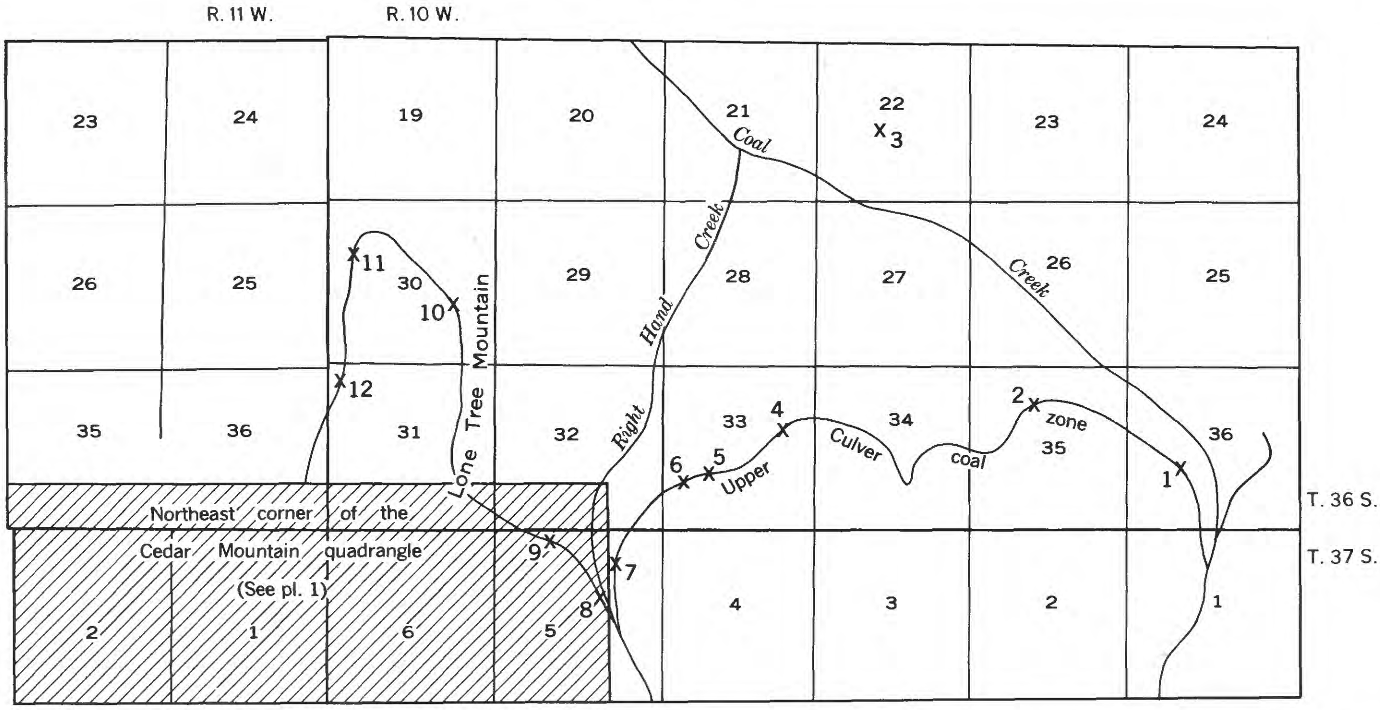

FIGURE 20.—Sketch map of parts of Tps. 36 and 37 S., Rs. 10 and 11 W., showing approximate position of outcrop of Upper Culver coal zone and approximate locations of mines and prospects north and east of the Cedar Mountain quadrangle. (See tables 2 and 3; pl. 2.)

Certain general features of the Upper Culver coal zone show clearly in the line of plotted sections. First is the characteristic layer or layers of dirty or impure coal at the top of the zone. This impure coal ranges in thickness from a few inches to more than 2 feet. At some places the impure coal is mined, and at others it is left in the roof, depending on its degree of impurity and on the thickness of the underlying coal. At the Tucker mine, locality 8, in the northeast corner of the quadrangle, the upper layers of impure coal are mildly radioactive. This feature of the coal is discussed in greater detail in the section on uranium.

The thickest and best coal in the Upper Culver coal zone generally lies just below the layers of impure coal. As shown in the sections, this part of the zone is highly variable, but typically shows a larger percentage of clean coal than the upper or lower parts of the zone.

The second most distinctive feature of the Upper Culver coal zone is the bed of gray marine marl that appears near the base of the zone in Shurtz, La Verkin, and Crystal Creeks. Although this bed appears to be two separate wedges on plate 2, it is actually only one. The illusion is brought about by the arrangement of the sections in a straight line. A comparison between the geologic map (pl. 1) and plate 2 will show that the sections in the Kanarra Mountain road area, which do not contain the lower bed of marl, are west of the sections in Shurtz and Crystal Creeks. Thus, if the sections had been plotted in true geographic position on the map, it would be immediately clear that the wedge is probably continuous between Shurtz and Crystal Creeks, and that it probably pinches out westward just short of the Kanarra Mountain road.

The wedge is very similar in appearance to the marine marl overlying the Upper Culver coal zone, but cannot be confused with it because the lower wedge is thin and is overlain by coal.

Figure 21, a photograph of the Upper Culver coal zone at the Culver coal mine (loc. 21), shows the typical appearance of the wedge, as well as the underlying and overlying coal.

Figure 22 is a photograph of the upper part of the Upper Culver coal zone at locality 34 in the cliffs at the head of La Verkin Creek, where the wedge and overlying coal are visible in a natural exposure.

In a section measured by Richardson (1909, p. 393) about 1 mile south of the Cedar Mountain quadrangle (loc. 39, pl. 2), the rocks at the position of the wedge are described as fossiliferous sandstone.

The suggestion from the direction of thinning of the wedge is that it represents a minor invasion of the sea, which came from a south or southeasterly direction. This is in accord with knowledge of movements of Cretaceous seas derived from sediments higher and lower in the section.

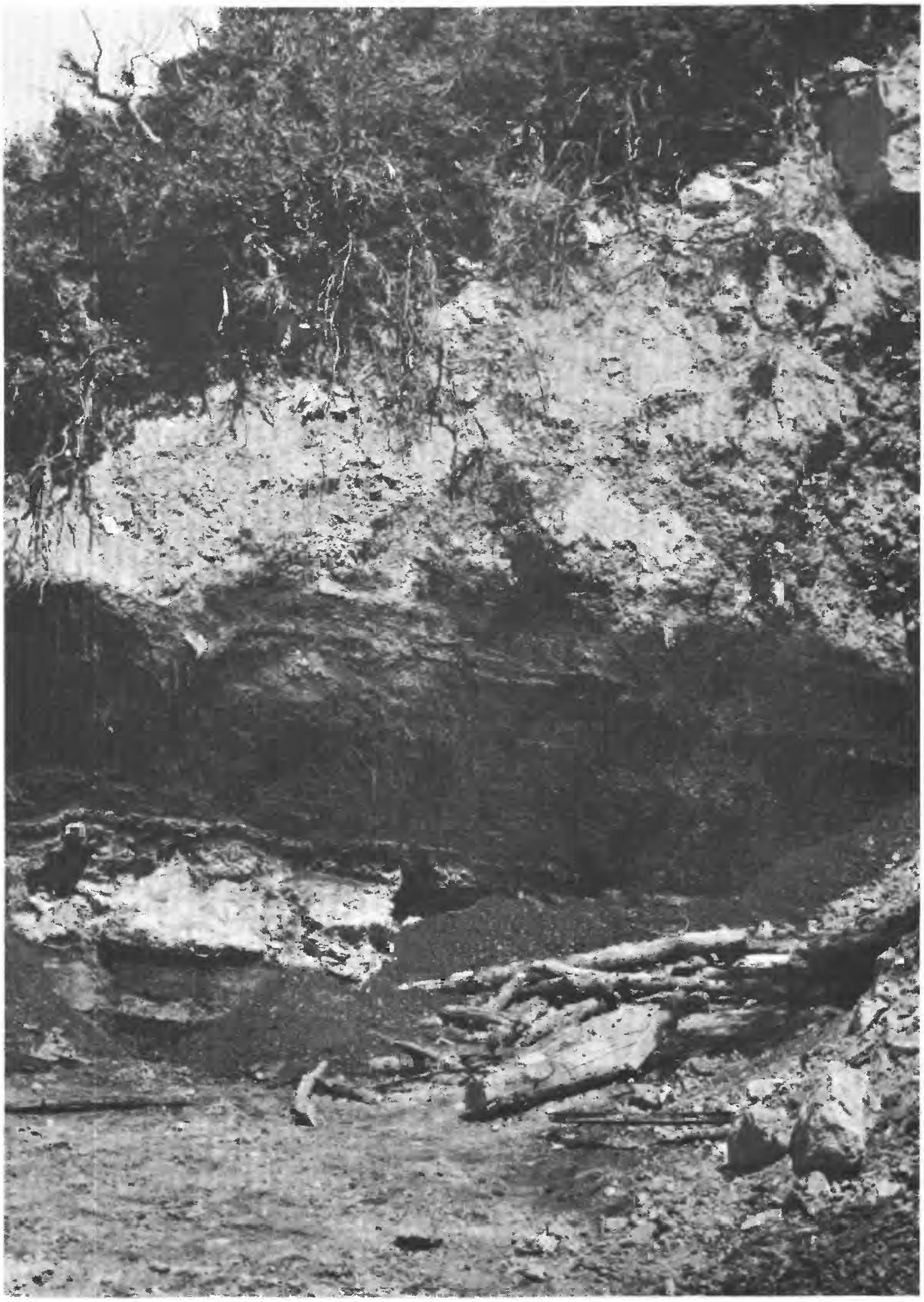

FIGURE 21.—Upper Culver coal zone at entrance to Culver mine (loc. 21), NW¼ sec. 24, T. 37 S., R. 11 W. Light-colored ledge below main coal is gray fossiliferous marine marl.

FIGURE 22.—Upper part of the Upper Culver coal zone at locality 34, SE¼NW¼ sec. 10, T. 38 S., R. 11 W. Light-colored ledge below hat is gray fossiliferous marine marl.

The coal below the marine wedge is generally too thin, or it contains too many partings to be of economic interest.

SEQUENCE BETWEEN UPPER AND LOWER CULVER COAL ZONES

Below the Upper Culver coal zone is a sequence of barren rock, ranging in thickness from 11 to 34 feet. Throughout the greater part of the Cedar Mountain quadrangle this sequence is 11 to 16 feet thick and is composed primarily of gray, somewhat sandy shale. In the head of Crystal Creek, however, the sequence ranges in thickness from 28 to 34 feet, and is composed of massive fine-grained sandstone and shale. As shown diagrammatically in figure 19, the marked increase in thickness of the sequence in the Crystal Creek area is explained by the incursion of a tongue of sandstone, which presumably thickens to the south and east and thins to the north and west.

LOWER CULVER COAL ZONE

The Lower Culver coal zone, which lies just below the sequence of barren rock described above, ranges in thickness from 7 to 13 feet, and like the Upper Culver zone is composed of coal and shale in varying proportions. Because of its position below a sequence of soft easily eroded rock, the zone is very poorly exposed in the Cedar Mountain quadrangle. Such exposures as are available are all in the southern part of the quadrangle on the Kanarra Mountain road and in the heads of Crystal and La Verkin Creeks where the local relief is greater than elsewhere. The sections measured at these localities are plotted on plate 3. The numbers on the sections correspond to those on plates 1 and 2 and in figure 19.

As shown in the sections, the only coal of possible economic interest in the zone is the thin layer at the top, which ranges in thickness from 25 to 34 inches and may contain one or more partings. This layer may be overlain locally by fossiliferous marine marl as much as 1 foot thick, but the relative thinness of both marl and coal prevent confusion with coal in the upper part of the Upper Culver zone.

The marine marl at this place in the sequence of rocks provides another demonstrable change from a continental to a marine environment, which is so characteristic of the upper part of the Tropic and the lower part of the Straight Cliffs sandstone.

About 3 feet below the uppermost coal in the Lower Culver coal zone in the Kanarra Mountain area is the top of a sequence of thin layers of carbonaceous shale and coal. A collection of small fossils from one of the carbonaceous shale layers at locality 33 in the NW¼ sec. 10, T. 38 S., R. 11 W., provided the following species, identified by the late John B. Reeside, Jr.:

Neritina (Velatella) bellatula Meek
Eulimella? sp.
Gastropod related to *Neritina*, not determined

Mr. Reeside considered that the assemblage would be typical of an estuarine rather than a fresh-water or marine environment, because other species characteristic of the latter environments are absent. An estuarine environment is an expectable stage in the alternation between continental and marine environments, and the fossil assemblage thus provides additional confirmation of the rhythmic changes in depositional environment.

Somewhere in the central or northeastern part of the quadrangle, the coal at the top of the Lower Culver zone may be thick enough to mine, and when circumstances permit, prospecting should be extended to test this possibility. Similarly, in trenching it is important to know the nature of the coal and overlying rocks in the Lower Culver zone, so that it will not be confused with the Upper Culver zone and thus lead to premature abandonment of the prospect.

WILLOW CREEK COAL ZONE

The Willow Creek coal zone, which is about 110 feet below the Lower Culver coal zone, is 8 to 9 feet thick. It contains a layer of coal as much as 10 inches thick at the top and another layer, typically 5 to 7 inches thick, at the base. Between the two coal layers is an 8-foot sequence of shale and fine-grained thin-bedded sandstone. The zone was noted only in sections in the cliffs at the head of Willow Creek, from which the name was derived, but it may well be present in other parts of the quadrangle. Three detailed sections of the Willow Creek zone are shown on plate 3, and a line showing the location of the zone at the head of Willow Creek is shown on plate 1.

The rocks in the sequence between the Willow Creek zone and the Lower Culver zone are typically thin-bedded fine-grained sandstone that breaks down readily on weathering. Three generalized sections through this sequence are shown in figure 19.

STRAIGHT CLIFFS COAL ZONE

The Straight Cliffs coal zone, which is 80 to 90 feet above the top of the Upper Culver zone, is only about 4 feet thick. This zone lies at the top of a strong ledge-forming sandstone sequence, and may be located in the field by its proximity to the ledge and to the Upper Culver zone, which lies at the base of the ledge. Although its location is well established, the Straight

Cliffs zone is very poorly exposed, and information about its thickness and nature is based on a very few observations. However, the few points of observation are well distributed, and thus suggest that the zone is present at its place in the sequence everywhere in the quadrangle.

The zone was examined in detail at locality 15 in Shurtz Creek where it contains 3 layers of coal totaling 35 inches in thickness, separated by 3 layers of shale totaling 11 inches in thickness. (See pl. 3.)

At localities 32a and 39, Richardson (1909, p. 392–393) recorded 4 feet of coal in the zone, which, if entirely free of partings, would be sufficient to merit additional attention.

LOCAL COAL BEDS

Although most of the coal in the Cedar Mountain quadrangle is concentrated in the four zones described above, several thin local beds occur higher in the stratigraphic section.

In the SW¼ sec. 9, T. 38 S., R. 11 W., are 2 local exposures of thin coal, each about 18 inches thick. The 2 exposures are about 300 feet above the top of the Upper Culver coal zone, and they lie one-half mile apart on opposite sides of the divide between Kanarra and Willow Creeks. Although precise correlation cannot be established between these two occurrences, it is very likely that an area of thin coal underlies the divide between the two localities.

In the NE¼ sec. 10, T. 38 S., R. 11 W., is an exposure showing 2 thin layers of coal, one 17 inches and the other 18 inches thick, separated by a 4-inch parting of gray shale. A section measured at this locality is given below:

Section of coal in the NE¼ sec. 10, T. 38 S., R. 11 W.

	Inches
Top: Concealed.	
Shale, gray	4
Coal	17
Clay, gray	4
Coal and shale (weathered)	18
Clay, brown and gray	2
Base: Concealed.	

This local coal zone is about 400 feet above the top of the Upper Culver coal zone. Considering that the coal in the SW¼ sec. 9, as described above, is only 300 feet above the top of the Upper Culver coal zone and is also about 18 inches thick, the possibility must be considered that the coal in the NE¼ sec. 10 is a correlative of the coal in the SW¼ sec. 9. The possibility must also be considered that the intervals of 300 and 400 feet, respectively, above the top of the Upper Culver coal zone may contain small accumulative errors in opposite directions. In particular, the top of the Upper Culver coal zone as mapped one-half mile south of the coal locality in the NE¼ sec. 10 is in a nearly vertical cliff where a small error in plotting horizontal location could result in a considerable vertical error.

In sec. 20, T. 37 S., R. 10 W., on the east side of Urie Creek, about 1,250 feet above the top of the Upper Culver coal zone is a zone of carbonaceous shale and thin coal that crops out over a horizontal distance of about three-quarters of a mile. The zone consists almost entirely of carbonaceous shale, but contains 2 layers of coal 3 and 8 inches thick, respectively. The shale and associated coal are mildly radioactive, and the 8-inch layer of coal, in particular, registered a count of 2.9 times background. The zone is described as units 20 to 25, inclusive, in the detailed section of the Straight Cliffs and Wahweap sandstones, beginning on page 29.

PROBABLE CORRELATION WITH COAL BEDS OF OTHER AREAS

In a stratigraphic section measured on the south flank of Kanarra Mountain near the southwest corner of the Cedar Mountain quadrangle, Gregory (1950a, p. 84) reported 3 thin coal beds in the lowermost 100 feet of the Tropic formation. Although only carbonaceous shale was observed at this stratigraphic position in sections observed in the central part of the Cedar Mountain quadrangle, Richardson (1909, p. 395) and, more recently, Cashion (1961) have reported coal beds of minable thickness in the basal 100 feet of the Tropic formation in the Orderville-Glendale area to the east of the Cedar Mountain quadrangle.

From these scattered observations it seems certain that there is a coal zone in the basal part of the Tropic formation that thins from east to west, and that probably pinches out in or near the Cedar Mountain quadrangle.

In the Orderville Canyon NW quadrangle to the southeast of the Cedar Mountain quadrangle, Pillmore (1956) selected as the base of the Straight Cliffs sandstone of that area the base of a sandstone ledge that lies just below the Lower Culver coal zone of the Cedar Mountain quadrangle. Therefore, the base of the Straight Cliffs sandstone of the Orderville Canyon NW quadrangle is about 150 feet lower stratigraphically than the base selected for the Cedar Mountain quadrangle. If the Upper and Lower Culver coal zones of the Cedar Mountain quadrangle persist to the southeast, they lie just above the basal ledge of the Straight Cliffs sandstone as mapped in the Orderville Canyon NW quadrangle.

RANK AND QUALITY OF THE COAL

The rank of the coal in the Cedar Mountain quadrangle and vicinity lies near the boundary line between high volatile C bituminous and subbituminous A, according to the standard classification of the American Society for Testing Materials (1954). 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 2 gives analyses of several different kinds of samples taken from different openings at various times in the past. Included are mine or bed samples of both fresh and weathered coal, samples of parts of beds, and samples of sized coal taken from the tipples. In determining the range of composition of coal from the Cedar Mountain quadrangle and vicinity, it is necessary to consider the same kind and condition of samples. The best comparison is one based on unweathered mine or bed samples analyzed since 1919 when analytical procedures were standardized. As recorded in the table, 13 samples comply with these conditions. In this group of samples the heat values range from 10,350 to 11,430 Btu on an as-received basis; the ash contents range from 4.7 to 12.2 percent; the sulfur contents range from 5.6 to 6.7 percent; and the moisture contents range from 6.1 to 13.5 percent.

From these data it is apparent that the coal in the Cedar Mountain quadrangle and vicinity has moderate heat values, moderate to high ash and moisture contents, and relatively high sulfur contents.

Although to a certain minor extent the differences recorded in table 2 are due to differences in the thickness of coal sampled, to minor differences in the degree of weathering, and possibly to differences in the amount of moisture in the mines, the samples record a consistent difference in the composition of the coal between the northern and southern parts of the area. In general, the coal in the northern part of the area seems to be lower in moisture, higher in ash, and slightly higher in heat value than coal in the southern part.

All the coal breaks down, or slacks, slowly upon exposure to the air, but not to a degree that interferes seriously with use.

HISTORY OF MINING

Coal was first mined in the Cedar City area in 1854 from the opening known as the Leyson mine in Right Hand Canyon (loc. 4, fig. 20). Near here also were the first coke ovens in the region, which yielded the low-grade coke used in some of the early attempts to produce iron from the deposits at Iron Springs. These activities constituted the first recorded use of any of Utah's large and varied mineral resources. As the coal was unsuited for the production of metallurgical coke and was soon replaced by charcoal, coal mining languished throughout the early years. A typical coal-mining operation lasted only a few years and yielded only a few hundred hard-won tons of coal before being abandoned either to another operator or in favor of another locality.

Most of the early mining operations were along Coal Creek and in Right Hand Canyon, where the coal is more accessible than elsewhere; but activities soon spread to Cedar and Kanarra Mountains. The Corry mine on Lone Tree Mountain (loc. 12) was opened in 1885, the old Kanarraville mine on the Kanarra Mountain road (loc. 31) was opened in 1896, and the Culver mine of the head of Shurtz Creek (loc. 21) was opened in 1903. By this time the location of the coal crop was established, and the nature of the coal was well understood.

The early pattern of intermittent small-scale pick-and-shovel type of mining operations continued into the 1940's, by which time more modern mechanized methods were gradually introduced. During the summer of 1955 the three largest mines in the area—the Koal Kreek (old MacFarlane), Webster, and Tucker mines (loc. 1, 7, 8, respectively) were highly mechanized and were set up and operating on a sustained, year-round basis.

Pertinent details about most of the mines and prospects in the Cedar City area are given in table 3.

TABLE 2.—*Analyses of coal in and near the Cedar Mountain quadrangle, Iron County, Utah*

[Kind of sample: M, mine or channel; T, tipple. Condition: 1, sample as received; 2, dried at 105° C.; 3, moisture and ash free]

Locality No. (pl. 1 or fig. 20)	Mine	Location	Remarks	Source of analysis	Laboratory No.	Date of sampling	Kind of sample	Condition	Analyses in percent: Proximate: Moisture	Proximate: Volatile matter	Proximate: Fixed carbon	Proximate: Ash	Ultimate: Sulfur	Ultimate: Hydrogen	Ultimate: Carbon	Ultimate: Nitrogen	Ultimate: Oxygen	Air-drying loss (percent)	Heat value (Btu)	Softening temperature of ash (°F.)
	Coal Creek and Right Hand Canyon																			
1	Koal Kreek or MacFarlane; formerly Jones or Jones-Bullock.	T. 36 S., R. 10 W., SE½ sec. 36.	100 ft. from entrance	U.S. Bur. Mines.	3762	1906	M	1	8.6	36.5	46.2	8.8	5.8					2.3		
			do	do	5304	1907	M	1	10.4	36.3	43.7	9.6	5.8	5.1	61.2	1.0	17.3	1.8	10,870	
								2		40.5	48.8	10.7	6.5	4.4	68.3	1.1	9.0		12,130	
								3		45.4	54.6		7.3	5.0	76.5	1.2	10.0		13,590	
			600 ft. from entrance	do	81080	1921	M	1	8.1	42.9	41.2	7.9	5.5					2.2	11,375	
								2		46.7	44.7	8.6	6.0						12,371	
								3		51.0	49.0		6.6						13,534	
			5 tons of 3-in. lump	do	B-68724	1941	T	1	7.8	41.9	39.9	10.4	5.9	5.4	61.6	1.1	15.6	2.6	11,140	2,140
								2		45.5	43.3	11.2	6.4	4.8	66.8	1.2	9.6		12,090	
								3		51.2	48.8		7.2	5.5	75.3	1.3	10.7		13,620	
			5 tons of 1½- by 3-in. nut	do	B-68725	1941	T	1	8.2	40.8	39.7	11.3	5.5					2.5	10,950	2,180
								2		44.5	43.2	12.3	6.0						11,930	
								3		50.7	49.3		6.8						13,610	
			10 tons of ⅜- by 1½-in. stoker.	do	B-68726	1941	T	1	8.6	40.3	39.8	11.3	5.4					2.7	10,880	2,190
								2		44.0	43.6	12.4	5.9						11,900	
								3		50.2	49.8		6.7						13,580	
			8 tons of 1⅝-in. lump	do	C-51950	1946	T	1	7.2	41.7	37.7	13.4	4.8					2.8	10,750	2,110
								2		44.9	40.6	14.5	5.2						11,580	
								3		52.5	47.5		6.1						13,540	
			15 tons of 1⅝-in. nut and slack.	do	C-51949	1946	T	1	8.1	41.2	38.3	12.4	5.5	5.2	59.6	1.0	16.3	3.0	10,800	2,120
								2		44.9	41.6	13.5	6.0	4.6	64.9	1.1	9.9		11,750	
								3		51.8	48.2		7.0	5.4	75.0	1.2	11.4		13,580	
			3 tons of 1⅝-in. lump	do	D-65258	1951	T	1	6.6	41.7	39.5	12.2	5.3					1.2	11,020	2,220
								2		44.6	42.3	13.1	5.7						11,790	
								3		51.3	48.7		6.5						13,570	
			8 tons of 1⅝-in. nut and slack.	do	D-65259	1951	T	1	7.1	41.8	39.3	11.8	5.3	5.1	60.5	1.1	16.2	1.4	10,970	2,150
								2		44.9	42.4	12.7	5.7	4.6	65.1	1.2	10.7		11,810	
								3		51.5	48.5		6.5	5.3	74.5	1.4	12.3		13,520	
5	Wood and Taylor	T. 36 S., R. 10 W., SW¼ sec. 33.		do	3760	1906	M	1	4.9	38.0	43.2	13.9	6.6					2.1		
								2		39.9	45.4	14.7	6.9							
7	Webster-Nelson; formerly Brayton.	T. 37 S., R. 10 W., NE¼ sec. 5.	Face of main entry	do	A-20190	1926	M	1	6.4	40.7	41.7	11.2	6.5					3.1	11,370	
								2		43.5	44.5	12.0	6.9						12,150	
								3		49.4	50.6		7.8						13,800	
			90 ft. from entrance	do	A-20191	1926	M	1	6.1	40.9	40.8	12.2	6.5					2.2	11,230	
								2		43.6	43.4	13.0	7.0						11,960	
								3		50.0	50.0		8.0						13,740	
			do	do	A-20192	1926	M	1	6.0	40.7	41.1	12.2	6.5					2.2	11,230	
								2		43.3	43.7	13.0	7.0						11,950	
								3		49.7	50.3		8.0						13,740	
			do	do	A-20193 (Composite A-20190-92)	1926	M	1	6.0	41.1	40.9	12.0	6.5	4.9	61.1	1.0	14.5	2.6	11,260	
								2		43.7	43.6	12.7	7.0	4.5	65.0	1.1	9.7		11,980	
								3		50.1	49.9		8.0	5.2	74.4	1.2	11.2		13,730	
			4 tons of 1⅝-in. lump	do	C-51470	1945	T	1	5.9	41.0	41.2	11.9	6.4					2.4	11,190	2,090
								2		43.6	43.7	12.7	6.8						11,890	
								3		49.9	50.1		7.8						13,620	
			5 tons of 1⅝-in. lump	do	C-51471	1945	T	1	6.1	39.7	39.6	14.6	6.1	4.8	58.2	1.0	15.3	2.7	10,670	2,150
								2		42.3	42.2	15.5	6.5	4.4	62.0	1.0	10.6		11,360	
								3		50.0	50.0		7.7	5.2	73.4	1.2	12.5		13,440	
8	Tucker	T. 37 S., R. 10 W., NE¼ sec. 5.	8 tons of 3-in. lump	do	C-51468	1945	T	1	6.2	41.1	40.3	12.4	6.3	5.1	60.6	1.1	14.5	2.2	11,020	2,130
								2		43.8	42.9	13.3	6.7	4.7	64.6	1.2	9.5		11,750	
								3		50.5	49.5		7.7	5.4	74.4	1.4	11.1		13,540	
			12 tons of 3-in. minus	do	C-51469	1945	T	1	6.5	39.9	36.6	17.0	6.1					2.8	10,280	2,130
								2		42.7	39.1	18.2	6.5						10,990	
								3		52.2	47.8		8.0						13,440	

TABLE 2. *Analyses of coal in and near the Cedar Mountain quadrangle, Iron County, Utah*—Continued

Locality No. (pl. 1 or fig. 20)	Mine	Location	Remarks	Source of analysis	Laboratory No.	Date of sampling	Kind of sample	Condition	Analyses in percent: Proximate: Moisture	Proximate: Volatile matter	Proximate: Fixed carbon	Ash	Ultimate: Sulfur	Ultimate: Hydrogen	Ultimate: Carbon	Ultimate: Nitrogen	Ultimate: Oxygen	Air-drying loss (percent)	Heat value (Btu)	Softening temperature of ash (°F.)
Green Hollow-Cedar Mountain																				
11	Monolith-Portland Cement Co. Prospect 5A.	T. 36 S., R. 10 W., 2,000 ft. S., 400 ft. E., NW. corner sec. 30.	Weathered	Monolith-Portland Cement Co.	5A	1949	M	1				13.9							8,940	
12	Corry	T. 36 S., R. 10 W., NW¼ sec. 31.	29-in. cut	U.S. Bur. Mines.	3761	1906	M	1	5.2	39.8	43.5	11.5	6.8					1.7		
								2		42.0	45.9	12.1	7.2							
			77-in. cut	do	5494	1907	M	1	4.9	37.2	44.9	13.0	6.7	5.1	63.0	.9	11.3	1.4	11,410	
								2		39.2	47.1	13.7	7.1	4.8	66.3	1.0	7.1		12,000	
								3		45.4	54.6		8.2	5.6	76.8	1.1	8.3		13,910	
Shurtz Creek																				
15	Monolith-Portland Cement Co. Prospect 7B.	T. 37 S., R. 11 W., W½NE¼ sec. 12.	Weathered; units 1 and 2 of sec. 15.	Monolith-Portland Cement Co.	1 and 2 averaged.	1952	M	1	6.3	42.8	39.9	10.9	6.9						10,560	
								2		45.7	42.6	11.7	7.4						11,288	
			Weathered; unit 3 of sec. 15.	do	3	1952	M	1	10.4	42.1	37.2	10.3	6.6						10,290	
								2		46.9	41.6	11.5	7.4						11,489	
			Weathered; unit 4 of sec. 15.	do	4	1952	M	1	4.5	45.6	38.2	11.6	7.3						10,550	
								2		47.8	40.0	12.2	7.6						11,055	
			Weathered; unit 5 of sec. 15.	do	5	1952	M	1	7.9	45.1	42.3	4.7	6.5						10,960	
								2		48.9	46.0	5.1	7.1						11,905	
			Weathered; unit 6 of sec. 15.	do	6	1952	M	1	6.9	43.1	40.1	9.9	6.0						10,400	
								2		46.3	43.1	10.6	6.5						11,168	
			Weathered; unit 7 of sec. 15.	do	7	1952	M	1	5.2	43.5	42.2	9.1	7.0						10,880	
								2		45.9	44.5	9.6	7.4						11,487	
			Weathered; unit 8 of sec. 15.	do	8	1952	M	1	6.1	36.8	31.8	25.2	6.8						8,740	
								2		39.2	33.9	26.9	7.2						9,307	
			Weathered; unit 9 of sec. 15.	do	9	1952	M	1	13.7	35.9	37.7	12.7	5.2						8,480	
								2		41.6	43.7	14.7	6.0						9,835	
18	Monolith-Portland Cement Co.: Prospect X2A	T. 37 S., R. 11 W., Cen. sec. 13.	Weathered	do	13	1952	M	1	17.8	46.1	26.7	9.4	4.9						9,380	
								2		56.0	32.5	11.5	5.9						11,428	
19	Prospect X3A	T. 37 S., R. 11 W., NE¼SW¼ sec. 13.	do	do	12	1952	M	1	12.0	42.6	39.2	6.2	6.2						9,710	
								2		48.4	44.6	7.0	7.0						11,035	
21	Culver	T. 37 S., R. 11 W., NW¼ sec. 24. 125 ft. from entrance.	95-in. cut	U.S. Bur. Mines.	3687	1906	M	1	13.2	35.6	41.7	9.5	4.4					5.4		
								2		41.0	48.0	10.9	5.1							
			do	do	5305	1907	M	1	14.2	33.4	42.5	9.9	5.4	5.2	55.3	.9	23.3	2.8	9,930	
								2		38.9	49.5	11.6	6.3	4.2	64.4	1.0	12.5		11,570	
								3		44.0	56.0		7.1	4.8	72.8	1.1	14.2		13,080	
				Monolith-Portland Cement Co.	Culver	1952	M	1	6.9	44.9	40.5	7.7	6.7						10,350	
								2		48.2	43.5	8.3	7.2						11,132	

Kanarra Mountain Road

25	Kleen Koal or Graff	T. 37 S., R. 11 W., NW¼NW¼ sec. 28.	100 ft from entrance	U.S. Bur. Mines.	B-24200	1937	M	1	10.3	37.7	47.3	4.7	5.7					2.8	11,270	2,150
								2		42.0	52.7	5.3	6.3						12,550	
								3		44.4	55.6		6.7						13,250	
			850 ft from entrance	do	B-53039	1940	M	1	13.1	35.5	45.6	5.8	5.8					6.3	10,880	2,250
								2		40.8	52.5	6.7	6.7						12,510	
								3		43.7	56.3		7.2						13,410	
			900 ft from entrance	do	B-53040	1940	M	1	13.5	35.5	45.4	5.6	5.9					7.1	10,860	2,210
								2		41.0	52.5	6.5	6.9						12,560	
								3		43.8	56.2		7.3						13,430	
			do	do	B-53041	1940	M	1	13.0	35.1	46.2	5.7	5.8					6.7	11,050	2,160
								2		40.4	53.1	6.5	6.6						12,690	
								3		43.2	56.8		7.1						13,570	
			do	do	B-53042 (Composite B-53039-41).	1940	M	1	13.0	35.7	45.6	5.7	5.8	5.7	59.8	1.0	22.0	6.7	10,930	
								2		41.1	52.4	6.5	6.7	4.9	68.7	1.2	12.0		12,570	
								3		44.0	56.0		7.2	5.3	73.6	1.3	12.6		13,450	
			10 tons 3-in. lump	do	B-68727	1941	T	1	12.8	37.9	43.6	5.7	5.9	5.7	60.1	1.1	21.5	3.8	10,830	2,200
								2		43.5	49.9	6.6	6.7	4.9	68.9	1.3	11.6		12,420	
								3		46.5	53.5		7.2	5.2	73.8	1.4	12.4		13,290	
			10 tons 2- by 3-in. nut	do	B-68728	1941	T	1	12.5	38.1	42.9	6.5	5.9					3.3	10,790	2,250
								2		43.6	48.9	7.5	6.7						12,340	
								3		47.1	52.9		7.2						13,330	
			¼- by 2-in. stoker	do	B-68729	1941	T	1	12.8	37.1	42.5	7.6	6.0					3.8	10,500	2,230
								2		42.5	48.7	8.8	6.9						12,040	
								3		46.6	53.4		7.5						13,200	
			¼-in. slack	do	B-68730	1941	T	1	15.0	35.9	39.7	9.4	5.9					6.8	9,990	2,230
								2		42.2	46.7	11.1	6.9						11,740	
								3		47.5	52.5		7.8						13,200	
29	Williams No. 1	T. 37 S., R. 11 W., NW¼ sec. 33.	Above road	do	81078	1921	M	1	12.2	39.7	40.0	8.1	5.6					3.7	11,430	2,080
								2		45.2	45.6	9.2	6.3						13,020	
								3		49.8	50.2		6.8						14,339	
31	Kanarraville	T. 37 S., R. 11 W., NW¼ sec. 33.	8½ ft cut	do	5307	1907	M	1	12.6	36.4	46.2	4.8	5.2	5.7	62.1	.9	21.3	1.6	10,940	
								2		41.7	52.8	5.5	6.0	4.9	71.1	1.1	11.4		12,510	
								3		44.1	55.9		6.3	5.2	75.2	1.1	12.2		13,240	
			do	do	3830	1906	M	1	13.4	38.3	42.9	5.4	5.7					5.0		
32	Williams No. 2	T. 37 S., R. 11 W., NW¼ sec. 33.	Below road	do	B-53043	1940	M	1	13.4	35.4	45.3	5.9	5.7	5.8	59.2	1.0	22.4	6.8	10,710	2,160
								2		40.9	52.3	6.8	6.5	4.9	68.4	1.2	12.2		12,370	
								3		44.0	56.0		7.0	5.3	73.4	1.3	13.0		13,280	
			3 tons of 2-in. lump	do	C-51472	1945	T	1	12.6	37.9	42.5	7.0	5.4					4.2	10,740	2,230
								2		43.3	48.7	8.0	6.2						12,290	
								3		47.1	52.9		6.7						13,360	
			5 tons of 2-in. slack	do	C-51473	1945	T	1	13.1	38.1	42.0	6.8	5.9	5.6	59.1	.9	21.7	5.2	10,660	2,260
								2		43.8	48.4	7.8	6.8	4.8	68.1	1.1	11.4		12,270	
								3		47.5	52.5		7.4	5.2	73.9	1.2	12.3		13,320	

TABLE 3.—*List of coal mines and prospects in and near the Cedar Mountain quadrangle, Iron County, Utah*

Locality No. (pl. 1 or fig. 20)	Name	Owner	Operator	Location	Previous name or names	Date opened	Laboratory No. (table 2)	Remarks
	Coal Creek and Right Hand Canyon							
1	Koal Kreek or MacFarlane.	Zion Security Corp	Guy C. Tucker & Sons.	T. 36 S., R. 10 W., S½ sec. 36	Jones and Bullock; Jones; No. 1 of pl. 25 of Richardson (1909).	1890	81080 5304 3762	Opened by Heber Jensen and Frank B. Adams.
2	Cluff	Thos. A. Thorley	Ernest Webster	T. 36 S., R. 10 W., NW¼ sec. 35	Cluff Jensen; Jensen; No. 2 of pl. 25 of Richardson (1909).	1885		Opened by Peter Fife. Section from Gregory (1950a, p. 147).
3	Walker prospect			T. 36 S., R. 10 W., SW¼ sec. 22				At mouth of Maple Canyon on west side of Coal Creek. Coal impure. Section from Richardson (1909, p. 389).
4	Leyson	Rulon Wood; Harry Leigh.	Lew Webster	T. 36 S., R. 10 W., sec. 33	No. 3 of pl. 25 of Richardson, (1909).	1854		Oldest mine in region; worked 1854 to 1890. First coke ovens nearby. Daggett (1883, p. 77) reports upper bench 2 ft and lower bench 4 ft separated by clay parting.
5	Wood and Taylor	do		T. 36 S., R. 10 W., SW¼ sec. 33	Wood; near No. 4 of pl. 25 of Richardson (1909).	1881	3760	One-half mile west of Leyson. Section from Richardson (1909, p. 391).
6	Condies		George Condie	T. 36 S., R. 10 W., SW¼ sec. 33				Operated very little.
7	Webster or Webster-Nelson.	U.S. Government	Lew Webster	T. 37 S., R. 10 W., NE¼ sec. 5, lot 1.	Dean F. Brayton	1941	A-20190-93	Older Brayton opening was ¼-mile south of Webster opening.
8	Tucker		Guy C. Tucker and Sons.	T. 37 S., R. 10 W., NE¼ sec. 5		1938±	C-51468 C-51469	Opened by Kenneth MacFarlane.
9	General Steam prospect.			T. 37 S., R. 10 W., NW¼ sec. 5				
10	Rail Tram		Frank Ennis	T. 37 S., R. 10 W., sec. 30				Adit 100 to 200 ft long. Shipped very little.
	Green Hollow—Cedar Mountain							
11	Prospect 5A	U.S. Government	Monolith-Portland Cement Co.	T. 36 S., R. 10 W., 2000 ft S., 400 ft E., NW corner sec. 30.		1949	5A	Prospecting permit 070807. No detailed section
12	Corry		Andrew Corry	T. 36 S., R. 10 W., NW¼ sec. 31	No. 5 of pl. 25 of Richardson (1909).	1885	5494 3761	Working in 1907. Section from Monolith-Portland Cement Co.
	Shurtz Creek							
13	Prospect X2D	U.S. Government	Monolith-Portland Cement Co.	T. 37 S., R. 11 W., SE¼SW¼ sec. 1.		1952		Prospecting permit 070806.
14	Drill hole		do	T. 37 S., R. 11 W., NE corner sec. 12.		1952		Showed 4 ft coal, dirty coal, and clay in Straight Cliffs zone; 12 ft 4 in coal and bone in Upper Culver zone. No detailed section available.
15	Prospect 7B	U.S. Government	do	T. 37 S., R. 11 W., S½NE¼ sec. 12.		1952	1-9	
16	Prospect X2B	do	do	T. 37 S., R. 11 W., SE¼ sec. 12		1952		Section from Monolith-Portland Cement Co.
17	Prospect X2C	do	do	T. 37 S., R. 11 W., SW¼SE¼ sec. 12.		1952		Do.
18	Prospect X2A	do	do	T. 37 S., R. 11 W., Cen. sec. 13		1952	13	Do.
19	Prospect X3A	do	do	T. 37 S., R. 11 W., NE¼SW¼ sec. 13.		1952	12	Do.
20	Prospect 7D	do	do	T. 37 S., R. 11 W., SW¼ sec. 13		1949		Opened by Monolith-Portland Cement Co. Coal and partings estimated 7 ft 3 in. No detailed section.
21	Culver		F. L. Culver; G. E. Burns.	T. 37 S., R. 11 W., NW¼ sec. 24	No. 7 of pl. 25 of Richardson (1909).	1903	5305 3687	Adit 260 ft long. See fig. 21.
22	Monolith adit	U.S. Government	Monolith-Portland Cement Co.	T. 37 S., R. 11 W., S½NW¼ sec. 24.		1954		Opened for development; no production.
23	Outcrop			T. 37 S., R. 11 W., NE¼SW¼ sec. 23.				In cliff on south side of Shurtz Creek amphitheater.
24	Thompson prospect			T. 37 S., R. 11 W., SW¼ sec. 23	No. 8 of pl. 25 of Richardson (1909).	1906±		Did not produce.

				Kanarra Mountain road				
25	Kleen Koal	A. L. Graff	Guy C. Tucker	T. 37 S., R. 11 W., NW¼ sec. 28	Lone Tree; No. 9 of pl. 25 of Richardson (1909).	1937±	B-53039-42, B-24200	Used aerial tram. Adits 600 to 1,000 ft long. Section 25a by L. S. Gardner; 25b by B. W. Dyer.
26	Pollock			do	No. 10 of pl. 25 of Richardson (1909).			Section from surface near slumped entrance.
27	Leon Davis			T. 37 S., R. 11 W., NW¼NW¼ sec. 32.				Adit 300 to 400 ft long.
28	Graff	P. Arnold Graff	Guy C. Tucker	do		1915±		Adit 170 to 200 ft long; forks at back. Section by W. H. Bradley.
29	Williams No. 1		L. Jesse Williams	T. 37 S., R. 11 W., NW¼ sec. 33		1934±	81078	Above road; abandoned about 1938. Section from Gregory (1950a, p. 148). Exact sample locality uncertain; could be locality 30.
30	Prospect			do				Adit 75 ft long.
31	Old Kanarraville		L. Jesse Williams	do	No. 11 of pl. 25 of Richardson (1909).	1886	5307, 3830	Adit 270 ft long. Ruins of old coke ovens ½ mile north. Section from Lee (1907, p. 371).
32	Williams No. 2		do	T. 37 S., R. 11 W., W½ sec. 33		1938	B-53043	Below road; abandoned about 1950. Section by L. S. Gardner.
32a	Outcrop			T. 38 S., R. 11 W., sec. 8				On Bean Hill. Section from Richardson (1909, p. 392-393).
				La Verkin Creek				
33	Outcrop			T. 38 S., R. 11 W., NW¼ sec. 10				At head of Willow Creek.
34	do			T. 38 S., R. 11 W., SE¼NW¼ sec. 10.				At head of Willow Creek. See fig. 22.
35	do			T. 38 S., R. 11 W., SW¼ sec. 11				La Verkin breaks.
36	do			T. 38 S., R. 11 W., NE¼SW¼ sec. 11.				Do.
				Crystal Creek				
37	Outcrop			T. 38 S., R. 11 W., SE¼ sec. 1				In creek bottom.
38	do			T. 38 S., R. 10 W., W½ sec. 7				Do.
				South of Cedar Mountain quadrangle				
[1] 39	Outcrop			T. 38 S., R. 11 W., sec. 14				About 1 mile south of Cedar Mountain quadrangle. Section from Richardson (1909, p. 393).

[1] Not shown on pl. 1 or in fig. 20.

PRODUCTION

During the early years of coal mining in Iron County, production was both sporadic and intermittent. In some years no production was recorded; in others, production was only a few hundred tons. For the fiscal year ending June 30, 1895, production in Iron County totaled only 780 tons according to records of the Utah State Mine Inspector; for 1898 and 1899 production totaled only 524 and 575 tons, respectively.

In the period following the First World War, coal production increased somewhat, and for most years probably ranged between 1,000 and 2,000 tons per year. In 1920 and 1921, the Utah State Mine Inspector reported 2,350 and 1,280 tons, respectively.

Following the 1932 depression, production increased steadily and by 1942 reached 6,329 tons, as reported in the U.S. Bureau of Mines Minerals Yearbook for that year. Table 4 shows the total recorded coal production from Iron County for 1942 and subsequent years. The most significant feature of the table is the marked increase in production from 6,565 tons in 1947 to 19,858 tons in 1948. This increase was the result of the completion in 1947 of a modern coal-fired electric-generating plant of 2,500 kilowatts capacity, owned by the California-Pacific Utilities Co. The plant is located on Coal Creek about 1 mile east of Cedar City. The construction of this plant, which consumes the major part of the coal mined in Iron County, had been made necessary by the postwar increase in production of iron ore at the several mines in the nearby Iron Springs district and by the rapid increase in use of deep wells as a source of water for irrigation in the Cedar City Valley. In recent years the use of electricity for pumping water has grown to such proportions that record peaks in the generation of electricity and in coal production have been attained during the summer months.

TABLE 4.—*Production and value of coal and number of men employed in mining coal in Iron County, Utah, 1942–58*

[Data from U.S. Bureau of Mines Minerals Yearbook (1943–58)]

Year	Production (in short tons)	Average value per ton	Average number of working days	Average number of men employed daily	Average tons per man per day
1942	6, 329	$3. 45	254	7	3. 57
1943	7, 701	4. 45	288	8	3. 34
1944	7, 477	2. 96	236	7	4. 53
1945	9, 577	3. 61	257	11	3. 39
1946	8, 786	2. 64	255	9	3. 83
1947	6, 565	3. 00	273	7	3. 44
1948	19, 858	4. 55	280	14	5. 07
1949	20, 941	5. 07	270	19	4. 09
1950	24, 689	4. 66	270	18	5. 08
1951	24, 113	5. 10	260	20	4. 63
1952	22, 069	4. 75	275	23	3. 50
1953	31, 241	4. 49	266	19	6. 17
1954	33, 701	4. 78	236	23	6. 20
1955	31, 753	4. 48	259	12	10. 23
1956	36, 996	5. 15	279	17	7. 80
1957	39, 612	4. 65	287	18	7. 67
1958	34, 714	5. 24	228	17	8. 97

MINING METHODS

All the coal in the Cedar City area is mined by the room-and-pillar method. The rooms are filled with rock waste as mining advances, and the pillars are normally not recovered. Because the roof rock is relatively soft and because the upper layers of coal are relatively impure, the upper layers of coal are usually left in place to help support the roof.

In each of the three operating mines the coal is undercut, loaded by machinery, and moved to the surface by endless belts. At the mine mouth the larger pieces of waste are handpicked from the coal, and it then goes directly to the tipple without further treatment.

The productivity rate of the Iron County mines has increased steadily through the years as a result of increased mechanization. Between 1942 and 1958, for example, the average output per man per day increased from 3.57 to 8.97 tons, whereas the national average, which includes the largest and most efficient mines in the United States, increased from 5.12 to 11.33 tons (U.S. Bureau of Mines, 1945, 1959).

The mined coal is moved by truck to Cedar City and nearby communities.

USES

Most of the coal mined in the Cedar City area is used for the production of electric power at the previously mentioned 2,500 kilowatt steam-electric plant owned by the California-Pacific Utilities Co. A much smaller amount is used for household fuel in Cedar City and nearby communities. All the coal is consumed locally.

Because of the moderate to high ash, high sulfur, and relatively low rank, the coal is unsuited for the manufacture of coke. Because of the ash and sulfur contents, it is less than ideal as a household fuel. As a result, coal of higher quality from the Carbon and Emery Counties, Utah, fields is regularly imported into Cedar City and sold for household fuel at a premium over the price of the locally produced coal.

With the almost certain prospect that natural gas will soon be piped into Cedar City as an active competitor of coal as a household fuel, the near-term market for the local coal is fixed firmly by the requirements of the local electric plant.

In addition to the local electric plant, however, two large potential outlets exist for Cedar City coal. The first is at Hoover Dam, about 250 miles by rail to the southwest, where future demands for power may require the construction of a steam-electric plant to augment and firm up the fluctuating output of hydroelectric power.

The second potential outlet is for the manufacture of cement in the Los Angeles area, about 575 miles to the west. At present in the Los Angeles area cement kilns are fired by natural gas purchased at low cost on interruptable contracts. When natural gas is not available at times of peak household use, the industry turns to crude oil, which is more expensive than natural gas, or than imported coal would be. As the population and use of energy increase, the available amounts of natural gas may be diverted gradually to household use, which yields a premium rate, and the cost of fuel to the cement industry will increase correspondingly. Thus, the day may come when the cement industry of the Los Angeles area will convert to coal as the most economical and most reliable source of heat. The ash and sulfur contents of the Cedar City coal present no serious problems in its use in the manufacture of cement.

COAL RESERVES

The estimated coal reserves remaining in the ground in the Cedar Mountain quadrangle as of January 1, 1956, totaled nearly 260 million tons, of which 229 million tons, or nearly 90 percent, is in beds 72 inches or more thick. (See tables 5, 6.) Most of this large tonnage of thick coal is within 2 miles of known outcrops, and reasonably accessible to existing lines of transportation. It should be, therefore, of future interest and value to the Pacific Southwest where population and use of fuel are increasing rapidly.

METHODS OF PREPARING ESTIMATES

The coal reserves in the Cedar Mountain quadrangle were calculated and classified according to the standard procedures of the Geological Survey (Averitt, 1961) with a few minor exceptions, which follow.

AREAL EXTENT OF BEDS

The areal extent of coal beds and layers included in the estimate was determined in two ways. The thicker beds and layers in the upper part of the Upper Culver coal zone, which could be readily identified and correlated between all outcrops and openings, were considered to underlie all parts of the quadrangle enclosed by the line of outcrop.

The thinner beds and layers below the uppermost thick layers in the Upper Culver coal zone, which could be recognized and correlated only for short distances, were considered to extend back of the outcrops in semicircular areas having radii equal to one-half the length of the known outcrops. Such semicircular areas are considered to yield tonnage figures fairly representative of the amount of coal that might exist back of the outcrops, but they do not necessarily portray the exact shape or location of the assumed blocks of coal.

DISTINCTION BETWEEN MEASURED AND INDICATED RESERVES AND INFERRED RESERVES

In the Cedar Mountain quadrangle only a small amount of coal can be classed as measured because the points of observation are strung out along the line of outcrop, and locally are more than the recommended one-half mile apart. On the other hand, relatively large quantities of coal can be classed as indicated because almost all the points of observation are within the recommended interval of 1½ miles, and because they are so distributed that almost all the coal-bearing part of the quadrangle is within 2 miles of the outcrop. In reporting reserves in the quadrangle, therefore, these two classes are combined into a single class termed "measured and indicated."

The distinction between the combined class "measured and indicated" on one hand and "inferred" on the other is based on different criteria for beds and layers in different parts of the coal-bearing sequence. Because the coal in the upper part of the Upper Culver coal zone is thick, continuous, and readily correlated between exposures in all parts of the quadrangle, it is for the most part classed as "measured and indicated." However, an area of coal in the extreme east-central part of the quadrangle, which is more than 2 miles from any outcrop, is classed as "inferred." Similarly, an area in secs. 27, 28, 33, and 34, T. 38 S., R 11 W., which is largely covered by basalt, is also classed as "inferred."

For beds and layers lower in the coal-bearing sequence, which are markedly less continuous than the layers in the upper part of the Upper Culver coal zone, the arcs drawn as described under "Areal extent of beds" enclosed all the coal that was classed as "measured and indicated." Where good correlations could be established between beds in the head of Willow Creek and the head of Crystal Creek, limited areas of inferred reserves were considered to extend under the divide between the two streams.

TABLE 5.—*Estimated remaining coal reserves in the Cedar Mountain quadrangle, Iron County, Utah, by bed and township, as of January 1, 1956*

Bed	Reserves, in millions of short tons						Total	
	Measured and indicated			Inferred				
	Average thickness (inches)	Acres	Tons (millions)	Average thickness (inches)	Acres	Tons (millions)	Acres	Tons (millions)
T. 36 and 37 S., R. 10 W.								
Upper benches of Upper Culver coal zone	72	5, 890	63. 6	72	990	10. 7	6, 880	74. 3
Lower benches of Upper Culver coal zone: Locs. 17–20	25	120	. 5				120	. 5
Lower Culver coal zone: Locs. 37–38				26	285	1. 1	285	1. 1
Total		6, 010	64. 1		1, 275	11. 8	7, 285	75. 9
T. 37 S., R. 11 W.								
Straight Cliffs coal zone: Loc. 15	20	100	0. 3				100	0. 3
Upper benches of Upper Culver coal zone	78	4, 760	55. 7	78	1, 340	15. 7	6, 100	71. 4
Lower benches of Upper Culver coal zone:								
Locs. 13–15	17	125	. 3				125	. 3
Locs. 17–21	25	430	1. 6				430	1. 6
Lower Culver coal zone:								
Loc. 28	34	220	1. 1				220	1. 1
Locs. 33–38				26	270	1. 0	270	1. 0
Total		5, 635	59. 0		1, 610	16. 7	7, 245	75. 7
T. 38 S., R. 10 W.								
Upper benches of Upper Culver coal zone	77	2, 420	27. 9				2, 420	27. 9
Lower benches of Upper Culver coal zone: Locs. 37–38	16	60	. 1				60	. 1
Lower Culver coal zone: Locs. 37–38	26	470	1. 8	26	555	2. 2	1, 025	4. 0
Total		2, 950	29. 8		555	2. 2	3, 505	32. 0
T. 38 S., R. 11 W.								
Upper benches of Upper Culver coal zone	82	4, 500	55. 4				4, 500	55. 4
Lower benches of Upper Culver coal zone:								
Loc. 32a	30	145	. 7	20	355	1. 1	500	1. 8
Locs. 33–36	18	1, 340	3. 6				1, 340	3. 6
Locs. 37–38	16	145	. 3				145	. 3
Locs. 33–38				17	1, 300	3. 3	1, 300	3. 3
Lower Culver coal zone:								
Locs. 33–35	27	1, 130	4. 6				1, 130	4. 6
Locs. 37–38	26	325	1. 3				325	1. 3
Locs. 33–38				26	1, 500	5. 9	1, 500	5. 9
Total		7, 585	65. 9		3, 155	10. 3	10, 740	76. 2
Grand total		22, 180	218. 8		6, 595	41. 0	28, 775	259. 8

TABLE 6.—*Summary of estimated remaining coal reserves in the Cedar Mountain quadrangle, Iron County, Utah, as of January 1, 1956*

[The quadrangle contains no reserves in the thickness range of 42 to 72 in.]

Township	Reserves, in millions of short tons, in beds of thickness shown											Total
	Measured and indicated				Inferred				All categories			
	14–28 inches thick	28–42 inches thick	More than 72 inches thick	Total measured and indicated reserves	14–28 inches thick	28–42 inches thick	More than 72 inches thick	Total inferred reserves	14–28 inches thick	28–42 inches thick	More than 72 inches thick	
T. 36 and 37 S., R. 10 W	0.5	----------	63.6	64.1	1.1	----------	10.7	11.8	1.6	----------	74.3	75.9
T. 37 S., R. 11 W	2.2	1.1	55.7	59.0	1.0	----------	15.7	16.7	3.2	1.1	71.4	75.7
T. 38 S., R. 10 W	1.9	----------	27.9	29.8	2.2	----------	----------	2.2	4.1	----------	27.9	32.0
T. 38 S., R. 11 W	9.8	.7	55.4	65.9	10.3	----------	----------	10.3	20.1	.7	55.4	76.2
Total	14.4	1.8	202.6	218.8	14.6	----------	26.4	41.0	29.0	1.8	229.0	259.8

Table 5 shows the localities involved, the average thickness of coal calculated, the acreage assumed, and the reserve classification for each coal bed or layer considered in making the reserve calculations.

RECOVERABLE RESERVES

In the Cedar Mountain quadrangle all the coal is mined by the room-and-pillar method, which on a national basis results in the recovery of about 50 percent of the coal in the ground. The coal in the Cedar Mountain quadrangle also contains several partings, some of which may be left underground locally with a consequent loss of good coal. For these reasons it is likely that the overall average long-term recoverability for the quadrangle will be no more than 50 percent, though it is possible that individual mines from time to time may recover larger amounts. If it is desired to consider only recoverable reserves, the figures for remaining reserves in tables 5 and 6 must be divided by two.

AREAS EXCLUDED FROM ESTIMATE

In preparing the estimate several areas were excluded where the coal is likely to be cut by intrusive masses of basalt or to be disturbed by faulting. Much of the coal in these areas could be mined if necessary, but it does not need to be considered at present because of the availability of abundant quantities of more readily accessible coal. Following is a list of the excluded areas:

1. Lone Tree Mountain, in parts of sec. 36, T. 36 S., R. 10 W., and sec. 31, T. 36 S., R. 11 W., where several intrusive masses of basalt are visible on the surface.
2. Small circular area surrounding visible outcrops of basalt near central part of Pryor Knoll, sec. 18, T. 37 S., R. 10 W., and sec. 13, T. 37 S., R. 11 W.
3. Area about ¼ mile wide and 3 miles long extending from the northernmost of The Three Knolls to Co-Op Knoll in parts of secs. 23, 26, 34, and 35, T. 37 S., R. 11 W., and sec. 3, T. 38 S., R. 11 W., enclosing the line of peaks and many small masses of basalt.
4. Area of disturbed rocks on both sides of the Bear Trap fault in parts of secs. 3, 4, 9, and 10, T. 38 S., R. 11 W.

OVERBURDEN

Practically all the coal in the Cedar Mountain quadrangle lies between 500 and 1,000 feet below the surface. Only a very small amount is less than 500 feet below the surface because the beds crop out at the base of steep cliffs. Only a small amount is more than 1,000 feet below the surface because the topography east of the crest of the Hurricane Cliffs slopes eastward in the same direction as the coal beds.

The coal is 1,000 to 1,200 feet below the surface under the cinder cones, Pryor Knoll, The Three Knolls, and Co-op Knoll. As the coal under these cones is likely to be intruded locally by basalt plugs and associated dikes, a circle of about ½ mile diameter around Pryor Knoll and a strip of ground about ¼ mile wide and 3 miles long extending from the northernmost of The Three Knolls to Co-op Knoll have been excluded from the estimates. Thus, for this part of the quadrangle, the volume of coal excluded from the estimate is roughly equal to the volume that is more than 1,000 feet below the surface.

The coal reaches a maximum of about 1,200 feet below the surface locally along the east-central boundary of the quadrangle, in an area classified as inferred because the coal is more than 2 miles from an outcrop.

Therefore, all the coal classified as measured and indicated can be regarded as being less than 1,000 feet below the surface.

OIL AND GAS POSSIBILITIES

All the past drilling for oil in southwestern Utah has been concentrated in Washington County, about 30 miles south of the Cedar Mountain quadrangle, where the stratigraphy is virtually the same, and where the geologic structure is more favorable for the accumulation of oil than that in the Cedar Mountain quadrangle. One small oil field, the Virgin field, has been discovered as a result of the drilling in Washington County, but other localities and structures of equal or greater promise have proved to be dry. Inasmuch as there has been no drilling for oil in the Cedar Mountain quadrangle, an analysis of past exploration in Washington County will be helpful in appraising the chance of finding oil in the quadrangle.

The Virgin field, which is about 2 miles northeast of the town of Virgin, in Washington County, was discovered in 1907 and inaugurated a period of petroleum exploration that has continued intermittently for 50 years. Between 1907 and January 1, 1955, a total of 138 wells had been drilled in and near the Virgin field, and the small productive area outlined as a result of this drilling had yielded 183,300 barrels of oil (Hansen and Scoville, 1955; National Oil Scouts and Landmen's Association, 1955). However, it is believed that the overall cost of exploration and development in the field has exceeded the value of the oil produced (Hansen and Bell, 1949, p. 303–305). The Virgin field is on a very low, almost imperceptible terrace or dome in the Moenkopi formation. The producing horizon is a thin bed of limestone near the top of the Timpoweap member of the Moenkopi, about 600 feet below the surface. The oil is considered to have been derived locally from the Timpoweap member, which is fossiliferous.

The modest success in the Virgin field led to exploration on other structures in Washington County, and by January 1, 1955, about 29 additional wells had been drilled outside the area of the Virgin field.

Most of the wells in the Virgin field are less than 1,000 feet deep, and of all the 167 wells drilled in the County only 7 are more than 2,000 feet deep. A list of the areas or structures tested by deep wells and the oldest formation penetrated in each is given below:

Areas or structures in Washington County, Utah, tested by wells more than 2,000 feet deep

Area or structure	Total depth of test	Oldest stratigraphic unit penetrated
Pintura area	5, 496	Coconino sandstone.
Virgin field	2, 195	Supai formation.
Grafton dome	3, 508	Kaibab limestone.
Punchbowl dome	2, 590	Permian rocks.
Bloomington dome of Virgin anticline.[1]	2, 532	Supai formation.
	4, 114	(?)
St. George (White) dome	6, 347	Devonian rocks.

[1] Not to be confused with Virgin field.

Except for the cluster of shallow wells in the Virgin field, all other wells have been dry. One reason cited for the relatively poor results obtained in Washington County is the general paucity of carbonaceous beds in the underlying sequence. However, the sequence below the Moenkopi formation is not altogether unfavorable for the accumulation of oil, and it would be premature to say that the total possibilities of the region had been exhausted.

In the Cedar Mountain quadrangle where there are no structures as favorable for the concentration of oil as those in Washington County, the chance of finding oil is markedly less favorable than the chance in Washington County. The Shurtz Creek anticline is a visible structure of possible interest, but it is open to the south and has been faulted along the crest, thereby reducing the chance for oil concentration. On the other hand, the top of the Timpoweap formation is only about 400 feet below the surface at the point in sec. 4, T. 37 S., R. 11 W., where the north fork of Shurtz Creek crosses the axis of the anticline. The rocks on the east side of the Hicks Creek fault are updip from a large area of possible oil accumulation and here also the top of the Timpoweap formation is near the surface. As in Washington County the older, potential oil-bearing formations of Mississippian and Permian ages are also present at greater depths in both structures.

Because of the large area of possible oil accumulation on the east side of the Hurricane fault zone, and because the east half of the ancestral Kanarra fold is preserved on the east side of the fault, there is also a remote possibility of oil concentration along the trace of the fault where the older formations terminate against the fault surface.

However, the chance of finding oil in any of these structures is very small, and the risk of drilling could justifiably be assumed only by an operator with large resources.

GYPSUM

The Cedar Mountain quadrangle contains enormous quantities of gypsum, a hydrous calcium sulfate, $CaSO_4 \cdot 2H_2O$. This useful industrial mineral occurs in a massive and contorted layer about 100 feet thick at the base of the Curtis formation, which crops out in a crooked belt extending from the north-central margin of the Cedar Mountain quadrangle to the southwest corner. This unit is well exposed along State Highway 14 in Coal Creek Canyon, about 3 miles north of the quadrangle. Gypsum was quarried commercially at this point in the latter part of 1923 by the Mammoth Plaster & Cement Co., but operations lasted only about

1 year. The untreated gypsum was shipped to cement plants for use as a retarder (Santmyers, 1929). In the early history of the town of Cedar City gypsum from this locality was used to make small batches of plaster for local use.

Although the quantity of gypsum contained in the Curtis formation, both at the outcrop and at shallow depths behind the outcrop, is very large, the bed is impractical of access at most places in the Cedar Mountain quadrangle. It is easily accessible, however, at the point where the Shurtz Creek road crosses the crop of the Curtis formation, and only a little less accessible on the east side of sec. 29, T. 37 S., R. 11 W., below the Kanarra Mountain road.

Gypsum has many uses in the manufacture of cement, plaster, wallboard, and crayons; as a filler in paint and paper; as a conditioner for alkaline soil; and as a stabilizer for the ammonia present in manure. It is a valuable and versatile raw material, and its presence in quantity in the Cedar City area should be of ultimate benefit to the community.

URANIUM

The rocks of Triassic and Jurassic ages exposed in the Hurricane Cliffs are correlatives of the well-known uranium-bearing formations of the Colorado Plateau. Because of this fact, and because of the postwar boom in uranium in the Colorado Plateau, the Hurricane Cliffs were extensively prospected by means of Geiger and scintillation counters during the period 1952–55. Certainly, all roads, most stream channels, and many ridges have been traversed. As a result of the increased activity and interest, several claims were staked, particularly along the outcrop of the Shinarump member of the Chinle formation and the overlying and underlying beds. However, other than the staked claims and a few grubbed-out prospect pits, which were visible in the fall of 1955, there was not evidence of sustained physical exploration or development in the area covered by the quadrangle.

Several kinds of rock in the Cedar Mountain quadrangle are radioactive, at least locally; the largest concentrations—still far below minimum ore grade—are in coal and associated carbonaceous shale, the second largest are in volcanic rocks of Tertiary age, and the weakest are in noncarbonaceous shale and sandstone.

The most provocative occurrence of radioactivity in the Cedar Mountain quadrangle is the coal at the Tucker mine (loc. 8) in sec. 5, T. 37 S., R. 10 W. As noted in table 7, the coal is weakly radioactive from top to bottom, and includes one 4-inch parting near the center that contains a maximum of 0.019 percent uranium in the ash.

Most other outcrops of coal and carbonaceous shale that were examined gave beta and gamma ray readings generally less than 0.015 mr per hr (milliroentgen per hour), but several localities that gave readings of 0.02 mr per hr or more are listed in table 8. Table 8 also presents data on the radioactivity of the ash dump of the California-Pacific Utilities Co. powerplant in Coal Creek Canyon, and the waste dump of the Tucker mine (loc. 8) which gave higher readings of 0.03 and 0.03 to 0.04 mr per hr, respectively.

No radioactivity was observed in sandstone beds at the base of the Cretaceous, but uranium mineralization has been reported at this horizon at a locality about 20 miles southeast of the quadrangle in secs. 15 and 16, T. 40 S., R. 9 W. (Beroni and others, 1953).

TABLE 7.—Uranium and germanium content of selected layers of coal from the Tucker mine, sec. 5, T. 37 S., R. 10 W., Iron County, Utah.

[Face of main entry, 1,600 feet from entrance. Analysts, Joseph Budinsky, Mona Frank, and B. A. McCall]

Graphic coal section (thickness, in inches)	Description	Beta and gamma ray radiation measured in field (mr /hr)[1]	Analyses in percent					Laboratory No.
			Ash	U in ash	Ge in ash	U in sample[2]	eU in sample[2]	
6	Impure coal	0.015	13.7	0.002	0.01	0.0003	(3)	138465
2	Shale	.02	67.4	.001	(3)	.0007	0.001	138466
19	Impure coal	.032	29.8	.006	(3)	.0018	.001	138467
4	Shale	.042	56.5	.007	(3)	.0039	.003	138468
4	Coal	.032	10.2	.019	(3)	.0019	.001	138469
2	Shale }							
10	Coal }							
1	Impure coal }	.015	15.0	.002	.001	.0003	(3)	138470
34	Coal with few ¼- to ⅛- in. partings }							

[1] Includes normal background radiation of 0.01 mr per hr.
[2] Calculated from percent ash and percent uranium in ash.
[3] Less than 0.001 percent.

TABLE 8.—*Uranium content of rocks in and near the Cedar Mountain quadrangle, Iron County, Utah*

Locality	Unit examined	Beta and gamma ray radiation measured in field (mr/per hr) [1]	eU (percent)	U (percent)	Remarks
Webster mine (loc. 7, fig. 20)	4-in parting in coal	0.022			Same parting in Tucker mine (loc. 8) gave 0.042 mr/per hr.
California-Pacific Utilities Co. powerplant in Coal Creek Canyon.	Ash dump	.03	[2] 0.004	[2] 0.002	Coal in roughly equal parts from Tucker, Webster, and Koal Kreek mines.
Tucker mine (loc. 8, pl. 1)	Waste dump	0.03 .04			Partly burned.
NW corner sec. 15, T. 37 S., R. 11 W.	Shinarump member of Chinle formation.	.015			Shurtz Creek road.
Sec. 20, T. 37 S., R. 10 W	Carbonaceous shale in Wahweap sandstone.	.02	[2] .003	[2] .003	
Sec. 17, T. 37 S., R. 10 W	Kolob latite	.02	[3] .003	[3] .001	Urie Creek.
Sec. 1, T. 37 S., R. 12 W	Member E of Mackin (1954) welded tuff.	.02	[3] .003	[3] <.001	North Hills.

[1] Includes normal background radiation of 0.01 mr/per hr.
[2] From Zeller (1954).
[3] Analysts: Maryse Delevaux and Percy Moore.

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