DEPARTMENT OF THE INTERIOR
Hubert Work, Secretary

U. S. GEOLOGICAL SURVEY
George Otis Smith, Director

Professional Paper 150

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

1927

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UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1928

A SECTION OF THE KAIBAB LIMESTONE IN KAIBAB GULCH, UTAH

By L. F. Noble

INTRODUCTION

Of the Paleozoic formations in the plateau province of Arizona and Utah the Kaibab limestone, the youngest formation of the succession, is perhaps the best known. It is probably the most widely distributed Paleozoic formation in the province, its outcrops covering a large part of northern Arizona and appearing at many places in southern Utah. In southern Nevada, beyond the western boundary of the province, it is exposed in several mountain ranges, in one of which it extends to the border of California. At the Grand Canyon it is one of the chief elements in the landscape, constituting the surface of the Kaibab and Coconino Plateaus, through which the deepest part of the canyon is cut, and forming the first cliffs that drop away at the rim of the canyon. Its abundant fossil fauna and its position at the top of the Permian series beneath a widespread unconformity of erosion furnish interesting problems for the paleontologist and stratigrapher. At many places it is of considerable economic importance for the deposits of gypsum and lime that it contains.

The Kaibab limestone was named by Darton,[1] who states:

> The upper limestone of the Carboniferous in northern Arizona has heretofore been known as the "Aubrey" limestone, but as Aubrey has now been adopted by the United States Geological Survey for the group of which this limestone forms a part, a distinct name is required for it. Accordingly Kaibab has been selected, from the Kaibab Plateau, on the north side of the canyon, which is capped by the formation in typical development over a very large area.

Inasmuch as the formation not only makes the entire surface of the Kaibab Plateau but is magnificently exposed in cross section in the wall of the Grand Canyon all around the south end of the plateau, the name given to it by Darton is eminently appropriate. Curiously, however, although the Kaibab Plateau is the type locality for the Kaibab limestone, no detailed section of the formation has been made anywhere in the plateau. Consequently no type section of the formation is on record.

During a stratigraphic reconnaissance of the region north of Colorado River in Arizona and Utah in the summer of 1922,[2] Prof. H. E. Gregory and I had occasion to visit the Kaibab Plateau, and I took the opportunity to obtain a section of the Kaibab limestone in this, the type locality. Our search in the plateau for a place where unquestionably all the formation is exposed was rewarded in Kaibab Gulch, 8 miles southwest of the abandoned settlement of Paria. Kaibab Gulch, which lies in Utah about 6 miles north of the Arizona boundary, is a deep canyon cut entirely across the northern part of the Kaibab Plateau. The gulch enters the plateau abruptly from the west, crosses it in a course that is slightly south of east, and emerges at the point where the strata along the eastern margin of the plateau depart from their horizontal attitude and dip eastward in the east Kaibab fold. Here, where the gulch crosses the fold, a magnificent section of the Kaibab limestone with a part of the Hermit shale below it and a part of the Moenkopi formation above it is exposed along the bed of the stream.

So far as we could ascertain the region around and just north of Kaibab Gulch is the only area within or along the borders of the Kaibab Plateau where both the upper and the lower contacts of the Kaibab limestone are exposed. Elsewhere the characteristic red shale and sandstone that are unmistakably recognizable as belonging to the lower part of the overlying Moenkopi formation have been removed by erosion, so that it is impossible to tell how much of the top part of the Kaibab limestone remains. Owing to this uncertainty the many fine exposures of the limestone in the cliffs of the Grand Canyon around the south end of the plateau and the exposures in the escarpment of the west Kaibab fault along the western border of the plateau are considered inappropriate for a type section, although many of these exposures reveal the beds of the formation in every detail from the base upward and are far more accessible than the exposures in Kaibab Gulch. The section in Kaibab Gulch is therefore proposed as the type section of the Kaibab limestone, because it is the only section in the type area that is known to be complete.

The location of the section in Kaibab Gulch and of other sections of the Kaibab limestone and the formations immediately above and below it that have been measured within a radius of 90 miles of the Kaibab Gulch section is shown on Figure 1. The distance and direction of each section from Kaibab Gulch, the formations included in each, and the report in which each measurement appears, if published, are given in a table below the map.

Kaibab Gulch is shown on the Kanab topographic map published by the United States Geological Survey, but its name is not printed on the map. It may be identified as a deep canyon coming from the west

[1] Darton, N. H., A reconnaissance of parts of northern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, p. 28, 1910.

[2] Gregory, H. E., and Noble, L. F., Notes on a geological traverse from Mohave, Calif., to the mouth of San Juan River, Utah: Am. Jour. Sci., 5th ser., vol. 5, pp. 229-238, 1923.

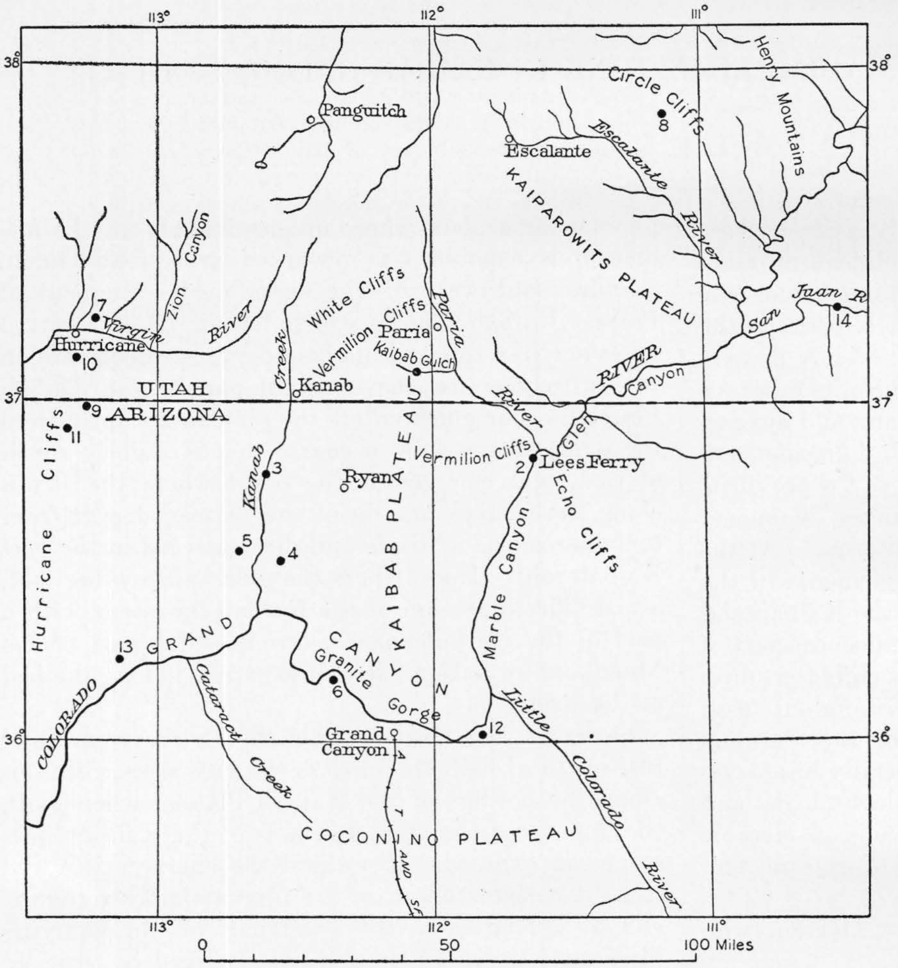


FIGURE 1.—Index map of parts of Utah and Arizona showing location of columnar section (dot numbered 1) in Kaibab Gulch given in Plate 12 and location of other sections of Carboniferous and Triassic strata in the area covered by the map. The location of each section is designated by a numbered dot

and intersecting the eastern boundary of the quadrangle at a point 6 miles north of the southeast corner.

SECTION IN KAIBAB GULCH

The section measured in Kaibab Gulch includes the entire exposed thickness of the Kaibab limestone, a small part of the overlying formation, and a part of the underlying formation. The overlying formation, as elsewhere in the Grand Canyon region, is the Moenkopi. The underlying formation, however, is not the one that is found in contact with the Kaibab limestone elsewhere. At all other places in the Grand Canyon region where its lower contact is exposed the Kaibab rests upon the Coconino sandstone, but at Kaibab Gulch it rests upon the Hermit shale, the formation next older than the Coconino. The absence of the Coconino sandstone is a unique feature of the section. The contacts of the Kaibab limestone with the overlying Moenkopi formation and with the underlying Hermit shale are shown in Plate 13, *A*, *B*, and *C*.

No. on map	Locality	Approximate distance from Kaibab Gulch (miles)	Direction from Kaibab Gulch	Formations measured	Author and report
1	Kaibab Gulch, Kaibab Plateau			Moenkopi formation (base), Kaibab limestone (Coconino sandstone absent), Hermit shale (top)	Noble, L. F., this report.
2	Lees Ferry, Colorado River	30	S. 52° E.	Moenkopi and overlying Mesozoic formations, Kaibab limestone, Coconino sandstone.	Longwell, C. R., Miser, H. D., Moore, R. C., Bryan, Kirk, and Paige, Sidney, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, p. 16, 1923.
3	Canyon of Kanab Creek, 22 miles south of Kanab.	38	S. 56° W.	Kaibab limestone (base), Coconino sandstone, Hermit shale (top).	Noble, L. F., and Gregory, H. E., unpublished data.
4	Jumpup Canyon, near Kanab Creek	50	S. 38° W.	Kaibab limestone (base), Coconino sandstone, Hermit shale, Supai formation (top).	Noble, L. F., this report.
5	Hacks Canyon, near Kanab Creek	53	S. 46° W.	Kaibab limestone, Coconino sandstone, Hermit shale, Supai formation (top).	Reeside, J. B., jr., and Bassler, Harvey, Stratigraphic sections in southwestern Utah and northwestern Arizona: U. S. Geol. Survey Prof. Paper 129, p. 69, 1922.
6	Bass trail, Grand Canyon	65	S. 17° W.	Kaibab limestone, Coconino sandstone, Hermit shale, Supai and underlying Paleozoic formations.	Noble, L. F., A section of the Paleozoic formations of the Grand Canyon at the Bass trail: U. S. Geol. Survey Prof. Paper 131, pp. 23–73, 1922.
7	Virgin River Canyon. Four sections designated 9, 10, 11, and 12 by the authors.	68	N. 81° W.	Moenkopi formation (base), Kaibab limestone (top).	Reeside, J. B., jr., and Bassler, Harvey, op. cit., pp. 72–73.
8	Circle Cliffs	70	N. 43° E.	Kaibab limestone, Coconino (?) sandstone (top).	Longwell, Miser, Moore, Bryan, and Paige, op. cit., pp. 20–21.
9	Rock Canyon. Two sections designated 6 and 7 by the authors.	70	S. 84° W.	Moenkopi formation (base), Kaibab limestone, Coconino (?) sandstone, Supai (?) formation (top).	Reeside, J. B., jr., and Bassler, Harvey, op. cit., pp. 70–71.
10	Hurricane Cliff, 6 miles south of Hurricane. Section designated 8 by the authors.	72	N. 89° W.	Moenkopi formation (base), Kaibab limestone, Coconino (?) sandstone, Supai (?) formation (top).	Idem, pp. 71–72.
11	Hurricane Cliff, 18 miles south of Hurricane. Section designated 4 by the authors.	75	S. 80° W.	Kaibab limestone (base), Coconino sandstone and Supai formation (undifferentiated).	Idem, p. 70.
12	Cedar Mountain, Grand Canyon	75	S. 10° E.	Shinarump conglomerate, Moenkopi formation, Kaibab limestone (top).	Noble, L. F., op. cit. (Prof. Paper 131), pp. 71–72.
13	Toroweap Canyon, near Grand Canyon.	85	S. 47° W.	Kaibab limestone, Coconino sandstone, Hermit shale, Supai formation.	Reeside, J. B., jr., and Bassler, Harvey, op. cit., pp. 69–70.
14	San Juan River, near Zahns Camp	85	N. 81° E.	Moenkopi and overlying Mesozoic formations (Kaibab limestone absent), Coconino sandstone.	Longwell, Miser, Moore, Bryan, and Paige, op. cit., p. 17.

The columnar section (pl. 12) shows diagrammatically the topographic profile of the beds, their sequence and general lithology, and the subdivisions into which the writer has grouped them. The number at the right of each bed or set of beds in the columnar section is the number used to designate the same bed or set of beds in the detailed section given in the text. In the columnar section the strata are represented as horizontal, but actually they dip eastward at angles ranging from 10° to 20°. The section was measured in a traverse along the bed of the gulch by ascending the walls to measure each set of strata at the place where it was best exposed, then locating at the next favorable place the stratum last measured and resuming measurement at that stratum. The length of the traverse necessary to obtain the complete section, following the windings of the gulch, was about a mile. The measurements were made with a Locke level. They are not as accurate as they would have been if the strata were horizontal and were exposed in a single vertical section, as in the wall of the Grand Canyon; nevertheless the windings of the gulch afforded so many exposures in cliff faces parallel with the strike that the writer believes the error was not great.

The section is given below in two forms—a general section showing the major subdivisions and a detailed section with comments on the several beds. The Moenkopi formation was measured and described by Professor Gregory; the Kaibab limestone and the Hermit shale by me.

Section in Kaibab Gulch

General section

	Feet
Moenkopi formation (Lower Triassic):	
Dark reddish-brown shale and thin-bedded sandstone with here and there a thin irregular bed of conglomerate at the base. All higher Moenkopi strata have been removed by erosion	12
Unconformity.	
Kaibab limestone (Permian):	
A. Very irregular beds of coarse breccia-conglomerate, interstratified with buff shale and calcareous sandstone and capped by massive beds of buff limestone. The limestone forms a strong cliff; the shales and sandstones form a slope broken by irregular cliffs of breccia	77
B. Massive gray crystalline limestone, cherty and fossiliferous, containing a bed of sandstone in the middle and passing at top into alternating beds of chert and buff earthy limestone. The beds of gray crystalline limestone form strong cliffs; the alternating beds of chert and buff limestone above the gray limestone form a steep ledgy slope	326
C. Buff and reddish fine-grained sandstone, poorly consolidated and irregularly bedded, interstratified with beds of sandy breccia and travertine; forms slope	150
Kaibab limestone (Permian)—Continued.	
D. Massive buff siliceous limestone, cherty and somewhat fossiliferous, containing some calcareous sandstone near the middle and a well-defined bed of hard fine-grained buff cross-bedded sandstone near the base. All beds except the calcareous sandstone in the middle of the member form strong cliffs	119
E. Alternating beds of arenaceous limestone and irregularly bedded fine-grained buff sandstone. One thin bed of limestone, in the middle of the member, is very fossiliferous. The member forms a steep ledgy slope, broken by small cliffs	45
	717
Hermit shale (Permian):	
Red sandy shale and fine-grained massive friable red sandstone, which exhibits concretionary structure; base of formation concealed; beds form slope	55

Detailed section

	Feet
Moenkopi formation:	
1. Sandstone, dark reddish-brown, thin bedded, each bed consisting of overlapping laminae; foliation surfaces show abundant mud cracks and ripple marks; weathering forms "slab talus"	3
2. Shales, dark reddish brown, very unevenly bedded, sun baked, glistening foliation surfaces	4
3. Conglomerate, gray and brown, composed essentially of flat pebbles of limestone and red shale; in some places forms a definite bed 4 to 8 inches thick; in other places lenses of conglomerate are embedded in yellow lime shale and brown sandy shale through a vertical distance of 3 to 5 feet; in still other places the conglomerate is underlain or even replaced by thin layers or aggregates of quartz. Contact with underlying limestone is sharp and somewhat uneven; appears to represent a surface of erosion	⅓–5
	12
Unconformity.	
Kaibab limestone:	
A. 1. Massive buff limestone containing a little chert; fossiliferous, but all forms seen were too poorly preserved to be determinable; weathered surfaces of the rock feel sandy or gritty	2
2. Chert	½
3. Massive buff limestone like No. 1; contains many cavities, formed probably by the solution of fossils. Calcite fills many cavities and occurs in veins. Fossils occur sparingly, but all those seen were too poorly preserved to be determinable. Chert not abundant	12
4. Chert and sand	1
5. Massive buff limestone like No. 3; appears to form one solid bed	9

Kaibab limestone—Continued.	Page
A. 6. Buff shale, soft, sandy, and very thinly laminated. The laminae are wavy and many are as thin as paper; some are reddish. A few layers of calcareous sandstone averaging one-fourth inch thick are interbedded with the shale	2
7. Dense fine-grained sandy buff limestone	½
8. Buff shale, like No. 6; basal 4 feet consists entirely of sandy mud; upper 3 feet contains a few ½-inch layers of fine-grained calcareous buff sandstone	7
9. Massive bed of coarse breccia; forms strong cliff; rests upon an uneven surface, which exhibits considerable relief, the breccia bed ranging in thickness from 4 to 14 feet in a horizontal distance of 100 feet. Most of the breccia fragments are chert but some are limestone and sandstone; they are of all sizes up to 6 inches in diameter; all are angular. The matrix is buff sand	4–14
10. Irregular bed consisting partly of sandy breccia and partly of calcareous sandstone. Contacts with overlying and underlying beds are uneven	1–4
11. Buff calcareous sandstone with thin partings of shale at the bottom and lenses of chert at the top; bedding planes wavy	5
12. Massive buff calcareous sandstone; thickness ranges from 1 to 3 feet in a horizontal distance of 100 feet	1–3
13. Greenish sandy shale; laminae wavy; thickness ranges from 1 to 3 feet in a horizontal distance of 100 feet. Contacts with overlying and underlying beds uneven	1–3
14. Conglomerate composed of chert and sandstone fragments embedded in a matrix of sand, which exhibits gnarly, contorted structure; thickness ranges from 1 to 3 feet in a horizontal distance of 100 feet. Contacts with overlying and underlying beds uneven	1–3
15. Irregular bed composed entirely of hard chert. Contacts with overlying and underlying beds uneven, wavy	1
16. Partly concealed interval forming a gentle débris-covered slope; the few outcrops consist of buff soft calcareous sandstone	10
	77
B. 1. Buff crystalline limestone forming a small cliff	2
2. Beds of buff earthy limestone alternating with beds composed almost entirely of chert nodules; much of the chert is white. The alternations are very regular, the limestone beds averaging 6 inches in thickness and the chert beds 3 inches. The beds form a ledgy slope. This unit resembles alternating beds of chert and calcareous sandstone that occur at the top of the Kaibab limestone in the southern rim of the Grand Canyon near Cedar Mountain (locality 12: see fig. 1)	55

Kaibab limestone—Continued.	Feet
B. 3. Very fossiliferous, very cherty, gray to buff crystalline limestone. The chert is in large lumps, which are scattered irregularly through the rock and most of which are several inches in diameter. The bedding planes of the limestone are obscure, but the beds appear to be very thick, some as much as 20 feet. The rock forms an almost vertical cliff. This unit resembles and corresponds in position to the Kaibab beds that form pinnacles of erosion at many places along the north rim of the Grand Canyon	85
4. Chert and fine-grained sand forming a ledge	10
5. Very massive bed of hard, dense, fine-grained buff sandstone, practically a quartzite; forms strong cliff; weathered surfaces exhibit cross-bedded structure; contains a few tiny rounded pebbles, the largest of which does not exceed a quarter of an inch in diameter; otherwise the rock resembles in composition the Coconino sandstone of the Kaibab division of the Grand Canyon. The cement appears to be all siliceous. The sandstone rests with wavy, uneven contact upon a bed of chert and sand	14
6. Very cherty, very fossiliferous, gray crystalline limestone, weathering buff; forms strong cliffs. The beds of limestone average about 5 feet in thickness and are separated by beds of chert and sand, most of which are less than 1 foot thick, but some of which are as much as 4 feet. Chert occurs throughout the limestone in nodules and in bands. Cavities lined with quartz crystals are fairly abundant. The fauna of the unit is of the familiar normal Kaibab type (the "*Productus ivesi* fauna")	140
7. Gray crystalline limestone in massive beds, separated by thin beds of sandstone with wavy, irregular contacts; forms strong cliff; contains a small quantity of chert in bands and nodules. Fossils and cavities lined with quartz crystals occur sparingly. The limestone beds average 4 feet in thickness	20
	326
C. 1. Soft sandstone; bedding contorted. Contacts with overlying and underlying beds are uneven, wavy	1
2. Gray crystalline limestone, texture sugary	1
3. Irregularly bedded hard sandy limestone; under surface very uneven; this and the two overlying beds make small cliffs	3
4. Soft buff contorted sandstone; contains lenses of red shale averaging less than an inch thick; makes a slope and alcove; outcrops partly concealed	15
5. Irregularly bedded porous sandy limestone seamed with calcite; the rock is in part travertine; bedding wavy throughout; rests upon an uneven surface; forms a cliff	7

Kaibab limestone—Continued.

	Feet
C. 6. Soft buff sandstone; bedding exceedingly contorted; contains a few brecciated beds and some sandy travertine; rests upon an irregular surface; forms a slope and alcove	8
7. Gray sandy limestone, in part travertine; makes a small cliff	3
8. Beds of breccia and travertine interstratified with irregularly bedded yellowish-buff sandstone; make a cliff. The upper 2 feet is entirely travertine. The breccia consists of sandstone fragments of all sizes up to 4 feet in diameter embedded in a matrix of contorted calcareous sand. All beds are very irregular and in all of them the bedding is contorted and wavy	8
9. Beds of breccia and soft sandstone like No. 8; make a slope; much of the breccia resembles fanglomerate	17
10. Brownish-buff fine-grained calcareous sandstone in beds up to 1 foot thick; almost a limestone	6
11. Reddish sandstone; forms slope; outcrops partly concealed	3
12. Buff hard fine-grained sandstone, composed of tiny transparent quartz grains, which sparkle in the sunlight; material resembles that of the Coconino sandstone of the Grand Canyon; forms a small cliff	2
13. Reddish soft fine-grained sandstone	8
14. Buff to brown porous calcareous brecciated sandstone seamed with calcite; largely travertine; forms a small cliff	2
15. Red soft sandstone; bedding gnarly and contorted; outcrops largely concealed	15
16. Buff to brown calcareous sandstone seamed with calcite; forms small cliff; bedding irregular, gnarly	2
17. White soft fine-grained sandstone; bedding irregular, gnarly; rests upon a wavy surface exhibiting relief of a foot or more in a distance of 50 feet	2
18. Red soft fine-grained sandstone; outcrops largely concealed	12
19. Breccia; angular fragments of sandstone, shale, limestone, and chert of all sizes up to several feet in diameter embedded in a matrix of gnarled and contorted yellowish-buff sand. Much of the deposit is cemented with carbonate of lime and exhibits the characteristic porous structure of travertine	5
20. Largely concealed; the few outcrops seen consist of brownish-buff soft sand	12
21. Gnarly buff calcareous sandstone	3
22. Concealed; probably soft sandstone	12
23. Breccia in travertine, like No. 19	3
	150

Kaibab limestone—Continued.

	Feet
D. 1. Platy gray limestone in beds averaging one-fourth inch thick	4
2. Dense siliceous buff limestone in beds ranging from 1 to 3 feet thick. Bands of chert nodules abundant	10
3. Dense siliceous limestone like No. 2; forms two massive beds each 9 feet thick; contains many cavities lined with quartz crystals; contains also nodules of chert, but the chert is not conspicuously abundant	18
4. Massive arenaceous limestone exhibiting gnarly contorted bedding on weathered surfaces	7
5. Buff arenaceous limestone or calcareous sandstone forming a single massive bed; bedding planes level and even. This and the five overlying beds of D unite in forming a sheer high cliff	12
6. Soft calcareous sandstone; bedding irregular, gnarly; forms alcove	10
7. Arenaceous limestone; most beds exhibit faint cross-bedding on weathered surfaces, but some exhibit gnarly bedding; makes a steep ledgy slope	16
8. Buff limestone in massive beds from 6 inches to 4 feet thick; forms a strong cliff; weathered surfaces feel sandy or gritty. Thin platy partings of calcareous sandstone separate most of the beds. The limestone contains a large amount of chert, most of which is in rounded masses or nodules of all sizes up to a foot in diameter, but some of it occurs in bands. Fossils, chiefly large brachiopods, are abundant, and the rock contains many cavities formed by the solution of fossils. Most of the cavities are lined with quartz crystals. This limestone resembles the massive siliceous limestone in the lower part of the Kaibab at Bass trail, Grand Canyon	22
9. Massive bed of chert; forms an alcove	1
10. Massive bed of hard fine-grained buff sandstone; forms strong cliff. The rock is vesicular, and weathered surfaces are cavernous. Basal 3 feet strongly and conspicuously cross-bedded; remainder of bed contorted, gnarly. The sand grains consist of quartz and are tightly packed together; most of them are transparent and rounded. The cementing material appears to be carbonate of lime, but some of it may be silica. The rock sparkles in the sunlight like the typical Coconino sandstone of the Grand Canyon. The lower part of the bed contains lenses of fine conglomerate, whose constituent pebbles are tiny sheaflike aggregates of radially disposed quartz crystals. Most of these aggregates are less than a quarter of an inch in diameter, but some are as much as 1 inch. They appear to represent weathered quartz geodes	9
11. Buff shaly sandstone, soft, poorly exposed; forms alcove	2
12. Gray crystalline limestone in massive beds ranging from 4 inches to 2 feet thick. Rock hard and more or less vesicular; forms strong cliff	8
	119

Kaibab limestone—Continued.	Feet
E. 1. Buff gnarly sandstone; soft; forms alcove; weathered surfaces are cavernous. The basal 2 inches of the bed is a conglomerate consisting of chert fragments that average a quarter of an inch in diameter	8
2. Alternating beds of buff sandy shale in paper-thin laminae and buff chert. One chert bed is 6 inches thick	2
3. Buff hard fine-grained arenaceous limestone or calcareous sandstone; seamed with calcite; exhibits faint cross-bedded structure on weathered surfaces	2
4. Lumpy and gnarly fine-grained sandstone; soft; forms alcove	½
5. Buff hard fine-grained arenaceous limestone or calcareous sandstone; seamed with calcite; forms a cliff	2
6. Alternating beds of gray chert and buff sand. The chert beds average an inch thick; some of them are composed of solid chert, others are bands of elongated nodules	2
7. Buff hard fine-grained arenaceous limestone or calcareous sandstone; forms cliff	2
8. Irregularly bedded buff soft fine-grained sandstone; structure contorted and gnarly	5
9. Sandy buff crystalline limestone; hard; weathers into nodular lumps; very fossiliferous, but all fossils seen were too poorly preserved to be determinable	½
10. Buff calcareous shale	½
11. Sandy buff limestone, somewhat cherty; fossiliferous but fossils very poorly preserved	½
12. Soft lumpy sandstone, very irregularly bedded; largely a conglomerate or breccia of sandstone lumps embedded in a matrix of churned-up sand	3
13. Buff sandy calcareous shale	1
14. Yellowish-buff hard fine-grained evenly bedded sandstone	2
15. Buff soft fine-grained sandstone; bedding gnarly and contorted	5
16. Buff fine-grained hard arenaceous limestone or calcareous sandstone; laminae very thin, horizontal; makes a small cliff	1
17. One-inch parting of calcareous shale in paper-thin laminae.	
18. Arenaceous limestone or calcareous sandstone, like No. 16	2
19. Two-inch parting of calcareous shale, like No. 17.	
20. Arenaceous limestone or calcareous sandstone, like No. 16	1
21. Same kind of rock as No. 20, but even more thinly laminated	1
22. Arenaceous limestone or calcareous sandstone, like No. 16	2
23. Six-inch parting of calcareous shale, like No. 17.	
24. Arenaceous limestone or calcareous sandstone, like No. 16	1
	45
Total thickness of Kaibab limestone	717

Hermit shale:	Feet
1. Buff and greenish-buff slightly sandy clay shale containing stringers of gypsum. Brownish streaks of limonite occur along the stringers and between laminae of the shale. Some of the gypsum stringers are as much as half an inch thick. The shale resembles a consolidated playa mud.	
2. Greenish-buff massive fine-grained sandstone exhibiting marked concretionary structure; in weathering splits off in concentric shells along the concretionary surfaces; differs only in color from the concretionary red sandstone (3) lying beneath it. The greenish-buff sandstone (2) and the topmost foot of the underlying red sandstone (3) appear to constitute a sort of mud-ball conglomerate	1
3. Very fine grained massive red sandstone, essentially a consolidated sandy mud; exhibits marked concretionary structure and weathers into rounded surfaces or into huge balls that shell off in layers, like an onion. This concretionary structure is exactly like that characteristic of the upper part of the Hermit shale in the Kaibab division of the Grand Canyon. The material of which the sandstone is composed does not differ in any respect from that which constitutes the shale and sandstone beds of the Hermit shale in the Grand Canyon. The sandstone contains a few buff streaks, but the difference in color bears no relation to bedding. The rock exhibits no partings or bedding planes and is not cross-bedded	7
4. Very massive bed, like No. 3; upper portion contains buff streaks and blotches	22
5. Red sandy shale; not conspicuously different from the overlying sandstone in composition but is laminated and soft, whereas the sandstone exhibits no bedding planes and is relatively compact	7
6. Massive red concretionary sandstone, like No. 3	3
7. Red soft sandy shale, like No. 5	8
8. Massive red concretionary sandstone, like No. 3	4
	55

Talus, extending downward to the bed of Kaibab Gulch and concealing all underlying rocks.

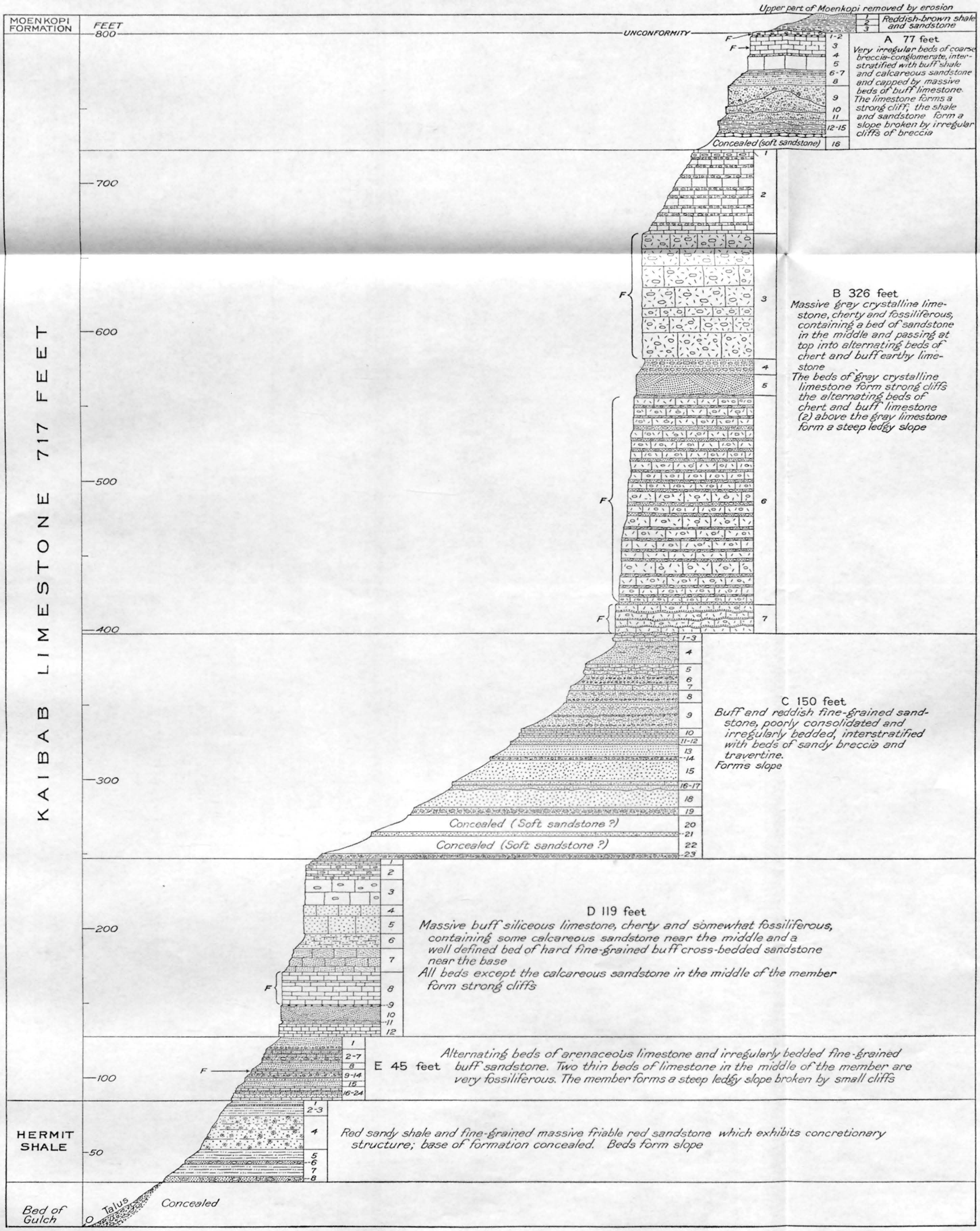
COMPARISON WITH OTHER SECTIONS

SECTION AT BASS TRAIL

In 1916 I measured a detailed section of the Paleozoic formations of the Grand Canyon at the Bass trail, in the Shinumo region, to supersede the generalized and inadequate reconnaissance section given in my report on the Shinumo quadrangle.[3] This detailed section is described in a report published in 1922.[4] The part of it that includes the Kaibab limestone, Coconino sandstone, and Hermit shale is reprinted below for comparison with the section in Kaibab Gulch. The locality (No. 6, fig. 1) is 65 miles southwest of Kaibab Gulch.

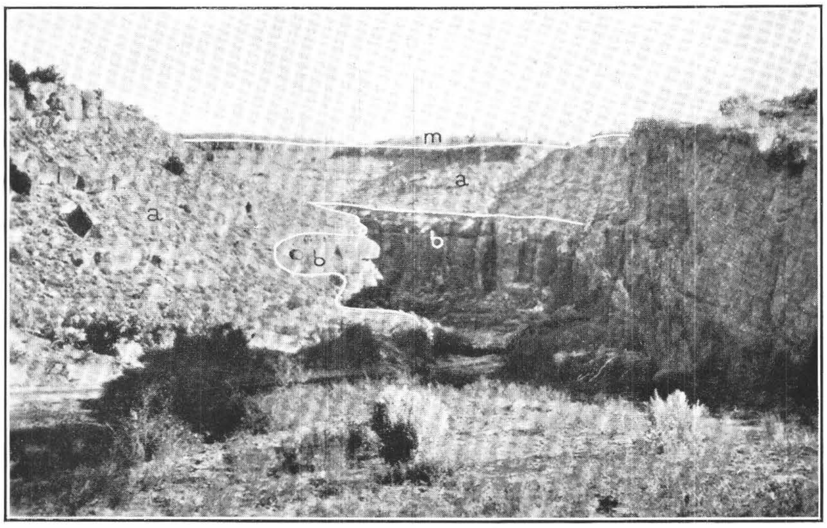
[3] Noble, L. F., The Shinumo quadrangle, Grand Canyon district, Ariz.: U. S. Geol. Survey Bull. 549, pp. 60–73, 1914.

[4] Noble, L. F., A section of the Paleozoic formations of the Grand Canyon at the Bass trail: U. S. Geol. Survey Prof. Paper 131, pp. 23–73, 1922.



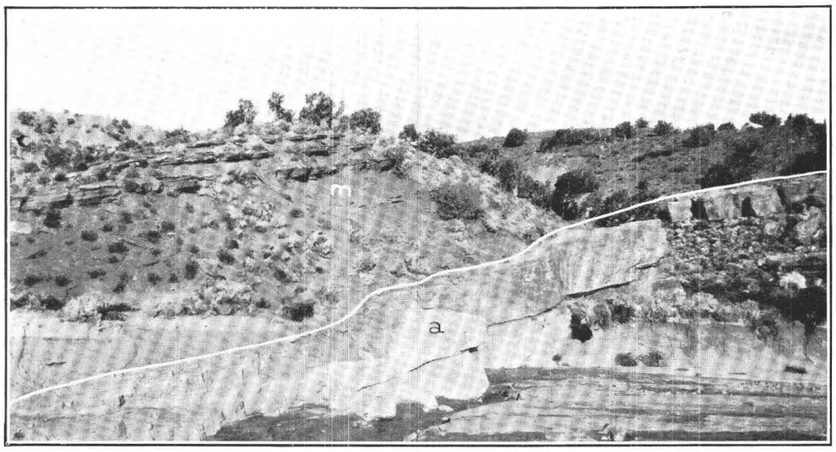
COLUMNAR SECTION OF THE KAIBAB LIMESTONE IN KAIBAB GULCH, UTAH

With a part of the overlying Moenkopi formation and of the underlying Hermit shale



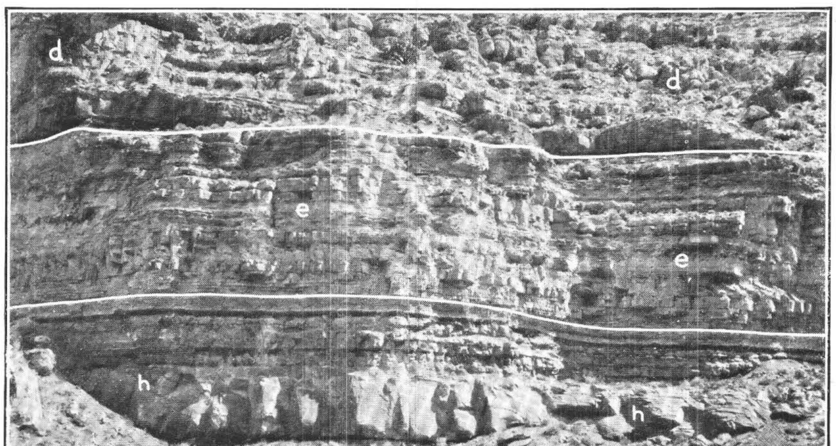
A. KAIBAB GULCH, UTAH, LOOKING WESTWARD UP THE GULCH FROM A POINT NEAR THE MOUTH

m, Moenkopi formation; a, b, subdivisions A and B of Kaibab limestone. The strata dip toward the observer, and the bed of the gulch descends in the same direction but at a lower angle, so that successively lower strata are encountered in ascending the gulch. The summit of the Kaibab limestone (shown in *B*) is crossed at the mouth of the gulch, and the base (shown in *C*) about a mile above the mouth. Thus a traverse of the bed of the gulch yields a complete section of the formation



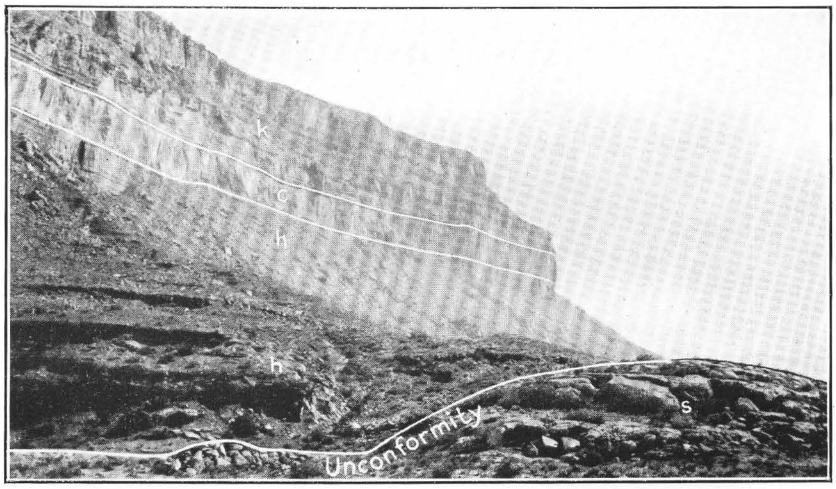
B. CONTACT BETWEEN MOENKOPI FORMATION AND KAIBAB LIMESTONE AT THE MOUTH OF KAIBAB GULCH

m, Moenkopi formation; a, limestone at top of subdivision A of Kaibab limestone

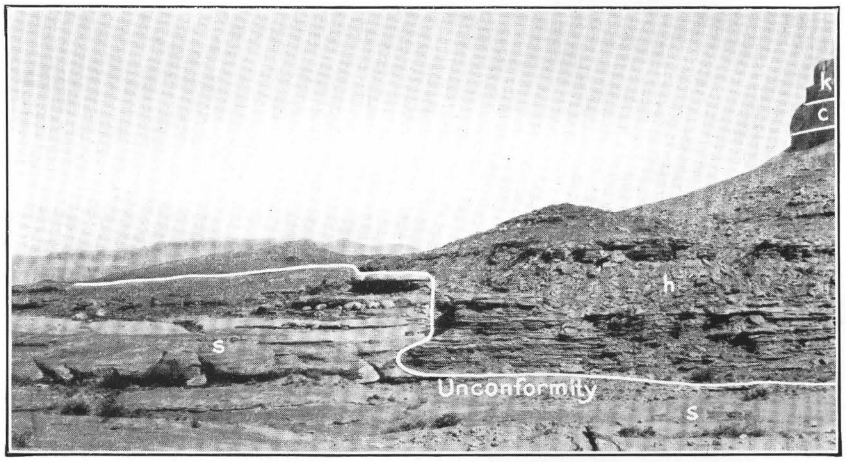


C. CONTACT BETWEEN KAIBAB LIMESTONE AND HERMIT SHALE IN KAIBAB GULCH

d, e, Subdivisions D and E of Kaibab limestone; h, Hermit shale



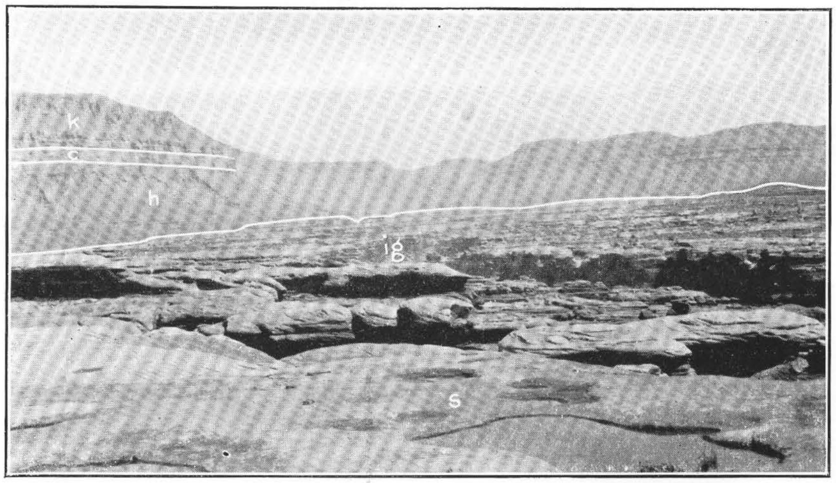
A



B

A, *B*. UNCONFORMITY BETWEEN HERMIT SHALE AND SUPAI FORMATION IN CANYON OF LOWER KANAB CREEK NEAR JUMPUP CANYON, UTAH

k, Kaibab limestone; c, Coconino sandstone; h, Hermit shale; s, Supai formation. In *A* the hill of sandstone of the Supai formation in the lower right corner projects 30 feet above the base of the Hermit shale in the hollow at the left of the hill. In *B* the base of the Hermit shale in the steep-sided hollow at the right is 40 feet below the summit of the sandstone of the Supai formation at the left of the hollow



C. CANYON OF LOWER KAIBAB CREEK, UTAH

Looking south near mouth of Jumpup Canyon, showing broad platform ("The Esplanade") on the summit of the Supai formation at the horizon of the unconformity shown in *A* and *B*. k, Kaibab limestone; c, Coconino sandstone; h, Hermit shale; s, Supai formation; ig, inner gorge of Kanab Creek. In structure, composition, and mode of weathering the cross-bedded sandstone at the top of the Supai sandstone shown in the view is strikingly similar to the Navajo sandstone exposed in Glen Canyon of Colorado River. A water pocket in the sandstone of the Supai is shown in the lower right corner

Section at Bass trail

General section

	Feet
Kaibab limestone (Permian):	
A. Gray crystalline limestone, very fossiliferous and somewhat cherty, passing at base and top into alternating beds of very cherty limestone and buff calcareous sandstone; forms cliffs and steep slopes	292
B. Buff and reddish fine-grained sandstone, poorly consolidated and irregularly bedded, containing beds of sandy breccia near top; forms slope	136
C. Buff sandstone and limestone in alternating beds, passing at top into massive siliceous limestone; upper portion forms a strong cliff; central portion forms cliffs and ledges; lower portion forms a slope	134
	562
Coconino sandstone (Permian):	
Pale-buff, uniformly fine-grained sandstone, characterized by cross-bedding on a huge scale; presents the appearance of a single massive bed; forms the strongest and highest cliff in the upper wall of the canyon	330
Hermit shale (Permian):	
Deep brick-red sandy shale and fine-grained friable sandstone; characterized in upper portion by concretionary structure; beds form slope	332
Unconformity.	

Detailed section

	Feet
Kaibab limestone:	
A. 1. Limestone, buff, compact; effervesces strongly with dilute hydrochloric acid; caps a small cliff on the rim of the Grand Canyon at the head of Bass trail. Bass Camp, on the Coconino Plateau, at the head of the trail, is built on this stratum. Higher beds, which form the surface of the plateau just east of the camp, are not included in this section	2
2. Limestone, buff, siliceous; texture compact, chalky; contains small cavities lined with tiny crystals	6
3. Sandstone, buff, fine grained, calcareous; effervesces with acid	5
4. Alternating thin beds of variegated chert and fine-grained calcareous sandstone	25
5. Limestone, gray, crystalline, very cherty, fossiliferous. The chert occurs in nodules and in bands; in places it constitutes half of the rock. Aside from the abundance of chert the limestone resembles No. 6	40
6. Limestone, gray, hard, crystalline, somewhat cherty, very fossiliferous; effervesces strongly with acid. Beds differ greatly in thickness; some are a few inches thick, others several feet. The chert occurs in scattered nodules and in bands but is not a conspicuous feature of the rock	126
7. Alternating beds of fine-grained buff calcareous sandstone, buff limestone, and chert; form small conspicuous cliff	10
8. Limestone, gray, hard, crystalline, somewhat cherty, fossiliferous; resembles No. 6	60
Kaibab limestone—Continued.	
A. 9. Sandstone, lemon-buff, fine grained, calcareous; bedding irregular, gnarly; forms a gentle slope covered in most places by talus	10
10. Limestone, thin bedded, very cherty; effervesces with acid. The chert constitutes more than half of the rock and occurs in parallel bands whose average thickness is 2 inches	8
	292
B. 1. Sandstone, buff, massive, fine grained, calcareous; effervesces weakly with acid	4
2. Breccia composed chiefly of angular fragments of evenly bedded buff fine-grained sandstone embedded in a matrix of fine lemon-buff sand; contains a few fragments of siliceous limestone. The fragments range in diameter from less than an inch to more than 4 feet. The contact of the breccia with the underlying sandstone is wavy and irregular, exhibiting in places inequalities of several feet	17
3. Sandstone, buff, fine grained, friable. The component grains are quartz, as in other sandstones of the Kaibab, but are very loosely cemented, so that the rock crumbles to sand when struck with the hammer	1
4. Sandstone, like No. 3 but bright red	2
5. Buff sandstone, like No. 3	8
6. Bright-red sandstone, like No. 4	2
7. Lemon-buff sandstone, like No. 3	5
8. Bright-red sandstone, like No. 4; contains a 1-inch layer of pale-green sandstone in the central part	7
9. Sandstone, lemon buff, fine grained, friable; bedding irregular, gnarly; contact with underlying sandstone slightly wavy and irregular	3
10. Sandstone, bright red, shaly; bedding gnarly; contact with underlying breccia wavy and irregular, exhibiting inequalities of 2 feet or more	3
11. Breccia composed of angular fragments of fine-grained sandstone averaging 4 inches in diameter. Very little matrix between the fragments. The contact with the underlying sandstone is irregular, exhibiting inequalities of several feet	4
12. Reddish-buff loosely consolidated fine-grained sandstone in indistinct but fairly even beds, some of which display gnarly structure; forms débris-covered slope; exposures poor. The upper 3 feet of the sandstone is bright red and thinly laminated	12
13. Sandstone, like No. 12, but more compact, forming a weak cliff; gnarled and twisted structure very pronounced; color lemon-buff to reddish buff	10
14. Sandstone, like No. 12, very soft, forming a gentle slope that is covered nearly everywhere by talus; no good exposures obtainable; white, lemon-buff, greenish, and bright red; in some places the color is in blotches or streaks; in other places a single color characterizes each bed	58
	136

Kaibab limestone—Continued.	Feet
C. 1. Limestone, buff, dense, siliceous; in heavy, massive beds; forms a strong cliff; contains much chert in bands and nodules and many small cavities lined with crystals of quartz or calcite. In appearance the rock suggests silicified chalk. Some beds effervesce weakly with acid	48
2. Limestone, like No. 1 but in thinner beds (1 foot or less), which are separated by thin partings of buff fine-grained shaly sandstone; forms a steep ledgy slope	12
3. Limestone like No. 1; forms a cliff	16
4. Shaly sandstone, lemon-buff, soft, thin bedded, fine grained; makes alcove under overhanging cliff of No. 3	2
5. Limestone, buff, in heavy beds with thin sandy partings; not notably siliceous; effervesces strongly with acid; forms cliff	8½
6. Shaly sandstone, like No. 4; makes alcove under overhanging cliff of No. 5	3
7. Limestone, like No. 5 but in thinner beds (1 or less); forms slope	11
8. Limestone, buff, dense, siliceous, in heavy beds; contains many crystal-lined cavities apparently formed by the solution of brachiopods; does not effervesce with acid	5½
9. Limestone, like No. 7, in beds separated by very thin partings of sand	5
10. Sandstone, buff, fine grained	5
11. Limestone, like No. 7, but in a single bed	1½
12. Sandstone, buff, fine grained	6
13. Limestone, buff, siliceous, fossiliferous; does not effervesce with acid; contains many small cavities lined with calcite crystals	1½
14. Alternating beds of lemon-buff fine-grained sandstone and buff limestone; beds average 3 inches thick	6
15. Limestone, buff, not notably siliceous; effervesces strongly with acid	½
16. Sandstone, lemon-buff, fine grained	2
17. Sandstone, red, fine grained. The base of this layer truncates inclined laminae of the underlying Coconino sandstone, which dip 15° S	½
	134
Coconino sandstone: Pale-buff fine-grained sandstone, cross-bedded on a huge scale; appears like single massive bed; forms highest cliff in upper wall of canyon. The base of the sandstone is marked by an abrupt change from buff sandstone to underlying red shale, and the contact is an even line. In places the under surface of the sandstone shows impressions of sun cracks. For 25 feet above the base the cross bedding is on a small scale, and horizontal layers alternate with cross-bedded layers; then the coarse cross-bedding begins and continues upward until the sandstone is truncated by the level base of the Kaibab	330
Hermit shale:	
1. Sandstone, red, soft, fine grained, massive, with a thin layer of green shale at the top. Exhibits well-marked concretionary structure; the concretions are spheroidal forms which range from half an inch to 4 feet in diameter and consist of the general mass of the rock; in weathering the rock splits off in concentric shells along the concretionary surfaces	5

Hermit shale—Continued.	Feet
2. Sandstone, fine grained, massive; resembles the Coconino sandstone in texture and composition but is not cross-bedded; lower half buff; upper half red with buff blotches	6
3. Concretionary sandstone, like No. 1, in massive layers	16
4. Shale, deep red, thinly laminated, sandy	24
5. Beds of soft massive concretionary red sandstone like No. 1 alternating with thinner beds of deep-red shale like No. 4; sandstones and shales not conspicuously different in composition	28
6. Shale, deep red, sandy	16
7. Sandstone, pink, hard, very fine grained; contains cracks and cavities filled with crystals of calcite (dog-tooth spar); rock itself does not effervesce with acid; forms small prominent cliff	6
8. Shale, soft, brick-red, thinly laminated, sandy	28
9. Sandstone, brick-red, friable, massive; forms weak cliff	2
All underlying beds of shale are like No. 8; all underlying beds of sandstone like No. 9. The beds designated shale and sandstone actually differ little in composition; both consist essentially of sandy mud colored red by a strong ferritic pigment. The beds designated sandstone are massive and relatively compact, as contrasted with the beds designated shale, which are thinly laminated and soft. Both types of rock are friable.	
10. Shale, containing beds of massive friable sandstone near the top	33
11. Sandstone in massive beds; contains a 1-foot layer of shale in the middle part; forms weak cliffs	8
12. Shale	11
13. Sandstone; forms weak cliff	10
14. Shale	33
15. Alternating lenticular beds of intraformational conglomerate and red fine-grained sandstone averaging 1 foot in thickness; beds display indistinct sun cracks and rain prints; form weak cliff. The conglomerate consists chiefly of flattened pebbles of fine-grained sandstone or sandy shale less than 1 inch in diameter, embedded in a matrix of red sandy mud but contains some nodular or concretionary fragments of limestone	6
16. Shale	11
17. Sandstone	3
18. Shale	40
19. Sandstone	2
20. Shale	6
21. Sandstone; forms weak cliff	5
22. Shale	16
23. Sandstone; forms weak cliff	5
24. Shale	12
	332

A comparison shows that the section at Kaibab Gulch and the section at the Bass trail are remarkably alike, notwithstanding the fact that they are 65 miles apart. The major subdivisions of the Kaibab limestone seen at the Bass trail are at once recognizable in the section at Kaibab Gulch, each subdivision at either place consisting of beds that are similar in lithology and succession and exhibit a similar topographic profile to those that make up the corresponding subdivision at the other place. Many beds at corresponding horizons in the two localities are lithologically identical. The chief differences between the two sections are the absence of the Coconino sandstone at Kaibab Gulch and the fact that the topmost subdivision of the Kaibab limestone (subdivision A of the Kaibab Gulch section) apparently is not represented at the Bass trail. Moreover, all the subdivisions of the Kaibab are somewhat thicker at Kaibab Gulch than they are at Bass Canyon, and most of them include a somewhat greater variety of beds.

There can be no reasonable doubt that the 55 feet of red shale and sandstone exposed beneath the Kaibab limestone in Kaibab Gulch is equivalent to a part of the Hermit shale of the Bass Canyon section. The evidence upon which this correlation is based is the peculiar and distinctive character of the beds at the top of the Hermit shale. At the Bass trail, as may be seen in the detailed section, many beds in the upper 79 feet (units 1 to 5) of the Hermit shale exhibit a well-marked concretionary structure that appears only on weathered surfaces of the rock. A similar structure is characteristic of the upper part of the formation at other localities where I have examined it in detail—at Hermit Basin, the type locality;[5] and at Jumpup Canyon in the valley of lower Kanab Creek. (See p. 54.) Inasmuch as the localities are widely separated, it is evident that the concretionary structure is a persistent and widespread feature of the upper part of the Hermit shale. Now the red sandy shale and sandstone beneath the Kaibab limestone in Kaibab Gulch are identical in composition and appearance with the rocks that constitute the Hermit shale at the Bass trail and at the type locality in Hermit Basin, and they exhibit the concretionary structure just described. They can not possibly represent the Coconino sandstone, a buff cross-bedded sandstone, whose appearance and lithologic character are distinctive and unmistakable, and they do not resemble the rocks characteristic of the upper part of the Supai formation, which are chiefly hard cross-bedded sandstones. I have therefore assigned them to the Hermit shale and correlated them with the upper part of that formation as exposed at the Bass trail. The thickness of the Hermit shale at Kaibab Gulch is of course unknown, because the base is not exposed there.

The series of beds that constitutes subdivision C, the lowest subdivision of the Kaibab limestone at the Bass trail, corresponds closely in lithology, succession, and topographic expression to the series that constitutes subdivisions D and E of the section at Kaibab Gulch and is almost certainly its stratigraphic equivalent. When I measured the section at the Bass trail I could have divided subdivision C into two units, which in lithology and topographic profile would be as distinct from each other as subdivisions D and E at Kaibab Gulch. The lower part of subdivision C at the Bass trail consists of beds 9 to 17, described in the detailed section (p. 48). This series of alternating sandstone and limestone, which is 28 feet thick at the Bass trail, closely resembles the series of alternating sandstone and limestone that constitutes subdivision E at Kaibab Gulch and is 45 feet thick. At both localities the sandstones range from buff and pink to a peculiar shade of lemon-yellow and are fine-grained, soft, and for the most part thinly laminated, and the limestones are buff, thin bedded, and more or less siliceous. In general the sandstones are somewhat more irregularly bedded at Kaibab Gulch than at the Bass trail, and the limestones are rather more sandy, but these differences are not essential. At both localities these beds form a slope which is in strong topographic contrast with the cliffs formed by the massive limestone above them. In view of all these facts I have correlated the slope-forming part of subdivision C at the Bass trail with subdivision E at Kaibab Gulch.

At the Bass trail a thin bed of very fossiliferous limestone (No. 13) occurs in the lower middle part of the slope-forming unit of subdivision C. At Kaibab Gulch two very thin beds of similar fossiliferous limestone (Nos. 9 and 11), separated by a 6-inch parting of calcareous shale, occur in the lower part of subdivision E. No other beds in the two units appear to contain fossils at either locality. Although the distance between the localities is much too great for correlation of individual thin beds, the occurrence of the fossiliferous beds at approximately the same horizon in the two sections suggests that these fossiliferous beds are stratigraphically equivalent and serves further to emphasize the lithologic similarity of the two sections.

The upper part of subdivision C at the Bass trail consists of beds 1 to 8 described in the detailed section (p. 48), is 106 feet thick, and is composed almost entirely of limestone. The topmost bed (No. 1) is a massive buff siliceous limestone containing bands and nodules of chert and many small cavities lined with crystals of quartz or calcite. This bed, which is 48 feet thick, is very hard and forms a strong cliff. Below it is a bed (No. 2) composed of layers of similar limestone separated by thin partings of shaly sandstone. This bed, which is 13 feet thick, forms a steep ledgy slope. Below the slope-forming bed is a set of beds (Nos. 3 to 8) consisting chiefly of massive buff cherty and vesicular limestone like No. 1 but including a few thin interbedded layers of sand-

[5] Noble, L. F., A section of the Paleozoic formations of the Grand Canyon at the Bass trail: U. S. Geol. Survey Prof. Paper 131, pl. 19, 1922.

stone. This set of beds, 46 feet thick, makes a series of cliffs broken at intervals by narrow ledges at the horizons where partings of sand occur.

Subdivision D of the Kaibab Gulch section, like the cliff-forming unit at the Bass trail just described, consists chiefly of limestone that makes strong cliffs, includes also a few beds of sandstone, and is 119 feet thick. Most of the limestone is similar in composition and appearance to that which constitutes the cliff-forming unit at the Bass trail, for it is buff, massive, siliceous, more or less cherty, and vesicular, containing many small cavities lined with quartz crystals. Indeed, the limestones are so alike at both localities that, aside from differences in thickness, the lithologic description of any one of beds 2, 3, or 8 at Kaibab Gulch might be applied without change to any one of beds 1, 3, or 8 at the Bass trail.

Accordingly I have correlated the upper or cliff-forming unit of subdivision C at the Bass trail with subdivision D at Kaibab Gulch. Although the distance between the localities makes definite correlation of individual beds impossible, it is probable that the limestone bed, No. 1, which makes a cliff at the top of the cliff-forming unit of subdivision C at the Bass trail, is roughly equivalent to the limestone beds, Nos. 1 to 5, which make a cliff at the top of subdivision D at Kaibab Gulch; that the underlying slope-forming bed of limestone and shaly sandstone, No. 2, at the Bass trail is roughly equivalent to the slope-forming beds of calcareous sandstone and arenaceous limestone, Nos. 6 and 7, at Kaibab Gulch; and that the lower cliff-forming beds of limestone and sandstone, Nos. 3 to 8, at the Bass trail are roughly equivalent to the similar cliff-forming beds, Nos. 8 to 12, at Kaibab Gulch.

The only rock in subdivision D at Kaibab Gulch that has no counterpart in the corresponding unit at the Bass trail is a 9-foot bed of hard fine-grained buff sandstone, No. 10, which lies 10 feet above the base of the subdivision. A peculiar feature of this sandstone is the occurrence in it of lenses of fine conglomerate whose constituent pebbles are tiny sheaflike aggregates of radially disposed crystals. The basal 3 feet of the sandstone is strongly cross-bedded, whereas the upper 6 feet exhibits gnarly, contorted bedding. The radial aggregates of quartz crystals appear to be confined to the cross-bedded lower part of the sandstone. Where free from conglomerate the cross-bedded sandstone at first sight resembles the typical Coconino sandstone of the Grand Canyon—so much so that, when I first encountered blocks of the sandstone in talus in the bed of Kaibab Gulch, I thought that they were fragments of the Coconino sandstone and that I should therefore find the Coconino below the base of the Kaibab higher up the gulch. However, when I traced the fragments to their source and found the parent bed (No. 10) in the Kaibab limestone at a horizon more than 50 feet above the base of beds lithologically similar to Kaibab beds that overlie the Coconino at the Bass trail, it was evident that the bed could not possibly represent the Coconino sandstone. Closer inspection showed that it differs from the Coconino of the type locality in that the sand grains are bound together by calcareous cement, whereas the cementing material of the typical Coconino is siliceous. Moreover it is vesicular, whereas the Coconino sandstone is compact and massive. Nor are streaks of conglomerate known to occur in the Coconino, one of whose distinctive features in the type locality is its uniform fineness of grain.

Subdivision B of the Kaibab limestone at the Bass trail, 136 feet thick, is composed entirely of sandstone and is the most sharply defined unit of the formation in the Kaibab division of the Grand Canyon. The sandstone is soft and friable, so that everywhere the subdivision makes a gentle slope, in contrast with the cliffs and steep slopes formed by the overlying and underlying limestone subdivisions. At most places the sandstone exhibits reddish and yellowish hues, which contrast strikingly with the grays and pale buffs of the adjacent limestone. The lithologic character of the subdivision, moreover, is peculiar and distinctive. Much of the sandstone exhibits a gnarly, contorted structure, which appears to be a form of cross-bedding. Wavy, irregular contacts separate many of the beds. Local unconformities are common. Interbedded with the sandstone are irregular beds of sandy breccia, which, although they do not occur everywhere at the same horizon, are a constant feature of the subdivision wherever it is exposed. At some places in the Kaibab division the breccia consists of angular fragments of sandstone and other rocks in an irregularly bedded matrix of sandy material, resembles a coarse fanglomerate, and is clearly of detrital origin; at other places it has the appearance of rock that has been brecciated in place, either by pressure or by the beds caving in and breaking because some soluble material, perhaps gypsum, was leached out of them. In places the breccia is associated with deposits of travertine. At some places, although not at the Bass trail, lenses of sandy red shale are interbedded with the sandstone and breccia.

Subdivision C at Kaibab Gulch, 150 feet thick, occupies the same position in the Kaibab limestone that subdivision B occupies at the Bass trail. It consists of soft slope-making beds of sandstone and sandy breccia that exhibits all the distinctive characteristics just described and is a no less sharply defined unit than subdivision B. Unquestionably, therefore, subdivision B at the Bass trail is the stratigraphic equivalent of subdivision C at Kaibab Gulch. As may be seen in the detailed sections there is no essential difference in the lithology of the two subdivisions. In general, the beds at Kaibab Gulch are more calcareous than those at the Bass trail, for they include beds of travertine and a few beds of limestone. Lenses of red shale occur at Kaibab Gulch but not at the Bass trail. However, beds of red shale, travertine, and sandy limestone similar to those at Kaibab Gulch occur in subdivision B at places in the Grand Canyon not far from the Bass trail.

The sandstone breccia unit just described is certainly a widespread and persistent member of the Kaibab limestone. Its presence at Kaibab Gulch, as well as throughout the Kaibab division of the Grand Canyon, indicates that it underlies all the Kaibab Plateau. It is exposed at many localities in a wide region west and northwest of the Kaibab Plateau, as is shown in the sections of the Kaibab limestone measured by Reeside and Bassler.[6] It is present in the region around Cataract Creek, as shown in a section measured by Newberry.[7] The origin of this member of the Kaibab is an interesting problem, for although the member is overlain and underlain by fossiliferous limestones that are unquestionably marine, some lithologic features suggest that not all parts of it are of marine origin. The beds of travertine at Kaibab Gulch, for example, are indistinguishable in appearance from certain beds of fresh-water limestone that occur in Tertiary deposits of the desert region of California and Nevada, notably at Callville Wash, in southern Nevada, and in the Death Valley region of California. The presence of breccia beds resembling fanglomerate is suggestive, as is also the presence of red shale. Some of the shale exhibits sun cracks. West of the Kaibab Plateau the member contains beds of gypsum at many horizons, as is shown in the sections measured by Reeside and Bassler and by Newberry. A section that I measured at Jumpup Canyon, near Kanab Creek, where the member contains a great deal of gypsum, is given on pages 54–57, for comparison with the section at Kaibab Gulch. Similar occurrences of gypsum are very common in Tertiary and Quaternary beds of the Great Basin region that are certainly not marine. On the other hand, beds of fossiliferous marine limestone occur in the upper part of this sandstone breccia member at Jumpup Canyon not far above beds that contain gypsum, and in different parts of the region gypsum occurs in other members of the Kaibab that contain fossiliferous marine limestone.

Subdivision A at the Bass trail, 292 feet thick, is composed chiefly of gray crystalline fossiliferous cherty limestone but includes beds of calcareous sandstone. The chert is exceedingly abundant in this subdivision throughout the Grand Canyon region, and it is to this feature that the Kaibab limestone owes the old name "cherty limestone," given to it by the early geologic explorers. At the Bass trail the chert is most abundant near the base and top of the subdivision; near the top it forms a conspicuous set of beds (No. 4) composed of almost solid layers of chert alternating with layers of calcareous sandstone. This set of alternating beds is present and easily recognizable everywhere in the Kaibab division of the canyon. The limestone beds in the middle part of the subdivision (Nos. 5, 6, and 8) are exceedingly fossiliferous, and the fauna of beds 6 and 8, at least, is the so-called "*Productus ivesi*" fauna of the "normal Kaibab" type [8] and not the upper "*Bellerophon* limestone" fauna of the Kaibab. Whether bed 5 or the overlying beds at the top of the subdivision at the Bass trail contain the "*Bellerophon*" fauna or the "*Productus ivesi*" fauna has not been determined. The subdivision as a whole is a strong cliff maker, and its topographic profile is a succession of cliffs and steep slopes.

Subdivision B at Kaibab Gulch, 326 feet thick, consists of beds that differ in no essential particular from those that constitute subdivision A at the Bass trail; they are composed chiefly of massive gray crystalline limestone, which is fossiliferous and cherty. As in A at the Bass trail, the limestones in the middle of subdivision B at Kaibab Gulch (beds 3 and 6) are very fossiliferous, and bed 6, at least, contains the "*Productus ivesi*" fauna; as in A, the chert becomes particularly abundant near the top of the subdivision, where it forms a set of beds alternating with earthy limestone layers (No. 2), which are a counterpart of the alternating chert and calcareous sandstone beds (No. 4) near the top of A. Like A, the entire subdivision is a cliff maker. Disregarding a few feet of beds at the base and top of A at the Bass trail whose correlation is uncertain, the subdivision is undoubtedly the stratigraphic equivalent of B at Kaibab Gulch.

Although it is not possible definitely to correlate individual beds in the two sections owing to the distance that separates the localities, it seems probable that beds 5 to 10 of the Bass trail subdivision are together roughly equivalent to beds 3 to 7 of the Kaibab Gulch subdivision; and that bed 4 at the Bass trail, consisting of alternating layers of chert and calcareous sandstone, is equivalent to bed 2 at Kaibab Gulch, consisting of a similar set of alternating layers of chert and sandy limestone. It is possible, however, that bed 5 at the Bass trail is also all or in part equivalent to bed 2 at Kaibab Gulch. Bed 5 at Kaibab Gulch, a hard quartzitic cross-bedded sandstone, appears to have no counterpart in the section at the Bass trail. The correlation of beds 1, 2, and 3 at the top of subdivision A at the Bass trail is altogether uncertain; they may be equivalent to beds at the summit of B

[6] Reeside, J. B., jr., and Bassler, Harvey, Stratigraphic sections in southwestern Utah and northwestern Arizona: U. S. Geol. Survey Prof. Paper 129, pp. 58–59, 69–77, 1922.

[7] Newberry, J. S., Report upon the Colorado River of the West, explored in 1857–58 by Lieut. J. C. Ives, pt. 3, Geological Report, 1861.

[8] Reeside, J. B., jr., and Bassler, Harvey, op. cit., pp. 66–67.

at Kaibab Gulch, but it is conceivable that they, together with some overlying beds exposed on the Coconino Plateau that are not included in the Bass trail section, are equivalent to a part of A, the topmost subdivision of the Kaibab limestone at Kaibab Gulch.

SECTIONS MEASURED BY REESIDE AND BASSLER IN SOUTHWESTERN UTAH AND NORTHWESTERN ARIZONA

In 1919 J. B. Reeside, jr., and Harvey Bassler made a stratigraphic reconnaissance of southwestern Utah and northwestern Arizona in the course of which they measured 22 detailed sections of the Paleozoic and Mesozoic rocks at separate localities scattered over this wide region. These sections are described in a report published by the Geological Survey in 1922.[9] Most of the sections include a part of the Kaibab limestone, and many of them include all of it. The location of all these sections that lie within a radius of 85 miles of Kaibab Gulch is shown in Figure 1. These sections are by far the most important contribution to the study of the formation that has been made. As summarized and discussed by Reeside and Bassler they constitute the standard section to which all sections of the Kaibab limestone in the neighboring region must be referred for comparison and correlation.

The general section of the Kaibab limestone for the area studied by Reeside and Bassler is summarized as follows:

Section of Kaibab limestone

	Feet
5. Harrisburg gypsiferous member: Gypsum, shale, and limestone, with platy chert. Locally the "*Bellerophon* limestone" at top	0–280±
4. Upper limestone member: Massive cliff-forming cherty gray limestone	185–455
3. Upper slope-forming member: Soft beds resembling basal member	80–285
2. Lower limestone member: Massive gray limestone with much chert	150–230
1. Lower slope-forming member: Gypsum, gray and yellow shale, soft gray sandstone, and some thin-bedded dark-drab limestone	0–100

The writers state:[10]

In most of the exposures seen in our work the Kaibab limestone shows a fivefold topographic and lithologic division—(1) a lower soft member consisting of gypsum, gray and yellow shale, soft gray sandstone, and subordinate amounts of thin-bedded dark-drab limestone; (2) a lower cliff-forming member of gray massive limestone with much brown to black concretionary chert; (3) an upper soft member with much the same character as the lower one; (4) an upper massive cliff-forming limestone which is similar to the lower one but contains more chert and which from Bright Angel Creek to southwestern Utah shows towerlike erosion forms along its upper cliff face; (5) a topmost member, less resistant than the underlying beds and highly variable in composition and thickness, consisting of shale, gypsum, and limestone. The limestone of the top member is at some places arenaceous, at others partly silicified, at still others filled with masses of light-colored chert that breaks into flat platy fragments; at many places the upper layers contain many small angular fragments of chert. In color it is light gray, yellowish brown, pink, and rarely a sugary white. The sandstone is gray to yellow, calcareous, and locally gypseous—that is, it has a gypsum cement. The shale may be gray, yellow, or rarely red. It is usually gypseous and in some places sandy.

These divisions of the Kaibab limestone vary much in thickness from point to point, and it seems unlikely that exactly the same beds enter into the same divisions at all localities. * * *

The topmost member (5) is composed of peculiar and characteristic rocks. It may be recognized, in spite of its variability, wherever it occurs, and as it is a definite unit between the upper cliff-forming limestone of the Kaibab and the basal beds of the Moenkopi formation it is here named the Harrisburg gypsiferous member, from its occurrence in the Harrisburg dome, 8 miles east of St. George. A section measured here shows a thickness of 280 feet. This member may be absent from some of the sections examined, but in others it reaches a thickness of nearly 300 feet. It is apparently the same unit as that designated "Super-Aubrey beds" by Huntington and Goldthwait. The uppermost limestone beds locally contain an abundance of a species of *Bellerophon* and are the "*Bellerophon* limestone" of some of the earlier geologists.

The section of the Kaibab limestone at Kaibab Gulch shows a fivefold topographic and lithologic division comparable to the fivefold division of the general section for southwestern Utah and northwestern Arizona just described, and it appears highly probable that the subdivisions of the section at Kaibab Gulch are equivalent to the subdivisions of Reeside and Bassler's general section, although the correlation of A, the topmost subdivision at Kaibab Gulch, is more uncertain than that of the other four. Inasmuch as the nearest section measured by Reeside and Bassler (locality 5, fig. 1) is 53 miles from Kaibab Gulch and all the other sections more than 68 miles distant, it is hardly to be expected that equivalent subdivisions would correspond in all details of lithology and contain exactly the same beds. Nevertheless, in a broad way, they correspond remarkably—as closely, indeed, as the subdivisions at the Bass trail correspond with those at Kaibab Gulch; so that correlation can be made with at least as much confidence as that between the Bass trail and Kaibab Gulch sections.

Subdivision E, the basal slope-making unit at Kaibab Gulch, which consists chiefly of soft sandstone and includes thin beds of limestone, some shale, and a thin bed or two of sandy breccia, is almost certainly the correlative of No. 1, the "lower slope-forming member" of Reeside and Bassler, composed of gypsum, gray and yellow shale, soft sandstone, and thin-bedded limestone. Like subdivision C, which is composed of soft sandstone, sandy breccia, and shale similar to those which occur in E, the unit contains gypsum west of the Kaibab Plateau in the region studied by Reeside and Bassler but does not contain it at Kaibab Gulch nor in the Kaibab division of the Grand Canyon.

Subdivision D, which constitutes the lower cliff-making unit of the Kaibab limestone at Kaibab

[9] Reeside, J. B., jr., and Bassler, Harvey, op. cit.
[10] Idem, p. 58.

Gulch and consists chiefly of massive siliceous cherty limestone of a distinctive type, is certainly roughly equivalent to No. 2, the "lower cliff-forming member" ("lower limestone member") of Reeside and Bassler, which consists of similar limestone.

Subdivision C, the sharply defined slope-making unit in the middle of the Kaibab at Kaibab Gulch, which is composed of soft sandstone, sandy breccia, and travertine, is the equivalent of No. 3, the "upper slope-forming member" of Reeside and Bassler, which, like No. 1, consists of soft sandstone, shale, and thin-bedded limestone and includes beds of gypsum. Subdivision C does not contain gypsum at Kaibab Gulch; nevertheless its correlation with No. 3 is definitely established, for at Jumpup Canyon (locality 4, fig. 1), on the border of the region studied by Reeside and Bassler, where I measured a section of the Kaibab limestone (p. 54), the equivalent unit contains many beds of gypsum interstratified with beds of soft sandstone, breccia, and shale that are lithologically identical with the beds of sandstone, breccia, and shale that constitute subdivision C at Kaibab Gulch.

Subdivision B, the upper cliff-making member of the Kaibab at Kaibab Gulch, is composed of the type of rock that is most commonly associated with the name Kaibab limestone in the minds of geologists who have worked in the plateau region—the massive gray or buff cherty fossiliferous limestone that is conspicuously exposed in the cliffs under the rim of the Grand Canyon in the Kaibab and Coconino Plateaus. All the lower half of the subdivision contains fossils of the typical "*Productus ivesi*" fauna in great abundance. Fossils are almost as abundant at many horizons in the upper half, but unfortunately I did not determine whether they represent the "*Productus ivesi*" fauna or the higher "*Bellerophon*" fauna. No. 4, the "upper limestone member" (or "upper massive cliff-forming member") of Reeside and Bassler, consists, like subdivision B, of the familiar cherty limestone which "from Bright Angel Creek to southwestern Utah shows towerlike erosion forms along its upper cliff face." The abundant fossils that it contains represent the "*Productus ivesi*" fauna. In all probability the whole of subdivision B is equivalent to No. 4, although it is barely possible that the upper part of B, the character of whose fauna has not been determined, may represent a part of the Harrisburg member of Reeside and Bassler. The beds in the upper half of B, however, do not at all suggest those of the Harrisburg member in lithology and order of succession, notwithstanding the fact that the Harrisburg member is an exceedingly variable unit.

Subdivision A at Kaibab Gulch, which consists at the top of massive buff limestone and contains at the base very irregular beds of coarse breccia-conglomerate interstratified with shale and soft sandstone, apparently represents No. 5, the Harrisburg gypsiferous member of Reeside and Bassler, which, as shown by those writers, occupies the stratigraphic position of A and which, although exceedingly variable in lithology, consists at many places of rocks very similar to those that constitute subdivision A. The fact that the Harrisburg member contains gypsum in the region studied by Reeside and Bassler, whereas A at Kaibab Gulch does not contain it is not at all inconsistent with the lithology of A. As I have already shown, two other subdivisions of the Kaibab limestone, C and E, which are gypsiferous west of the Kaibab Plateau are not gypsiferous at Kaibab Gulch, but they contain at Kaibab Gulch beds of sandy breccia, soft sandstone, and shale. Similar beds of breccia, sandstone, and shale are interstratified with the gypsum at many of the places west of the Kaibab Plateau where the subdivisions are gypsiferous. Accordingly this association appears to be significant; in other words, the breccia, sandstone, and shale beds in A at Kaibab Gulch are what would be expected at a horizon where gypsum occurs at other localities.

I have tentatively correlated subdivision A at Kaibab Gulch with the Harrisburg member of Reeside and Bassler and have included it in the Kaibab limestone. Nevertheless the possibility exists that it belongs at the base of the Triassic Moenkopi formation, for it may represent a basal member of the Moenkopi that occurs here and there in the region studied by Reeside and Bassler, contains Triassic fossils, and has been named by them the Rock Canyon conglomeratic member. This member of the Moenkopi is described as follows:[11]

> The basal discontinuous unit [of the Moenkopi formation] is an exceedingly variable assemblage of shale, limestone, gypsum, conglomerate, and a minor amount of sandstone. To this unit we have given the name Rock Canyon conglomeratic member, from Rock Canyon, 5 miles north of Antelope Spring, Ariz. A detailed section at this locality [locality 9, fig. 1] is given on page 70 (section 6). The limestone is gray to pink, is usually coarse, and contains chert fragments. The shale may be gray, yellow, or red. The conglomerate is made up of limestone and chert boulders, locally as much as 3 feet in diameter but usually less than a foot, in a limestone cement and occurs in very irregular beds, which may lie at any stratigraphic level in the basal unit. Locally the included limestone fragments are angular and the material is really a breccia, though at most points observed they are rounded or only subangular. Locally this basal member is absent, as the sections show, and the lower red beds of the Moenkopi formation rest directly on limestones containing Kaibab fossils. At the head of Rock Canyon a great gash 700 feet wide and 250 feet deep has been cut into the Kaibab and filled with a confused mass of limestone, shale, gypsum, and conglomerate. This mass contains thin veins of asphaltite and zones impregnated with asphaltic material.

In lithology subdivision A corresponds as well to the Rock Canyon member of the Moenkopi just described as it does to the Harrisburg member of the

[11] Reeside, J. B., jr., and Bassler, Harvey, op. cit., p. 60.

Kaibab, as may be seen by comparing the detailed section of subdivision A (pp. 43–44) with Reeside and Bassler's detailed section of the Rock Canyon member at the type locality and with their section of the Harrisburg member at the narrows of Virgin River.[12] Both these sections, like the section at Kaibab Gulch, consist at the base of irregular beds of breccia and conglomerate, soft sandstone or shale, and limestone or chert, which pass up into gray and buff limestones. The correlation of subdivision A therefore remains uncertain and can be settled only by determination of the fossils that the subdivision contains. Fossils are fairly abundant in the limestone at the top of the subdivision, but all those that I saw were too obscure or too poorly preserved to be determinable, and I had not time to search carefully for better specimens. A systematic search at Kaibab Gulch would undoubtedly yield determinable material, which would establish definitely the correlation of the subdivision.

SECTION IN JUMPUP CANYON

During the eary part of our stratigraphic reconnaissance in the summer of 1922 Professor Gregory and I measured an incomplete section of the Kaibab limestone, Coconino sandstone, and Hermit shale in Jumpup Canyon, a tributary gorge that enters the lower canyon of Kanab Creek from the east at a point about 6 miles north of the junction of Kanab Creek with Colorado River. The section is interesting because it shows in detail the lithology of the slope-making unit of the middle Kaibab (the correlative of subdivision C at Kaibab Gulch, of B at the Bass trail, and of No. 3 of Reeside and Bassler) at a place where the unit contains gypsum; because it shows in detail the lithology of the Hermit shale at a place where that formation is extraordinarily thick and calls attention to the presence in the canyon of lower Kanab Creek of an unconformity at the base of the Hermit shale similar to the unconformity that is well displayed at the type locality of the formation in the canyon of Hermit Creek in the Grand Canyon; and because it affords data concerning the thinning of the Coconino sandstone northward of Kanab Creek. The section is therefore included in this report for comparison with the section at Kaibab Gulch, although in the Kaibab limestone at Jumpup Canyon only the unit mentioned above was measured in sufficient detail to make the section of much value for comparison with the standard sections of the region.

Jumpup Canyon is shown on the Kaibab topographic map published by the United States Geological Survey, but the name of the canyon is not printed on the map. It may be identified as the first large gorge that enters the canyon of Kanab Creek from the east above the junction of Kanab Creek and Colorado River. The location of the section is shown on figure 1 (locality 4). It is roughly 50 miles southwest of Kaibab Gulch, 25 miles northwest of the Bass trail, and 10 miles southeast of Hacks Canyon, where the nearest section of Reeside and Bassler was measured (locality 5, fig. 1). It is not far from the general locality on Kanab Creek where Walcott measured the section shown in columnar form in my report on the Paleozoic rocks of the Grand Canyon,[13] but inasmuch as Walcott's section is a composite section measured along 25 miles of Kanab Canyon between Shinumo Canyon and Colorado River, the writer does not know just what parts of Walcott's section were measured near Jumpup Canyon.

Subdivision C of the Hermit shale and subdivision A of the Supai formation were measured by Professor Gregory in Jumpup Canyon at different places 1 to 4 miles above the junction of Jumpup Creek with Kanab Creek. The Kaibab limestone, Coconino sandstone, and subdivisions A and B of the Hermit shale were measured by me in the walls of Jumpup Canyon at different places 4 to 7 miles above the mouth of Jumpup Creek.

Section in Jumpup Canyon

General section

	Feet
Kaibab limestone:	
Summit of formation not exposed.	
A. Massive gray fossiliferous cherty limestone, forming strong cliffs and steep slopes. Not examined in detail nor measured, but exposed thickness appears to exceed 250 feet	250+
B. Gypsiferous member: Yellowish-buff and pinkish fine-grained sandstone, poorly consolidated and irregularly bedded, interstratified with beds of gypsum and gypsiferous shale; contains near the top beds of sandy breccia and a few thin beds of fossiliferous gray limestone; forms a gentle slope	161
C. At the base buff sandstone and limestone in alternating beds, passing up into massive siliceous buff limestone, fossiliferous and cherty, which constitutes the greater part of the subdivision and makes strong cliffs	172±
Coconino sandstone: Fine-grained buff sandstone, cross-bedded throughout; forms a sheer cliff	90
Hermit shale:	
A. Alternating beds of red sandy shale and fine-grained massive friable sandstone; form a slope; many beds exhibit concretionary structure	44
B. Alternating beds of red shale and sandstone, forming a slope; beds do not exhibit concretionary structure but otherwise are like A	450
C. Alternating beds of red shale and sandstone; like B in composition, but the sandstone beds are rather more massive and resistant than those of B, so that the subdivision forms a ledgy slope broken by weak cliffs and exhibits a profile distinctly steeper than that of B	307
	801

[12] Idem, p. 75.

[13] Noble, L. F., A section of the Paleozoic formations of the Grand Canyon at the Bass trail: U. S. Geol. Survey Prof. Paper 131, pl. 19, 1922.

Unconformity, obscure at the place in Jumpup Canyon where this section was measured, because the surface of erosion exhibits no relief there, but very distinct at many localities 1 to 5 miles away, where the surface of erosion exhibits a relief of 40 feet or more in distances of a few hundred feet.

Supai formation:

A. Upper cliff-making member: Violently and persistently cross-bedded fine-grained hard calcareous sandstone in heavy, massive beds, which everywhere form strong cliffs; pale red to pale yellowish red, contrasting with the prevailing deep red of the Hermit shale. Partings of red sandy shale or platy red sandstone separate many beds of the massive cross-bedded sandstone. The summit beds of this cliff-making subdivision of the Supai form the floor of a broad platform in Jumpup Canyon and throughout the lower canyon of Kanab Creek; this platform is the Esplanade of the western Grand Canyon. Thickness of subdivision not measured, probably about 400 feet.

Detailed section

	Feet
Kaibab limestone:	
A. Massive gray fossiliferous cherty limestone, forming strong cliffs. Not measured.	
B. 1. Concealed; probably yellow sandstone; makes slope	5
2. Gray limestone in beds averaging 6 inches thick; makes small cliff	4
3. Concealed; probably yellow sandstone; makes slope	5
4. Dense fossiliferous gray limestone forming small cliff	2
5. Yellowish breccia, base concealed. The breccia consists of fragments of sandstone and limestone embedded in a matrix of yellow sand	6
6. Dense fossiliferous gray limestone	1
7. Breccia like No. 5	5
8. Concealed. The few outcrops seen are very soft fine-grained yellowish sandstone	24
9. Massive gypsum	4
10. Yellowish-buff sandy shale, largely concealed; contains at least three 6-inch beds of massive gypsum	15
11. Massive gypsum	8
12. Pinkish sandy shale, partly concealed; contains several 1-foot beds of massive gypsum	16
13. Gypsum containing a small amount of whitish shale and exhibiting very thinly laminated structure	22
14. Gypsiferous yellowish sandy shale, containing three 6-inch beds of massive gypsum	11
15. Massive gypsum, containing a small amount of yellow sand	5
16. Sandy shale impregnated with gypsum and cut by many tiny stringers of gypsum	16
17. Soft whitish-buff fine-grained sandstone in beds averaging 4 inches thick; probably a calcareous sandstone; largely concealed, but many beds of the sandstone appear to be separated by layers of gypsiferous shale. Outcrops are covered by puffy, gypsiferous soil	12
	161

	Feet
Kaibab limestone—Continued.	
C. 1. Pale-buff arenaceous limestone in two 2½-foot beds, which are separated by a thin parting of shaly sandstone. Forms cliff	5
2. Pale-buff arenaceous limestone, containing lenses, bands, and nodules of chert that become less abundant toward the top. Weathered surfaces of the rock feel gritty and exhibit a faint thinly laminated structure. Forms a steep ledgy slope	8
3. Dense siliceous buff limestone in massive beds, some of which appear to be more than 20 feet thick, fossiliferous and cherty; contains many cavities. The chert occurs in lenses, bands, and nodules and in some beds is very abundant. The limestone forms strong cliffs. Not examined closely nor measured. Thickness estimated roughly	135±
4. Buff fine-grained sandstone. No bedding planes observable. Rather soft; forms an alcove under the high cliffs of No. 3	5½
5. Three 1-foot beds of dense siliceous buff limestone separated by two 2-inch layers of sandy shale. The bottom bed of limestone rests upon a wavy, irregular surface, which exhibits vertical inequalities of a foot or more in a distance of 100 feet	3½
6. Whitish-buff dense fine-grained sandstone. No bedding planes observable	2½
7. Hard dense fine-grained buff crystalline limestone in four beds ranging in thickness from 6 inches to 2 feet	4½
8. Reddish soft sandstone, partly concealed. No bedding planes observable. The sand grains resemble those of the underlying Coconino. The base of the bed truncates with level, even contact the inclined wedges of the underlying Coconino sandstone	8
	172
Coconino sandstone: Fine-grained buff sandstone, cross-bedded throughout. Forms a sheer cliff. At the point where this section was measured one inclined wedge is nearly as thick as the entire formation. The laminae of the wedges dip south or southwest. Contact with underlying shale level, even	90
Hermit shale:	
A. 1. Greenish sandy shale (typical playa mud)	1
2. Fine-grained white sandstone	5
3. Red sandy shale, exhibiting concretionary structure on weathered surfaces	3
4. Red sandstone	5
5. Concretionary red shale, like No. 3	6
6. Reddish-buff calcareous sandstone	2
7. Red shale	2
8. Reddish-buff calcareous sandstone	5
9. Concretionary red shale, like No. 3	4
10. White sandstone, fine grained, calcareous, massive	3
11. Concretionary red shale, like No. 3	8
	44

Hermit shale—Continued.

		Feet
B. 1.	Massive fine-grained friable red sandstone	3
2.	Sandy red shale	3
3.	Sandstone, like No. 1	7
4.	Shale, like No. 2	4
5.	Sandstone	4
6.	Shale	5
7.	Sandstone	4
8.	Shale	5
9.	Sandstone	12
10.	Shale	17
11.	Sandstone	5
12.	Shale	11
13.	Sandstone	4
14.	Shale	8
15.	Sandstone	6
16.	Shale	6
17.	Sandstone	11
18.	Shale	19
19.	Sandstone	1
20.	Shale	3
21.	Sandstone	1
22.	Shale	1
23.	Sandstone	1
24.	Shale	5
25.	Sandstone	4
26.	Shale	5
27.	Sandstone	2
28.	Shale	7
29.	Sandstone	9
30.	Shale	10
31.	Sandstone	3
32.	Shale	1
33.	Sandstone	5
34.	Shale	8
35.	Sandstone	3
36.	Shale	6
37.	Sandstone	1
38.	Shale	5
39.	Sandstone	1
40.	Shale	7
41.	Sandstone	1
42.	Shale	5
43.	Sandstone	3
44.	Shale	23
45.	Sandstone	5
46.	Shale	5
47.	Sandstone	6
48.	Shale	12
49.	Sandstone	5
50.	Shale	18
51.	Sandstone	4
52.	Shale	17
53.	Sandstone	5
54.	Shale; contains greenish bands at intervals	59
55.	Sandstone	4
56.	Shale; basal 2 inches greenish	5
57.	Sandstone	2
58.	Shale	3
59.	Sandstone	3
60.	Shale	5
61.	Sandstone	2
62.	Shale	4
63.	Sandstone	2
B. 64.	Shale	24
65.	Sandstone	5
		450

[All beds below this point were measured and described by H. E. Gregory]

		Feet
C. 1.	Hard massive buff to red calcareous sandstone; contains greenish blotches; forms small cliff	4
2.	Sandy red shale containing greenish spots and layers	8
3.	Red sandstone, hard, lumpy; weathers into knobs; forms vertical cliff. The rock is composed of fine uniform quartz grains bound together by calcareous cement, cross-bedded. Thickness estimated	40
4.	Red shale or thin-bedded sandstone; breaks into small chunks of hardened sand or mud; shows worm trails and mud pellets; includes several greenish-white sandy bands; has mica sprinkled on surface; forms slope	35
5.	Red sandstone, massive, chunky	2
6.	Like No. 4; includes four greenish-white sandy bands	42
7.	Red sandstone, chunky	2
8.	Red shale, lumpy, nodular, uneven, sandy; forms flat slope	20
9.	Red sandstone, massive; forms cliff	2
10.	Red sandy shale; forms slope	38
11.	Red sandstone, unevenly bedded; forms two layers the bottoms of which are white and exhibit mud cracks, mud holes, worm trails, etc	12
12.	Red, unevenly bedded shaly sandstone or sandy shale, lumpy and friable with no apparent change in texture or composition; forms two shale slopes and two broken cliffs	55
13.	Red friable sandstone	6
14.	Red shaly sandstone with greenish-white spots	8
15.	Red sandstone, uniformly fine-grained; roughly separated into three beds, cross-bedded	10
16.	Red mud shale, plastered against uneven under surface of No. 15	1
17.	Red shale or sandstone; weathers into thin sandy shales like mud in arid stream. Greenish-white streaks of thinly laminated shale make three parting planes. Beds are very uneven; contacts wavy	22
		307

Supai formation:

		Feet
A. 1.	Sandstone, calcareous; weathers into hoodoo forms; exhibits greenish-white streaks, blotches, and dots. The rock is cross-bedded, and the sand grains are uniform in size and very small. In texture and color it is exactly like No. 4, below	4
2.	Light-red sandstone, composed of quartz grains bound together with calcareous cement; forms two massive beds separated by crumbly sandstone; has amorphous lumps of limestone	11

Supai formation—Continued. Feet

A. 3. Calcareous cross-bedded sandstone, like No. 1. Texture and color like No. 4 ... 5

4. Sandstone, light red to yellow-red; makes striking contrast with dark-red Hermit and white Coconino, which appear on same valley wall; everywhere makes strong cliffs. The sandstone is roughly arranged in beds 10 to 50 feet thick, whose appearance is strikingly like that of the Navajo sandstone. Parting planes are marked by nothing or by lenses and short beds of sandstone and sandy shale that resemble the sandstone and shale of the Chinle formation. Nearly all beds are cross-bedded tangentially and angularly. The component sand grains are surprisingly uniform in size and composition and are mostly quartz with lime cement; all grains are almost microscopic; a few red specks are garnet. This cliff-making sandstone unit (No. 4) with the three overlying beds (Nos. 1, 2, and 3) is the rock that floors the Esplanade throughout the canyon of Kanab Creek and in the neighboring Grand Canyon. It constitutes the upper cliff-making subdivision of the Supai, and its steep profile is everywhere in sharp contrast with the gentler profile of the overlying Hermit and underlying Supai beds. At most places in the Canyon of Kanab Creek the surface of the Esplanade lies at the top of No. 4, but at some places it lies at the top of one of the overlying beds, 1, 2, or 3; the surfaces of all four beds weather into water pockets. An all-day search in Jumpup Canyon failed to reveal a place where the cliffs of No. 4 could be descended; consequently this unit could not be examined in detail nor measured. Thickness estimated; may be as much as ... 400

Subdivision A of the Supai formation on lower Kanab Creek does not differ essentially in composition from A, the corresponding cliff-making subdivision of the Supai at the Bass trail. Like that subdivision, it forms the resistant unit which underlies the Esplanade and determines its floor. The sandstone of which the unit is chiefly composed is, however, much more violently and persistently cross-bedded at Kanab Creek than it is at the Bass trail and appears to form thicker and more massive beds. In composition it is astonishingly like the Navajo sandstone, which I studied later in the Glen Canyon region of Colorado River, and under erosion assumes forms like those assumed by the Navajo sandstone. Some of the bedding is of the "gnarled" or "contorted" type.

Along Kanab Creek just below the mouth of Hacks Canyon I was able to examine some of the beds in the upper part of B, the underlying subdivision of the Supai, but I could not examine the subdivision in detail, as it was impossible at the time to descend along Kanab Creek, owing to high water. I was interested to find, in the upper part of B, beds of limestone conglomerate similar to a bed that occurs in subdivision B in the Kaibab division of the Grand Canyon.[14] One bed is 20 feet thick, and another, higher in the subdivision, is 1 foot thick. The lower bed occurs at approximately the horizon at which the similar bed occurs at the Bass trail. The rock strikingly resembles the "saurian conglomerate" of the Chinle formation, which I had opportunity later to examine in the Vermilion Cliffs. The occurrence of the distinctive beds of conglomerate at Kanab Creek indicates that they are a persistent feature of the Supai over a wide area, for they occur also in the Aubrey cliff near Seligman as well as throughout the Kaibab division of the Grand Canyon. Further study of the Supai formation will be necessary to determine the stratigraphic significance of these conglomerate beds; it is conceivable that they mark a widespread zone of unconformity within the formation or at any rate a datum plane that will prove useful for correlation.

The unconformity that separates the Hermit shale from the Supai formation in Kanab Canyon is an exact counterpart of the unconformity which separates these formations in the Kaibab division of the Grand Canyon and which I have described in another paper.[15] In Kanab Canyon as in the Grand Canyon it is so clear at some places that it may be recognized at a glance and so obscure at other places that it can not be detected. The unconformity lies at or just above the general level of the Esplanade, the platform developed on the hard summit beds of the Supai. Along the east side of Kanab Canyon, between the mouth of Hacks Canyon and Jumpup Canyon, it is clearly exposed for a distance of 3 or 4 miles and is unmistakable. The surface of erosion exhibits considerable relief; in places channels 40 feet deep have been eroded in the Supai beds. These hollows are filled with the Hermit shale. At places residual hills of Supai, 30 feet or more high, project into the Hermit shale. The photographic views in Plate 14 show some of these details of the unconformity. Near the mouth of Jumpup Canyon where the section given above was measured, the unconformity could not be detected, notwithstanding the fact that good exposures of it appear in the canyon of Kanab Creek a mile away. It is therefore possible that some of the beds assigned to the base of the Hermit shale in the sections are Supai beds, although it is improbable from the observed stratigraphic position of the unconformity at places not more than a mile away that the base of the Hermit lies much higher than the position assigned to it in the section. All the beds in the section that are assigned to the Supai, at any rate, are unquestionably

[14] Noble, L. F., A section of the Paleozoic formations of the Grand Canyon at the Bass trail: U. S. Geol. Survey Prof. Paper 131, p. 61, 1922.

[15] Idem, pp. 63–64.

Supai. I experienced a similar difficulty in determining the base of the Hermit shale at the Bass trail, where the unconformity is also obscure.

Although the unconformity just described appears to be a widespread feature in the Grand Canyon region, as is indicated by its presence in Kanab Canyon as well as in the Kaibab division of the Grand Canyon, it probably does not mark any great or significant time interval, for subdivision A of the Supai below the unconformity as well as the Hermit shale above it is believed to be of Permian age. Inasmuch as the unconformity coincides roughly with the general level of the Esplanade or lies just above it, the Esplanade might be regarded as an exhumed and now more or less dissected erosion surface of Permian time.

At Jumpup Canyon I divided the Hermit shale into three subdivisions, A, B, and C, for convenience in measuring the section. These subdivisions have no particular stratigraphic significance, because the formation is essentially a unit in lithology, all parts of it consisting of similar material—sand and red sandy mud, which form alternating beds of sandstone and sandy shale. Other geologists might subdivide the same section differently or might not subdivide it at all. For example, the subdivisions into which Reeside and Bassler [16] have divided the formation at Hacks Canyon and those into which Walcott [17] has subdivided it along Kanab Creek do not correspond with those into which I have subdivided it at Jumpup Canyon, although the three sections are essentially similar in lithology. Subdivision A of the Hermit shale at Jumpup Canyon differs from other subdivisions of the formation at that locality only in that many beds in it exhibit a peculiar concretionary structure on weathered surfaces that does not appear in the other subdivisions. Subdivision C differs from A and B only in that the beds of which it is composed are rather more massive than those of A and B, so that the subdivision exhibits a somewhat steeper topographic profile than the other subdivisions.

In lithology the section of the Hermit shale at Jumpup Canyon does not differ in any essential respect from the sections of that formation at the Bass trail and at the type locality in Hermit Basin.[18] At Jumpup Canyon, as at these other localities, the upper part of the formation is marked by concretionary structure, and the Hermit beds exposed at Kaibab Gulch (see p. 46) evidently represent this concretionary part of the formation. The most noteworthy feature of the Hermit shale at Jumpup Canyon is its great thickness (800 feet) as contrasted with its thickness at the Bass trail (332 feet) and at Hermit Basin (317 feet), from which it is evident that the formation maintains at least as far as Kanab Canyon the steady increase in thickness northwestward that it exhibits in the Kaibab division of the Grand Canyon. The fact that the Coconino sandstone thins steadily in the same direction (see below) is in accordance with the observation [19] that in the Kaibab division of the Grand Canyon the thickness of the Coconino is everywhere in inverse ratio to that of the underlying Hermit. The significance of this relation is not known.

The three subdivisions, A 1, A 2, and A 3 of the Aubrey group in Walcott's composite section along Kanab Creek [20] correspond in lithology and in aggregate thickness (775 feet) to the Hermit shale (801 feet) at Jumpup Canyon and undoubtedly represent that formation. Walcott's underlying subdivision B, composed of massive cross-bedded sandstone (315 feet thick) undoubtedly represents subdivision A of the Supai in the section at Jumpup Canyon.

The upper 550 feet, at least, of the beds classed as Supai in Reeside and Bassler's section at Hacks Canyon,[21] and perhaps a part of the underlying beds, are Hermit shale.

In our traverse down Kanab Creek from Fredonia to Jumpup Canyon we had an opportunity to trace the Coconino sandstone continuously for 20 miles in the eastern wall of Kanab Canyon—from the point where it first appears in the bed of Kanab Creek to the mouth of Jumpup Canyon. We found that between these points the sandstone thins steadily northward, its thickness diminishing from 90 feet at Jumpup Canyon to 15 feet in the bed of Kanab Creek (locality 3, fig. 1). Throughout this long exposure in Kanab Canyon the Coconino appears to be one bed, made up of cross-bedded wedges, not several beds; and this bed is continuously traceable from Jumpup Canyon into the thick bed that constitutes the formation in the Kaibab division of the Grand Canyon, the type locality of the Coconino sandstone. West of Kanab Canyon, however, the Coconino, as identified by Reeside and Bassler,[22] consists of several members, and it is uncertain whether one or all of these members should be correlated with the single massive bed that represents the formation at the type locality. Near Ryan, 25 miles northeast of Jumpup Canyon in the general direction of Kaibab Gulch, the Coconino is exposed in the escarpment along the West Kaibab fault. Here, as seen from a distance of a mile, it appears to be about 25 feet thick and, as at Jumpup Canyon, to constitute a single bed. It rests upon beds of Hermit shale whose exposed thickness appears to be at least 600 feet.

The facts just noted show that the Coconino must wedge out to the vanishing point somewhere between the localities on Kanab Creek and at Ryan, where it

[16] Reeside, J. B., and Bassler, Harvey, op. cit., p. 69.

[17] Noble, L. F., op. cit., pl. 19.

[18] Idem, pp. 64–65.

[19] Noble, L. F., op. cit., p. 67.

[20] Idem, pl. 19.

[21] Reeside, J. B., jr., and Bassler, Harvey, op. cit., p. 69.

[22] Idem, p. 57.

has decreased, respectively, to 15 and 25 feet, and Kaibab Gulch, where it is absent.

The Coconino-Hermit contact is a well-marked spring horizon in Jumpup Canyon and other tributary gorges of Kanab Canyon, just as it is throughout the Kaibab division of the Grand Canyon and along the western border of the Kaibab Plateau. Evidently the Hermit shale is much more impervious than the Coconino sandstone and offers everywhere a barrier to percolation. This relation may be worthy of consideration, for it is conceivable that fuller knowledge of the thickness and distribution of the Coconino in the plateau country will reveal geologic structure favorable for the accumulation of underground water above the contact in sufficient quantity to be recoverable by wells.

In a broad way the units into which the Kaibab limestone is divisible at Jumpup Canyon exhibit the distinctive features of lithologic character, succession, and topographic expression that corresponding units of the formation display at Kaibab Gulch, at the Bass trail, and in the region studied by Reeside and Bassler, so that the section at Jumpup Canyon may be correlated confidently with these other sections. Subdivisions A, B, and C at Jumpup Canyon are obviously equivalent, respectively, to subdivisions A, B, and C at the Bass trail. Apparently beds 4, 5, 6, 7, and 8 of C, the alternating beds of sandstone and limestone at the base of the Kaibab at Jumpup Canyon, are equivalent to subdivision E at Kaibab Gulch and to No. 1, the "lower slope-forming member," of Reeside and Bassler; and beds, 1, 2, and 3 of C at Jumpup Canyon, composed of massive buff siliceous limestone, are equivalent to subdivision D at Kaibab Gulch and to No. 2, the "lower limestone member," of Reeside and Bassler, which are composed of limestone of this distinctive type.

Subdivision B, the gypsiferous member of the Kaibab at Jumpup Canyon, is certainly equivalent to C at Kaibab Gulch and to No. 3, the "upper slope-forming member," of Reeside and Bassler. The section of this unit at Jumpup Canyon affords a connecting link between the sections at Kaibab Gulch and the Bass trail, where the unit contains no gypsum, and the sections in the region studied by Reeside and Bassler, where it is composed chiefly of gypsum. At Jumpup Canyon the unit not only contains the characteristic beds of breccia, soft sandstone, and shale that constitute it at Kaibab Gulch and Bass Canyon and the beds of gypsum that are characteristic of it in the sections of Reeside and Bassler but contains also, in its upper part, beds of fossiliferous limestone interstratified with the distinctive sandy breccia. Subdivision C at Jumpup Canyon, which I did not measure, is the familiar cherty limestone member of the Kaibab and is the correlative of a part, at least, of B at Kaibab Gulch and of No. 2, the "upper limestone member," of Reeside and Bassler. In all probability No. 5, the overlying Harrisburg member of Reeside and Bassler, with which I have tentatively correlated subdivision A at Kaibab Gulch, is represented by beds on the Kaibab Plateau along the rim of Jumpup Canyon, but I did not have an opportunity to examine these beds.

SECTION NEAR LEES FERRY

Near Lees Ferry, 30 miles southeast of Kaibab Gulch, the following section (No. 3, fig. 1) was measured by Bryan:[23]

Section near Lees Ferry

	Feet
Moenkopi formation: Red sandy shale and thin-bedded sandstone with seams of gypsum; in places has beds of red and gray sandstone 2 to 6 feet thick and in one locality 12 feet of gypsiferous limestone at the top. Base generally 1 to 10 feet of chert conglomerate	500 ±
Unconformity.	
Kaibab limestone: Yellow limestone with many more or less rounded nodules of chert	250
Coconino sandstone: Gray cross-bedded massive sandstone	300
Unconformity (?).	
Hermit (?) shale: Red shale and sandstone	500 ±
Unconformity (?) (not observed).	
Supai formation: Red shale with beds of blue limestone	

Bryan's section of the Kaibab limestone is not sufficiently detailed to afford a basis for determining what part of the Kaibab at Kaibab Gulch is represented at Lees Ferry. As described by Bryan the Kaibab limestone at Lees Ferry consists entirely of cherty limestone; this limestone might represent that of either subdivision B or subdivision D at Kaibab Gulch or both. Subdivision C at Kaibab Gulch, the well-defined soft sandstone and breccia member of the middle Kaibab, does not appear to be represented at Lees Ferry. Its absence there seems surprising, for Lees Ferry is much nearer Kaibab Gulch than any other locality from which a measured section of the Kaibab has been published. One would expect to find at least as close a correspondence between the Kaibab Gulch and Lees Ferry sections as between the Kaibab Gulch and Bass trail sections, which are more than twice as far apart. The absence of the Coconino sandstone at Kaibab Gulch and its presence at Lees Ferry, only 30 miles away, where it is 300 feet thick, is even more surprising. The Kaibab limestone, moreover, is only a little more than one-third as thick at Lees Ferry as it is at Kaibab Gulch. These differences in thickness serve further to emphasize the contrast between the sections at the two localities.

[23] Longwell, C. R., Miser, H. D., Moore, R. C., Bryan, Kirk, and Paige, Sidney, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, p. 16, 1923.

SECTION IN THE CIRCLE CLIFFS

In the Circle Cliffs, 70 miles northeast of Kaibab Gulch, the following section (No. 8, fig. 1) was measured by R. C. Moore:[24]

Section in Circle Cliffs

	Feet
Moenkopi formation.	
Kaibab limestone:	
Yellow dolomitic limestone in massive, evenly bedded ledges; weathers in large angular blocks pitted by solution; part contains many dendrites of manganese oxide and concretions of a mineral resembling wad; contains fossils; forms resistant cap of prominent bench	37
Light-yellow soft dolomitic massive limestone, filled with angular fragments of chert; weathers in smooth slope; exposed	15
Soft light creamy-yellow thin to medium bedded limestone; weathers in slope; partly concealed	37
White very sandy limestone, rounded sand grains scattered rather evenly; weathers in thick ledges	34
White medium to coarse grained massive sandstone; rounded quartz grains in a lime matrix	19
White very sandy limestone; rounded sand grains scattered rather evenly; weathers in thick ledges; forms bench	21
	163
Coconino (?) sandstone: White medium to coarse grained moderately soft massive sandstone; rounded quartz grains in a lime matrix; breaks into irregular blocks on weathering; exposed	73

At the Circle Cliffs, as at Lees Ferry, it is impossible with any degree of assurance to correlate the section in detail with the section at Kaibab Gulch. The fossiliferous and cherty limestones in the Circle Cliffs section, which, as shown by Moore,[25] contain the typical "*Productus ivesi*" fauna, might represent either the limestones of subdivision B at Kaibab Gulch or those of subdivision D. Sandstones occur in all the subdivisions of the Kaibab at Kaibab Gulch, and any of them except those in subdivision A might represent sandstones in the Circle Cliffs section. The sandstone assigned to the Coconino at the Circle Cliffs appears to differ somewhat from the Coconino of the type locality in the Kaibab division of the Grand Canyon; the grains of sand, as described by Moore, are medium to coarse, whereas in the type locality they are uniformly fine; and the cementing material is calcareous at Circle Cliffs, whereas it is siliceous at the type locality. However, these differences are not necessarily significant in view of the distance that separates the sections.

SECTION NEAR ZAHNS CAMP, SAN JUAN RIVER

In a section measured by H. D. Miser[26] at Zahns Camp on San Juan River (No. 14, fig. 1), 85 miles east of Kaibab Gulch, the Kaibab limestone is entirely absent and the Moenkopi formation rests upon the Coconino sandstone.

CONTRAST WITH SECTIONS EAST OF KAIBAB PLATEAU

The sections at Lees Ferry, Zahns Camp, and the Circle Cliffs, which lie, respectively, southeast, east, and northeast of Kaibab Gulch, present a striking contrast with the sections that lie south, southwest, and west of Kaibab Gulch in the degree of certainty with which they can be correlated in detail with the Kaibab Gulch section. As shown in this report, the members of the Kaibab limestone in the section to the south, southwest, and west are represented by members at Kaibab Gulch that are immediately recognizable as equivalent units, whereas correlation of the members of the Kaibab at Kaibab Gulch with those in the sections to the southeast, east, and northeast is difficult if not impossible, and in the section at Zahns Camp the Kaibab limestone is not represented at all. It is therefore evident that the Kaibab limestone experiences much greater changes in lithology in the region immediately east of the Kaibab Plateau than it does over a very wide region west of the plateau. The fact that, as described by Longwell,[27] the formation as far west as the Muddy Mountains in Nevada consists of units corresponding closely to the four lowest subdivisions at Kaibab Gulch indicates that its comparative uniformity west of the Kaibab Plateau is widespread indeed.

The absence of the Coconino sandstone from the section at Kaibab Gulch taken in connection with its thinning almost to the vanishing point up Kanab Creek, its presence as a thin bed (25 feet thick) overlying the Hermit shale on the West Kaibab fault at Ryan, and its thickness of 300 feet near Lees Ferry (measured by Bryan) and of 250 to 650 feet, increasing southeastward, in the Kaibab division of the Grand Canyon, appears to mark the Coconino as a well-defined lentil that wedges out northward from the type locality in the Kaibab division and disappears in the region around Kaibab Gulch. (See fig. 1.) Accordingly the presence at Kaibab Gulch of massive cross-bedded sandstone (bed 10 of subdivision D) in the lower part of the Kaibab but above fossiliferous limestone (beds 9 and 11 of subdivision E) suggests the possibility that sandstone assigned to the Coconino in the Circle Cliffs region northeast of Kaibab Gulch may form a part of the Kaibab, if the name Coconino sandstone is restricted to the single definite bed that represents the formation in the type locality. It is conceivable also that the Coconino and Kaibab interfinger in the Circle Cliffs region.

[24] Longwell, C. R., and others, op. cit., pp. 20-21.
[25] Idem, p. 9.
[26] Idem, p. 17.
[27] Longwell, C. R., Geology of the Muddy Mountains, Nev.: Am. Jour. Sci., 5th ser., vol. 1, p. 48, 1921.