The Geology of Kane County

Geology
Mineral Resources
Geologic Hazards

by

H. H. Doelling and F. D. Davis

with a special section on petroleum

by

Cynthia Brandt

1986

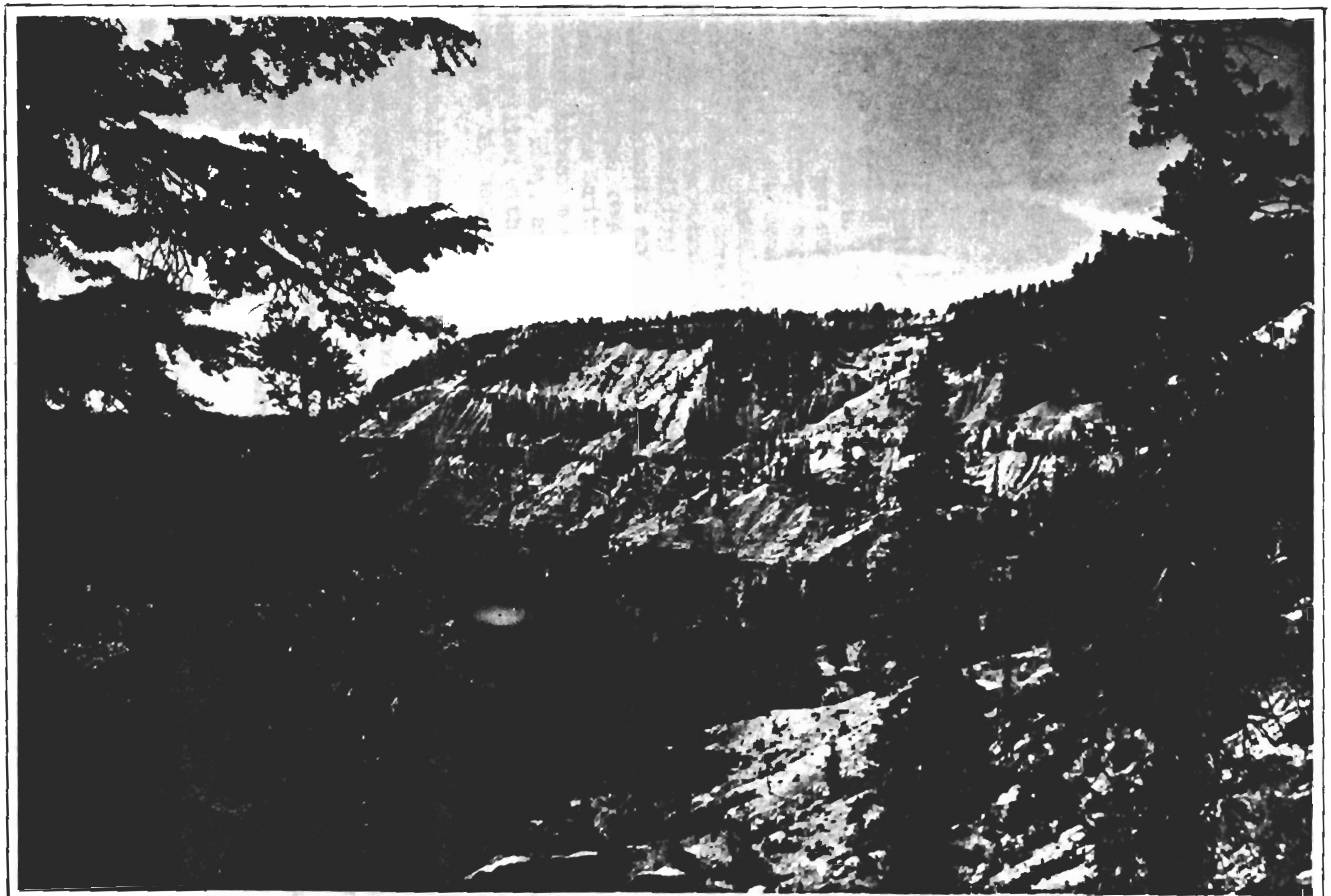

Photo 1. (Frontispiece) The Pink Cliffs at the south end of the Markagunt Plateau. They mark the upper riser of the Grand Staircase in western Kane County and are formed of outcrops of the Tertiary Claron Formation.

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INTRODUCTION:

The total value of the mineral production of Kane County, Utah through 1985 is estimated at about $21,854,000. Over 95 percent of this sum is attributed to construction materials mined or quarried to build and maintain highways. The county has produced sand and gravel, crushed stone, coal, gem stones, pumice and volcanic ash, manganese ore, gold, uranium, silver, copper, and lead. Presently the most important commodities are construction and gem materials. The annual rate of production of these items is erratic, but the value averages a few hundred thousand dollars annually. The production of the construction materials depends on the schedules of the Utah Department of Transportation and other road building agencies. Gem materials are mined intermittently to supply the wants and whims of the tourists that frequent the area. There are no large, regularly producing mining operations in the county at the time of this writing. Other mineral deposits reported in Kane County include titanium and zirconium, gypsum and anhydrite, limestone and dolomite, clay, and vanadium. About 29 tests for petroleum have thus far been drilled without significant success. However, many had interesting shows of oil and gas and the potential for its discovery remains high.

Public awareness of geologic hazards of Kane County is probably not widespread inasmuch as the area is sparsely settled. Kane County has experienced earthquakes and there are active, even "chronic" landslide problems. One of the most serious problems is road maintenance because flash floods regularly cut away sections of road, weaken bridge abutments and generally make travel impossible when they occur. Kane County increased its population by over 66 percent between 1970 and 1980 and the trend continues. Home builders should be aware of compactible soils and rock fall areas.

Kane County is also famous for its scenic beauty which is principally inspired by its colorfully displayed rock formations, and fantastically obvious geologic features; faults, folds, arches, monoclines, joints, crossbeds, cliffs, lava fields, and canyons. The county area has had an interesting geologic history and important "finds" have added much to our knowledge of world geology.

HISTORY:

Kane County was created in 1864 or 1865 as settlements began to appear along the better water courses of the area. Originally larger in area than at present, the county was reduced to its present configuration in 1882. Minerals were not overly important in the early days, but the pioneers did utilize native stone to construct some of their more important buildings. Cass Hite discovered gold in the Colorado River gravels at the mouth of Trachyte Creek in Garfield County in 1883, and soon prospecting spread to all parts of the river. Records are sparse, but a little production was undoubtedly achieved along the Kane County portion of the river, especially between 1886 and 1889. An occasional ounce or two was intermittently produced thereafter until the 1930s. Prospectors discovered minute amounts of flour gold in the Chinle shales near Paria and a promotional effort to develop a viable operation took place between 1910 and 1913. The prospects were investigated by C. A. Lawson (1913) and humorously deemed impractical:

> "At present the occurrence is interesting from a geological rather than a practical point of view. We may safely assume on the sampling at Paria that the Shinarump (Chinle) clay there contains on the average 5 cents per cubic yard. The same formation appears to be similarly auriferous throughout its extent. The formation underlies a territory of about 100,000 square miles and its average thickness may be placed at 300 feet. Reckoning 5 cents to every cubic yard of this ground the gold content of the Shinarump (Chinle) clay is about $1,500,000,000,000! All of which goes to show that universities should not despair of some day securing an adequate financial endowment" (Lawson, 1913, p. 447-448).

The excitement brought in many prospectors, however, and many claims were filed as interesting shows of copper, silver, and lead were discovered in thin fissures and collapse features in the Navajo and Carmel Formations along the Cockscomb and along and at the top of the White Cliffs. Most of these prospects proved too small to be economical, but a small amount of the metals were produced, including some recorded production in the mid-1930s. In addition to the precious and base metals, uranium and manganese minerals were discovered at the same time. Hess (1914), reports the presence of autunite and uranospinite near Paria (Pahreah); nothing is found in the literature about the manganese until 1940, but county records indicate a much earlier discovery date. Evenso these were neglected until World War II. The prospects were developed and tested from 1940 to about 1960, the manganese in response to World War II needs and the uranium in response to the government-inspired boom to make atomic bombs in the 1950s. Only small tonnages of these ores were produced, the total value small and insignificant.

The vast coal deposits of the county were immediately discovered by the settlers, but were not exploited until 1900. The local forests provided plenty of fuel for the sparse settlers. The Dakota Formation coals along the Cockscomb and near Cannonville were reported in 1875 by both Howell and Gilbert. The Alton coals were reported by Richardson in 1909 and the Kaiparowits Plateau coals were not reported on until 1931 by Gregory and Moore. From 1900 to 1972, a little over 90,000 tons of coal were mined, first limited by the small local market and later restricted by environmental considerations and stringent safety regulations.

Tourism became an important industry to Kane County after the tunnel in Zion National Park was completed in 1930 and local prospectors realized profit by collecting some of the unusual rocks of the region and offering them for sale. A portion was exported and the sale of these items continues to the present. The commodities are collectively classified as gem stones, but consist of concretions, petrified wood, jasper, agate, "picture stone" and just plain colored sand. Records of the mining of these items are lacking or incomplete, but the cumulative value of production is estimated to exceed $500,000.

Construction materials were used locally until 1930 when the highway system began to be developed in southern Utah. The principal materials include sand and gravel, volcanic gravels and grits (pumice and volcanic ash), and crushed stone. Since 1930 the construction or maintenance of highways has fostered considerable use of these materials. Although erratic, with no production reported in some years, the average value from 1930 to 1960 is about $10,000 per year. In 1961-1963, almost $19,000,000 worth of construction materials wer produced to construct the highway between Kanab and Page, Arizona and for other needs connected with the construction of the Glen Canyon Dam. Since then production has averaged $75,000 per year, again being erratic from year to year. The total value of the produced materials for the county since 1864 is estimated at $20,950,000.

Table 1. Estimated value of mineral production in Kane County, 1864-1985

Commodity	Value
Construction materials (sand and gravel, volcanic ash, crushed stone)	$20,950,000
Gems or semi-precious stones (conretions, petrified wood, jasper, agate, "picture stone, sand, etc.)	500,000
Coal	401,000
Precious and base metals	2,000
Manganese, uranium, etc.	1,000
Total value:	$21,854,000

GEOGRAPHY:

Social

Kane County lies along the south-central margin of Utah adjacent to the Arizona border and has a land area of 4,105 square miles, being twice the size of the state of Delaware. Kanab is the largest town and county seat. Kane County is sparsely populated, in 1970 averagin 0.6 persons per square mile. At the time of this writing (1985) the average number of persons per square mile in the United States is estimated to be about 65 while that in Kane County has increased to more than 1.0. Most of the county's population is concentrated in the western part, either along the East Fork of the Virgin River or along Kanab Creek. Glen Canyon City (now Big Water) appeared as a new community (circa 1958) in the eastern half of the county along Wahweap Creek during the construction of the Glen Canyon Dam. This community and its satellites have maintained a small population since. More recently Kane County has been chosen for retirement homes and modest increases in the population are being experienced in the existing communities and along Johnson Creek near the Vermilion Cliffs. Historical and present population data is given in table 2. The population of Kane County increased 66.2% from 1970 to 1980.

Table ~~2~~ 1. Population statistics for Kane County, Utah

Historical Population

1870	1,513
1880	3,085
1890	1,685
1900	1,811
1910	1,652
1920	2,054
1930	2,235
1940	2,561
1950	2,299
1960	2,667
1970	2,421
1980	4,020

By community, 1960,70, and 80

Community	1960	1970	1980
Alton	116	62	75
Glendale	223	200	237
Kanab	1,645	1,381	2,148
Mount Carmel	125	75	138
Mt. Carmel Jct.	10	15	25
Orderville	398	399	423
Other areas (Big Water, Johnson Cyn, Church Wells, Bullfrog, etc.)	150	289	968

Transportation

County accessibility is provided mainly by highways and roads. Kanab is served by airport facilities designed for small aircraft and light commercial planes. In addition landing strips are present near the recreation centers. There are no railroads. The principal highway artery is U. S. Highway 89, which enters the county from the north near Long Valley Junction, then passes southward along the East Fork of the Virgin River to Mount Carmel Junction, thence southeasterly to Kanab. There the highway divides, the alternate route passes directly into

Arizona providing access to the north rim of the Grand Canyon, the main route passes easterly through the county along its southern boundary to Glen Canyon City (Big Water) and then into Page, Arizona. Utah Highway 14 extends westerly from U. S. Highway 89 at Long Valley Junction to Zion National Park. Access to all other areas of the county is over secondary roads, most of which are not paved. The more important roads are shown on figure 1, dashed lines denote those routes that are not paved. Most of these are well maintained, but occasionally become impassable to low-centered vehicles, especially after prolonged rainy or snowy weather. The terrain over which the roads pass is often rugged, marked by deep canyons and precipitous cliffs, the routes definitely influenced by these topographic features.

Physiography and Topography

Kane County is located near the western margin of the Colorado Plateaus physiographic province (figure 2), but is entirely within it. The province consists of a series of plateaus, mesas, and buttes which reflect the internal structure and geology. Interrupting the horizontal or gently dipping strata are major faults, monoclinal folds, and groups of anticlines and synclines, domes and basins. Rivers have gouged and eroded deep canyons or precipitous escarpments in most areas. Extrusive igneous rocks are common around the margins of the province and volcanic cones and flows are found in northwestern Kane County. Essentially Kane County is divided into two subprovinces by a north-northeast trending structural feature known as the East Kaibab monocline (The Cockscomb). The western half of the county is known as the Grand Staircase, described as a series of benches and cliffs sequentially losing altitude to the south (photo 1 - frontispiece). The eastern half is mostly a structural basin, the Kaiparowits Basin, that is filled with Jurassic and Cretaceous sediments. The topographic expression is that of a plateau plunging northward. In the extreme eastern corner of the county is another monocline, the Waterpocket Fold, east of which is another basin, the Henry Mountains Basin.

A series of high plateaus mark the western boundary of the Colorado Plateaus in Utah; two of them terminate in Kane County as cliffs, the uppermost step of the Grand Staircase. These and other divisions of the Colorado Plateaus physiographic province in Kane County are shown on figure 3. General elevations drop from north to south in the county as illustrated by the generalized topographic map, figure 4. In Kane County the High Plateaus are represented by the Markagunt and Paunsaugunt Plateaus and are located to the northwest (photo 2). Elevations of the upper surfaces range from 8,000 to 9,500 ft. The Markagunt Plateau upper surface is tilted northeasterly, the Paunsaugunt Plateau is warped into a gentle syncline plunging northeasterly. Tertiary lacustrine sediments cap both plateaus and cinder cones and lava flows are present on the higher parts of the Markagunt. The south margins of these plateaus are marked by the Pink Cliffs, the principal attraction at Bryce Canyon National Park. The two plateaus are separated by a north-northeast trending valley and the Sevier fault, known as Long Valley. That part of the valley north of Long Valley

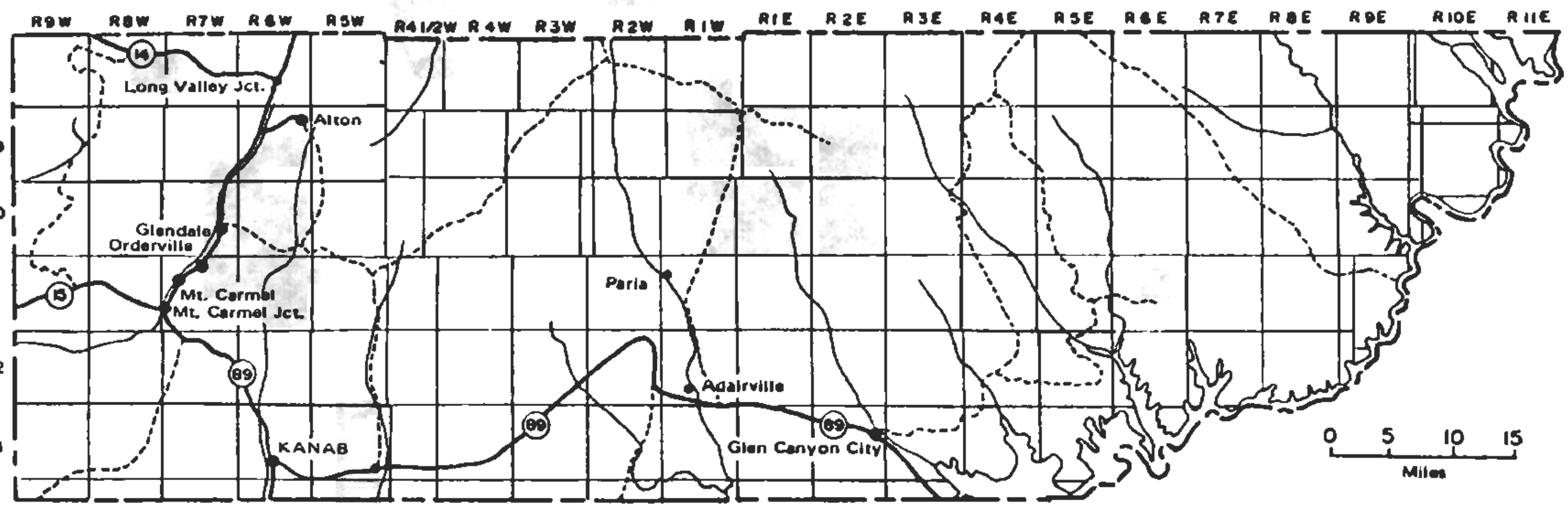


Figure 1. Principal highways, roads, and communities, Kane County, Utah

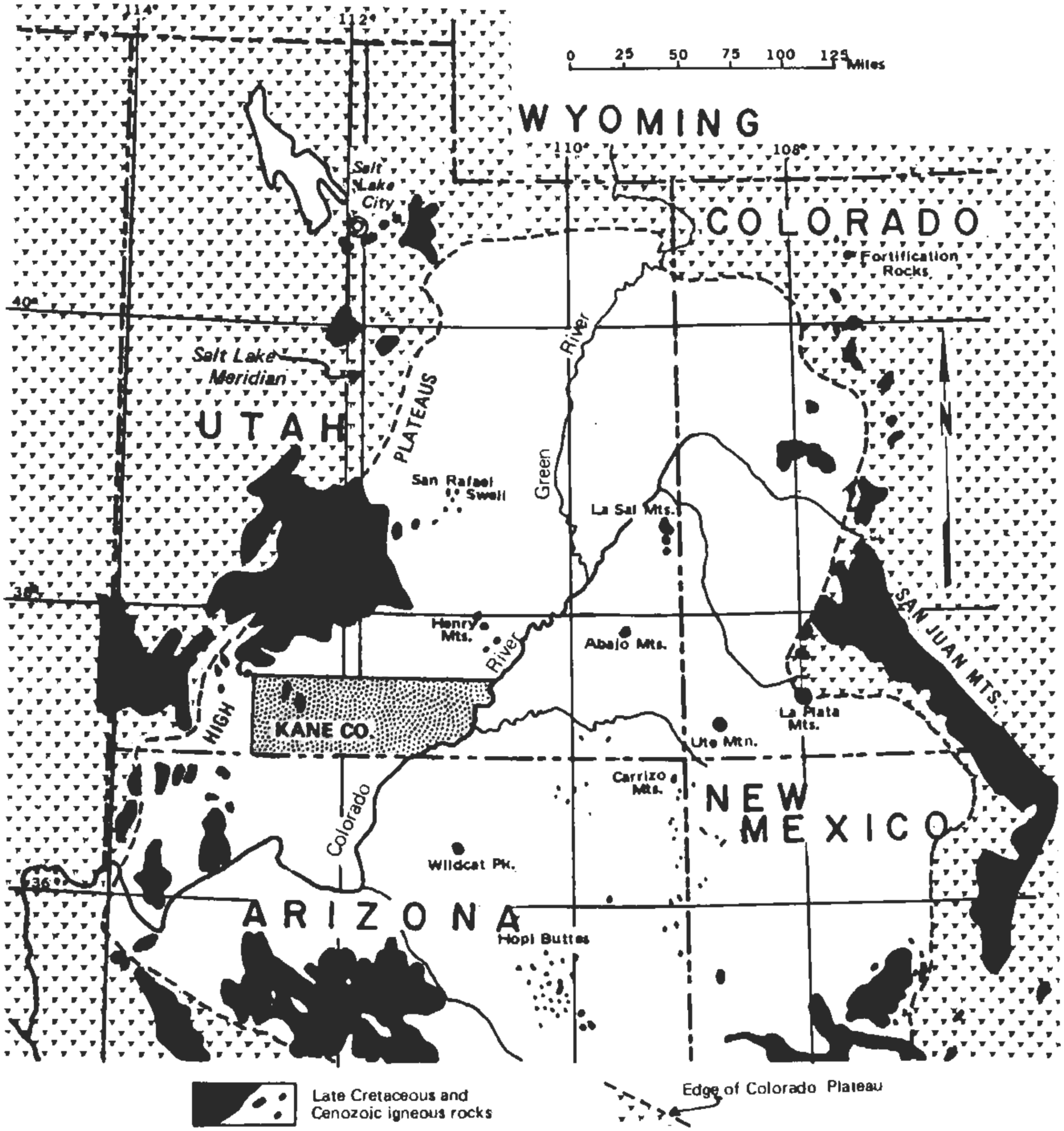


Fig. 2. Index map to the Colorado Plateaus and Kane County, Utah (after Hunt, 195

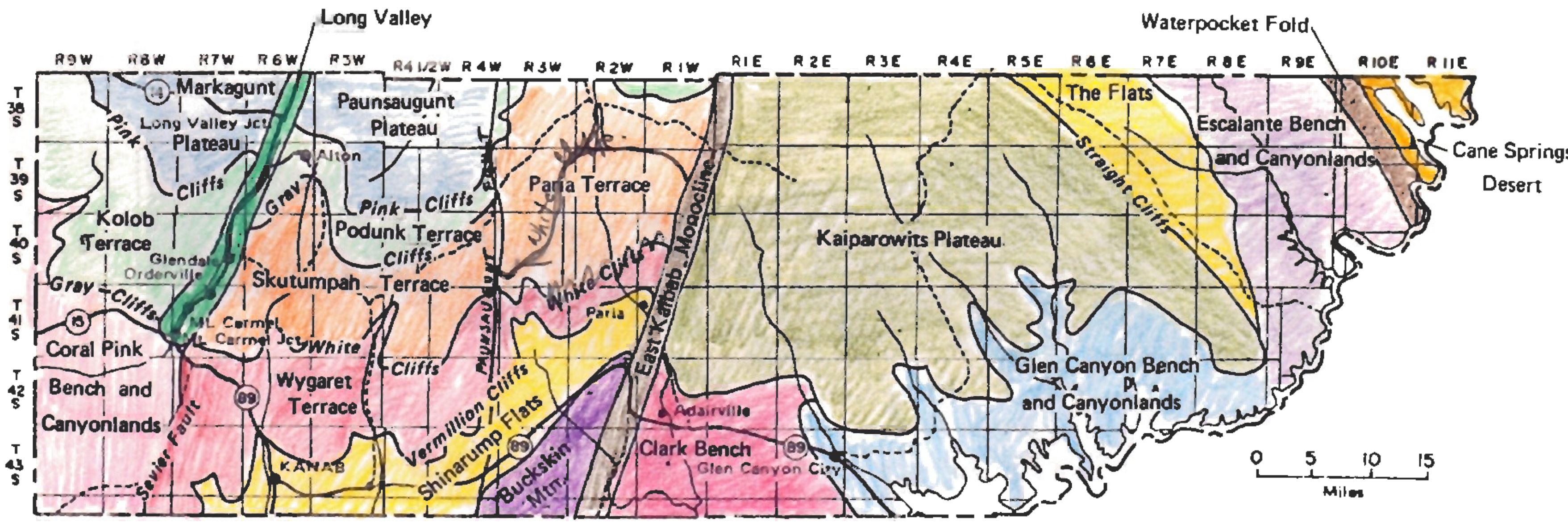


Figure 3. Physiographic subdivisions of Kane County, Utah

Photo 2. Drainages at the top of the high plateaus flow northward into the Great Basin. Rock exposures are poor and the upper surfaces are heavily vegetated. The valleys between paralleling ridges are generally alluvium filled.

Junction drains northerly into the Great Basin as do the upper surfaces of the Markagunt and Paunsaugunt Plateaus. That part south of Long Valley Junction drains to the south and contains the East Fork of the Virgin River, a tributary of the Colorado River.

The Kolob Terrace lies below the Pink Cliffs west of Long Valley. This is mostly an area of rough bench and slope land deeply incised by the local drainages. The exposed rocks are principally gray or tan shales, sandstone, and siltstones of fluvial and marine origin. The southwestern margin of the Kolob Terrace ends with the Gray Cliffs, supported by the Cretaceous Dakota Formation, which contains valuable coal beds. The Podunk Terrace lies beneath the Pink Cliffs of the Paunsaugunt Plateau and is similarly bounded on the south by the Gray Cliffs. Its description is identical to that of the Kolob Terrace, but it is more narrow. Elevations on both terraces range from 6,000 to 8,000 feet.

The Coral Pink Bench and Canyonlands lie in the southwestern corner of the county below and south of the Gray Cliffs and west of the Sevier fault. The exposed bedrock is mostly sandstone and siltstone eroded to flat-topped benches and steeply rounded picturesque buttes. Here and there the area is cut by a deep canyon, especially the one in which the Virgin River flows. Large amounts of loose sand have accumulated in sheets and dunes in the low areas between the buttes. Elevations range from 4,800 to 6,500 feet. The poorly developed White Cliffs cut the Coral Pink Bench and Canyonlands in half from east to west and the south margin is formed by the Vermilion Cliffs.

The Skutumpah Terrace lies below the Gray Cliffs between the Sevier fault and the Paunsaugunt fault. It is bounded on the south by the White Cliffs. Flat-topped benches are divided by deeply incised canyons; the benches are capped by siltstones and limestones, the White Cliffs are sandstone. The northern half of the benches immediately below the Gray Cliffs are generally covered by a veneer of alluvium, eolian sand, sandy soils, or pediment gravels. The wider Paria Terrace is similar to the Skutumpah Terrace in its description and lies between the Paunsaugunt fault and the East Kaibab monocline (The Cockscomb).

The Wygaret Terrace is an east-west trending area that extends from the Sevier fault on the west across the Paunsaugunt fault to the East Kaibab monocline on the east, and from the White Cliffs on the north to the Vermilion Cliffs on the south. The surface is principally sandstone or loose sand and is dotted with steeply rounded sandstone buttes and monuments. The elevations range from 5,500 to 6,500 feet. The Shinarump Flats lie below the Vermilion Cliffs and consist of smooth appearing sandy flats and rough badland hills. The south border is marked by the discontinous Shinarump Cliffs and by Buckskin Mountain. Elevations range from 5,000 to 5,500 feet, the surface rocks consist of Triassic reddish siltstones, fine-grained sandstones, and varicolored shales. Buckskin Mountain lies southeast of the Shinarump Flats and ends abruptly against the East Kaibab monocline (The Cockscomb). The mountain is an anticlinal upwarp, the uplifted strata are composed of hard Permian carbonate rocks. Two or three streams have cut deep canyons into the upward which rises from 5,000 to 6,500 feet.

The Cockscomb is an impressive topographic feature and Triassic and Cretaceous units bend and fold eastward into the Kaiparowits Basin. In places the fold is cut by both paralleling and transverse faults which offset or eliminate strata. A narrow strike valley persists throughout its length, which is bounded by steep cliffs and hogbacks.

The Kaiparowits Plateau is an area of undulating plateau surfaces periodically incised by steep-walled canyons. The area extends from the East Kaibab monocline (The Cockscomb) eastward to a prominent erosional escarpment known as the Straight Cliffs or Fiftymile Mountain. The Plateau extends northward into Garfield County and southward to a line of cliffs 6-12 miles north of the Arizona border and Lake Powell. The surface rocks are mainly fluvial or marine, Cretaceous gray or tan sandstones, siltstones, and shales, and some of the units are coal-bearing. Elevations range from 5,500 to 7,200 feet, being highest to the north and east. The anticlines and synclines that warp the plateau trend north-south and northwest-southeast.

Clark Bench lies between the Cockscomb and Lake Powell below the Kaiparowits Plateau. Sandy soils cover most of the surface which is underlain by Jurassic sandstones and siltstones. A few drainages have deeply cut into the bench (Paria River, Buckskin Gulch) creating narrow canyons. Glen Canyon Bench and Canyonlands consists of a series of broad flat-topped benches separated by vertical-walled canyons that are now partially filled with the water of Lake Powell (photo 3). Bench surfaces lie at elevations of 4,000 to 5,000 feet. The surface of Lake Powell, when the reservoir is filled, is approximately 3,700 feet.

East of the Straight Cliffs, strata dip very gently southwestward, gradually rising to the east. Along the foot of the cliffs and extending eastward are a series of coalescing flats interrupted by occasional rough lands of "slickrock" and gypsiferous siltstone and red sandstone. "Slickrock" is the name given to the bare rounded outcrops of the Jurassic Entrada Sandstone. The Flats extend northward into Garfield County and eventually pinch out to the south before reaching Lake Powell. They are usually covered with a veneer of loose sand or sandy soils, and dunes are found in a few areas (photo 4). Farther east the Flats disappear and are replaced by the Escalante Bench and Canyonlands which are cut in half by the canyon of the Escalante River. The area is similar to the Glen Canyon Bench and Canyonlands, except that the benches are narrower. The elevations along the Flats range from 4,200 to 5,500 feet, the lower areas being to the south. Escalante Bench and Canyonlands elevations range from 3,700 feet (Lake Powell) to 6,000 feet. The Escalante Bench and Canyonlands terminate eastwardly against the Waterpocket Fold. Mostly Jurassic rocks are downfolded eastwardly beneath the Henry Mountains Basin, here represented by the Cane Springs Desert. This extreme northeastern corner of the county has largely been inundated by Lake Powell, but the remaining land areas consist of hilly "slickrock" alternating with sandy areas at elevations 3,700 to 4,000 feet.

Photo 3. Vertically walled narrow canyons are characteristic of the Bench and Canyonlands physiographic subdivisions in Kane County.

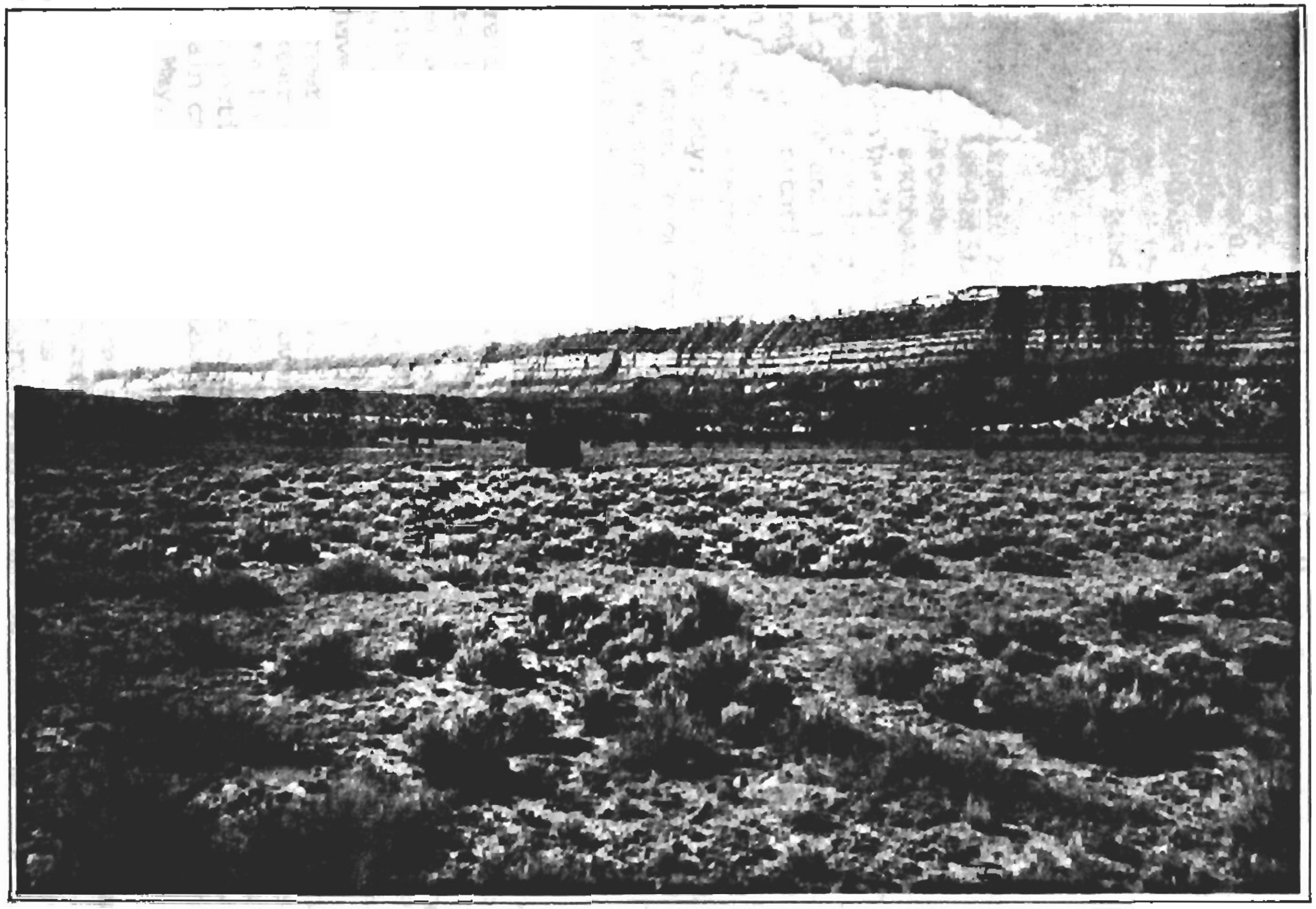


Photo 4. The Straight Cliffs or Fiftymile Mountain marks the eastern boundary of the Kaiparowits Plateau. This magnificent line of cliffs stretches for 30 miles without a canyon in Kane County. In the foreground an alluvial veneer covers the Entrada and Carmel Formations in a physiographic subdivision known as the Flats.

Status of Topographic Mapping in Kane County, 1985

Kane County is entirely covered by U. S. Geological Survey (USGS) topographic mapping. The available coverage consists of both 15 and 7 1/2 minute quadrangles. The USGS is currently working to replace the 15 minute quadrangles (scale 1:62,500) by 7 1/2 minute quadrangles (scale 1:24,000. Schedules indicate this might be complete by 1989. Figure 5 shows the names of the quadrangles that were available in 1979 and the names of the new quadrangles that will be available in 1989.

Climate and Weather

Three climatic zones affect Kane County; mountain, mid-latitude steepe, and mid-latitude desert. A mountain climate is experienced in the higher plateaus, the Markagunt and Paunsaugunt. The deserts are found in the southeastern parts, coinciding with the lowest elevations around Lake Powell. Most of the county experiences a mid-latitude steppe or semi-arid climate. A steppe climate is transitional between a humid climate and a desert, nevertheless, it is one in which evaporation exceeds precipitation. Climographs of several Kane County stations are shown on figure 6, which present average temperature and precipitation data. The characteristic unreliability of semi-arid stations holds true in Kane County; in some years Kanab may receive as much as 25 inches of precipitation, in others as little as 5 inches. In the case of temperature, unusually warm days in winter are not rare and high elevation stations can experience a summer frost.

Kane County average precipitation ranges from less than 6 inches to more than 40 inches and is controlled by elevation. A comparison of the Generalized Topographic map (figure 4) with the isohyetal map (figure 7) generally supports this, however, a low location site surrounded by higher ground will usually receive more precipitation than a comparably low area more openly situated. The Markagunt and Paunsaugunt Plateau areas receive from 20 to more than 40 inches of precipitation annually and have two peaks; one in the winter from cyclonic storms and one in the summer from convectional storms. The winter storms bring snow and the higher areas remain covered for several months. Meltwaters are adequate to maintain several permanent rivers, streams, and springs. The convectional storms are generally spotty, and are often severe, and much rain can fall in a short period of time. The driest months are April, May, and June.

The steppe climate area receives 7 to 20 inches of rain annually and the peaks are experienced in winter and summer as they are in the High Plateaus. These peaks become less pronounced at the lower elevations and in the deserts often become so subtle as to be unnoticeable. The rainfall of both the steppe and desert areas is insufficient to maintain permanent streams and springs diminish in number and in the volume of water they produce as the elevation drops. The severe summer thundershowers that fall on the steppe areas often cause considerable flooding damage. The dry washes and gulches are

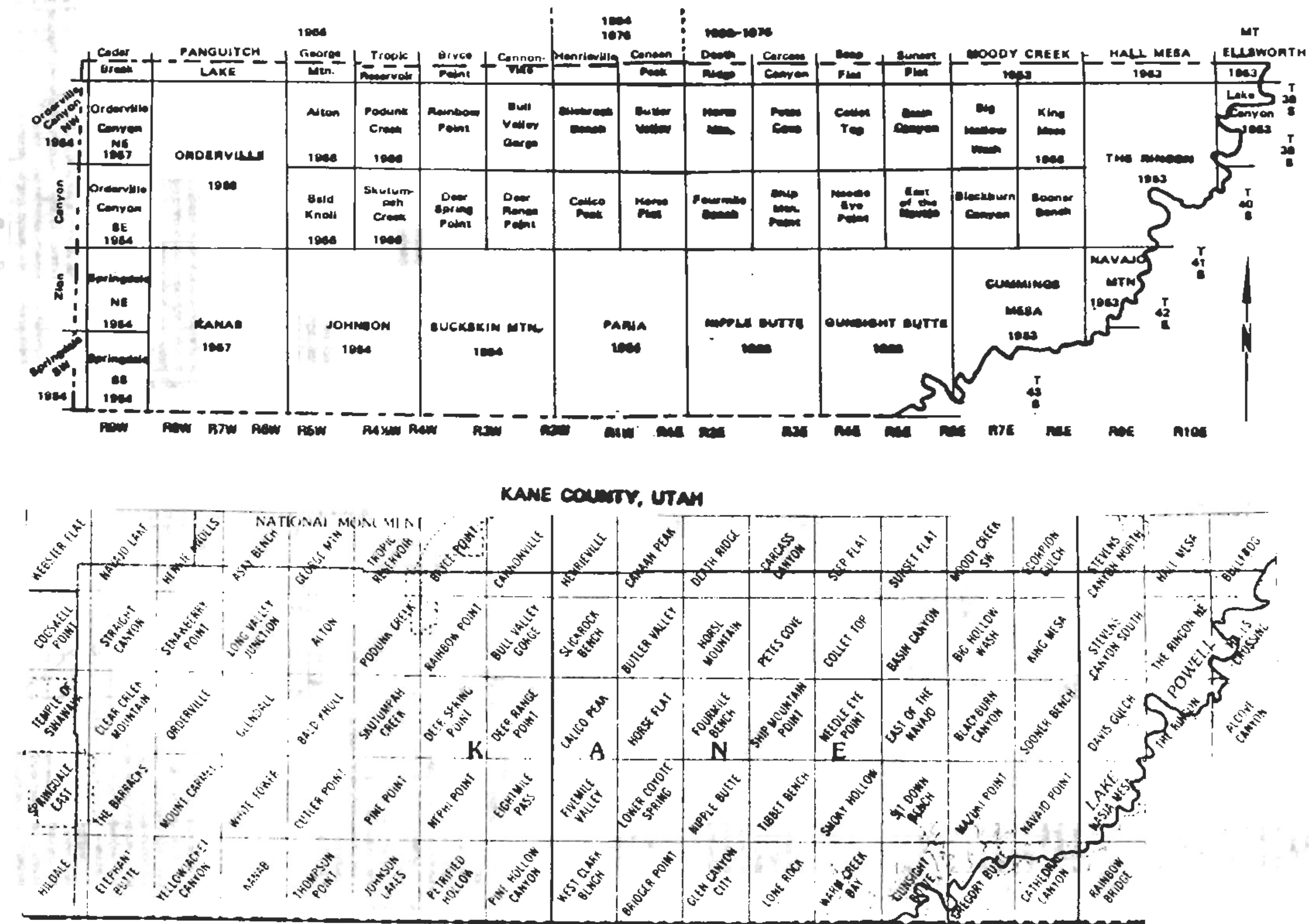


Figure 5. U. S. Geological Survey topographic map coverage. Upper diagram shows quadrangles available in 1979. Lower diagram shows quadrangles as will be available after 1989. Larger area maps, such as Kanab, are at a scale of 1:62,500 (1 inch = 1 mile) whereas smaller area maps are at the larger scale of 1:24,000 (1 inch = 2,000 feet).

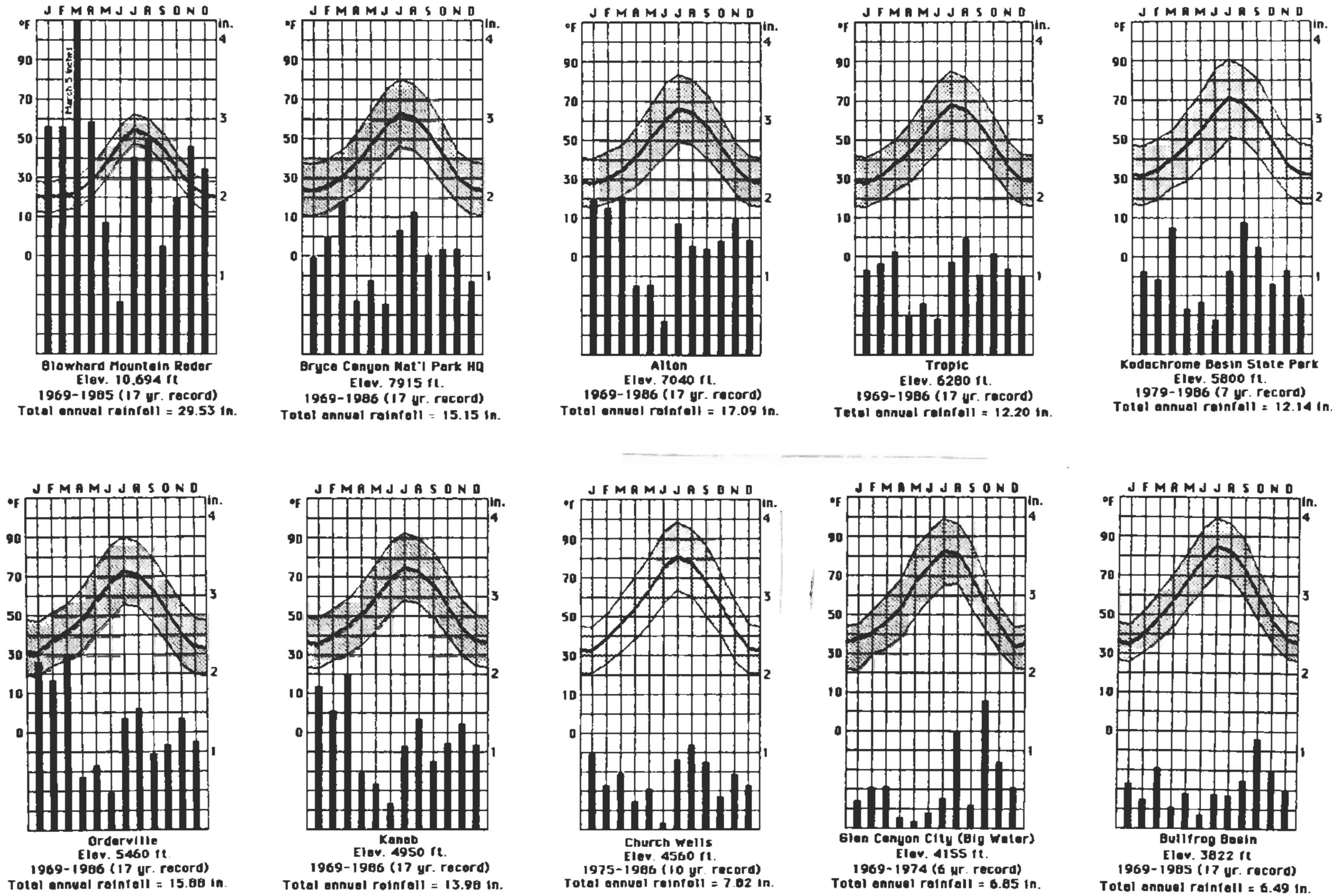


Figure 6. Climographs of important Kane County stations. Blowhard Mountain Radar is located a few miles north of the Kane County line in the Markagunt Plateau of Iron County. Bryce Canyon National Park Headquarters and Tropic are Garfield County stations not far north of the county line. The climographs are arranged according to station elevation.

quickly filled, and in their descent to Lake Powell or the lower Colorado River, destroy roads, rip out culverts, and fill in irrigation canals or stock watering ponds.

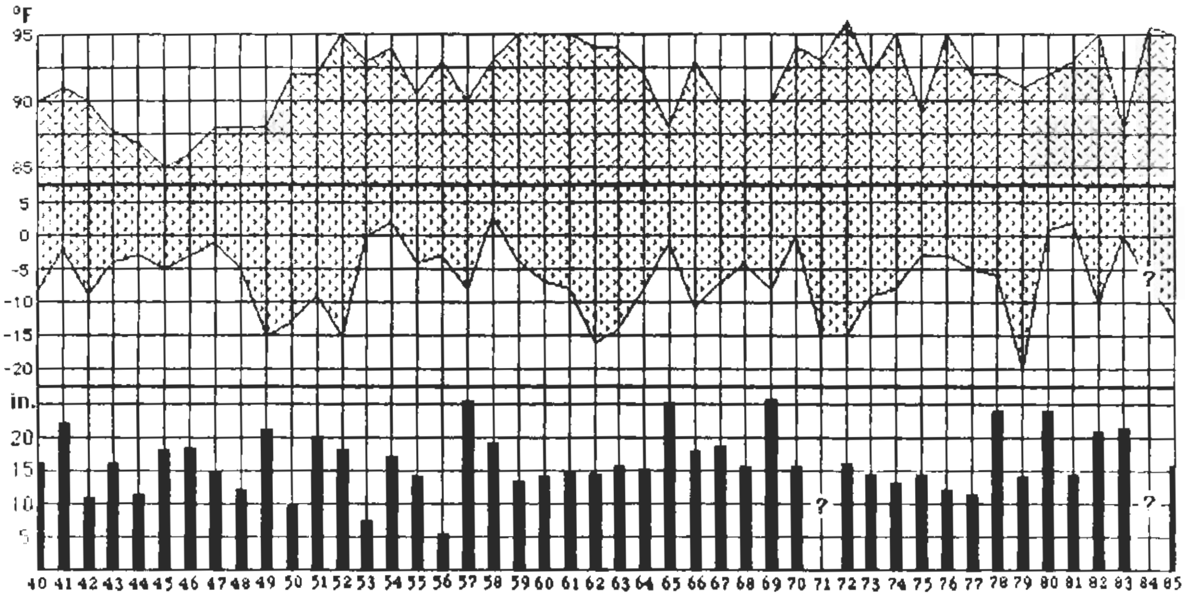
Kane County temperatures are marked with large seasonal and diurnal ranges. The average temperatures are largely a function of elevation, Lake Powell may have a slight moderating influence. On the Paunsaugunt or Markagunt Plateaus the average January temperature is about 20 degrees, daily varying from about 10 to 38 degrees Fahrenheit. Winter extremes range from -20 to 70 degrees. The average July temperature is 55-60 degrees, daily varying from 45 to 80 degrees. In the very highest locations the diurnal variation is less, often as little as 15 degrees. Temperatures as high as 95 or as low as 25 degrees arfe not uncommon in the summer. In the Bullfrog Basin, a desert station on Lake Powell, the average July temperature is 83 degrees, the daily range averages 69 to 100 degrees, with extremes ranging from 50 to 115 degrees. In January the average temperature of Bullfrog Basin is 37 degrees, daily rising from 26 to 46 degrees. The extreme winter temperatures are -5 and 80 degrees. Kanab is a typical steppe station with a January temperature averageof 36 degrees and with an average low and high of 22 to 49 degrees. In July the average rises to 70 degrees with a low of 58 and a high of 92 degrees. It has been as hot as 108 degrees in Kanab.

The climographs of figure 6 have been arranged according to altitude. Blowhard Mountain Radar station is located in Iron County, a few miles north of the northwest corner of Kane County on the Markagunt Plateau. Bryce Canyon National Park Headquarters station is found in Garfield County on the Paunsaugunt Plateau. Tropic is also in Garfield County in the amphitheatre below Bryce Canyon. Both the Tropic and Kodachrome Basin stations are in the amphitheatre and hence in the rain shadow of the Paunsaugunt Plateau. Kodachrome Basin State Park and all other stations represented by the climographs are in Kane County.

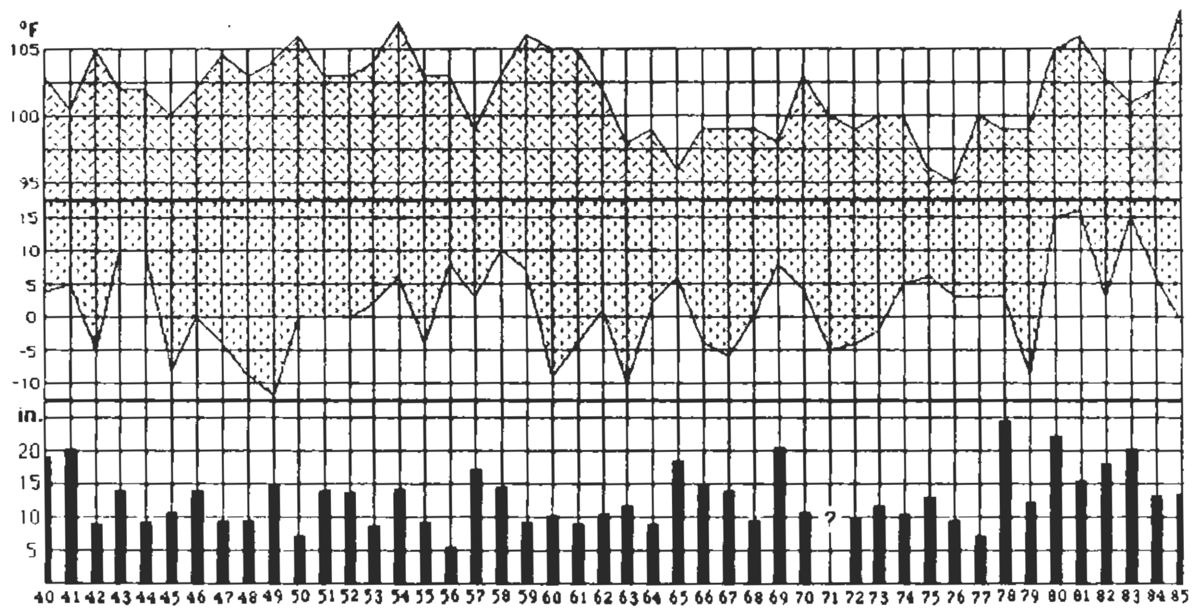
Figure 8 shows temperature extremes and annual precipitation for two stations in Kane County as recorded over a 46 year period. The irregularity of rainfall is indicated by both stations. Note the dryer cycle between 1970 and 1977 followed by the wet cycle 1978 to the present for both stations. Between 1963 and 1979 summers were miled in Kanab and between 1940 and 1948 winters were mild and summers were mild at Alton.

Land Ownership

The 2,627,200 acres (4,105 square miles) of Kane County are owned as shown in figure 9 and listed in table 3. Bureau of Land Management (BLM) administered lands represent the largest block (56.9%), and, together with much of the state land (7.9%), comprise the least desirable recreation land. Recreational land is used as a guide since all the major land decisions made for southern Utah by the Federal Government in the last 20 years have been based on this factor alone. Most (BLM) and state lands are considered multiple use lands. The U. S. National Forest Service controls most of the High Plateaus section of



Annual high temperature extreme (top graph) and annual low temperature extreme (middle graph) and annual total precipitation (lower graph)
ALTON, KANE COUNTY,
UTAH



Annual high temperature extreme (top graph) and annual low temperature extreme (middle graph) and annual total precipitation (lower graph)
KANAB, KANE COUNTY,
UTAH

Figure 8.

the county along with the foothills, its lands amount to 4.9 percent of the county. The forest is a part of the Dixie National Forestg and are also considered multiple use lands. A small part of the forest acreage takes care of some single use recreational purposes, such as camping and picnicking.

The Escalante and Glen Canyon National Recreation Areas take up 16.9 percent of the county which surrounds the Escalante River Canyon and the shores of Lake Powell to the southeast. Drilling for petroleum may be allowed on these lands, but mining activity is restricted is restricted or disallowed. There are parts of two national parks in Kane County. Bryce Canyon National Park is shared with Garfield County to the north and Zion National Park is shared with Washington County to the west. National Park lands take up only 0.7 percent of the county area, which disallow mining or drilling activity and are geared to the single use of recreation by definition. In addition the Federal Government has withdrawn another 2.9 percent from full multiple use; much of this land is used as campgrounds or as buffer zones for the recreation areas. Additional lands are being considered for wilderness or roadless areas.

Table 2. Land ownership in Kane County, Utah

Proprietor	Approximate acreage	Percent
Bureau of Land Management	1,494,600	56.9
National Recreation & Wilderness areas	445,100	16.9
National Forest Service	127,600	4.9
Special Federal withdrawals	69,250	2.6
National Park Service	18,450	0.7
Total Federal lands	2,155,000	82.0
Privately owned lands	261,440	10.0
State lands	206,880	7.9
State Parks	3,880	0.1

State of Utah land is dispersed within the Bureau of Land Management controlled areas. According to law, sections 2, 16, 32, and 36 of eatch township or 11.1 percent of all lands, except privately owned territory, is or should be state-owned, but the state is presently short of this figure by about 123 square miles. Surface rights to about 1/2 percent of the state lands have been sold to private interests, but the mineral rights have been retained in most cases. Privately owned lands are principally concentrated in an apron surrounding the forest lands or along some of the principal drainages (where the towns are located) and comprise 10 percent of the county area.

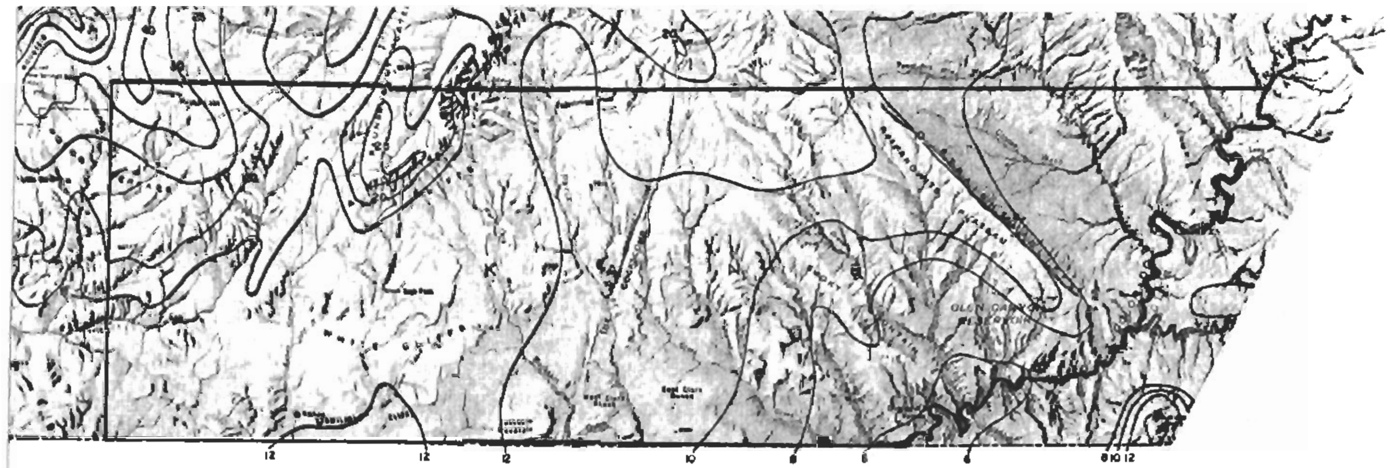


Figure 7: Normal annual precipitation (in inches), Kane County, Utah

GEOLOGY:

Sedimentary rock types dominate the rock exposures of Kane County, which lies entirely within the Colorado Plateaus physiographic province. The dominant lithology is sandstone, but siltstones, mudstones, shales, and limestones are common. Relatively recent volcanic activity has produced a few volcanos and flows of basaltic material in the northwestern part of the county. The sedimentary units are normally tilted or folded at gentle angles and are occasionally cut by normal faults. The county is divided into east and west halves by a steep monoclinal fold. Another such structure is found near its east margin. The individual stratigraphic units are colorfully exposed in a "Grand Staircase" leading down to the south, with the risers appearing as magnificent cliffs between wide terraces.

Stratigraphy

Stratigraphic units exposed in Kane County are Permian to Quaternary in age and Pennsylvanian, Mississippian, Devonian, Cambrian, and Precambrian rocks have been penetrated by drillholes (table 4). The units vary in thickness and character from west to east across the county, some of the features and relationships are shown on figure 10. Ordovician and Silurian rocks are not believed to underlie any part of the county. Not considering the Quaternary surficial and basaltic rocks, strata thicknesses over the Precambrian amount to about 15,000 feet. Some systems thicken or thin regionally across the county, or are truncated by important regional unconformities, but the total uneroded sedimentary accumulation present over the county is approximately uniform.

Precambrian

Only one well has positively penetrated Precambrian rocks beneath the county, this being the Tidewater No. 1-A Kaibab Gulch well (Munger and others, 1965). Another well, the McDermott No. 1 State, is also reported to have reached the Precambrian, but lithologic correlations do not substantiate this. Chuar Group sediments are reported to be about 1,040 feet thick and about 20 feet of Shinumo Sandstone of the Unkar Group were cut at the bottom of the hole. Reportedly an abundant amount of carbonaceous material and plant spores were discovered in dark gray shales from 5,340 to 6,240 feet (140 to 1,040 feet below the top of the Precambrian.

Paleozoic

Formations that have been recognized in Kane County that were deposited during the Paleozoic Era are listed in table 5:

Table 4. GENERALIZED CHARACTERISTICS OF ROCK UNITS, KANE COUNTY, UTAH

GEOLOGIC AGE	FORMATION OR MEMBER	THICKNESS	BRIEF DESCRIPTION	POSSIBLE ECONOMIC VALUE
Quaternary	Unconsolidated deposits	0-200 ft	Alluvium, eolian sand, alluvial gravel (stream, terrace, pediment), mixed eolian and alluvial sand, mass-wasting deposits (colluvium, talus, landslides).	Sand and gravel, road metal, gold, fill, good aquifers.
	Olivine basalt	Flows to 60' Cones to 300'	Blocky lava flows, cinder cones, scoria bombs, lapilli, cinders, ash, and dust.	Lava tubes, ornamental stone, volcanic bombs, lightweight aggregate, road metal.
— unconformity —				
Tertiary	Claron Formation	1300+ ft	Red or pink limestone and conglomerate, white dolomite.	Limestone and dolomite, road metal, good aquifer, highly scenic and sculptured unit, forms Pink Cliffs.
— unconformity —				
Cretaceous	Kaiparowits Formation	400-2200 ft	Drab gray mostly slope forming arkosic sandstone.	Petrified wood, dinosaur bone, fossils, badlands scenery.
	Wahweap Formation	400-1700 ft	Mostly gray to yellowish-gray interbedded mudstone, claystone, sandstone, siltstone, and conglomerate	Petrified wood, dinosaur bone, fossils.
	Straight Cliffs Formation	85-1600 ft	Interbedded cliff forming sandstone and mudstone	See members.
	Drip Tank Member	140-550 ft	Yellow gray and yellow brown fine to medium grained, lenticular sandstone.	Petrified wood, aquifer.
	John Henry Member	590-1100 ft	Yellow gray slope and ledge forming sandstone, mudstone, carbonaceous mudstone, and coal.	Important coal bearer, titanium, zirconium, monazite, petrified wood, minor jet coal, ironstone concretions, shark teeth, pyrite nodules, fossils, decorative "clinker" stone.
unconformity				
	Smoky Hollow Member	24-234 ft	Interbedded white and gray sandstone, mudstone, carbonaceous mudstone, and coal.	Minor coal bearer, decorative "clinker" stone.
	Tibbet Canyon Member	70-185 ft	Yellowish gray to brown, cliff forming sandstone.	Occasional marine fossils, aquifer.
	Tropic Shale	500-1000+ ft	Dark gray, drab marine shale with subordinate gray sandstone.	Septarian concretions, clay, fossils.
	Dakota Formation and sub-Dakota Conglomerate	3-450 ft	Interbedded sandy shale, carbonaceous shale, shaly sandstone, conglomerate, and coal.	Important coal bearer, bentonitic clay, petrified wood, fossils, aquifer, forms Gray Cliffs.
— K unconformity —				
Jurassic	Morrison Formation	0-700 ft	Gray, yellow, and brown lenticular conglomeratic sandstone and sandstone, subordinate green, gray, or purple mudstone.	Petrified wood, dinosaur bone?, uranium, radioactive anomalies, scenic unit.
J-5 unconformity				
	Summerville Fm., Romana Mesa Ss., Henrieville Ss.	0-234 ft	Sandstone, siltstone, mudstone, shale.	Scenic cliff former, road fill.
J-3 unconformity				
	Entrada Sandstone	0-950+ ft	Reddish-brown or white cliff forming sandstone.	See members.
	upper member (Escalante and Cannonville Members	0-560 ft	Reddish-brown, fine grained sandstone; upper part cliffy, lower non-resistant and often covered with sandy alluvium. Earthy weathering and eolian facies.	Forms flat areas for roads.
	lower member ("slickrim") or Gunsight Butte Mbr.	0-570 ft	Orange brown fine grained sandstone forming smooth "slickrim" erosional forms and and cliffs.	Scenic unit, forms monuments, goblins, unusual cliffs, arches, Kodachrome pipes, aquifer.

			(earthy weathering) and gypsum.	Laminated alabaster gypsum.
	Winsor Member	0-320 ft	Reddish or yellow slope forming and earthy weathering silty sandstone.	
	Paria River Member	50-230 ft	Gypsum, reddish siltstone and sandstone, with white chippy limestone at top.	White rock gypsum, road metal (limestone).
	Page Sandstone and Thousand Pockets Tongue of Page Ss.	0-200 ft	Yellow, white, or brown crossbedded sanstone, often with reddish siltstone at base.	Host rock for copper, lead, silver. Scenic unit.
	Crystal Creek Member (Carmel Formation)	0-180 ft	Brown banded earthy weathering sandstone.	Fill.
	Judd Hollow Tongue (Carmel Formation)	0-230 ft	Interbedded sandstone, siltstone, and reddish and lavender limestone.	Road metal where Kolob Limestone is is developed.
	Kolob Limestone Member (Carmel Formation)	0-250 ft	Thin to medium bedded light gray limestone and tan limestone shale.	Cement rock, building stone, road metal, fossils, gypsum.
– J-2 unconformity				
	Temple Cap Sandstone	0-150 ft	Light crossbedded sandstone with reddish	Scenic unit on Navajo Sandstone.
– J-1 unconformity				
	Navajo Sandstone	950-2000 ft	White, pink, and brown, highly crossbedded sandstone that forms cliffs, domes and bare rock outcrops.	Highly scenic, forms White Cliffs, main attraction at Zion National Park, ironstone concretions, picture rock, limestone, colored sand, glass sand, host rock for copper, lead, silver, excellent aquifer.
	Tenney Canyon Tongue of Kayenta Formation	90-170 ft	Slope forming reddish brown siltstone, mudstone, and fine grained sandstone.	
	Lamb Point Tongue of Navajo Sandstone	90-410 ft	White or light gray highly crossbedded cliff forming sandstone.	Scenic, colored sand, glass sand, picture rock, excellent aquifer.
	Kayenta Formation	190-340 ft	Ledge and slope forming lenticular sandstone, siltstone, limestone, and intraformational conglomerate. Mostly reddish, but lavender white, and brown sandstones common.	Minor flagstone, forms upper part of Vermilion cliffs, scenic.
	Moenave Formation	260-435 ft	Reddish flatbedded fine grained sandstone and siltstone, thin to thick cliff forming beds.	Dimension stone, fish fossils, forms major part of Vermilion Cliffs, scenic.
	Wingate Sandstone	240-400 ft	Reddish-orange or brown cliff forming massive sandstone.	Scenic vertical cliff at Lake Powell, aquifer.
– J-0 unconformity				
Triassic	Chinle Formation	500-930 ft	See members	See members
	upper (Petrified Forest Member)	500-900 ft	Varicolored, banded, slope forming mudstone, claystona, sandstone, siltstone, limestone, and conglomerate.	Petrified wood, chalcedony, chert, jasper, manganese nodules, concretions, bentonitic clay, scenic.
	lower (Monitor Butte and Shinarump Members)	0-155 ft	Conglomeratic sandstone, sandstone, mudstone; lenticular and cliffy.	Petrified wood, minor coal, uranium, picture rock, host rock for copper.
– unconformity				
	Moenkopi Formation	1000+ ft	See members	See members
	Upper Red Member	abt 125 ft	Brown fine grained sandstone in thin to thick cliffy beds.	
	Shnabkaib Member	abt 220 ft	Light brown and white earthy weathering sandstone, siltstone, and gypsum.	gypsum, badlands scenery.
	Middle Red Member	abt 370 ft	Light reddish-brown, lightly banded, fine grained gypsiferous and earthy weathering sandstone.	Road fill, satin-spar gypsum.
	Virgin Limestone Member	abt 30 ft	Tan, platy to thinbedded calcareous sandstone.	Flagstone, road metal.
	Lower Red Member	abt 220 ft	Reddish fine grained slope forming sandstone and siltstone.	Road fill.
	Timpoweap Member	20-120 ft	Hard limestone, sandstone, siltstone, chert breccia.	Petroleum reservoir rock, chert.
– unconformity				
Permian	Kaibab Formation	0-500 ft	Thick to massive cliff forming fossiliferous and cherty limestone. (Mostly subsurface)	Petroleum reservoir rock, chert, karst topography, fossils.
	Toroweap Formation-White Rim Sandstone (includes Coconino Sandstone)	260-450 ft	White Rim is light colored sandstone, Toroweap is cyclic limestone, dolomite, anhydrite and gypsum, and sandstone. (mostly subsurface)	White Rim is aquifer, tar sands?, Toroweap has gypsum, anhydrite, oil shows, carbonates.
	Hermit Formation-Organ Rock Shale	106-624 ft	Reddish-brown silty sandstone. (mostly subsurface)	Gypsum stringers.
	Queantoweap and Cedar Mesa	600-1100 ft	Yellow, tan, and brown sandstone or quartzite.	Aquifer, oil shows.
	Pakoon-Halgaito Shale	150-600 ft	Interbedded carbonates and sandstone, includes red siltstone and thin anhydrite beds. Halgaito (east) is sandy redbed. (entirely subsurface)	Oil shows.
– unconformity				
Pre-Permian Paleozoic	Callville-Hermosa Formations Molas, Redwall, Ouray, Temple Butte-Elbert, Muav Bright Angel, and Tapeats		Limestone, dolomite, sandstone, siltstone, chert, shale, etc. (entirely subsurface)	oil shows.

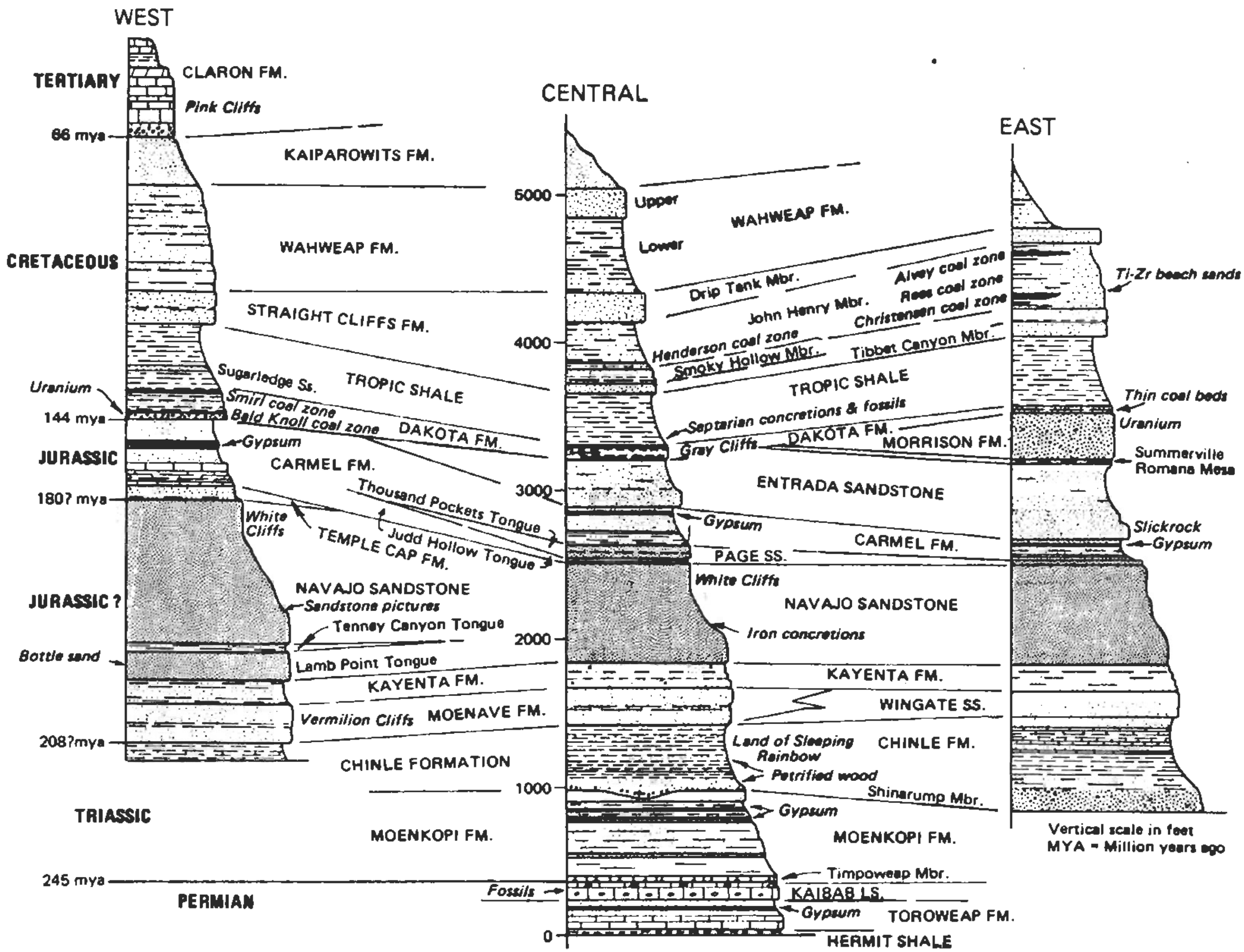


Figure 10. Stratigraphic units of Kane County, Utah showing relationships from west to east.

Table 3. List of Paleozoic Formations deposited in Kane County

Period	Formation	(*Eastern equivalent)
Permian	Kaibab Limestone	
	White Rim Sandstone	
	Toroweap Formation	
	Coconino Sandstone	
	Hermit Shale	(Organ Rock Shale)
	Queantoweap Sandstone	(Cedar Mesa Ss)
	Pakoon Limestone	
Pennsylvanian	Callville Limestone	(Hermosa Formation)
		(Molas Formation)
Mississippian	Redwall Limestone	
Devonian	Temple Butte Formation	(Ouray Formation)
		(Elbert Formation)
Cambrian	Muav Limestone	
	Bright Angel Shale	
	Tapeats Sandstone	

*Units shown in parentheses are names or facies more commonly used in the eastern part of the county.

Permian strata are the oldest exposed at the surface, a measured section indicates that 772 feet are exposed in Kaibab Gulch, extending down to the Hermit Shale (Noble 1927, p. 43-36). All other units are subsurface. To date (1985), 29 wells have been drilled in Kane County and all have penetrated Permian rocks. Of these, 12 have reached the Pennsylvanian, 11 the Mississippian, 9 the Devonian, and 6 the Cambrian rocks. As of the end of 1985 only one well had penetrated the entire Paleozoic column in Kane County, the previously mentioned Tidewater No. 1-A well, SE 1/4, NW 1/4, Sec. 34, T. 42 S., R. 2 W. The well was spudded in the Permian Kaibab Formation (or in the Triassic Timpoweap Member of the Moenkopi Formation) and reached the Precambrian at about 5,200 ft, indicating the approximate thickness of the entire Paleozoic column.

Cambrian Formations

Six wells have penetrated Cambrian rocks, but only one has passed through the complete interval. Isopachous lines worked out for the Cambrian, considering data from surrounding areas, generally trend northeasterly across Kane County and the total thickness for the System ranges from 1,200 feet near Lake Powell to about 2,000 feet at the northwest corner. Three units are generally recognized; a basal Tapeats Sandstone, the Bright Angel Shale, and the Muav Formation. The thickness of the units are illustrated by seven wells, arranged west to east across the county with the easternmost in San Juan County to provide continuity (table 4).

Table ~~6~~ 4. Thicknesses of Cambrian Formations in and around Kane County

Location	Name of Well	Muav	Bright Angel	Tapeats	Total
R 8 W	McDermott #1 State	1230 ft	345 ft	328+ ft	1903+
R 7 W	Superior #32-16	1216	340	86+	1642+
R 2 W	Tidewater #1-A	1120	322	290	1732
R 2 E	Union #1 Judd Hollow	172+			172+
R 5 E	Byrd #1 Rees Canyon	459+			459+
R 7 E	Shell #1 Soda Spr.	27+			27+
R 12 E	Skelly #1-A Nokai	626	292	46+	964+

Tapeats Sandstone: The Tapeats Sandstone is described as mostly brown to white quartzitic sandstone and conglomerate with occasional interbeds of gray to green micaceous shale, glauconitic limestone, and white to tan glauconitic sandstone. The very fine-grained to very coarse-grained to conglomeratic quartzitic sandstone is usually crossbedded and was deposited in a littoral environment. The Cambrian sea transgressed eastward and at least part of the Tapeats is Lower Cambrian in the western part of the county, the eastern occurrence may be completely Middle Cambrian in age (Lochman-Balk, 1972, p. 65). The thickness of the Tapeats in the Kaibab Gulch (Tidewater #1-A) well, as suggested by Munger and others (1965, fig. 2), is 290 ft, while the thickness reported through the picking of formational tops by the well geologist is 390 ft.

Bright Angel Shale: The Bright Angel Shale is 300-350 ft thick and is a Middle Cambrian unit consisting of gray to green micaceous shale, glauconitic limestone and dolomite, and white to tan glauconitic sandstone. Carbonates increase in western sections. Munger and others (1965, fig. 2) have correlated Bright Angel Shale members to two Kane County wells with McKee's (1945) Grand Canyon members (figure 11). In the McDermott No. 1 State well the lower member is 172 feet thick, the Meriwitica carbonate Tongue is 48 feet thick and the Flour Sack Member is 125 feet thick. In the Tidewater Kaibab Gulch well the lower member is 192 feet thick, the Meriwitica Tongue is 30 feet, and the Flour Sack Memberis 100 feet thick. In the eastern part of the county the Meriwitica Tongue is presumed to disappear and the unit cannot be subdivided into members.

Muav Formation: The Muav Formation consists of gray to white oolitic and dolomitic limestone, with significant interbeds of gray to green micaceous shales, silty limestones, and glauconitic sandstones, with some upper dolomites that are oolitic, pisolitic, and mottled. The thicknesses of the upper dolomites are 600 to more than 700 feet to the west and are gradually thinned eastwardly by a post-Cambrian - pre-Devonian unconformity. The lower limestones maintainan even 500 to 600 feet of section across the county. Wood (1956) called the upper dolomitic unit the "Supra-Muav dolomites" and Heylmun (1958) recognized them as an unnamed formation. In a later paper (Heylmun (1960) discarded the use of the unnamed formation and called the entire interval the Muav

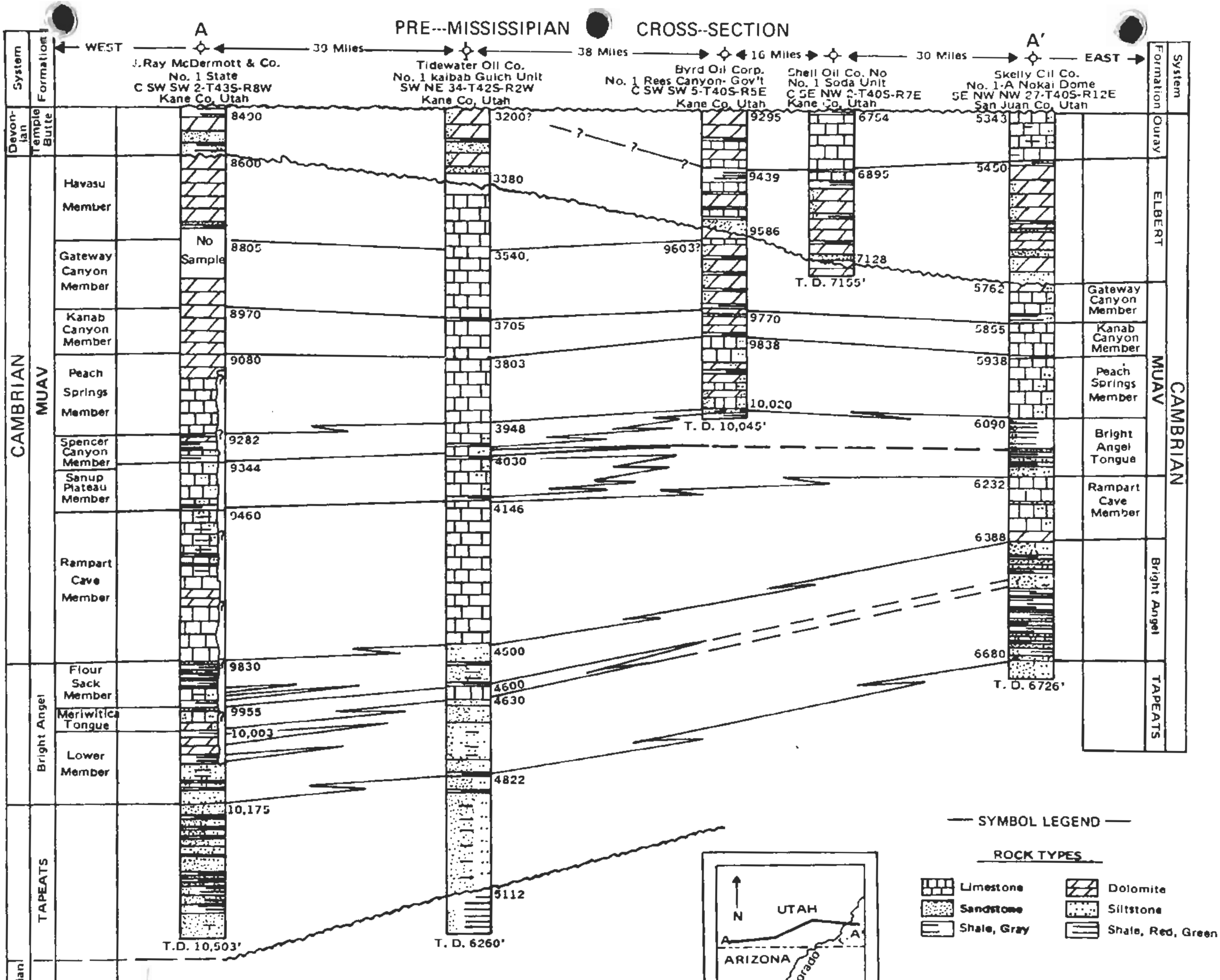


Fig 11. DEVONIAN AND CAMBRIAN CROSS--SECTION
West to East through Kaiparowits Area

Limestone. Loleit (1963) referred these dolomites to the Lynch(?) Dolomite, a term applied to Upper Cambrian dolomites in the Great Basin. Munger and others (1965) acknowledged the presence of the upper dolomites, but were able to correlate them to members of the Muav established by McKee (1945) at the Grand Canyon (figure 10). Lochman-Balk (1972) also recognized the upper dolomites and preferred the use of "Supra-Muav." The entire Muav Formation, including the upper dolomites, is estimated to be 700 to 1300 feet thick in the county, with the thickest sections to the west.

Devonian Formations

Devonian rocks unconformably overlie the Muav Formation and are unconformably overlain by the Mississippian Redwal Limestone. In most of the county the Devonian is represented by the Ouray Limestone and Elbert Formation. To the southwest the overlying Ouray disappears under the Mississippian unconformity and the remaining unit is called the Temple Butte Formation. The total Devonian thickness ranges from 100 feet in the southwest to more than 400 feet to the northeast (figure 12).

Elbert-Temple Butte Formation. This unit is mostly thinbedded limestone and dolomite interbedded with gray-green waxy shale and glauconitic sandstone. There are discontinuous sandstone beds of marine origin near the base of the unit. These sandstone beds rarely exceed 20 feet in thickness and vary in number from place to place. The greatest amount of sandstone found to date has been in the Tidewater No. 1 Kaibab Gulch well where 6 beds total 64 feet in thickness. At the McDermott No. 1 State well 20 feet of sandstone was found in two beds, in the Superior No. 32-16 well three beds of sandstone totalled 12 feet, in the Byrd No. 1 Rees Canyon well two sandstone beds amounted to 19 feet and in the Shell No. 1 Soda Springs hole only 5 feet of sandstone in a single bed was encountered. Munger and others (1965) have indicated that the southwest Kane County area falls on the edge of a post-Devonian highland from which the Ouray and some of the Elbert-Temple Butte was removed. This high has a northwest-trending axis and Kane County lies entirely on its northeast flank. The isopachs of the Elbert-Temple Butte also shows a north trending feature extending to the Byrd No. 1 Rees Canyon unit where a thinner section was encountered than either to the east or west. Since this last feature is indicated by only one well, it may be local. The Union No. 1 Judd Hollow unit was drilled after the work of Munger and others (1965) and figure 12 represents their isopach maps of the Elbert-Temple Butte and the total Devonian System modified to consider the data offered in the well log.

Ouray Formation. The Ouray is present under Kane County in thicknesses ranging from 0 to 160 feet. It is missing to the southwest and is thickest to the northwest. It is principally light gray to tan dense limestone or dolomite with occasional green shale partings. Sometimes the strata contain a profuse conodont fauna of Late Devonian age. Both the Ouray and Elbert-Temple Butte Formations were deposited under shallow marine conditions with a fluctuating shoreline. Deposition

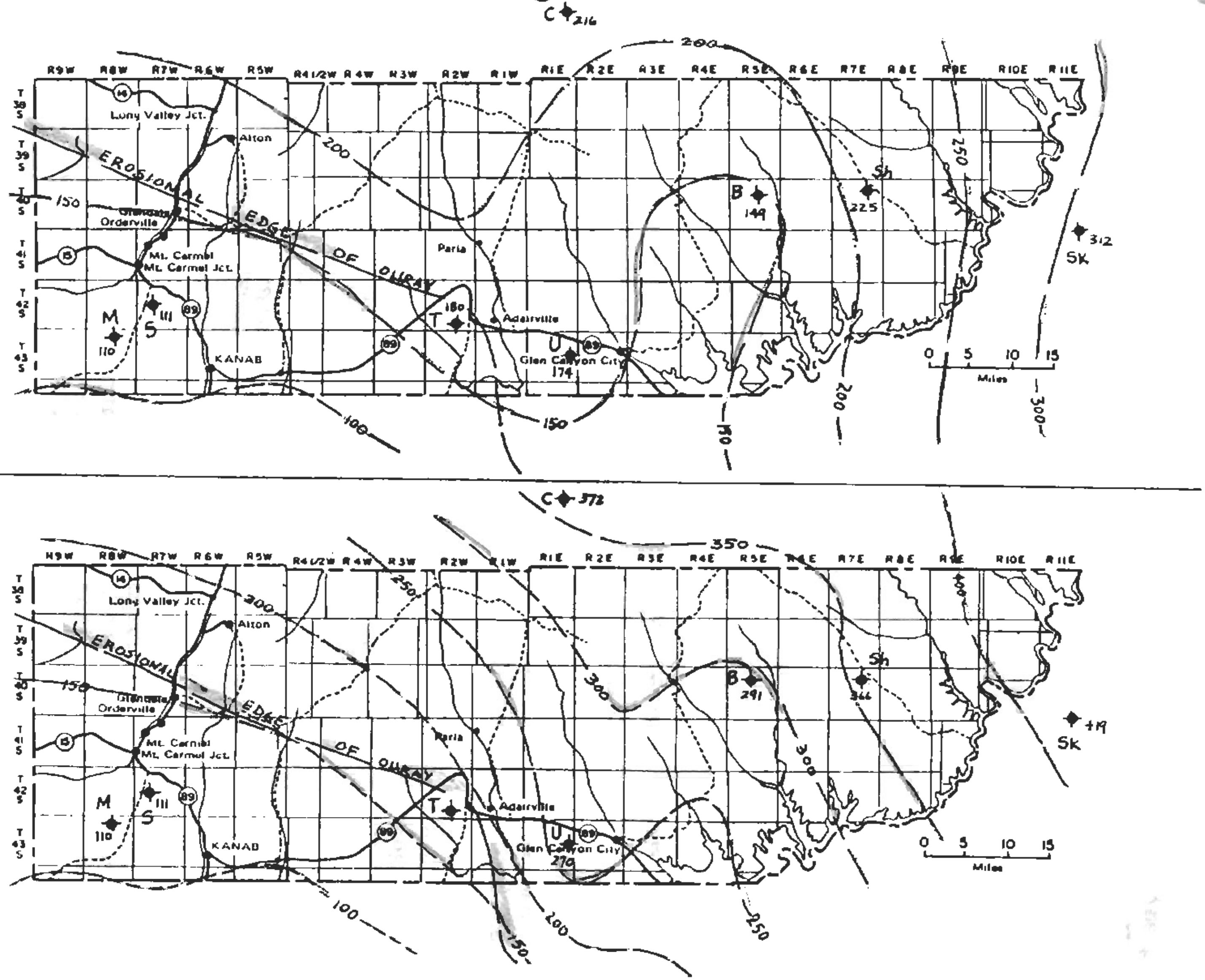


Figure 12. Devonian isopach maps: upper is of Elbert-Temple Butte Formation, lower is of total Devonian System. Modified from the work of Munger and others, 1965. M=McDermott, S=Superior, T=Tidewater, U=Union, C=Calco, B=Byrd, Sh=Shell, Sk=Skelly

took place in mudflat or beach and open marine conditions. Upper Ouray rocks are similar in appearance to the overlying Mississippian Redwall Limestone and the recognition of the separating unconformity is difficult.

Mississippian Formations

Redwall Limestone. The Mississippian System is represented by a single formation, the Redwall Limestone. White, pink, and gray crystalline dolomite and limestone characterize the widespread unit, which contains varying amounts of chert. The Redwall also exhibits vuggy to cavernous porosity and is typically massive. In Kane Counmty, the Redwall was deposited under open marine conditions on a shelf to the east of the Cordilleran geosyncline. In contrast to the Devonian, there were few shoreline fluctuations and most of the sediment was deposited below the effective wave base. Locally silty and oolitic horizons indicate deposition under agitated conditions (Heylmun (1958, p. 1787). After its deposition the Redwall was subjected to subaerial erosion and solution and a karst topography developed on its upper surfaces. Voids and sinkholes were later filled by the first Pennsylvanian unit (Molas Formation). Borehole thickness estimates are given in table ~~7~~ 5.

Table ~~7~~ 5. Thickness estimates of the Mississippian Redwall Limestone in several Kane County drillholes.

		Munger et al (1965)	Reported Drillhole tops	Heylmun (1958)
West	McDermott #1 State	865	935	885
	Superior #32-16	840	905	---
	Houston #41-11	---	898	---
	Tidewater #1 Kaibab G.	773	616	---
to	Pan American #1-X Paria	---	576	---
	Marathon #1 Butler V.	---	698	---
	Union #1 Judd Hollow	---	604	---
	Byrd #1 Rees Canyon	681	745	---
East	Shell #1 Soda Springs	634	634	---

Isopach maps of the Redwall show a thickening of the unit from 600 feet along Lake Powell northwesterly, so that the unit may exceed 1,000 feet in the northwest corner of the county. Munger and others (1965) were able to subdivide the Redwall into four members as suggested by McKee (1964). These members are lettered A to D in ascending order. McKee's names include the Whitmore Wash Member ("A" Member), Thunder Springs Member ("B" Member), Mooney Falls Member ("C" Member), and the Horseshoe Mesa Member ("D" Member)(figure 13).

Pennsylvanian Formations

Pennsylvanian rocks are known to underlie at the east half of Kane County. To the east the Pennsylvanian System thickens toward the Paradox Basin and is represented by the basal Molas Formation and the Hermosa

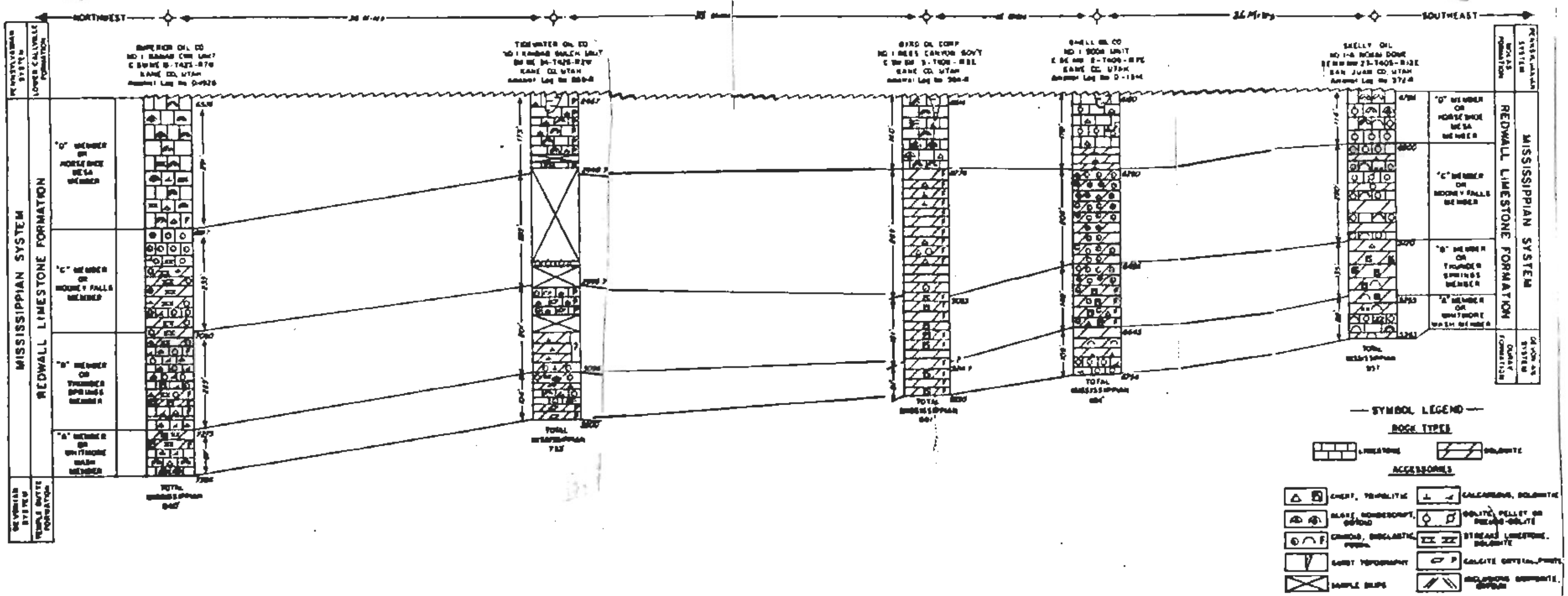


Figure 13. Restored Mississippian cross-section across Kane County with nomenclature of McKee (1964) as interpreted by American Stratigraphic Company (Munger and others, 1965, Figs., 6, 7, & 8).

Formation. To the west, in Washington County, the Pennsylvanian also thickens and the Callville Limestone is recognized. Heylmun (1963) indicates that orogenic activity occurred in Early Pennsylvanian time creating the Kaibab Uplift. This uplift is located over western Kane County and is called the Piute Platform by Mallory (1972) and Hintze (1973). Both Mallory and Hintze indicate that Permian rocks directly overlie Mississippian rocks as suggested by Heylmun (1958). Mississippian-Pennsylvanian-Permian relationships are illustrated in figure 14.

Picked oil well information tops indicate the presence of Pennsylvanian throughout the county; Hermosa and Molas Formations are recognized from central Kane County eastward and Callville Limestone is recognized to the west. The reported thicknesses are about 600 feet along the west margin of the county to less than 200 feet in the central part and nearly 800 feet in the eastern part. Heylmun (1958) indicates the presence of an interbedded carbonate and sandstone unit above an unconformity at the top of the Pennsylvanian, which is Wolfcampian in age, which is easily mistaken for the Hermosa or Callville. This lowermost Permian unit is known as the Pakoon Limestone to the west (McNair, 1951) and as an unnamed unit to the east. Still farther east this unnamed unit may be equivalent to the Elephant Canyon Formation or "Rico" of Grand and San Juan Counties. Heylmun has additionally indicated that units ascribed to the Pennsylvanian in the Tidewater No. 1 Kaibab Gulch unit should be assigned to the Pakoon Limestone. Oil well information tops show 500 to 600 feet of Pennsylvanian in western wells (McDermott No. 1 State--536 feet, Superior No. 32-16--589 feet, and Houston #41-11--575 feet). Bissell (1963) has interpreted that at least 320 feet of this interval in the McDermott well and 150 feet in the Tidewater No. 1 Kaibab Gulch well belong to the Permian Pakoon.

Molas Formation. The Molas Formation has been recognized in all wells east of the Kaibab Uplift-Piute Platform. It ranges in thickness from 50 to almost 300 feet, with the thicker sections to the east. Red shale and siltstone, sandstone, limestone, and reworked Mississippian limestone and dolomite characterize the Molas (Heylmun, 1958, p. 1789), which lies unconformably on the Redwall karst topography. Its erratic thicknesses are explained in the differences of relief on the Redwall surface. Millerella sp., suggestive of Morrow age (upper Lower Pennsylvanian), was found in a Garfield County well, 18 miles north of the Kane County line.

Hermosa Formation. The Hermosa Formation overlies the Molas and consists of interbedded sandstone and carbonate. Near the bottom the carbonates dominate and near the top the sandstones dominate. To the south red shales and siltstones of the Supai Formation interfinger with thinbedded limestones. The Hermosa is only 125 feet thick at the Union NO. 1 Judd Hollow unit (Sec. 19, T. 43 S., R. 2 E.) and is 573 feet thick at the Shell No. 1 Soda Springs well (Sec. 2, T. 40 S., R. 7 E.). No Pennsylvanian is indicated in the Tidewater No. 1 Kaibab Gulch well (Sec. 34, T. 42 S., R. 2 W.). The Hermosa is at least partly correlative with the Supai and Callville Formations to the south and west. Like the Hermosa, the Callville consists of interbedded carbonates (dolomite, limestone, dolomitic limestone, calcareous dolomite) and sandstone.

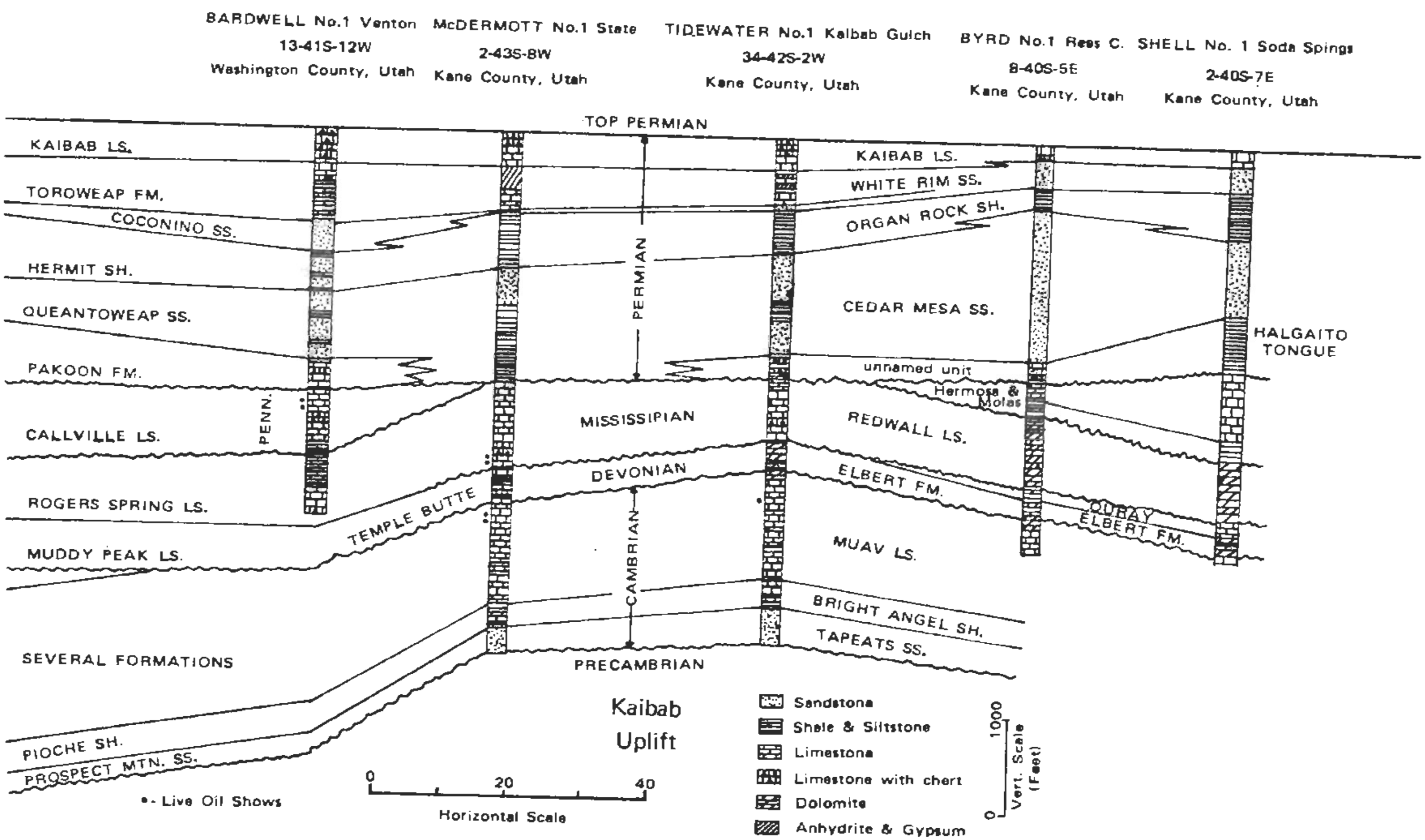


Fig. 14. Correlation of Paleozoic units east-west across Kane County, Utah, after Heylmun, 1960.

Permian Formations

Permian units appear to undelie the entire county and wells which have penetrated the complete section indicate the thickness to range from 1,694 to 2,641 feet. The uppermost Permian units do outcrop in the south-central part of the county at the north end of the Kaibab Uplift (figure 15). A little less than two percent of the county's land area exposes these rocks. Wells in the western part show the thickness of the Permian strata to be about 2,000 ft represented by 5 formations. In ascending order these include the Queantoweap Sandstone, Hermit Shale, Coconino Sandstone, Toroweap Formation, and Kaibab Formation.

In the central part of the county, to the north and around the outcrops of the Kaibab Uplift, the thickness of the rock strata is most varied, in fact the minimum and maximum measurements for Permian rocks of Kane County are only 6 or 7 miles apart and vary by nearly 700 feet. In addition changes in nomenclature and facies take place in some of the units. The Queantoweap Sandstone becomes the Cedar Mesa Sandstone, the Hermit Shale becomes known as the Organ Rock Shale, and the Toroweap Formation begins to intertongue with the White Rim Sandstone. In some wells both the Toroweap and White Rim are recognized.

To the east, the Permian sequence averages 2,300 feet in thickness. An additional unit appears below the Cedar Mesa Sandstone and above the unconformity at the top of the Pennsylvanian rocks. This is the Halgaito Shale. As it pinches out to the west it undergoes a facies change and in some wells has been called an "unnamed unit" or "Lower Permian Carbonates" or the Pakoon Formation. The Pakoon Formation occupies this position to the west of Kane County, but it appears to be missing in western and central Kane County (figure 14). In the far eastern part of the county the Toroweap Formation changes completely into the White Rim Sandstone, which cannot be differentiated from the thin Coconino Sandstone that persists beneath it. Thus the eastern assemblage of Permian formations consists of the Halgaito Shale, Cedar Mesa Sandstone, Organ Rock Shale, White Rim Sandstone, and Kaibab Limestone.

<u>Pakoon Formation-Unnamed Unit-Permian Carbonates-Halgaito Shale</u>. These units are all related with respect to geologic time and stratigraphic position. Each lies immediately above the unconformity at the top of the Pennsylvanian rocks and is considered Wolfcampian in age. At its type locality at Pakoon Ridge, Mohave County, Arizona, it is 688 feet thick and consists of gray and tan-gray, thin to medium bedded dolomitic limestone. Bissell (1963) indicates that the unit is at least 300 feet thick at the Hurricane Cliffs near Anderson Junction in Washington County, that it is 320 feet at the McDermott No. 1 State well in Kane County and 150 feet thick in the Tidewater No. 1 Kaibab Gulch well farther to the east. Lithologies intercepted by these wells include dolomite, anhydrite, gypsiferous siltstone and related evaporitic sediments. Heylmun (1960) did not project the Pakoon easterly to the McDermott well and refers to the interval as an unnamed unit in the Tidewater well (figure 14). In central Kane County and at the Upper Valley oil field, just across the line in Garfield County, this interval

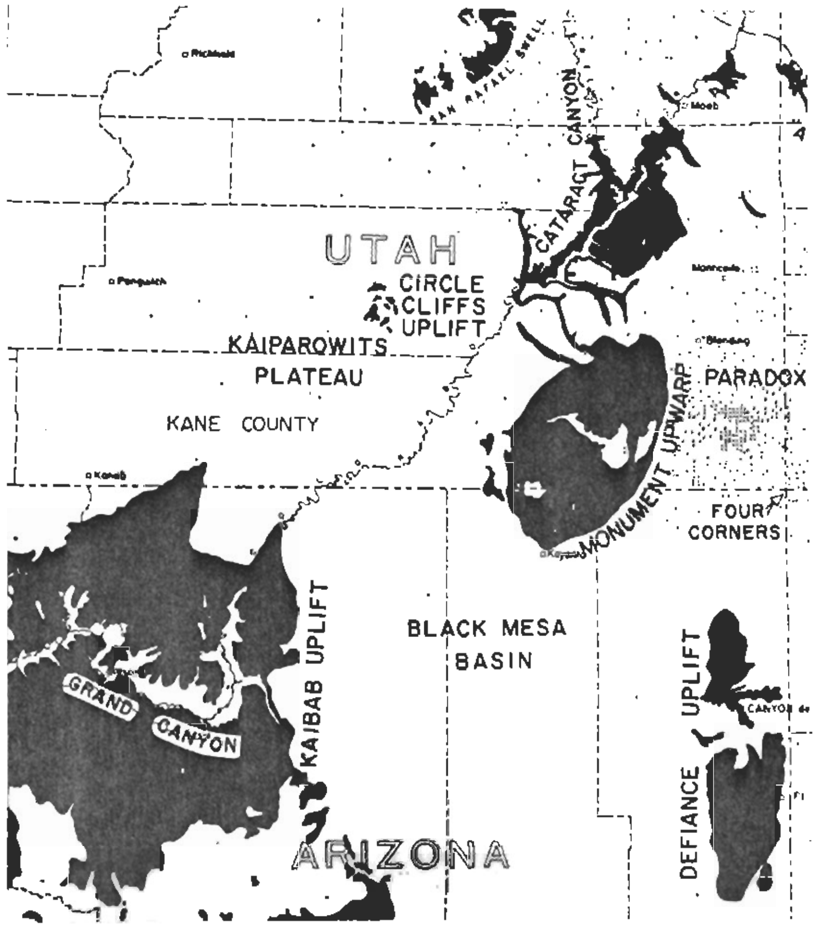


Figure 15

Map of that part of the Colorado Plateaus surrounding Kane County, Utah, with Permian outcrops indicated in black (modified from Baars, 1962, p. 152.).

has been called the Pakoon Formation or Lower Permian Carbonate unit. Here it consists of interstratified tan to light brown chert, limestone and dolomite, white fine-grained sandstone, red siltstone, arkosic sandstone, and thin beds of anhydrite.

At the Shell No. 1 Soda Springs unit, Peterson (1975) indicates the presence of 583 feet of Halgaito Shale described as interbedded white to light brown fine grained sandstone; pink, red, orange, and light brown siltstone; red shale, pink and light brown limestone, and pink to red dolomite. The Halgaito Shale represents marine deposition on a broad marginal mud flat alternatively receiving fluvial and marine sediment. The unnamed carbonates or Pakoon Formation in Kane County were deposited seaward from the Halgaito mud flats in a shallow marine situation, often under restrictive conditions and with occasional influxes of land-derived sediment. The Pakoon dolomitic limestone to the west, in Washington County, was undoubtedly deposited in deeper marine water with much less influence from the continent. Neither the Pakoon, unnamed unit, or Halgaito have much potential for oil and gas or other resources. The beds of anhydrite are generally too thin and deep to be of economical value. The sequence correlates with the Elephant Canyon (Rico) to the northeast and perhaps with the lowermost basal limestones of the Supai Formation in the Grand Canyon (see Baars, 1962, p. 156, 179).

<u>Queantoweap-Cedar Mesa Sandstone</u>. The Queantoweap Sandstone was named by McNair (1951, p. 525-527) in Queantoweap Valley, northwestern Arizona. This term has been used for the interval of rock overlying the Pakoon or lower carbonates in the western part of Kane County, whereas the term Cedar Mesa Formation or Sandstone has been used in eastern areas. The Queantoweap is described as a sandstone with subangular to subround, fine grained to medium grained quartz sand tightly cemented by calcareous and dolomitic cement. The Cedar Mesa Sandstone is described as white to light-brown fine grained sandstone with lesser amounts of red, orange, pink, maroon, green, and light brown siltstone, red to green shale, and minor amounts of light brown silty and cherty limestone. The clastics are subangular to well rounded quartz grains, manyh of which are frosted. The unit is hard and calcareous and cross-stratified. Bissell (1963, p. 47) believes the name Queantoweap should be extended at least into central Kane County, because of the dolomitic cement and poorer sorting characteristic of that unit.

Accurate measurements of the Queantoweap-Cedar Mesa interval are probably non-existent because the drill hole tops generally do not differentiate the interval from the underlying Pakoon or Lower Permian carbonate unit. The Queantoweap is estimated to be 600 feet thick in southwestern Kane County. The interval thickens gradually eastward and maximum thicknesses may be as much as 1,100 feet (Cedar Mesa Sandstone). Peterson (1975) indicates the Cedar Mesa Sandstone to be 818 feet thick at the Shell #1 Soda Springs unit to the east and Irwin (1971, p. 1986) indicates that the thickness increases northward in the eastern half of the county. The Cedar Mesa and Queantoweap represent basin-edge littoral and beach sand facies and the two units are considered to be mostly Wolfcampian in age, although the upper parts may be Leonardian.

<u>Hermit-Organ Rock Shale</u>. Noble (1922, p. 26) named the Hermit Shale for exposures in the Grand Canyon of Arizona and McNair (1951, p. 527-528) changed the name from the Hermit Shale to Hermit Formation noting that the unit is mostly fine grained sandstone at the type section. The Organ Rock Shale is its eastern correlative and was named by Baker and Reeside (1929) as a part of the Cutler Group of southeastern Utah. Ther Hermit is described as reddish silty sandstone, siltstone, micaceous shale, claystone, and minor dolomite. The upper part exhibits concretionary structure. The Organ Rock is dark reddish brown siltstone and mudstone. Baars (1962, Fig. 14), in an isopach map of the Hermit-Organ Rock Shale, shows two deeps in the depositional basin. The first is centered in southeastern Utah and contains the Organ Rock Shale. The second is centered just north of the Grand Canyon in Arizona and contains the sandier Hermit Formation. The divide between the two deeps parallels Fiftymile Mountain where the interval is 300 to 400 feet thick.

The thickness for the Hermit-Organ Rock has been determined in about 9 wells and ranges from 106 to 624 feet. The unit appears to thicken to the south and measurements to the southwest are slightly thicker than those to the southeast. Baars (1962) indicates that the Organ Rock was deposited on a marginal marine lowland dominated by streams, flood plains, and tidal flats. He noted the presence of fossil plant and vertebrate remains that date the unit as early Leonard (lower Middle Permian). Irwin (1976) suggest the regular bedding implies a nearshore, very shallow marine environment and that the fluvial influence may have been modified by marine reworking. Mullens (1960), for exposures in San Juan County, suggested an eolian environment for the lower part, fluvial environment for the middle, and a tidal flat environment for the upper part. The Hermit Formation was deposited similarly to the Organ Rock and both floodplains and shallow marine mud flat environments have been suggested.

The Hermit Formation is the oldest unit exposed at the surface in Kane County (photo 5). The exposure is located in Buckskin Gulch (formerly Kaibab Gulch). The section was first measured and published by Noble (1928, p. 46), and only the upper 55 feet project above the surface:

Measurement of the Hermit Formation in Buckskin Gulch, Sec. 9, T. 43 S., R. 4 E., Kane County, Utah, by A. E. Noble (1928, p. 46).

(place the measurement here.)

<u>Coconino Sandstone</u>. At the Grand Canyon the Coconino Sandstone is 330 to 350 feet thick, consisting of a uniform fine grained, crossbedded, white to light gray sandstone with siliceous cement. The lower contact is gradational with the Hermit Formation and there is a disconformity at the top. Heylmun (1958, p.1796-1797) mentions that the Coconino is less than 200 feet thick in Tidewater's #1 Kaibab Gulch test, but most isopach maps show the unit to be missing in the northern half of the county and less than 100 feet thick to the south. In southwestern Kane County it is reported in two wells as less than 25 feet thick. In north-central Kane

County two wells report its presence at less than 50 feet in thickness. The sandstone probably interfingers with dolomite and limestone at the base of the Toroweap Formation.

In Buckskin Gulch (Kaibab Gulch) Noble (1928, pl. 12) describes the rocks immediately overlying the Hermit Formation as alternating beds of arenaceous limestone and irregularly bedded fine grained buff sandstone. Two of the limestones are identified as very fossiliferous. He also describes a massive 9 foot bed of hard fine grained cliff forming sandstone, 55 feet above the Hermit Formation. He states that "the rock sparkles in the sunlight like the typical Coconino Sandstone of the Grand Canyon." Perhaps 64 feet of Coconino equivalent is present, but the interval could just as well be included with the Toroweap Formation above (photo 5). The hard sandstone is overlain by a recessed zone of chert which may indicate the disconformity described at the Grand Canyon. A general description of the 64 foot interval at Buckskin Gulch is given in the following measured section:

Measurement of the Coconino Sandstone(?) at Buckskin Gulch (formerly Kaibab Gulch), Sec. 9, T. 43 S., R. 2 W., Kane County, Utah, by E. A. Noble (1928, p. 46).

(place section of Coconino Sandstone(?) here)

<u>Toroweap-White Rim Formations</u>. The Toroweap Formation is exposed in its entirety in Buckskin Gulch (Kaibab Gulch) and the upper part is exposed in Pine Hollow Canyon, both exposures on the west side of thye East Kaibab monocline. It probably underlies the whole county, generally thickening from less than 150 feet to the southeast to more than 600 feet to the northwest (Lyons, 1983). The formation was named by McKee (1938, p. 12) for strata formerly included in the lower part of the Kaibab Limestone. The Toroweap contains Leonard fossils similar to those in the Kaibab. The Toroweap correlates with the lower 80 percent of the White Rim Sandstone to the east. Baars (1962), in an isopach map, indicates the White Rim Sandstone to be over 300 feet thick along the Colorado River and to thin to zero near the East Kaibab monocline. Irwin (1976) shows the Toroweap pinching out east of the Colorado River. Oil tests along the south border of the county report only the Toroweap. Logs of boreholes in the Kaiparowits Basin generally report thicknesses for the Toroweap or for both units. East of Fiftymile Mountain only the White Rim is usually reported (table ~~8~~ 6).

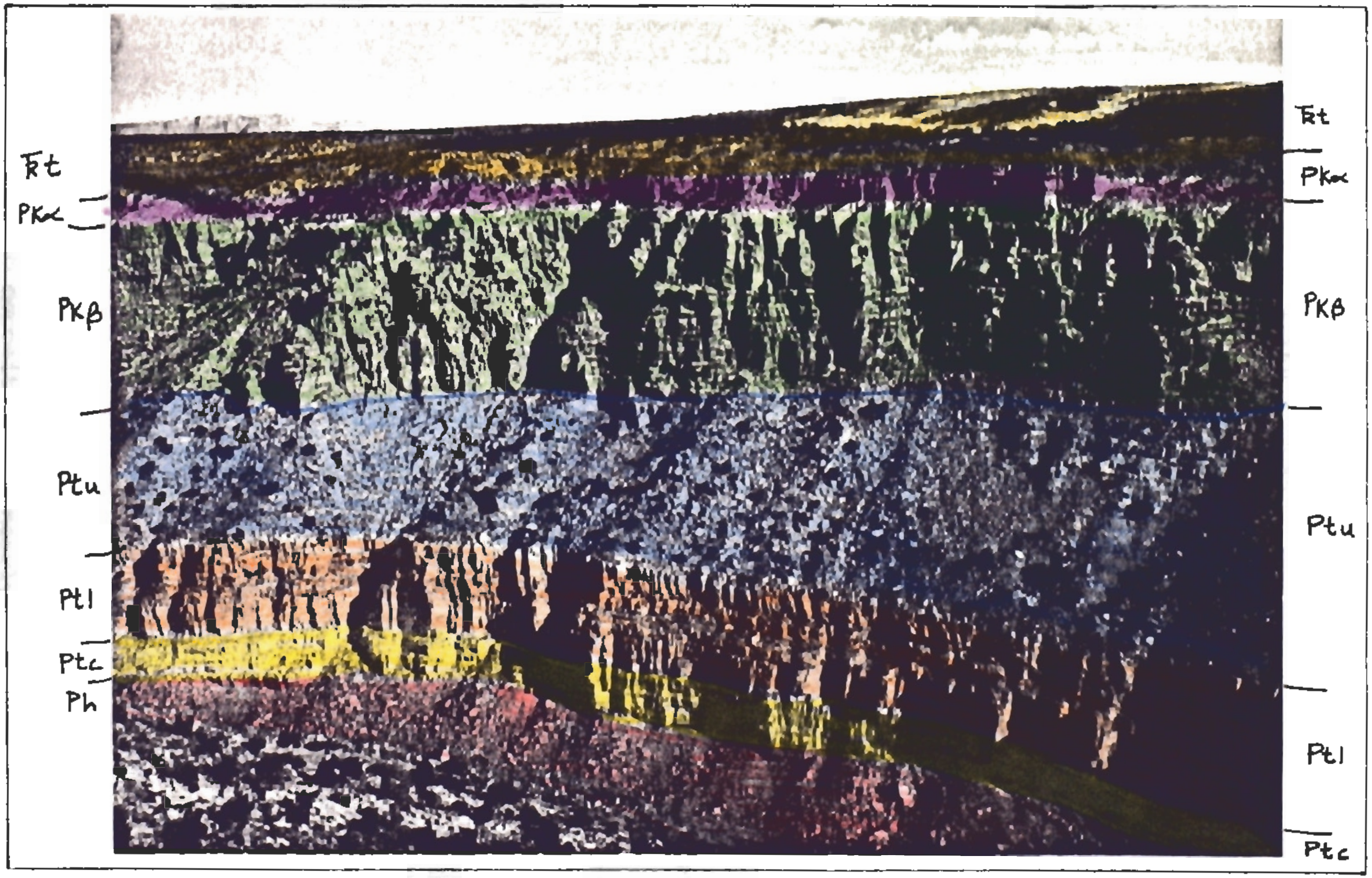


Photo 5. Exposed Permian section in Kane County. View northward across Kaibab Gulch. Ph=Hermit Formation, Ptc=Coconino Sandstone portion of lower Toroweap Formation, Ptl=remainder of lower Toroweap Formation, Ptu=upper Toroweap Formation, Pkβ=Beta Member of Kaibab Formation, Pkα=Alpha Member of Kaibab Formation, and ~~Trt~~ Ŧmt=Timpoweap Member of Moenkopi Formation (Triassic).

Table 6. Recorded Toroweap and White Rim Formation thicknesses in Kane County, Utah.

Borehole	Location	Toroweap	White Rim
J. R. McDermott #1 State	2-43S-8W	442 ft	---
Superior #32-16 Kanab Cr	16-42S-7W	432	---
Tidewater #1 Kaibab Gulch	34-42S-2W	330	---
Union Calif. #1 Judd H.	19-43S-2E	225	---
Texaco N-1, Govt Schneider	5-38S-2W	369	121
Marathon #1, Butler Valley	22-39S-1W	358	113
Tenneco #1, So. Upper V.	16-38S-2E	340	---
Sun #1 Lyons Fed	8-38S-3E	300	---
Cleary Funds Romex #1-16	16-40S-5E	264	130
Shell #1 Soda Springs	2-40S-7E	---	234
Romex #1 Fed. Rock Creek	19-41S-7E	---	209
Sojourner #1 Burger Fed	12-41S-8 1/2E	---	298

The Toroweap was deposited in or adjacent to a shallow sea. McKee (1938) indicated the unit was deposited as a single marine transgressive and regressive cycle. Baars (1962, p. 202) pointed out that the local travertine and intraformational conglomerates in the upper slope-forming unit indicate an arid subaerial depositional environment. Baker (1946) and Davidson (1976) have suggested an eolian beach origin for the White Rim Sandstone (eastern facies).

The Toroweap Formation is about 314 to 335 feet thick in Buckskin Gulch, including the approximately 64 feet of lower strata assigned to the Coconino Sandstone. The 90 feet of rocks above the Coconino are mostly yellowish-gray, cliff-forming, cherty, fossiliferous limestone, with subordinate amounts of calcareous sandstone. The upper 175 feet are slope-forming rocks, mostly very fine and medium grained bimodal sandstones. They are generally yellow tan to reddish, poorly cemented and porous, and calcareous and gypsiferous. There are also occasional marly or travertine beds, silty or sandy thinbedded cherty limestones, intraformational breccias, and discontinuous gypsum beds. Gypsum beds are generally better developed at exposures in Pine Hollow Canyon than at those in Bucksckin Gulch.

Measurement of the Toroweap Formation (less 64 feet previously described to the Coconino Sandstone [p. 18]), Sec. 9, T. 43 S., R. 2 W., by L. F. Noble (1928, p. 44-45).

(place measurement of Toroweap Formation here.)

<u>Kaibab Formation</u>. The uppermost Permian unit in Kane County is the largely subsurface Kaibab Formation (Darton, 1910, p. 28), which thickens from a feather edge in the northeastern part of the county (eastern edge of Kaibab deposition) to nearly 500 feet to the west. According to several published isopach maps, the thickening is not gradual or uniform so that thin or thick Kaibab sections may be expected anywhere in the county, but within the 0 to 500 foot thickness range. Reported borehole

thicknesses, for example, in the Cannonville-Butler Valley area (85-150 feet), are conspicuously thin. McKee (1938) divided the formation into three members. A transgressive sea deposited the Gamma Member, the extended sea deposited the Beta Member, and the retreating sea deposited the Alpha Member. The upper and lower members are sandier and lithologically more diverse, especially as the eastern beach area is approached (Irwin, 1976, p. 1990-1991). The Gamma Member is sandstone at its eastern limit (upper part of White Rim Sandstone) and grades westward to arenaceous marine carbonate. The Gamma-Beta contact is a relatively sharp facies change, sandstone to carbonate in the east and arenaceous carbonate to cherty, fossiliferous and massively bedded relatively clean carbonates in the west. In contrast to the Beta Member the Alpha Member consists of irregularly bedded carbonates, sandstone, siltstone, and anhydrite. The Alpha Member is present only in the western part of the county and has been identified in the Kanab area. Irwin (1976, Figs. 13 and 14, p. 1992 and 1994) shows that the Kaibab carbonates are largely dolomite in central Kane County.

The Kaibab Formation is exposed only in south-central Kane County on Buckskin Mountain. The Tidewater Oil #1 Kaibab Gulch well, Sec. 34, T. 42 S., R. 2 W., was spudded near the top of the mountain, perhaps in the Timpoweap Member of the Moenkopi Formation, and reached the Toroweap Formation at a depth of 370 feet. Noble (1928, pl. 12) indicates 403 feet of Kaibab (his units A and B) in his measurement in Buckskin Gulch (Kaibab Gulch), Sec. 9, T. 43 S., R. 2 W. However, Gregory (1948, p. 236-237) thought that the upper 77 feet of Noble's measurement should be assigned to the Timpoweap Member of the Triassic Moenkopi Formation. Gregory's map (pl. 1) reflects this and he shows the Moenkopi Formation covering most of Buckskin Mountain.

Blakey (1970, p. 20-24) reported on the Kaibab Formation at its exposures in Sand Gulch (north part of Buckskin Mountain). He measured a partial section of 162 feet and recognized both the Alpha and Beta Members. Blakey's Alpha Member (60 feet) probably corresponds to Noble's unit A (77 feet). Blakey notes that fossils should be rare or in poor condition in the Alpha Member, considering its mode of deposition and mentions none in his section. Noble concurs and mentions fossils only for the uppermost subunit, all too poorly preserved to be determinable. Gregory, however, (1948, p. 223 and 227) indicates that Triassic fossils have been found at the head of Kaibab Gulch and states, "In the spongelike masses of shell fragments from the Timpoweap Member in Kaibab Gulch, Reeside (1943) recognized 'Molds of various undetermined gastropods and the ammonite Meekoceras, Lower Triassic.'" We examined this uppermost limestone unit and also found the gastropods, as did Sargent and Hansen (1982, Map I-1033-1), but no cephalopods.

Blakey (1970, p. 23) reports the following fossils present in his Beta Member: the brachiopods Peniculauris bassi, Productus (Dictyoclostus) occidentalis, Echinauris subhorrida, and Koslowskia meridionalis, fenestrate and massive bryozoans, pelecypod fragments, and crinoid columnals. There are no diagnostic fossils in the slope overlying the vertical cliffs of the Beta Member; the gastropods are found in a limestone bed immediately below the Lower Red Member of the Moenkopi Formation. We have tentatively placed the Permo-Triassic boundary at the top of a gray limestone ledge in the middle of the slope above the vertical cliffs of the Beta Member, that is filled with vertical tubes of brown chert. According to this definition the lower half of Blakey's 60 foot measurement in Sand Gulch is the Alpha Member, but the upper half belongs to the Timpoweap Member of the Moenkopi Formation.

With this definition much of the upper surface of Buckskin Mountain is held up by the Timpoweap Member of the Moenkopi Formation, but exposures of the Kaibab are rather extensive in every drainage. The Kaibab consists mostly of a massive cliff of fossiliferous, cherty gray limestone and calcareous, often cherty, well-indurated fine-grained sandstone (Beta Member). Although chert is found in nodules, beds, and irregular bodies, the white, nearly spherical variety is the one that catches the eye (photo 6).

Above the cliff are 15 to 80 feet of mostly ledge and slope-forming rocks that belong to the Alpha? Member of the Kaibab Formation. At some exposures these rocks are entirely cliff-forming, in others they form a smooth slope, and elsewhere they form ledges and slopes. The lower part is mostly cherty limestone like that in the Beta Member, but the beds are less massive, some medium bedded, and unfossiliferous. Toward the top sandstone beds become prevalent along with a peculiar banded cherty unit. The unit is capped by a hackly weathering blocky gray limestone, the upper part with the vertical tubes filled with brown and rough weathering sandy chert. These tubes were probably originally bioturbation features.

The thickness of the Kaibab Formation at Pine Hollow Canyon is 160 feet, with 16 feet of Alpha? Member. At Buckskin Gulch (our measurement) the full Kaibab is about 280 feet thick and includes 80 feet of Alpha? Member. In Sand gulch the full Kaibab is not exposed but the Alpha? Member is about 30 feet thick.

Measurement of the Kaibab Formation, NW Sec. 5, T. 44 S., R. 2 W., Kane County, Utah, Pine Hollow Canyon section.

(place measurement of Kaibab Formation here.)

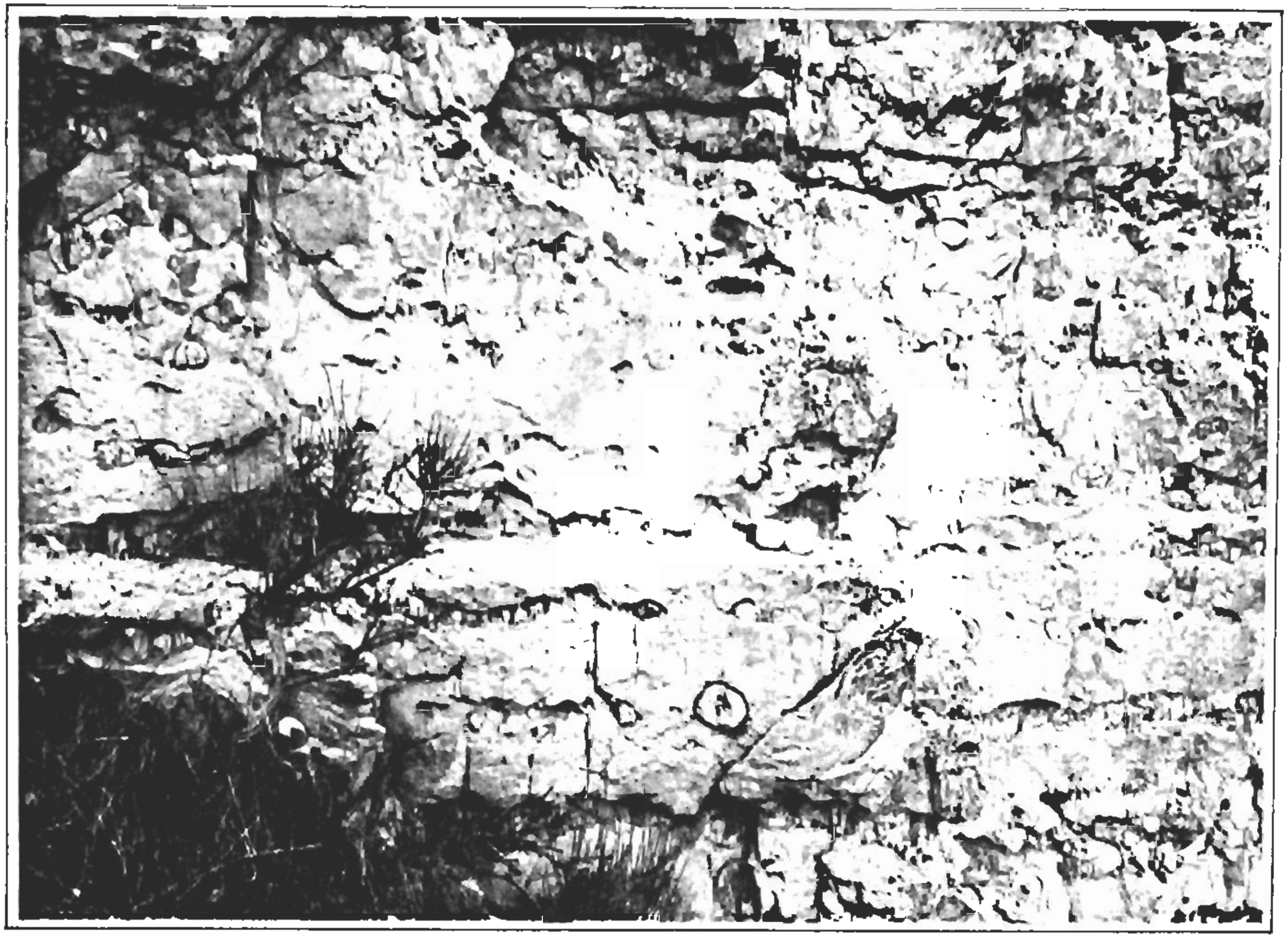


Photo 6. Cherty limestone in the Kaibab Formation in the Kaibab Gulch area. Note the brunton compass for scale. The chert nodules are white and nearly spherical.

Figure 16: Triassic outcrops of Kane County

Triassic Formations

Recent work by Imlay (1980) indicates that only the Moenkopi and Chinle Formations were deposited in the Triassic period in southern Utah. The total thickness of the units ranges from about 900 to 2,400 feet. Thicker sections are generally to the west, the thinnest along Lake Powell, to the east. The distribution of Triassic outcrops of Kane County are shown on figure 16.

<u>Moenkopi Formation</u>. Except for a small exposure, now inundated by Lake Powell, all of the Moenkopi Formation outcrops are located west of the Cockscomb in the southwestern part of the county. The formation underlies the entire county except locally on Buckskin Mountain. Borehol intercepts indicate the unit rapidly thickens from about 150 ft, along th Colorado River, to more t5han 1,200 feet along the west margin of the county.

The Moenkopi Formation can be divided into six members west of the Cockscomb, in ascending order: Timpoweap, Lower Red, Virgin Limestone, Middle Red, Shnabkaib, and Upper Red. The lowermost Timpoweap Member is only exposed on and around Buckskin Mountain. It has also been reported in the subsurface in all western drill holes and in the Kaiparowits Plateau just south of the Upper Valley oil field. It apparently pinches out southeast of a line extending from the place where the Paria River enters Arizona to the Circle Cliffs uplift.

At Buckskin Mountain the Timpoweap Member consists of carbonates, sandstone, chert breccia, and siltstone (photo 7). Some of the sandstone are pebbly. The overall color is generally a light tan or yellow gray an the individual beds are mostly thin to thickbedded and blocky. The upper half is more resistant and generally forms a cliff over the ledgy lower part. The Timpoweap Member at Buckskin Mountain correlates with the Sinbad Member of the Moenkopi Formation in the San Rafael Swell (Blakey, 1974, p. 50), where it is underlain by the Black Dragon Member. Typically, the Black Dragon consists of laminated to very thinbedded tan siltstone and sandstone. The lower Timpoweap at Buckskin Mountain exhibits tan and brown siltstone and sandstones reminiscent of the Black Dragon Member.

The thickness of the Timpoweap Member is 20 to 50 feet thick on and on the flanks of Buckskin Mountain, 80 to 120 feet thick in the wells of the Kanab Creek area and 50 to 150 feet thick in the Kaiparowits Plateau south of the Upper Valley oil field. At Buckskin Mountain it is difficul to separate from the underlying Kaibab Formation, the contact occurs in the middle of a slope and units above and below exhibit many of the same weathering characteristics. The Kaibab has more abundant chert and has a light gray overall hue, whereas the Timpoweap has a tan overall hue. The basal contact is generally a simple disconformity with the tan silty limestones of the Timpoweap overlying the upper cherty limestone of the Kaibab (photo 8). In Sand Gulch the lower part of the Timpoweap has scoured into the upper Kaibab and there is a thick breccia of Kaibab materials immediately above the contact.

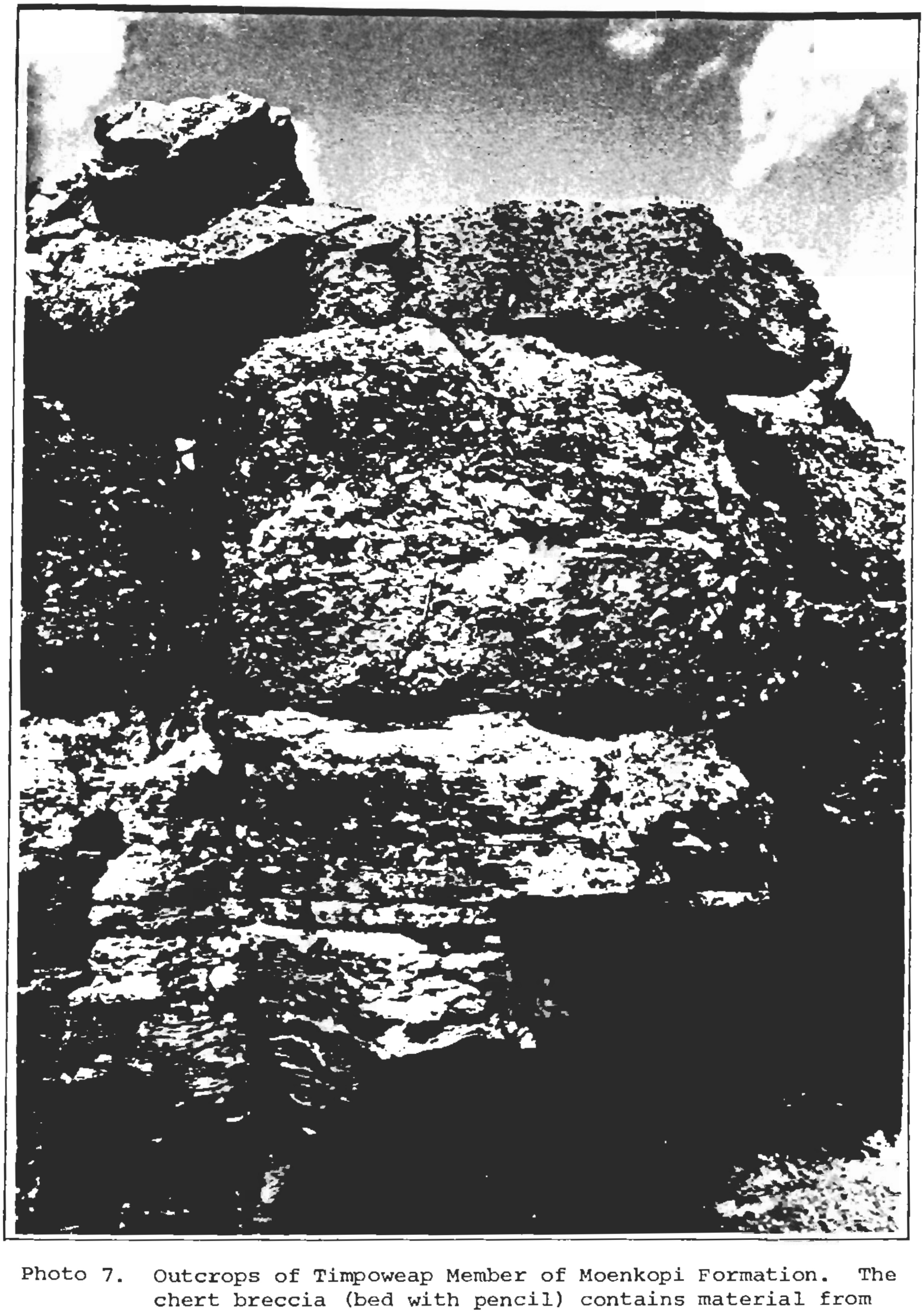


Photo 7. Outcrops of Timpoweap Member of Moenkopi Formation. The chert breccia (bed with pencil) contains material from the Permian Kaibab Formation. Sand Gulch.

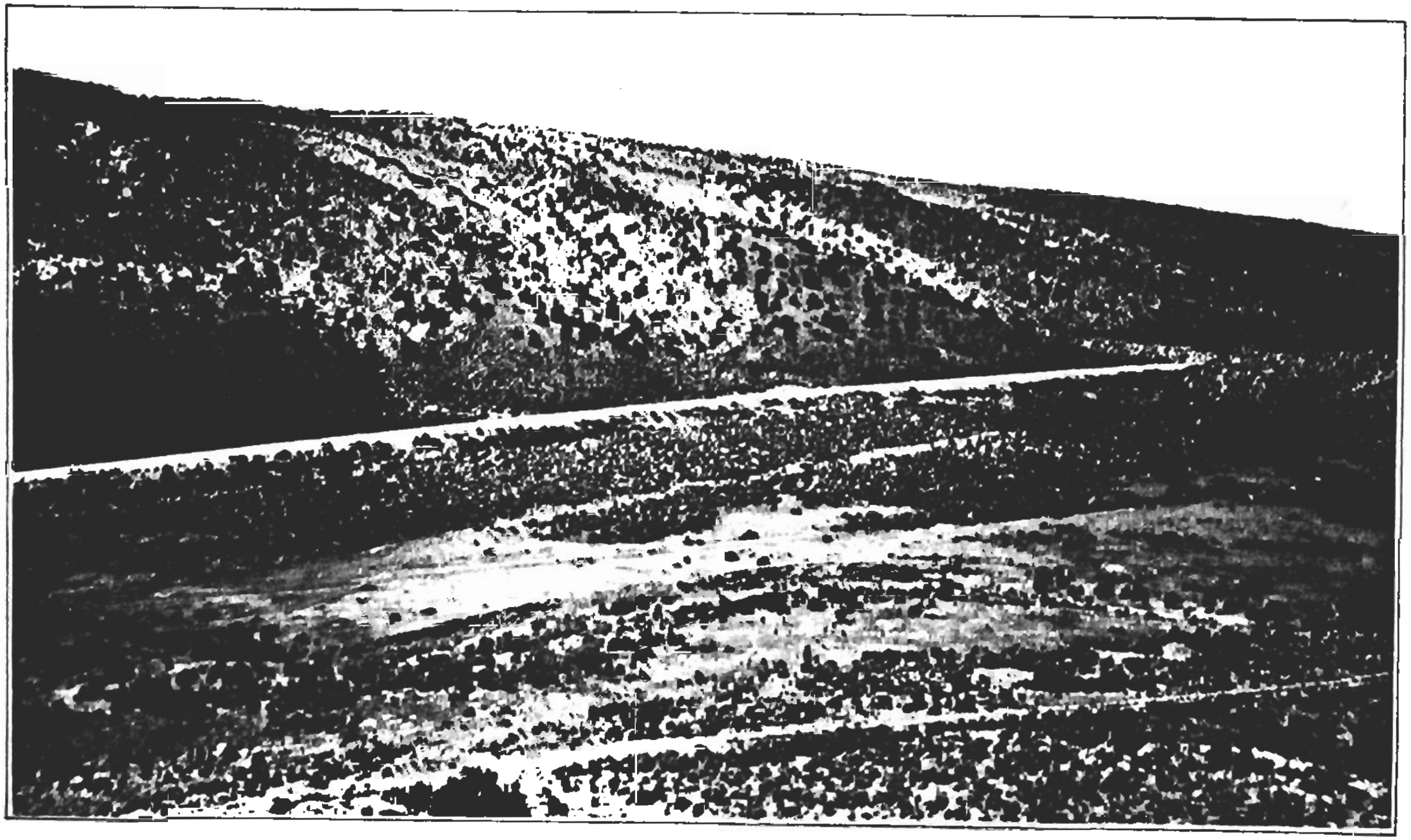


Photo 8. View westerly across U. S. Highway 89 near the north end of Buckskin Mountain. Most of the upper surface of this anticlinal mountain is surfaced with the Timpoweap Member of the Moenkopi (darker surfaces). The lighter outcrops of the Kaibab appear in many of the canyons.

Measurement of the Timpoweap Member of the Moenkopi Formation, east side of Buckskin Mountain, NE Sec. 26, T. 42 S., R. 2 W., Kane County, Utah.

(place measurement of the Timpoweap Member here)

Outcrops of the Lower Red Member are found around the flanks of Buckskin Mountain. It consists of reddish- to chocolate brown interbedded siltstone and fine-grained sandstone. The siltstone are earthy weathering and slope-forming. The sandstones are commonly silty, arkosic, and micaceous. They are platy to blocky weathering, calcareous, ripple-marked, and form slight ledges. The sandstones increase in number toward the top. The unit appears to grade into and ends under the prominent cliff or ledge of the overlying Virgin Limestone Member. Both Poborski (1954) and Gregory (1950) have reported an unconformity at the top of the Lower Red Member in Washington County and in the Zions Park area. However, at Buckskin Mountain, the contact with the overlying Virgin Limestone Member appears gradational with it (Blakey, 1970, p. 30).

The Lower Red Member was deposited on a tidal flat traversed by meandering streams (Irwin, 1976). It thickens westward across the county from less than 100 feet near Lake Powell to more than 300 feet. Near Zions National Park the Lower Red is 220 to 310 feet thick (Gregory, 1950), in the Kanab Creek wells the unit is 190 to 220 feet thick, and surrounding Buckskin Mountain, measurements indicate it to be 140 to 220 feet thick.

Measurement of the Lower Red Member of the Moenkopi Formation, near Road Canyon at the north end of Buckskin Mountain, W 1/2, Sec. 23, T. 41 S., R. 2 W., Kane County, Utah.

(place measurement of the Lower Red Member here.)

The Virgin Limestone Member of the Moenkopi is rather thin in outcrop around Buckskin Mountain, but is conspicuous because it forms a prominent ledge. The unit consists of interbedded yellow-tan cliff-forming sandstone, siltstone, and limestone. Even the limestone is sandy and grades into calcareous sandstone. The pinchout zone for the Virgin Limestone probably does not lie far to the east of Buckskin Mountain. Generally there is a lower calcareous sandstone, a thin intermediate slope-forming siltstone, and an upper calcareous sandstone or sandy limestone. The upper and lower subunits form strong ledges. In Washington County the Virgin Limestone is quite fossiliferous, containing fragments of mollusks, crinoid stems, and the guide fossil Tirolites. Ostracods and oolites are also present. The megafossils were not found at the Buckskin Mountain exposures. The Virgin Limestone was deposited in shallow marine or brackish water environments.

The Virgin Limestone beds increase from a feather edge somewhere under the Kaiparowits Plateau to more than 200 feet in the northwest corner of the county. In the Kanab Creek wells the Virgin is 30 to 50 feet thick and around Buckskin Mountain stratigraphic section measurements indicate it to range from 12 to 30 feet in thickness.

Measurement of the Virgin Limestone Member of the Moenkopi Formation near Road Canyon, SE Sec. 23, T. 41 S., R. 2 W., Kane County, Utah.

(place measurement of the Virgin Limestone Member here.)

The Middle Red Member of the Moenkopi Formation conformably overlies the Virgin Limestone in the Buckskin Mountain-Paria area. It is the thickest of all the Moenkopi Members in the Shinarump Flats and Cockscomb areas. It is exposed only east of the Paunsaugunt fault (in Kane County), to the west its outcrops are shunted into Arizona. Much of it is covered by alluvium, its softer and slope-forming nature has influenced many of the local drainages to flow along its strike, so that completely exposed sections are difficult to find. The member consists of interbedded medium brown mudstone or siltstone and light brown, tan, or gray-green, fine-grained, silty sandstone. Many of the beds are criss-crossed with gypsum veinlets (photo 9). The amount of gypsum in the Middle Red Member increases upward.

The Middle Red Member is 370 feet thick in the measured stratigraphic section given below. Blakey (1970, p. 154) measured 344 feet near Road Canyon in the NW Sec. 30, T. 41 S., R. 1 W. It is usually not differentiated in petroleum well logs, but in the Kanab Creek area Tapp (1963, p. 195) reports the member is 286 to 327 feet thick. Blakey (1974, p. 50) correlates the Middle Red Member to parts of the Moody Canyon and Torrey Members of the Moenkopi Formation in the Circle Cliffs area of Garfield County. At the Belted Cliffs at Isom Wash, 2 1/2 miles west of Virgin City in Washington County, Gregory (1950, p. 116-117) measured 436 feet of the Middle Red Member.

Measurement of the Middle Red Member of the Moenkopi Formation, west of Paria, W 1/2, Sec. 23, T. 41 S., R. 2 W., Kane County, Utah.

(place measurement of the Middle Red Member here.)

The Shnabkaib Member overlies the Middle Red Member conformably and the contact is placed at the base of the first bedded gypsum horizon (photo 10). It is also marked by a color change, from the orange tan Middle Red slopes to the whitish ledges and slopes of the Shnabkaib. The Shnabkaib Member consists of alternating white to light green silty gypsum, tan and brown very fine grained, earthy weathering sandstone, and subordinate earthy weathering red and green-gray siltstone. The ledges are produced by the gypsum beds and to a lesser extent by the sandstones.

The Kane County exposures are mostly between the Paunsaugunt fault and the Cockscomb. A small exposure is also found immediately west of the Paunsaugunt fault near the Arizona border. In the measured stratigraphic section shown below the Shnabkaib Member is 220 feet thick and Blakey (1970, p. 33) notes it to be 164 feet thick 1 mile south of the movie set along the monocline (Cockscomb) south of Paria. Tapp (1963, p. 195), in the wells of the Kanab Creek area, shows 385 to 400 feet of Shnabkaib. To the east its presence has not been recognized and Blakey (1974, p. 50) correlates it with the middle part of his Moody Canyon Member in the Circle Cliffs area. The upper contact of the Shnabkaib Member is conformable with the Upper Red Member.

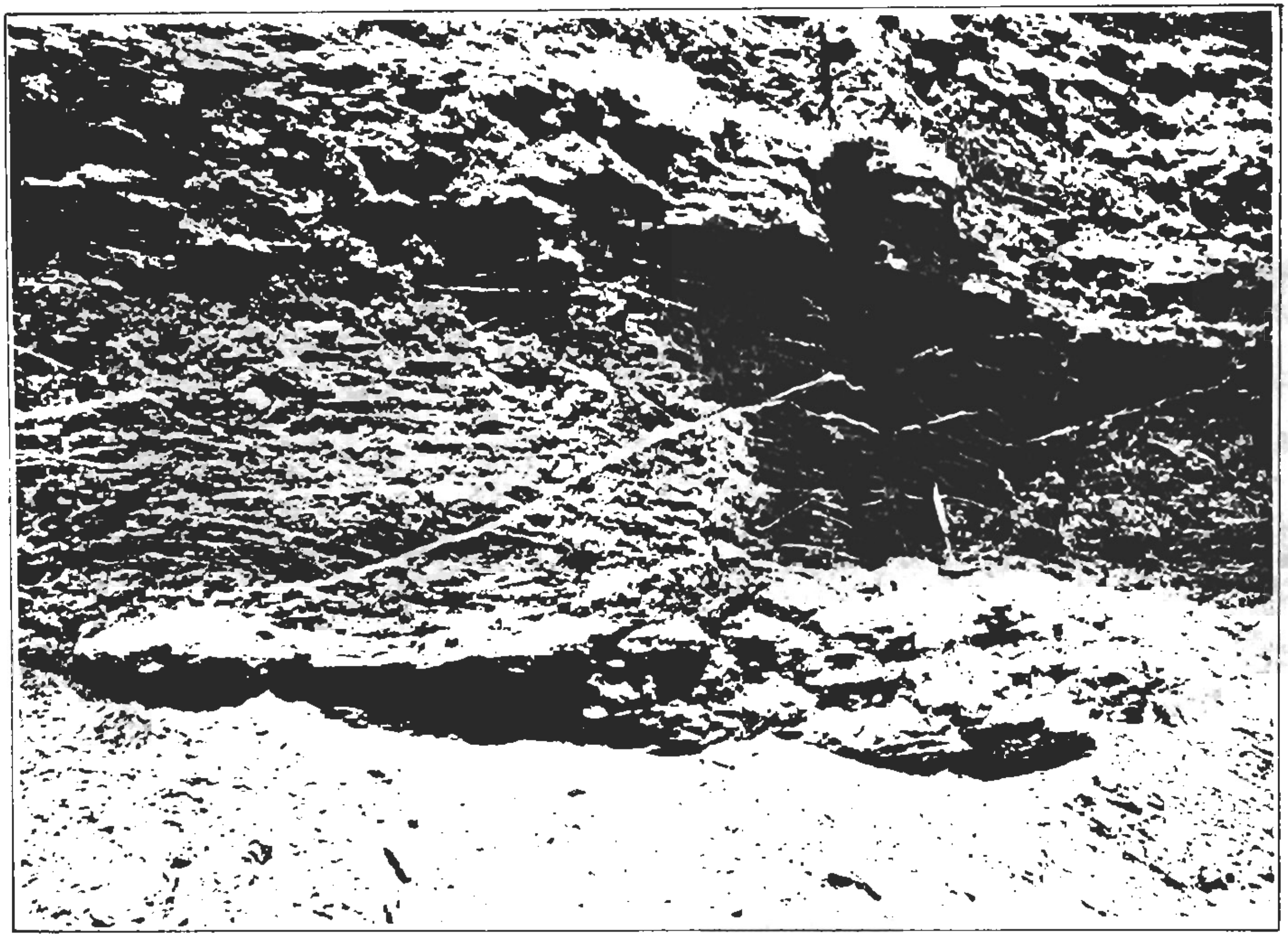


Photo 9. Crisscrossing gypsum veinlets in the Middle Red Member of the Moenkopi Formation, three miles west of Paria, Utah.

Photo 10. Moenkopi outcrops in central Kane County showing the contact between the Middle Red Member (dark) and Shnabkaib Member (upper and lighter).

Measurement of the Shnabkaib Member of the Moenkopi Formation west of Paria, SW Sec. 13, T. 41 S., R. 2 W., Kane County, Utah.

(place measurement of Shnabkaib Member here.)

The uppermost Moenkopi member is the Upper Red. Its outcrops extend from along the Arizona border at Johnson Creek northeastward along the Shinarump Flats nearly to Paria, and then turn southward along the Cockscomb. It is a brown to reddish brown unit of sandstone and siltstone. The lower half is generally slope-forming, the upper half is cliff-forming. The sandstones are light brown to reddish brown, very fine grained, ledge or cliff-forming, often micaceous and calcareous (photo 11). The principal sandstone ledges are medium bedded to massive, but can weather platy or shaly. Many of the plates are ripple-marked. The siltstones are dark brown to reddish brown and sandy, shaly to thin bedded and small flakes of mica are often present.

The upper contact of the Upper Red Member is a disconformity. It is overlain by the Shinarump Member of the Chinle Formation. The fluvial sandstones of the overlying Shinarump cut deeply into the Upper Red interval in several places (photo 12). The thickness of the Upper Red Member ranges from 99 to 164 feet around the Shinarump Flats, Paria, and along the Cockscomb. At the Shinarump Cliffs, 4 miles east of Fredonia, the Upper Red thickens to 185 feet.

Measurement of the Upper Red Member of the Moenkopi Formation, near Pioneer Gap, SWSE Sec. 32, T. 43 S., R. 4 W., Kane County, Utah.

(place measurement of Upper Red Member here.)

<u>Chinle Formation</u>. The uppermost Triassic unit exposed in Kane County is the Chinle and in most areas only two members are easily recognized. These are the basal Shinarump and the upper Petrified Forest Members. The latter is sometimes just referred to as the "Upper Member." In easternmost sections reference is also made to the Monitor Butte, Owl Rock, and Church Rock(?) Members. The Owl Rock overlies and interfingers with the Petrified Forest Member and the Church Rock(?) overlies and interfingers with the Owl Rock Member. The Monitor Butte Member is found between the Shinarump and the Petrified Forest Members and intertongues with both. In sections from the Cockscomb westward, reference is occasionally made to the Monitor Butte Member and where recognized, has the white or light tan overall color and sandy, gritty to conglomeratic nature of the Shinarump, but weathers into steep muddy slopes like the Petrified Forest Member. It is very lenticular, so that great variability in the thickness is to be expected when measuring it with the Shinarump Member.

Outcrops of the Chinle Formation wrap around the Buckskin Mountain upwarp in southwestern Kane County between Kanab and the Cockscomb. From Kanab westward the outcrops continue into Arizona and parallel the border a few miles to the south. Complete available measurements of the Chinle in this area range from 500 to 930 feet, but average 700 feet, with the Shinarump-Monitor Butte Member varying from 0 to 155 feet and averaging 55

Photo 11. Typical outcrops of the Upper Red Member of the Moenkopi near Paria, Utah. Light colored sandstone at the top is the Shinarump Member of the Chinle Formation.

Photo 12. Channel of the Shinarump Member of the Chinle Formation cutting out part of the Upper Red Member of the Moenkopi Formation 2 miles west of Paria.

feet. Tapp (1963) indicates the Chinle to be 480 to 574 feet thick in the Kanab Creek area oil tests (northwest of Kanab), with only 3 to 13 feet of Shinarump Member.

The upper Chinle is exposed in three deep canyons in northeastern Kane County; in the Escalante River Canyon, Stevens Canyon, and along Lake Powell opposite the Rincon. The latter is a complete exposure, but the lower part is now inundated by the lake. Stewart, Poole, and Wilson (1972, p. 301-306) measured the Chinle at the Rincon in San Juan County and measured 113.4 feet of Church Rock(?), 283.0 feet of Owl Rock, 223.0 feet of Petrified Forest, 225 feet of Monitor Butte, and 194.9 feet of Shinarump Member for a total of 1,039.5 feet (photo 13).

Thicknesses reported in wells between the Cockscomb and these northeastern exposrues range from 614 to 1,103 feet and average 750 feet. There are no uniform thickness trends across the county, but it appears that there is thinning from the southeast (1,000+ feet) to the northwest (450 feet). Variations of 150+ feet should not be considered unusual.

The lower sandstone and conglomerate member(s) of the Chinle Formation in Kane County are generally ascribed to the Shinarump Member, but detailed workers have also recognized the Monitor Butte Member. In Stewart, Poole, and Wilson's measurement at the Rincon, the Shinarump consists of nearly 200 feet of sandstone and conglomeratic sandstone that is very pale orange, grayish orange, yellowish gray, or very light gray in overall color. The sandstone is medium to coarse grained, fairly sorted with granules and pebbles up to 1 1/2 inches in diameter. The cementation is irregular and there is common carbonaceous and petroliferous material present. Crossbedding is present with thin to thick sets of medium scale low angle cross-laminae. The unit weathers to form a steep ledgy slope with the upper 40 feet making a prominent cliff. The Clyde Kissinger #1 Rincon Dome well, SESW Sec. 3, T. 40 S., R. 10 E., drilled across the lake in Kane County, recorded only 80 feet of Shinarump Member and indicates that the unit is extremely variable in thickness rather than indicating erros in picking the top.

The Shinarump is overlain by more than 250 feet of Monitor Butte Member, mostly silty claystone with subordinate amounts of sandstone and occasional limestone. The overal color is greenish-gray with lesser horizons of grayish-red or olive-gray. There ar occasional prominent ledges, but the unit usually forms steep earthy slopes. Carbonaceous material is often abundant. Across Lake Powell, in Kane County, the Shinarump is mostly inundated and that part of the Monitor Butte still exposed is largely covered by talus rubble or deformed by slumping.

The upper units have also participated in the slumping. That part of the Chinle Formation immediately under the Wingate Sandstone (upper 1/3d or 1/4th) has not participated in the slumping, but is covered by a thick veneer of talus. At the Rincon the Petrified Forest Member (223 feet) consists mostly of pale reddish brown siltstone, clayey siltstone, with lesser amounts of interbedded clayey very fine to fine grained sandstone, light greenish gray limestone and rare silty sandy granule conglomerate.

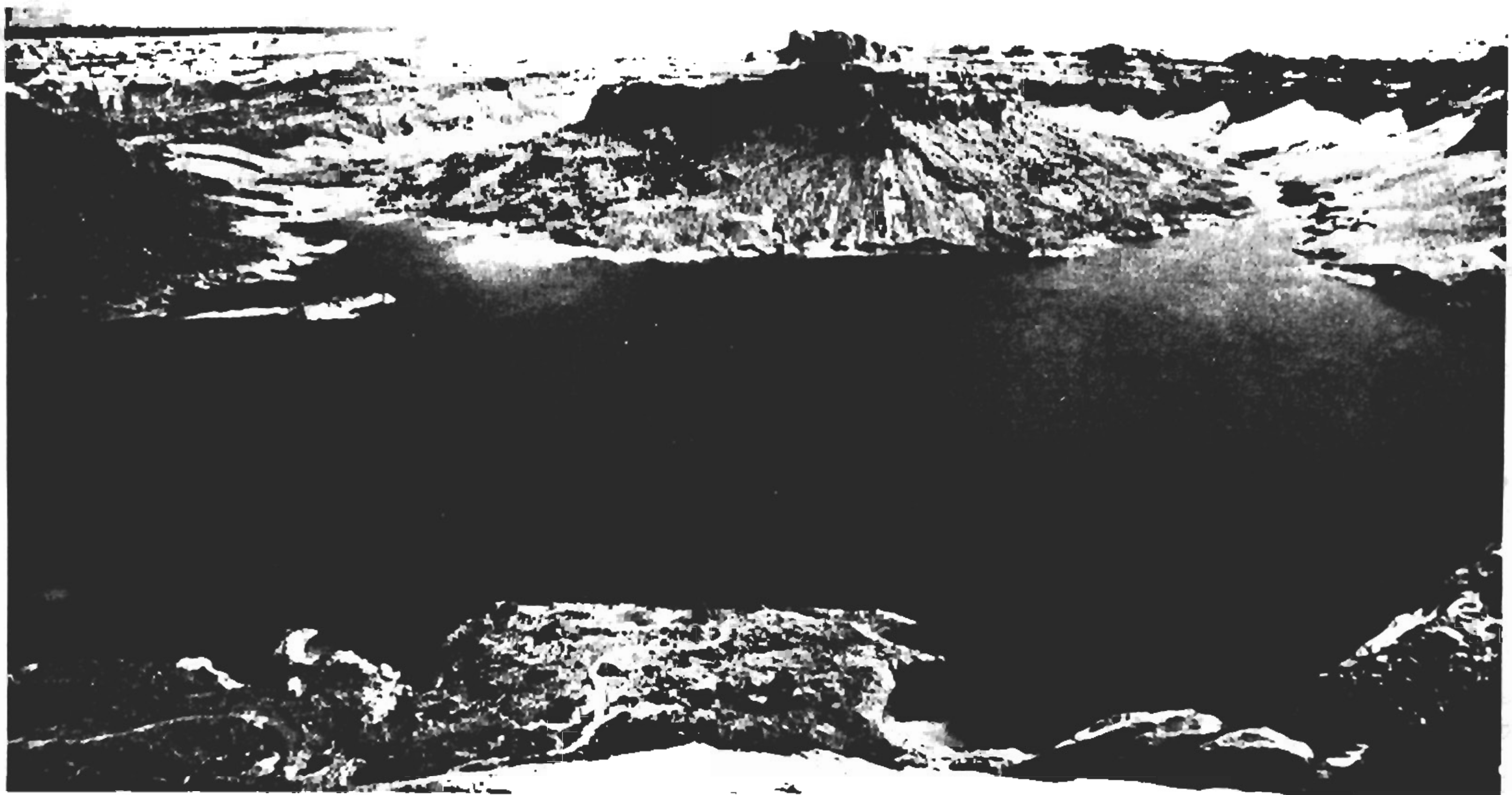


Photo ~~14~~ 13. View southward across Lake Powell to the Rincon of the Colorado River. The view is from Kane County into San Juan County. Note the Circle Cliffs anticline, the Chinle Formation slope and the Wingate and Kayenta Formations.

The Owl Rock Member (283 feet) overlies the Petrified Forest Member and consists of pale red siltstone with subordinate amounts of pale red or light greenish gray limestone developed as thin beds or as limestone pebble conglomerate. Some light greenish gray calcareous sandstone is also present. The whole unit forms a steep slope with occasional slight ledges of limestone. At the top is the Church Rock(?) Member, the lower 1/3d of which is reddish orange siltstone to very fine-grained sandstone that forms a ledge slope. The upper 2/3ds is cliffy, as is the overlying Wingate Sandstone, and is composed of very fine to fine grained moderate orange pink sandstone in blocky medium to thick beds. Some of the blocky sandstones are separated by shaly, darker weathering partings.

The upper members are also exposed in the deep canyons of the Escalante River and its tributaries to the north. The descriptions are similar. The steep reddish slopes are usually covered by the talus generated from the disintegration of the overlying Wingate Sandstone.

Around Buckskin Mountain, to the west, the Chinle Formation is found at the foot of the Vermilion Cliffs and the Cockscomb (East Kaibab monocline) as steep badland slopes or as poorly exposed hills, partly or completely covered by Quaternary alluvium and talus. Blakey (1970), has recognized the presence of four members near the abandoned townsite of Paria; the Shinarump, Monitor Butte, Petrified Forest, and Owl Rock Members. At Petrified Hollow and at Paria, Stewart, Poole, and Wilson (1972, p. 259-260) have recognized only the Petrified Forest and Shinarump Members. The question relates as to whether the members, as they appear in eastern Utah, truly correlate or are continuous with those in Kane County and southwestern Utah. Blakey's lithologies are at least similar to the corresponding units as found in eastern Utah.

Originally the "Shinarump Conglomerate" was designated a formation (Powell, 1873, p. 458; Gilbert, 1875, p. 176; and Howell, 1875) with the type section being the Shinarump Cliffs that extend from Pioneer Gap westward along the Utah-Arizona line to Kanab. In 1876, in "Geology of the Uinta Mountains," Powell proposed the name Shinarump Group and included the present Moenkopi, Chinle, and probably the Moenave Formations. In his section, measured along Kanab Creek in 1871, he lists 800 feet of badland sandstones, rapidly disintegrating; argillaceous; weathering in variegated hills" above the conglomerate. The Moenkopi Formation was separated out by Ward (1901, p. 403) and the Chinle was named by Gregory (1917, p. 43), both with type sections in Arizona. Finally Harshbarger and others (1957, p. 12-15) separated out the Moenave Formation, also with a type section in Arizona.

The Chinle Formation was intensively studied during the uranium boom of the 1950s and the "Shinarump Conglomerate" was reduced to a member of the Chinle Formation by Longwell (1952) and Stewart (1957). Stewart, Poole, and Wilson, (1972, plate 2), in a fence diagram, show the Shinarump Member to be variable in thickness but reasonably continuous in the Kanab area and discontinuous around Paria. This is confirmed by our observations, the continuous outcrops begin at Petrified Hollow and extend westward. The Shinarump also appears to be more continuous along the Cockscomb near the Arizona border (south of Catstairs Canyon). The more continuous Shinarump may be limited to the southern edge of Kane County, with exposures to the north becoming discontinuous. The Shinarump was deposited by rivers and streams that flowed from south to north. In the discontinuous areas the Shinarump cut channels into the underlying Moenkopi up to 80 feet deep. An outstanding channel is found two miles west of the abandoned townsite of Paria which has cut 30 feet into the Upper Red Member and is 400 feet wide. To the south, in the continuous area, the deposition probably occurred in a series of adjoining fans.

In the Shinarump Cliffs, in the continuous area, the Shinarump Member consists of lenticular and massive, cliff-forming beds of conglomerate, conglomeratic sandstone, and sandstone, with occasional thin partings of green or gray mudstone. The conglomerates are well cemented, the pebbles and cobbles do not exceed 3 inches in diameter and are composed of varicolored quartzite, quartz, chert, and sandstone. The matrix of these conglomerates often consists of calcareous grit. The conglomerates occasionally contain logs of petrified wood. The sandstones are usually medium to coarse grained, are poorly sorted and crossbedded, and exhibit an overall light gray color. Granules are often aligned along the crossbed laminae. In the Shinarump Cliffs area the unit is 6 to 50 feet thick.

In the southern part of the Cockscomb (East Kaibab monocline), the Shinarump is a yellowish-gray conglomeratic sandstone that displays small to medium scale, medium to high angle trough crossbedding. The sandstone is medium to coarse grained. The pebbles and grit occur as stringers and average 3/4 to 1 inch in diameter and are composed of quartzite, chert, petrified wood, and sandstone. It is 20 to 40 feet thick in most exposures.

The channel west of Paria is unusual in that the conglomeratic component is greatly diminished. The channel consists of a massive, crossbedded, cliff-forming, nearly white to yellowish gray, fine to medium grained quartzose sandstone. The few pebbles and granules are aligned along the crossbed laminae. Measurements along the 400 foot channel show the unit to be 80 to 110 feet thick. The Shinarump Member is discontinuous from U. S. Highway 89 northward to Paria and westward to Petrified Hollow. In another exposure of the Shinarump, near Kitchen Corral Canyon, the unit is again conglomeratic, but only about 25 feet thick.

Blakey (1970) recognized the Monitor Butte Member (with some reservations) in the Paria area. Phoenix (1963) used the term "sandstone and mudstone unit" for rocks overlying the Shinarump Member and underlying the Petrified Forest Member in the Marble Canyon area. This is the interval occupied by the Monitor Butte Member northeast of the area as recognized by Stewart, Poole, and Wilson (1972, plate 2). Repenning and others (1969, p. B18) indicate the unit is missing at Paria due to intertonguing with the Petrified Forest Member. Most workers have included these rocks with the Petrified Forest Member, a few have preferred to identify the unit. Lithologically it is dissimilar to the remainder of the Petrified Forest Member. It is mostly light colored sandstone with interbeds of gray silty mudstone or siltstone. The sandstones are thinbedded to massive, fine to medium grained and some horizons are gritty and even pebbly. This unit contains much of the petrified wood, especially where the Shinarump is absent. Jet coal was discovered in the unit near Petrified Hollow. Toward the top the mudstones, sandstone, nodular weathering brown limestones and gritty conglomeratic sandstones are complexly interbedded and highly lenticular. It grades upward into the variegated banded steep slopes of the Petrified Forest Member. The unit weathers into steep slopes like those of the overlying unit, but the slopes are interrupted by ledges, which increase toward the base. The unit is relatively continuous where the Shinarump is discontinuous, but appears to be missing or unimportant where the Shinarump is continuous. Thicknesses are variable, ranging from 0 to 185 feet. Part of the problem is the difficulty in properly defining the upper limit.

Gregory (1948, p. 238) records 40 to 60 feet of brown and gray sandstone at the base of his Petrified Forest Member. We recognize 50 feet at Petrified Hollow. At Paria, Blakey (1970, p. 156) measured 185 feet, and we measured only 62 feet in the southern part of the Cockscomb. Akers (1960) recognized no Monitor Butte, but indicates than an horizon of petrified wood exists 100 feet above the Shinarump Member and that the lower 50 feet are generally covered.

The thickness of the lower Chinle Formation members in well logs are usually lumped and are recorded as Shinarump. The Monitor Butte or lower Petrified Forest lithologies are the same or nearly the same as those of the Shinarump Member. The weathering characteristic differences are not available in the well cuttings. All borehole thicknesses for the Shinarump are thicker than surface observations indicate, except in the Mt. Carmel-Kanab Creek area, where only the lower conglomeratic horizons are ascribed to the member. Table 8 gives a listing of both the Shinarump and Chinle thicknesses as recorded from Kane County boreholes.

Stewart, Poole, and Wilson (1972, plate 2) show the Owl Rock Member extending westward to about the 112° Meridian in Kane County, near the townsite of Paria. Most investigators have recognized only the Petrified Forest Member at Paria and westward. Even Stewart, Poole, and Wilson (p. 261-264) did not consider the Owl Rock Member present at Paria. Only Blakey (1970, p. 155) has recognized its presence. The upper unit might be recognizable in detail, but is not mappable, hence the entire upper part of the Chinle is best designated the Petrified Forest Member. The member is best described as composed of varicolored and banded, badlands forming (steep slopes) mudstone and friable muddy sandstone, that also contains occasional horizons of conglomerate, siltstone, gritstone, and lavender or brown weathering nodular limestone. The best exposure is located near the abandoned townsite of Paria on what has been called Gingham Skirt Butte (photo 14). The color bands are bright and scenic with red, pink, reddish brown, lavender, purple, white, brown, yellow, maroon, and gray-green. This section is dominated by the mudstone, but in other locations muddy sandstone dominates. The upper 100 feet (Blakey's Owl Rock Member) is described as horizontally bedded, non-bentonitic mudstone and sandy siltstone that is moderate reddish brown or yellow-gray.

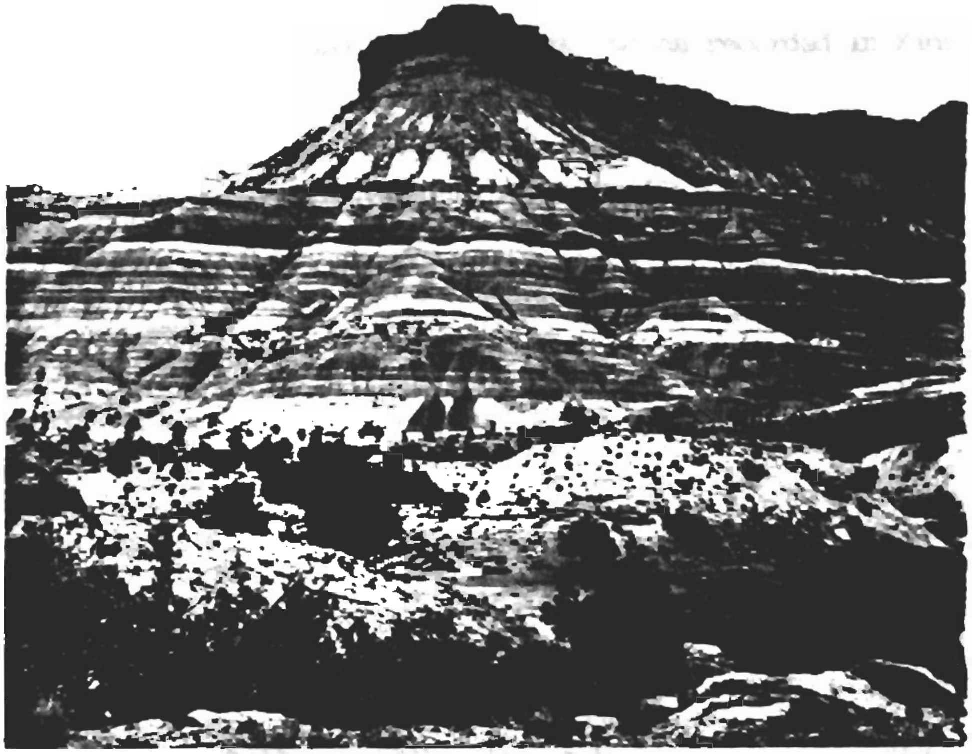


Photo 14. Gingham Skirt Butte near Paria, Utah. The brightly banded Petrified Forest Member of the Chinle Formation is beautifully exposed near Paria. The light outcrops near the base of the hill consist of the Monitor Butte Member. The Moenave and Kayenta Formations form the cliff at the top of the butte.

Table 7. Thicknesses of the Chinle Formation as recorded in Kane County boreholes.

Borehole	Location	Shinarump	Chinle	Total
Amerada Hess #1 Fed Skyline	SWNW 6-38S-1E	103	511	614
Tenneco Oil #1 So. Upper V.	NENE 16-38S-2E	150	655	805
Sun Oil #1 Lyons Federal	SENE 8-38S-3E	134	566	700
Amerada Hess #1 Midwest	SESE 12-38S-1W	143	502	645
Texaco #N-1 Schneider A	SESW 5-38S-4E	116	605	807
Great Western #2 Rees Cyn	SWSW 28-39S-4E	244	563	807
G. C. Bingham #1 Richter	SWSE 34-39S-7E	165	590	755
Webb Resources #28-13	SWSW 28-39S-8E	86	715	801
Marathon #1 Butler Valley	NENE 22-39S-1W	93	660	753
Tenneco #1 Tibbet Canyon	NENE 19-40S-2E	125	585	710
Byrd Corp. #1 Rees Canyon	SE 5-40S-5E	181	550	731
Cleary Funds Romex #1-16	NWNE 16-40S-5E	190	650	840
Shell #1 Soda Springs	SENW 2-40S-7E	140	603	743
W.W.West #1 Letts Federal	NWNE 11-40S-7E	103	633	736
Romex #1 Fed. Rock Creek	NWNW 19-41S-7E	196	625	821
Sojourner #1 Burger	NWSE 12-41S-8 1/2 E	158	711	869
Superior #32-16 Kanab Cr	SWNE 16-42S-7W	13	451	464
J. R. McDermott #2 Mt. C.	NENW 17-42S-7W	3	510	513
J. R. McDermott #1 Strat	SENW 19-42S-7W	5	469?	474?
Union Oil Calif #1 Judd H.	SWNW 19-43S-2E	209	894	1103
J. R. McDermott #1 State	SWSW 2-43S-8W	9?	471?	480

Akers (1960) measured 577 feet of Petrified Forest Member near the Arizona line along the Cockscomb with a total of 614 feet for the Chinle Formation. Several measurements were taken near Paria, near Gingham Skirt Butte. Blakey (1970) measured 582 ft (847 total Chinle), Akers (1960 measured 497 feet two miles south of Paria (608 total Chinle), we measured 556 feet (711 total Chinle), and Stewart (in Stewart, Poole, and Wilson, 1972, p. 261-264) measured 652 feet 2 miles NNW of Paria (652 total Chinle-no Shinarump). The color bands exposed at Paria seem to be coninuous and maintain even thicknesses at first glance, but close examination reveals them to be moderately lenticular, which may explain the 497-652 foot variation in measurements. At Petrified Hollow Craig and Mullens (in Stewart, Poole, and Wilson, p. 258-261) measured 519 feet (527 feet total Chinle) and we measured 628 feet (698 feet).

Measurement of the Chinle Formation at Petrified Hollow, Sec. 2, T. 43 S., R. 4 W., Kane County, Utah.

(place measurement of the Chinle Formation here.)

Gregory (1950, p. 123-124) measured the Petrified Forest Member 2 miles west of Kanab and recorded 902 feet (929 feet total Chinle), but well over 400 feet of the section was covered. Much of his section is sandstone as well as shale (mudstone). He also identifies the presence of marl and gypsum. This relatively thick measurement disagrees with what is reported in boreholes a few miles to the north (see table 7), and on

Stewart, Poole, and Wilson's (1972, plate 3) isopach map for the Chinle Formation.

Jurassic Formations

Jurassic rocks were deposited across Kane County averaging 3,100 feet to the east and 3,500 feet to the west. These rocks are represented by 5 to 8 formations, in ascending order; Wingate-Moenave Formations, Kayenta Formation, Navajo Sandstone, Page-Temple Cap Sandstones, Carmel Formation, Entrada Formation, Summerville-Summerville?-Romana Mesa-Henrieville Formations, and the Morrison Formation. Fewer formations are generally present in the western part of the county because of a regional unconformity at the top of the System which gradually truncates units east to west. To the east the uppermost recognized Jurassic unit is the Morrison Formation and to the west the uppermost Jurassic unit is the Carmel Formation. The distribution of Jurassic rocks in Kane County is shown in figure 17.

The Glen Canyon Group of formations have generally been regarded as Jurassic-Triassic in the past. In recent explanations by Pipiringos and O'Sullivan (1978) and Imlay (1980), the age of the Group is being re-evaluated and thought to be entirely Jurassic. The new age assignment is followed in this publication.

Wingate and Moenave Formations. The unit that overlies the Triassic rocks in the western half of the county is the Moenave Formation and in the eastern half is the Wingate Sandstone. In the middle of the county, along the East Kaibab monocline (The Cockscomb), both have been recognized with the Moenave resting on thin tongues of Wingate Sandstone. Blakey (1970, p. 53) recognized 42 feet of the Wingate Sandstone in the central part of the Cockscomb and about 60 feet near Paria. The lower contact of the Wingate (with the Chinle Formation) is described as a planar, sharp unconformity and the upper contact with the Moenave as gradational or intertonguing (figure 18). Stewart, Poole, and Wilson (1972, p. 262) also recognize the Wingate? Sandstone at Paria, where they measured 69.5 feet. About 4 1/2 feet of Wingate(?) is exposed in a slide near the Manganese King mine, in Sec. 2, T. 42 S., R. 3 W., about 100-200 feet west of a water well drilled to supply wash water for the mining operation. It is found at the base of the slumped Moenave, has the typical Wingate lithology and color with a 6 inch white bleached top.

In the subsurface the Wingate thickens easterly and where the unit is again exposed in the deep canyons of the Colorado and Escalante River, it is 200 to 300 feet thick and immediately overlain by the Kayenta Formation. West of Kitchen Corral Wash (Manganese King mine), the thin Wingate cliff disappears, and along the remainder of the Vermilion Cliffs the interval between the Chinle and Kayenta Formations is entirely filled by the 300 to 500 foot Moenave Formation. In drill holes east of the Cockscomb only the Wingate Sandstone has been recognized, which is only 100-200 feet thick around the northern part of the Cockscomb. Bower (1983), reports only 75 to 100 feet in the Butler Valley area.

The relationship between the Wingate and Moenave has been explained by Harshbarger, Repenning, and Irwin (1957, p. 8-17). Apparently they intertongue in the subsurface, but a tongue of the Wingate persists under

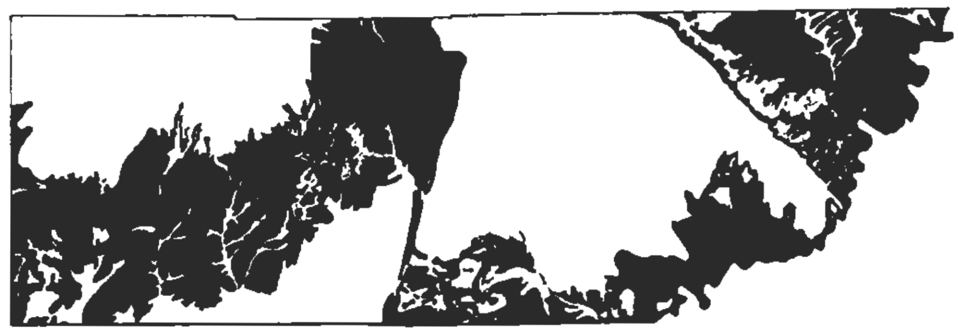


Figure 17 Jurassic outcrops of Kane County

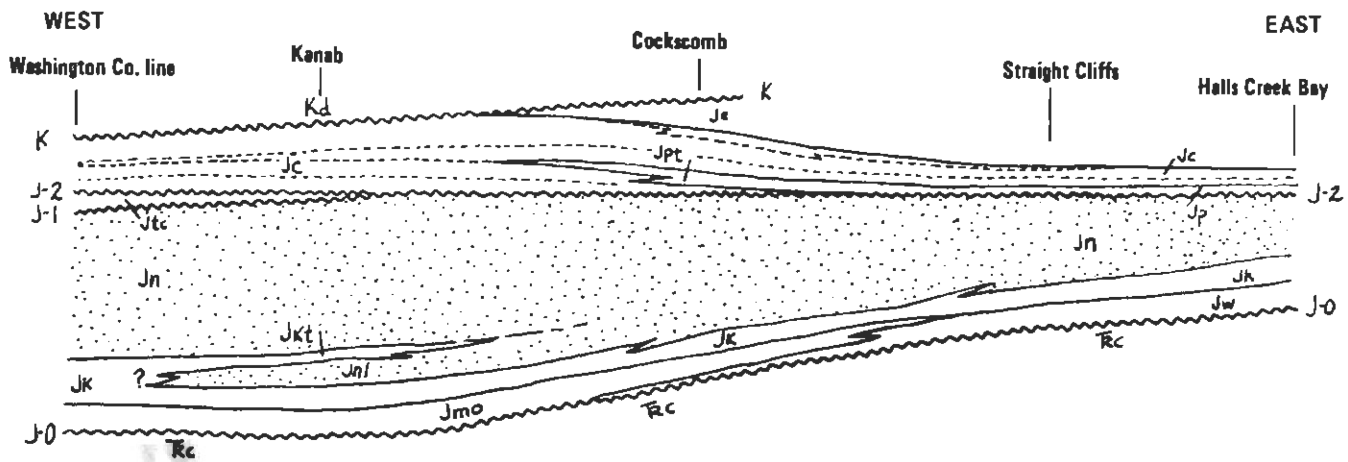


Figure 18. Generalized restored section of Glen Canyon Group and neighboring formations, east-west across Kane County. Unconformity designations after Pipiringos and O'Sullivan, 1978; J-0, J-1, J-2= Jurassic unconformities and K=basal Cretaceous unconformity. TRc= Chinle Formation, Jmo=Moenave Formation, Jw=Wingate Sandstone, Jk=Kayenta Formation, Jkt=Tenney Canyon Tongue of Kayenta Formation, Jnl=Lamb Point Tongue of Navajo Sandstone, Jn=Navajo Sandstone, Jtc=Temple Cap Sandstone, Jp=Page Sandstone, Jpt=Thousand Pockets Tongue of Page Sandstone, Jc=Carmel Formation, Je=Entrada Sandstone, and Kd=Dakota Formation.

the main body of the Moenave for a considerable distance (figure 18). Phoenix (1963, p. 26 and plate 2) recognized no Wingate Sandstone at Lees Ferry, Arizona, but Wilson (1965, p. 38) assigned 42 feet of the basalGlen Canyon Group at this location to the Wingate(?) Sandstone. The basal rocks of the Glen Canyon Group are Wingate-like at many places between Lees Ferry and Paria. In others it appears that only the Moenave Formation is present. Westward extending tongues may appear intermittently along the outcrops or they may not even be attached to the main mass of the Wingate Sandstone as exposed to the east. In northwestern Kane County information is not available about this interval because deep wells have not been drilled there. Wells drilled in the southwestern part of the county in the Kanab Creek area (Tapp, 1963) indicate that the Moenave Formation is present in the subsurface.

To the east the Wingate Sandstone (Dutton, 1885, p. 136-137) is represented by a single member, the Luckachukai Member (Harshbarger, Repenning, and Irwin, 1957, p. 10-12). Since there are no other members in Kane County, the unit is simply called the Wingate Sandstone as suggested by Stewart, Poole, and Wilson (1972, pl. 2). The Wingate Sandstone is exposed along the Colorado River (Lake Powell) opposite the Rincon from Iceberg Canyon westward to Bowns Canyon and again along Pollywog Bench near the mouth of the Escalante River. At most of these exposures only the upper part extends above the water level, but the whole unit is exposed along a stretch of four miles opposite the Rincon. The formation also appears in the canyons of the Escalante River and its tributaries from the juncture of the Escalante River and Stevens Canyon northward. The Wingate has been elevated at both eastern Kane County locations by the southward extension of the Circle Cliffs uplift. It is a prominent cliff-forming sandstone, mostly 240 to 400 feet thick, found between the slope-forming Chinle beneath and the step-like to cliffy Kayenta Formation above. Usually the towering Wingate cliff is nearly vertical with few horizontal bedding planes. The cliff is often stained dark brown to black with desert varnish, but is a light brown or orange brown on fresh surfaces. It erodes along vertical fractures that spall down the entire thickness of the unit. Wherever the Chinle is exposed beneath, it is littered with broken pieces of the Wingate Sandstone (photo 15). Close examination of the cliff walls reveal large scale, eolian type crossbeds and thick bedding. Weathering rarely etches out these features.

The Wingate Sandstone consists of very fine to fine grained, quartz grains, mostly lightly to moderately cemented with calcium carbonate. The contact with the Chinle Formation is sharp, easily identified with little or no relief, and is probably everywhere unconformable. In eastern Utah, where the Church Rock Member is identifiable, the Wingate-Chinle contact is thought by some to be conformable (Stewart, Poole, and Wilson, 1972, pl. 2), but where the Church Rock Member is missing the contact is unconformable. The Church Rock Member of the Chinle Formation is correlative with the Rock Point Member of the Wingate Sandstone of northern Arizona. Pipiringos and O'Sullivan (1978, p. A19) extend their J-0 unconformity everywhere under the Wingate and reject the Rock Point as a member of the Wingate Sandstone.

Photo 15. Lake Powell view of lower part of Glen Canyon Group. At base of cliff are mostly mass-wasting deposits covering the Chinle Formation. The lower part of the vertical cliff is the Wingate Sandstone and the upper part is the Kayenta Formation. The prominence in the middle is built of the lower part of the Navajo Sandstone. Compare this photo with photo 19. Ꞧc = Chinle Formation, Jw = Wingate Sandstone, JK = KAYENTA Formation, Jn = NAVAJO SANDSTONE

We made no attempt to map the Wingate(?) where it intermittently appears beneath the Moenave. For practical purposes only the Moenave is exposed between the Chinle and Kayenta Formation from the East Kaibab monocline (Cockscomb) westward. The Moenave Formation (Harshbarger, Repenning, and Irwin, 1957, p. 13-15) has three members in Kane County, which are not separated on the geologic map because they usually appear in a cliff (Vermilion Cliffs), making the plan view outcrop bands too narrow at the 1:100,000 scale (photo 16). These include a lower Dinosaur Canyon Member (Colbert and Mook, 1951, p. 151), a Whitmore Point Member (Wilson, 1958, p. 81) and an upper Springdale Sandstone Member (Gregory, 1950, p. 67).

The Dinosaur Canyon Member is mostly reddish orange to reddish brown siltstone with lesser amounts of very fine grained sandstone, claystone, and conglomerate. The other lithologies also reflect the dominant reddish coloration of the formation. The percentage of sandstone and coarse siltstone increases to the northeast and in outcrop is greatest northeast of Paria (Wilson, 1958, pl. 7). The coarser siltstones are calcareous and form thinbedded ledges, the finer ones are very thinbedded to laminated and characteristically form slopes. The siltstones are generally composed of angular fragments of quartz and the finer the clastic particles the greater the clay content.

In the sandstones over 90 percent of the grains are of clear quartz that are free from inclusions; the remainder consist of partly argillitized feldspar, chert, hematite, ilmenite, magnetite, garnet, tourmaline, and occasional mica. The sand is usually well-sorted, subangular to subround and loosely cemented with carbonate (calcite). The sandstones are usually found in thin to thick flat beds (photo 17). Conglomerate is occasionally reported present at the base of the unit, just above the Chinle Formation, the pebbles consists primarily of chert or clay pellets.

The member varies in thickness from 100 to 220 feet. Where the Wingate(?) is separated out and recognized along the monocline, the thickness of the Dinosaur Canyon Member may be less than 100 feet. The member thickens somewhat from Paria westward and southward and in Kitchen Corral Canyon and at Petrified Hollow is over 200 feet thick. South of Catstairs Canyon it is also mostly over 200 feet thick (combined Wingate(?) Sandstone and Dinosaur Canyon Member). West of Petrified Hollow the unit is a constant 150 to 200 feet thick. Tapp (1963), reporting the thicknesses of units drilled in the Kanab Creek area, shows the Dinosaur Canyon Member to vary from 370 to 419 feet, decidedly thicker than the 150 to 200 feet indicated for the outcrops along the Vermilion Cliffs.

West of Johnson Canyon the Dinosaur Canyon Member is overlain by the Whitmore Point Member. Since the Whitmore Point tongues into the lower part of the overlying Springdale Sandstone Member, some Springdale lithologies are included in its makeup. The member, as a whole, is difficult to separate from the Dinosaur Canyon when viewing the Vermilion Cliffs from a distance. It is a grayish or brownish red siltstone and

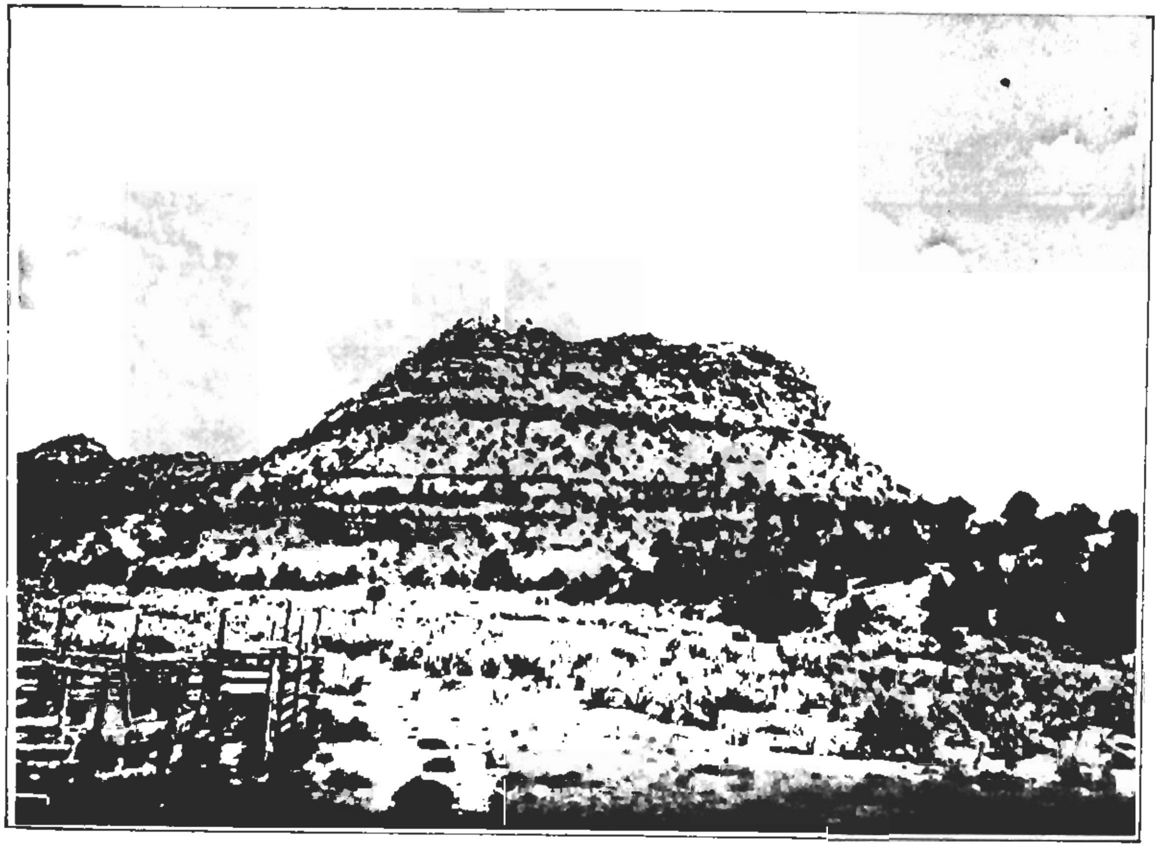


Photo 16. Exposure of Moenave Formation along the Vermilion Cliffs near Kitchen Corral Wash. The top of the Triassic Chinle Formation is just above the valley level and the base of the Kayenta Formation is at the very top of the butte.

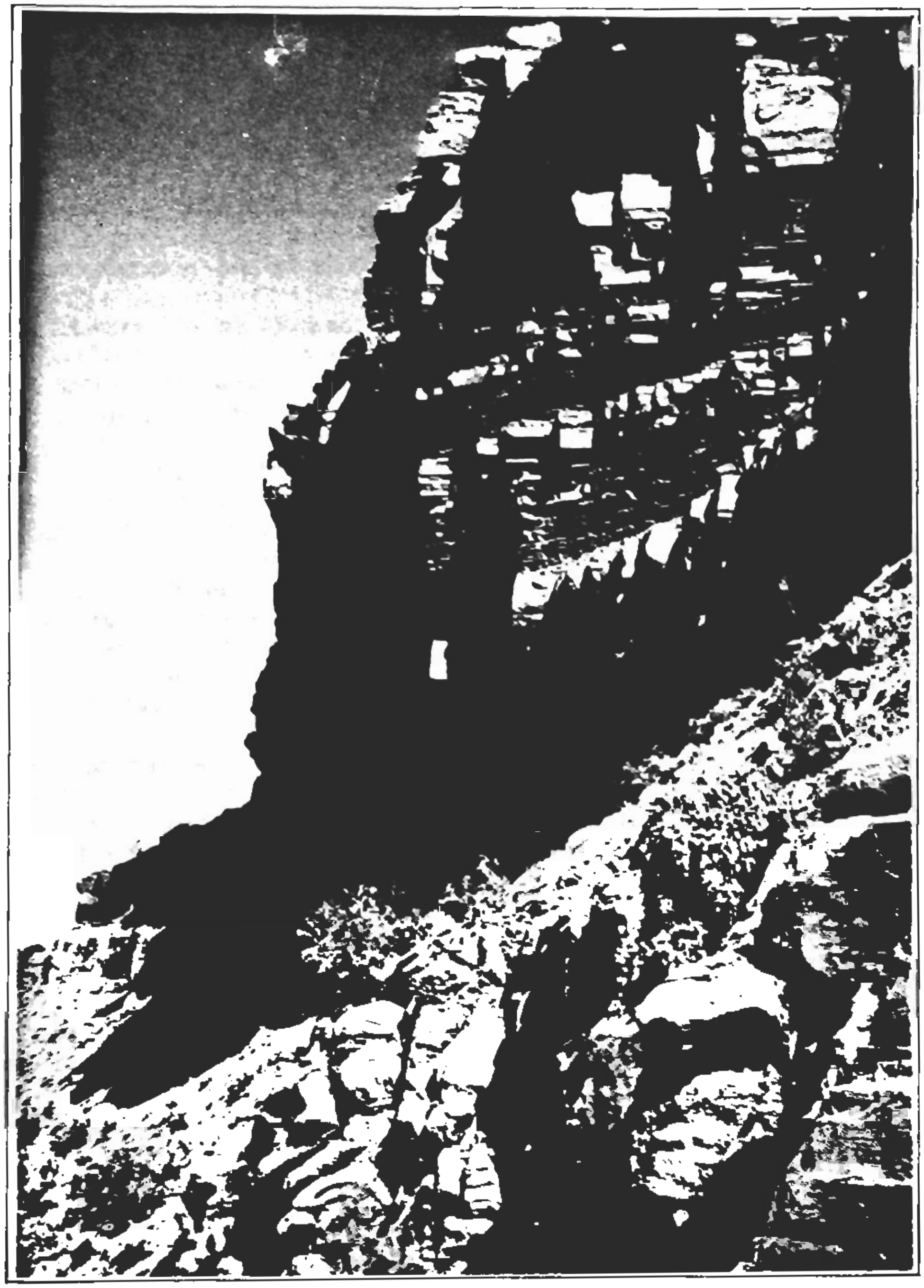


Photo 17. Thin to thick flat beds of the Moenave Formation on Gingham Skirt Butte near the abandoned townsite of Paria, Utah. The Moenave forms nearly unscalable cliffs in this area.

claystone unit interbedded with the pale red, fine grained sandstones typical of the overlying Springdale Sandstone. The siltstones and claystones are similar to those in the Dinosaur Canyon Member, but have a decided grayish or brown cast. The claystone is generally variegated and found in homogeneous units to 10 feet in thickness.

The Whitmore Point Member has yielded some interesting fresh-water fish fossils in the Kanab area. These were first discovered by C. D. Walcott in 1879 and were later described by Eastman (1905, 1917) as species of Lepidotus and Pholidophorus. Eastman described a new species, Lepidotus walcotti. Later studies by Schaeffer and Dunkle (1950) reassigned the Pholidophorus sp. as Seminotus kanabensis, a new species. Wilson (1958, p. 88) discovered additional fish horizons in the Whitmore Point Member. These fossils were dated as Upper Triassic and for this reason the lower Glen Canyon Group formations have appeared on most geologic maps as Triassic in age. Imlay (1980, p. 97) cites the presence of palynomorphs from the basal 15 feet of the Whitmore Point Member that have been dated of late Sinemurian to early Pliensbachian age or Lower Jurassic. It is assumed that the fish have a greater stratigraphic range than formerly thought.

The depositional environment of the Whitmore Point Member is apparently the same as for the Dinosaur Canyon Member, but lake covered flood plain-mud flat environments dominated at the expense of the fluvial channels. The thickness of the Whitmore Point Member in the Kane County outcrop areas ranges from 55 to 85 feet.

The upper Springdale Sandstone Member is mostly a fine to very fine grained sandstone with subordinate intraformational conglomerate that forms a cliff. It is a relatively uniform unit of lenticular overlapping beds of crossbedded sandstone. Occasionally thin siltstone and claystone seams separate the individual sandstone lenses. The sandstones have textures and mineralogies practically identical to those of the Dinosaur Canyon Member except that minor staurolite has been identified in the upper unit. The occasional intraformational conglomerate units occur as 3 to 5 foot lenticular wedges and are composed of claystone pellets and angular fragments of siltstone set in a quartz sand matrix.

The sandstones exhibit trough cross-stratification, ripple marks, and mud cracked surfaces. Cementation is loose and calcareous and the dominant color is a reddish brown. Fossils are quite rare but Wilson (1958, p. 104) reports that petrified logs up to 2 feet in diameter are occasionally found in the intraformational conglomerates and that worm borings are present up to 4 inches in diameter. Stewart, Poole, and Wilson (1972, p. 258) report fish plates present in the member near Petrified Hollow. Measured stratigraphic sections along outcrop indicate the member to be 100-300 feet thick, with most 100 to 225 feet thick. Tapp (1963) logged 96 to 220 feet of Springdale Sandstone in the Kanab Creek drillholes (T. 42 S., R. 7 and 8 W.), 6 to 10 miles north of the Vermilion Cliffs.

It is difficult to differentiate the members of the Moenave Formation, as exposed in Kane County. In addition the upper contact is gradational with the Kayenta Formation and difficult to place. The decision may cause variations in measured thicknesses to 100 feet on either side of the line. Generally the color and texture of the Moenave is more uniform than the overlying Kayenta.

Measurement of the Moenave Formation in Kitchen Corral Canyon in SESW Sec. 22, T. 41 S., R. 3 W., and NWNE Sec. 34, T. 41 S., R. 3 W., Kane County, Utah.

(place measurement of Moenave Formation here)

Kayenta Formation. The Kayenta Formation is widespread in Kane County and is exposed around the margins of the Kaibab Uplift at the top of the Vermilion Cliffs. It is exposed in the upper part of the cliffs and makes up part of the upper surface of the Wygaret Plateau. In Kane County these exposures extend from Moki Mountain (near Coral Pink Sand Dunes State Reserve) eastward to the Cockscomb (East Kaibab monocline). The cliffs continue east and west of the above limits in northern Arizona. Other exposures are found in the canyon and tributary canyons of the Escalante River and along Lake Powell in far eastern Kane County. Along Lake Powell the unit is completely exposed along a four mile length north of the Rincon. Another complete section is found in the cliff around Pollywog Bench. It is also recognized in all subsurface sections. A thin tongue of the Kayenta, known as the Tenney Canyon Tongue extends eastward into the lower part of the overlying Navajo Sandstone and its outcrops are found from Johnson Canyon westward. That part of the Navajo Sandstone between the main body of the Kayenta Formation and the Tenney Canyon Tongue is known as the Lamb Point Tongue. The main body of the Kayenta ranges from 190 to 340 feet in thickness with no specific trends.

The Kayenta Formation is a pile of lenticular, mostly medium-grained, fluvially crossbedded, thickbedded to massive sandstones in eastern exposures. Additionally there are thin reddish interbeds of siltstone and mudstone, occasional thin to medium beds of gray or lavender-gray limestones, and thin to thick beds of intraformational pebble conglomerate. The overall color varies from reddish brown to lavender, but individual beds are red, purple, tan, white, maroon, reddish-orange, and orange pink. The sandstone lenses are often quite persistent over a large area and form cliffs and ledges (photo 18). Even though the Kayenta is a resistant unit its ledges contrast sharply to the nearly vertical cliffs formed by the underlying Wingate and the lower part of the Navajo above. In some places along Lake Powell, however, the three units combine to for a towering 800 to 1,000 foot cliff.

Along the Vermilion Cliffs the Kayenta changes from the eastern facies described above and present near Paria, to a facies with considerably more siltstone and claystone. To the west the unit becomes less resistant and the overall color becomes a deep red. Instead of thickbedded to massive units dominating, the bedding is thin to thick. Some resistant ledges persist, however, as do the intraformational

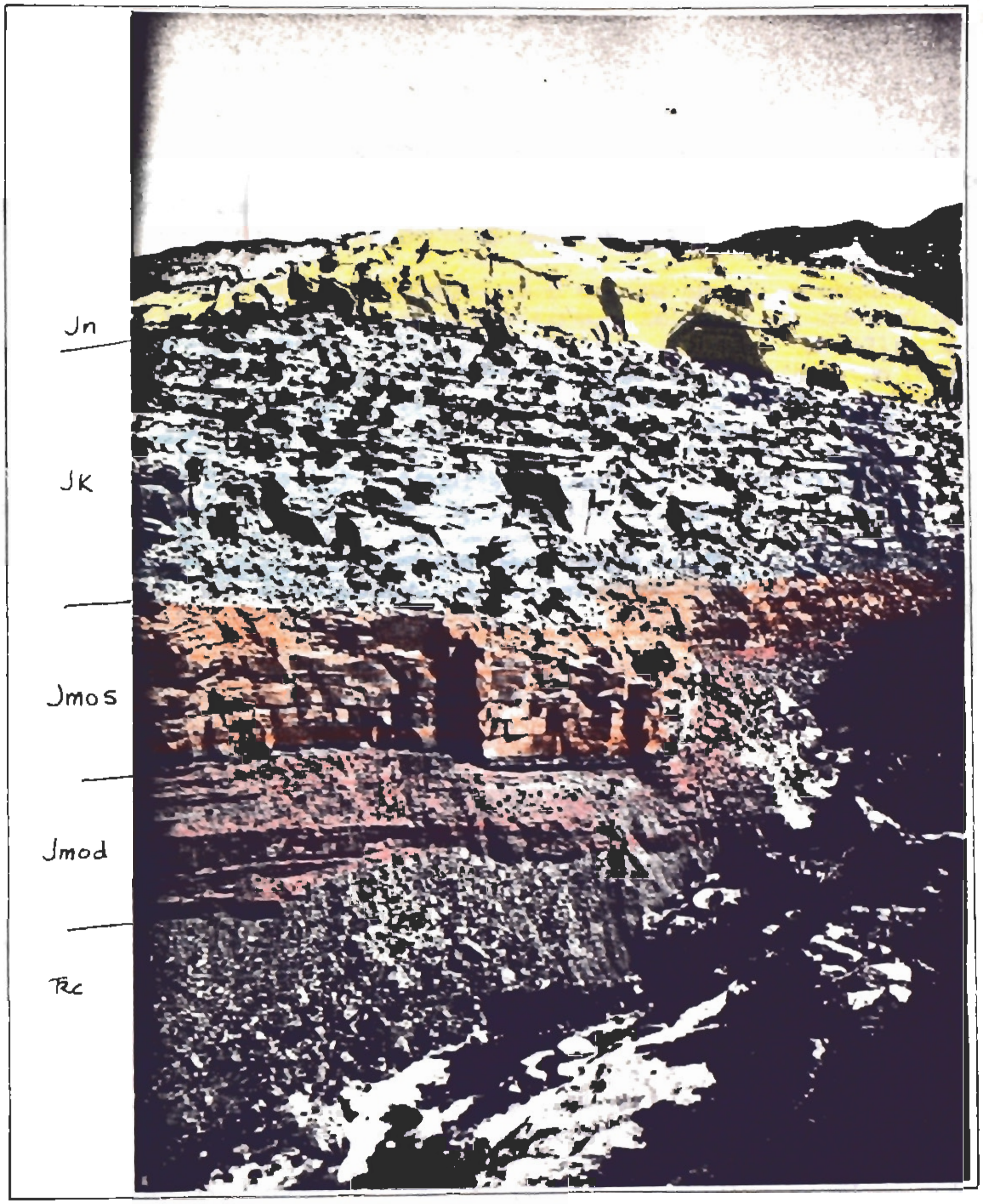


Photo 18. Cliff-face in Hackberry Canyon. At base is Triassic Chinle Formation, followed by Jurassic Dinosaur Canyon Member and Springdale Sandstone Member of Moenave Formation. The ledge-forming Kayenta Formation follows and is capped by the massive lower part of the Navajo Sandstone. TRc = Chinle Formation, Jmod = Dinosaur Canyon Member and Jmos = Springdale Sandstone Member of Moenave Formation, JK = Kayenta Formation, Jn = Lower cliff of Navajo Sandstone.

conglomerates, the thin limestones, and the varicolored nature of the individual beds. More fine-grained sandstone lenses are found in western exposures. Sandstone comprises at least 95 percent of the formation near Paria and may be less than 30 percent near Moki Mountain.

More than 90 percent of Kayenta sand grains are of subangular to subround quartz. Chert, partially decomposed feldspar, opaque and on-opaque minerals make up the remainder. Wilson (1958, p. 120-121) reports that the opaque minerals are dominated by ilmenite, and that the non-opaque accessories, in order of abundance, include tourmaline, garnet, zircon, muscovite, staurolite, and rutile. The cementation is generally a carbonate, but locally may be of clay or iron oxide. The Kayenta is mostly a fluvial deposit, but locally eolian and lacustrine horizons are present. The unit was deposited by shifting streams, the lesser eolian and lacustrine consitituents were deposited marginally in the interfluve areas. Dinosaur tracks are occasionally found in the Kayenta, and reptile bones belong to the superfamily Tritylodontoidea have been found in the unit near Kayenta, Arizona (Lewis and others, 1961, p. 1439-1440).

Measurement of the Kayenta Formation near the confluence of Coyote Creek and the Escalante River, Ne Sec. 13, T. 39 S., R. 8 E., Kane County, Utah.

(place measurement of Kayenta Formation here.)

Lamb Point Tongue. The Lamb Point Tongue overlies the main body of the Kayenta Formation in outcrops extending from the Paunsaugunt fault to the Sevier fault (Moki Mountain). In addition, the unit has been identified in wells of the Kanab Creek area (Tapp, 1963, p. 195). It consists of white, tan, or gray eolian crossbedded cliff forming sandstone with minor and thin reddish-brown siltstone and gray limestone. The upper and lower contacts with the Kayenta are sharp.

The Lamb Point sandstone is mostly fine to medium grained light colored sandstone with rounded to subrounded frosted grains. They are 90 percent quartz, 5 percent chert, and 5 percent feldspar. Heavy mineral and other opaque and non-opaque grains generally do not amount to a percent of the rock. The carbonate cementation is loose and irregular so that the rock is quite friable. Thick crossbed sets are the most striking characteristic and exceed 25 feet in places. The crossbed angles exceed 36 degrees at several locations. Some of the sets, especially those near the top, are contorted. The contorted crossbeds may represent slumping on the lee sides of dunes, although it may be difficult to explain all of the irregular folds and even recumbent folds that way. Another explanation may involve liquefaction by earthquakes. The contortions are generally confined to one crossbed set and may have been water saturated when the slumping occurred. Wilson (1958, p. 146) reports that dip directions for the unaffected crossbeds in the Lamb Point Tongue are consistently within S. 48° E. to S. 65° E. and differ from those recorded in the main body of the Navajo Sandstone above.

Measurement of the Lamb Point Tongue of the Navajo Sandstone in Cottonwood Canyon, SW Sec. 15, T. 43 S., R. 7 W., Kane County, Utah.

(place measurement of Lamb Point Tongue here.)

Tenney Canyon Tongue. This tongue consists of reddish-brown siltstone, mudstone, and fine-grained sandstone with an occasional thin gray limestone bed. Its contacts with the Lamb Point Tongue below and main body of the Navajo Sandstone above, are generally sharp (photo 19). The thickness ranges from 90 to over 170 feet, thickening generally east to west. It can no longer be mapped about 6 miles east of Johnson Canyon where it grades into eolian beds of the Navajo Sandstone, but the reddish-brown color persists to the canyon of the Paria River (figure 18). It is typically like the western facies of the Kayenta Formation containing a significant amount of siltstone, mudstone, or fine-grained sandstone and having the dark reddish-brown overall color. On fresh surfaces this dark reddish-brown is much lighter. Eastern sections generally contain more fine grained sandstones and western sections are dominated by the siltstones.

Measurement of the Tenney Canyon Tongue of the Kayenta Formation in Three Lakes Canyon, SWSE Sec. 30, T. 42 S., R. 6 W., Kane County, Utah.

(place measurement of the Tenney Canyon Tongue here.)

Navajo Sandstone. The Navajo Sandstone is an easily recognized and prominent unit in Kane County. Its outcrop band is wide and nearly continuous across the county and many of its scenic attractions are tied to it. Some of the outcrops along Lake Powell (Colorado River) are now inundated. The unit is buried under the Kaiparowits Basin. The Navajo is a relatively thick and homogeneous sandstone unit increasing in thickness from east to west. Because of its thick and homogeneous nature complete stratigraphic measurements and descriptions, as taken from the outcrop, are in short supply. Most have been written on the basis of "samplings," generally taken at the top or bottom of the unit. Thicknesses have been estimated or calculated by use of topographic contours on base maps. The few complete measurements have been made across monoclines and additional thicknesses have been obtained from drill hole logs. Even though the thickness generally increases from east to west, variations from the norm up to 200 feet are to be expected. The thinnest Navajo (about 950 feet) is found along Lake Powell (Colorado River) in the eastern part of the county. Wells in the eastern Kaiparowits Basin indicate the unit to be 1100-1400 feet thick and in the western Kaiparowits Basin to be 1400 to 1700 feet thick. Along the Cockscomb, in Hackberry Canyon, the Navajo is 1362 feet thick. Gregory (1948, p. 238) estimated 1600 feet along Park Wash near the mouth of Five Pines Gulch. Along Kanab Creek, Walcott in 1879, (in Cross, 1908, p. 105) assigned 1535 feet to the Navajo. The entire unit is exposed in a two-mile wide outcrop band extending from Parunuweap Canyon to the south facing side of Checkerboard Mesa along the west margin of the county (photo 20). Here the Navajo is calculated to be 1800 feet thick using the topographic contour method and considering the regional dip. Gregory (1950, p. 83) reported more than 1800 feet in the Zion Park region and a measured thickness of 2280 feet at the Temple of the Sinawava three miles west of the county line.

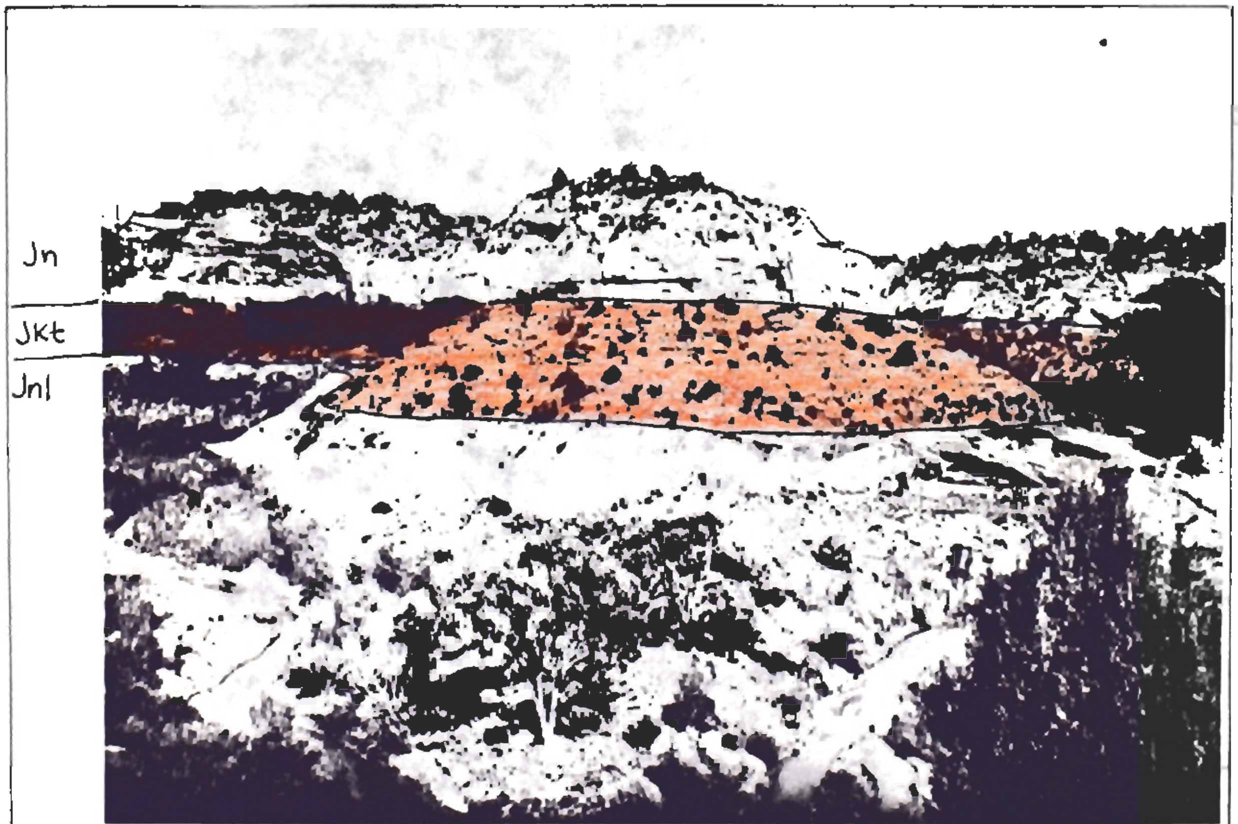


Photo ~~18~~ 19. Slope-forming Tenney Canyon Tongue of the Kayenta Formation as exposed along Kanab Creek. The massive sandstone at the base is the Lamb Point Tongue of the Navajo Sandstone, the overlying sandstone is the main body of the Navajo Sandstone. Jnl = Lamb Point Tongue, Jkt = Tenney Canyon Tongue, Jn = main body of Navajo Sandstone.

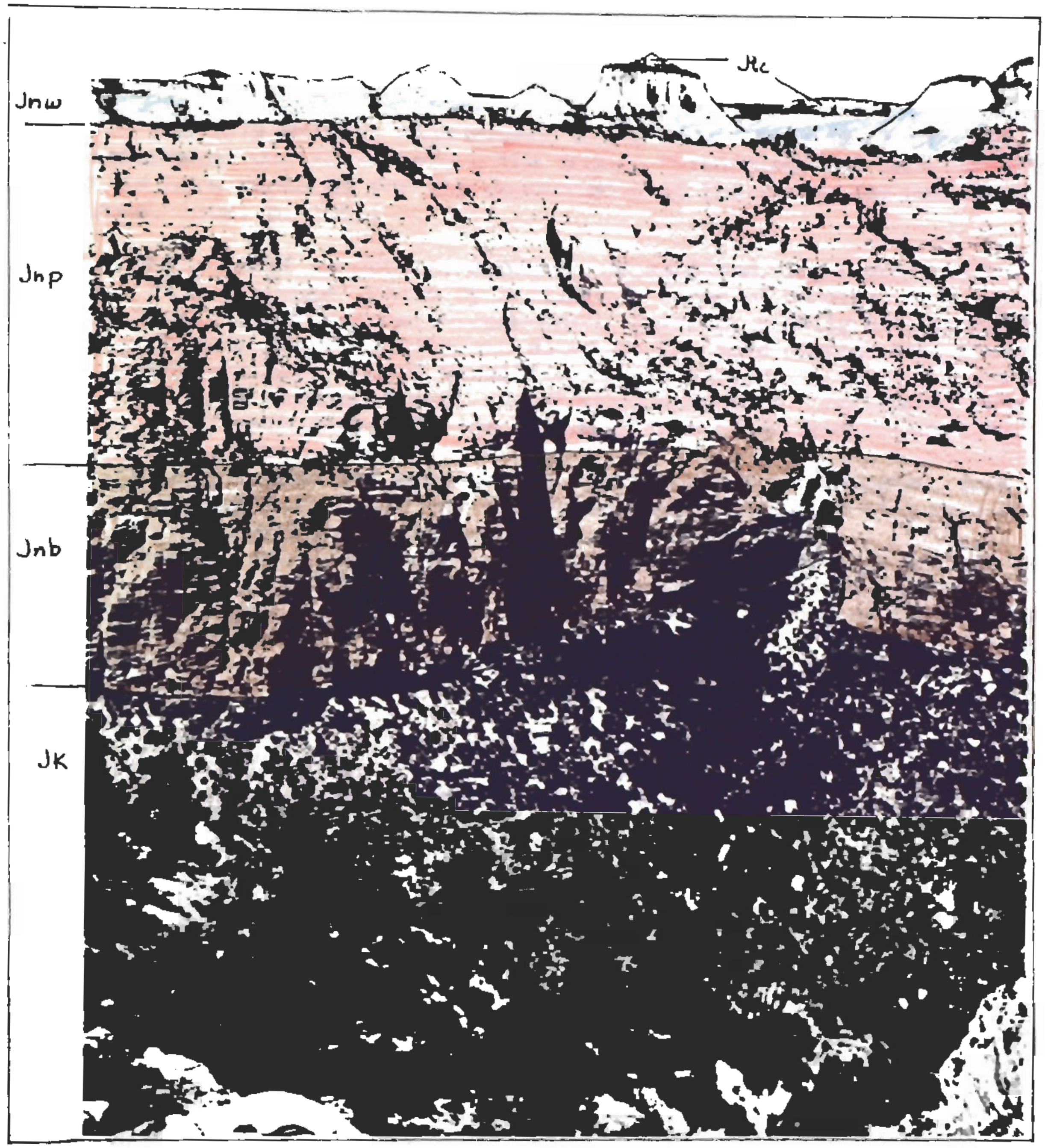


Photo 20. Northward view across Parunuweap Canyon near the Washington County line. This is one of the rare places where a person can see the entire Navajo Sandstone in western Kane County, here estimated to be 1800 feet thick. Walcott's 1879 division of the Navajo Sandstone can be observed here; at the base is 400 ft of gray and reddish-brown cliff-forming crossbedded sandstone, in the middle is 1000 ft of pink or vermilion less resistant sandstone, and at the top is 400 ft of white cliff-forming crossbedded sandstone. The Temple Cap Sandstone forms the thin sandstone horizon above the White Cliffs. JK = Kayenta Formation, Jnb = gray and reddish-brown Navajo, Jnp = pink or vermilion Navajo, Jnw = White Cliffs, and Jtc = Temple Cap Sandstone.

The 1879 Walcott measurement along Kanab Creek is of interest. This measurement was taken before the modern terminology had been established. It is here repeated for the convenience of the reader (as published in Cross, 1908, p. 105):

1. White cliff sandstone, massive, crossbedded, light gray, broken into five principal belts by horizontal lines of bedding . . . . . 585 ft
2. Vermilion sandstone; crossbedded, friable, readily disintegrating, forming the foothills and slope to the more compact sandstones at the northern end of Vermilion Cliffs Canyon . . . . 650 ft
3. Gray and reddish-brown, crossbedded sandstone. Horizontal beds of varying thickness divide the mass into bands from twenty-five to one hundred feet in thickness . . . . 300 ft
4. Evenly bedded red sandstones; upper portion an indurated, dark reddish-brown stratum; indurated layers alternate with more friable layers and shales beneath . . . . 120 ft
5. Massive gray sandstone, crossbedded; upper portion is a light gray massive friable bed. The entire mass is subdivided into six principal beds by subhorizontal lines of bedding of a dark, more indurated sandstone. The beds are from twenty to eighty feet in thickness, and may be seen on many steep escarpments along the canyon. . . . . 310 ft

Units 1 to 3 probably comprise the main body of the Navajo Sandstone and total 1535 feet. Unit 4 matches the thickness and description of the Tenney Canyon Tongue of the Kayenta Formation and unit 5 is probably the Lamb Point Tongue of the Navajo Sandstone. Walcott was able to differentiate the homogeneous unit on the basis of color and somewhat on the basis of topographic expression. This is a useful division in western Kane County, perhaps west of Johnson Canyon. At Parunuweap Canyon the upper white member (unit 1) is about 400 feet thick, the middle pink or vermilion sandstone (unit 2) is about 1000 feet thick, and the lower gray and reddish-brown sandstone (unit 3) is about 400 feet thick.

Gregory and Moore (1931, p. 67) make a strong point against the use of color in subdividing the Navajo. The present authors agree that little significance should be placed on the color for purposes of regional correlation or age determination. The lines dividing color change in the Navajo are often not exactly horizontal and cross the formation without regard to texture, stratification, or crossbeds. Occasionally the color contact lines have steep dips. In the area west of Johnson Canyon the color generally and coincidentally superimposes itself on other Navajo features that reinforce Walcott's tripartite division; the most significant of which is the topographic expression. The middle pink or vermilion sandstone is generally less resistant than the other two.

The Navajo Sandstone is generally a light colored, fine to medium grained friable sandstone, massive, weakly cemented with carbonate and iron oxide. It displays an elaborate array of high angle crossbeds and forms steep smooth cliffs or domes, monuments, and other bizarre erosional forms separated by broad bare rock surfaces and sand covered areas.

Locally thin lenses of limestone, dolomite, or dark reddish sandy mudstone are also present.

The light color of the Navajo Sandstone has been described with almost every hue; white, tan, buff, salmon, pink, vermilion, brown, red, yellow, cream, orange, and gray. Hematite produces the reddish colors, limonite the yellows, and ferruginous iron the browns and occasional greens. The color is due to the amount and oxidation state of the iron oxides present. The iron oxide is present in the cement or in the overgrowths of the sand grains. The grains are 90 to 98 percent crystal clear quartz; the remainder consists of such minerals as cloudy feldspar, magnetite, tourmaline, staurolite, zircon, garnet, and rare flakes of mica (Gregory, 1948 and 1950), suggestive of a metamorphic source. Locally magnetite, tourmaline, and other dark grains dominate and color the crossbed laminae black or dark gray. They are described as subrounded to well rounded, well sorted, and frosted. Most are imperfectly rounded and appear in spherical, discoidal, or lentiform shapes. The grains appear well sorted, but close observation indicates a scattering of coarser grains along crossbed laminae, some even approaching the size of grit. Gregory and Moore (1931) note that the sandstone is trimodal; about 3 to 5 percent consist of the coarser (usually medium grained) fraction, 70 percent are fine grained (0.1 to 0.25mm in diameter) intermingled with 25 percent "bits of dust." Freeman and Visher (1975) indicate that electron microscope studies of the grains show them to be covered with poorly to well developed overgrowths and pressure solution features. The original quartz grain surfaces are obscured by diagenetic chemical precipitation which is corroded to such an extent that saltation impact marks are not identifiable. They challenge the use of "frosted" to describe Navajo grains.

The Navajo is friable and weakly cemented. The cement is usually calcite or dolomite intermingled with varying amounts of iron oxide. The better the degree of cementation, the greater the resistance to erosion. Gregory (1950) thought that the degree of cementation made little difference in its effect on the erosion of the Navajo. The White Cliffs were cliffs because they were protected by the resistant limestones of the Carmel Formation above. In the absence of the resistant beds the unit would break down into mounds and conical towers. Although the present writers did not perform a microscopic study of the cementation, field examination of the sandstone indicates a better calcareous cementation near the top and the base of the formation across the county. The thickness of the better cemented zones varies as much as the color characteristic. In the western area, where Walcott's color divisions are applicable, the white and reddish-brown units are better cemented than the pink or vermilion unit. The former two are present as cliffs; the upper forming the magnificent White Cliffs (photo 21). The middle forms low domes and conical hills with large areas of loose sand or gently sloping bare rock surfaces between them. The sand of the famous Coral Pink sand dunes is thought to be derived from the pink member.

Faults and joints, especially along the Cockscomb, have been recemented by calcite and often stand as thin ridges extending for more than a mile. In other areas the joints and faults have not been recemented and the zone has been easy prey for erosion. The deeply eroded joints are another trademark of the Navajo Sandstone. They are especially well developed in western Kane County as they cross the deep canyon of the East Fork of the Virgin River (Parunuweap Canyon) at a place called the Barracks. The trend of the joints is northerly and the spacing is 500 feet to more than a mile. The jointing extends through or nearly through the entire formation. Locally some vertical movement can be demonstrated along the joints, the displacement rarely exceeding 100 feet. The jointing is rarely reflected in underlying or overlying units.

The Navajo Sandstone is often described as massive, as a single thick unit of sand, even as one bed of uniform texture (Gregory and Moore (1931). Baker (1946) notes the lack of true bedding planes and the abundance of elaborate crossbedding on a gigantic scale. Gregory (1948) states that the crossbedding is on an amazing scale that is more intricate than in any other unit, and this indeed is another trademark (photo 22). In most places the crossbedding laminae or cross-stratification is found in truncated sets to 30 feet in thickness. The sweeping crossbed angles range to more than 30 degrees. In most places these are etched out on the weathered rock surfaces and are vividly displayed. The contacts of sets are usually subparallel to the true attitude of the formation, rarely varying more than 10 degrees from it. Locally, however, the set contacts are inclined at steeper angles and have curved to irregular surfaces, as if the lower sets were scoured before the upper was deposited. In others the sets are either complexly arranged or wedge-shaped. Locally the sweeping crossbeds (especially in Three Lakes Canyon) were deformed, probably penecontemporaneously. The deformation is normally confined to one set and is demonstrated in convolutions, crenulations, or folds. The latter can be found as tight recumbent masses. In other areas a criss-cross pattern of fracturing has superimposed itself on some sets or series of sets with a spacing of 1 to 3 feet to superimpose a checkerboard pattern on the outcrops.

Locally, and especially near the base, the Navajo has some massive horizontal beds displaying both low and high angle crossbeds. These range from 8 to 50 feet in thickness (Blakey, 1970, p. 67-68). In the Paria area and along the Cockscomb a lower unit 200 to 300 feet can be differentiated on this basis. In Shurtz Gorge the lower unit is 272 feet thick and in Hackberry Canyon it is 227 feet thick.

Although the unit is mostly sandstone, there are a few lenticular beds of dense gray limestone or dolomite, and reddish-brown sandy and calcareous mudstones. These are generally quite resistant and form benches or shelves where present. In Kane County these lenses are thin and of limited aereal extent, few having diameters of more than a mile. A few of the limestone beds have been observed to contain gray shattered chert. These thin lenses display dessication cracks and ripplemarks that attest to an aqueous origin. The carbonate rocks are barren of fossils. These lenses are generally tight and impermeable when compared to the

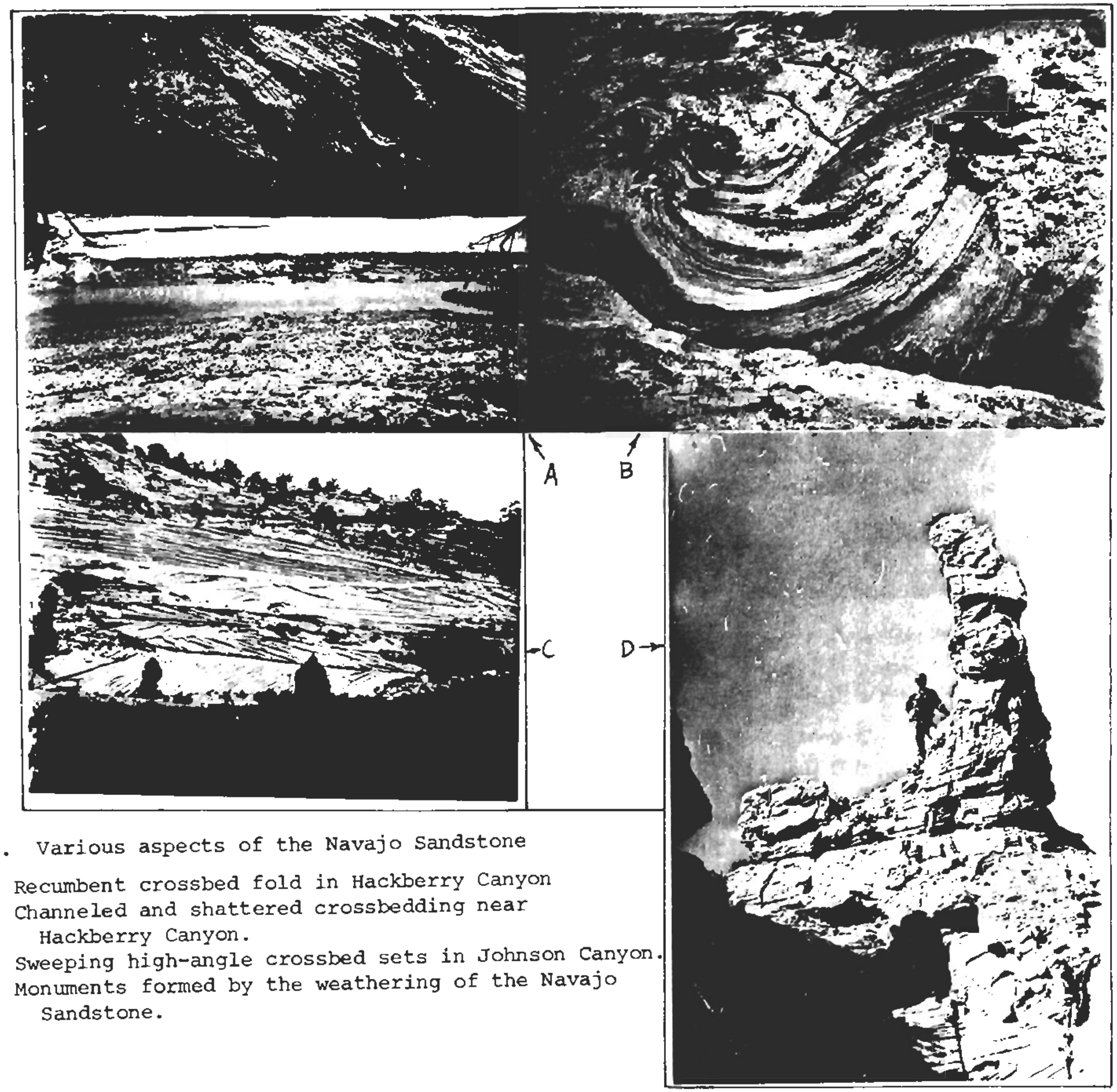


Photo 22. Various aspects of the Navajo Sandstone

A. Recumbent crossbed fold in Hackberry Canyon
B. Channeled and shattered crossbedding near Hackberry Canyon.
C. Sweeping high-angle crossbed sets in Johnson Canyon.
D. Monuments formed by the weathering of the Navajo Sandstone.

porous and friable sandstone of the main unit and act as aquicludes. Springs often appear at the upper surfaces to drain local perched groundwater reservoirs. Locally thin silty or muddy layers are found between the crossbed sets, these sometimes act as seep planes.

Another interesting feature of the Navajo Sandstone is the ironstone sheeting present in the rock (photo 23). Locally, these have been deformed into disks, balls, stove lids, pancakes, and dumb-bells (Gregory, 1948). The material is hard and resistant, dark grayish-brown to black, and contains about 15 percent or more of iron. It breaks up and accumulates as talus. Most of the ironstone sheets are found in the less well-cemented middle part of the Navajo. In places the sheets have been deformed and folded into recumbent forms. The thickness of the sheets vary to a few feet, most are less than an inch thick. They are assumed to have formed in the horizontal position; a thick iron scum perched on an old water table before the sand was fully consolidated. Deformation probably occurred before the diagenetic processes were completed.

The nature of the depositional environment of the Navajo is under controversy. The most widely accepted theory is that the sands were deposited under desert eolian conditions (terrestrial environment). This hypothesis was originally suggested by Huntington and Goldthwait (1904) and championed by Gregory (1917, 1948, and 1950). Others supporting this mode of origin include Reeside (1929), Baker (1946), Harshbarger, Repenning, and Irwin (1957), and Stokes (1968). Keller (1945), Grater (1948), Jordan (1965), Marzolf (1969), Freeman and Visher (1975), and others have postulated a marginal marine rather than desert eolian environment of deposition. Details of the desert eolian hypothesis are well described by Stokes (1948) and arguments for the marginal marine origin are summarized by Freeman and Visher (1975). No fossils have been found in the Kane County Navajo outcrops thus far that might help in settling the point.

The upper and lower contacts of the Navajo are generally sharp and easily discernible (figure 18). The lower contact with the Kayenta is an intertonguing relationship and in many places thick Navajo tongues are found near the top of the underlying unit. The upper contact is unconformable everywhere in Kane County, the J-1 and J-2 unconformities of Pipiringos and O'Sullivan (1978). From Johnson Canyon westward the Navajo Sandstone is directly overlain by the Temple Cap Formation (J-1 unconformity), between Johnson Canyon and Glen Canyon it is overlain by the Judd Hollow Tongue of the Carmel Formation, and east of Glen Canyon it is directly overlain by the Page Sandstone (J-2 unconformity). The Page Sandstone resembles the Navajo and in the northeastern part of the county is difficult to separate from it. The Page Sandstone is included with the Navajo Sandstone in our mapping.

Temple Cap Sandstone. The Temple Cap Sandstone overlies the J-1 unconformity and the Navajo Sandstone from Johnson Canyon westward and underlies the J-2 unconformity (figure 18). It thickens from a feather edge to as much as 190 feet along the west margin of the county. It has been divided into two units; a lower Sinewava and an upper White Throne

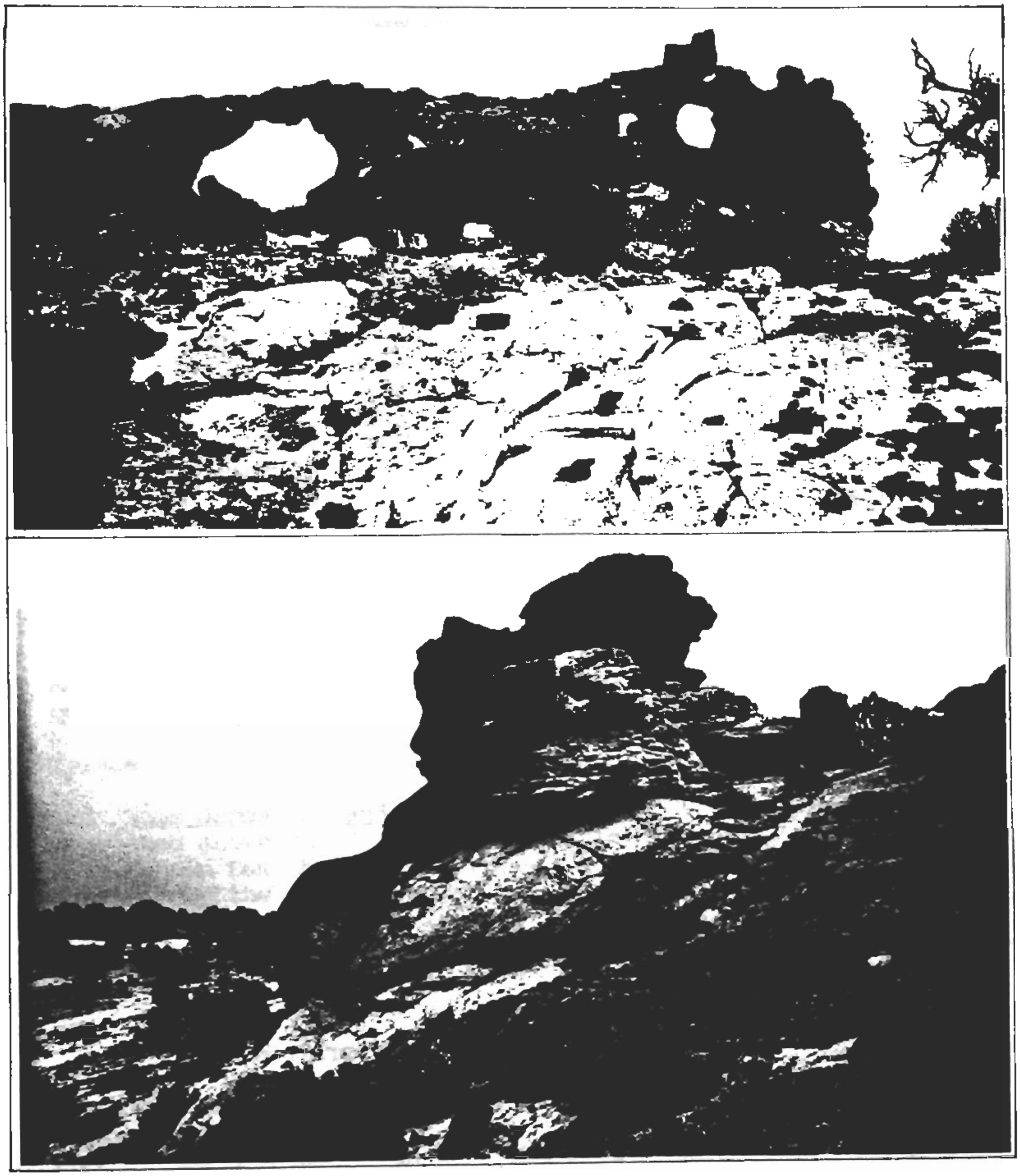


Photo 23. Side view of deformed iron sheet deformation in upper photo. Front view of same in lower photo.

Member. The Sinewava Member is mostly a reddish brown slope forming unit composed of reddish-brown siltstone or silty very fine grained sandstone and pinkish-gray fine grained sandstone that ranges to 40 or 50 feet in thickness. A reddish Sinewava bench is often all that remains of the Temple Cap Sandstone on top of buttes and projecting prominences of the White Cliffs, such as on top of Elephant Butte.

The contact between the two members is often difficult to place as Sinewava type reddish-brown beds often intertongue into the lower part of the White Throne Member. The White Throne Member reaches a maximum of about 150 feet in thickness near the west margin of the county. It can roughly be divided into two units on the basis of resistance to erosion. The upper part of the member resembles the upper "white" Navajo Sandstone and consists of fine grained, well sorted, crossbedded sandstone. The crossbed sets range to 30 feet in thickness and the crossbedding is at a high angle. It is a friable, calcareously cemented, cliff-forming unit. The lower part of the White Throne Member is mostly like the upper, but is less well-cemented, in places almost lacking cement. Interbedded with the massive crossbed sets are well bedded grayish-pink medium grained sandstones, reddish-brown siltstones or very silty, very fine grained sandstones, and platy weathering fine grained silty sandstone. One sandstone bed on Harris Mountain contains siliceous nodules up to 4 inches in diameter. This lower part of the White Throne Member weathers into a steep or ledgy slope.

Measurement of the Temple Cap Sandstone on Harris Mountain (Elephant Butte quadrangle) in S 1/2, Sec. 31, T. 42 S., R. 8 W., Kane County, Utah.

(place measured section of Temple Cap Sandstone here.)

Page Sandstone and Carmel Formation. These two formations were deposited above the J-2 unconformity in Kane County (figure 18). East of Glen Canyon Dam the Page Sandstone rests on the Navajo Sandstone and is overlain by the Carmel Formation. West of the dam the Carmel rests directly on the Navajo to Johnson Canyon, then on the Temple Cap Formation. Between Glen Canyon Dam and the Paunsaugunt fault the Thousand Pockets Tongue of the Page Sandstone is inserted between members of the Carmel Formation.

The Carmel Formation is as widespread in Kane County as is the Navajo Sandstone. It is, however, divisible into mappable members and changes character across the county. The thickness of the Carmel generally increases south to north and east to west, but an unconformity (K unconformity) over the unit to the west reduces it slightly there. It is less than 110 feet thick at Bullfrog Basin, 150 feet thick at Fiftymile Point and 215 feet thick at Early Weed Bench. The Page Sandstone is also present at these locations, but it is difficult to separate from the underlying Navajo Sandstone. At Fiftymile Point the Page Sandstone is less than 20 feet thick and Zeller and Stephens (1973) report it to be only 60 to 65 feet thick in the Seep Flat quadrangle near Early Weed Bench (photo 24).

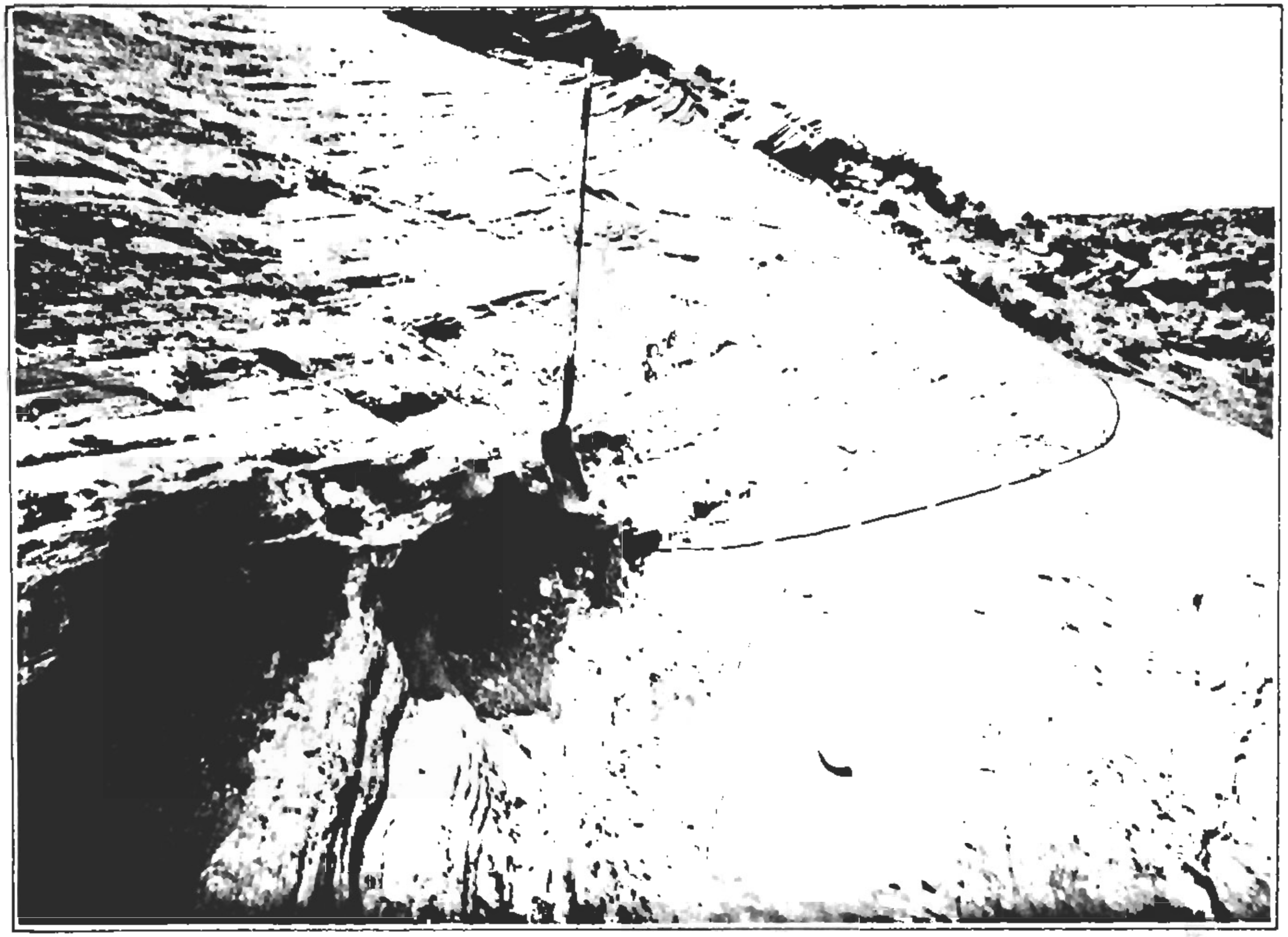


Photo 24. J-2 unconformable contact between Navajo Sandstone below and Page Sandstone above near Fiftymile Point. At this place the unconformity appears like the contact between crossbed sets. Just to the north of this location reddish siltstone lies above the contact.

The Carmel Formation thickens gradually westward along the south margin of the Kaiparowits Plateau. At West Cove, just north of U. S. Highway 89, the combined Thousand Pockets Tongue of the Page Sandstone and Carmel Formation strata exceed 850 feet in thickness. That part of the Carmel above the Thousand Pockets Tongue is about 600 feet thick. At the north end of the Cockscomb, in the Butler Valley area, the interval is also 850 feet thick (Bowers, 1983), with the part above the Thousand Pockets Tongue reaching 550 feet in thickness. Along the Cockscomb measurements of the Carmel indicate it to be thinner, but it is steeply folded along the monocline and the thicknesses may be unreliable. Westward those members of the Carmel beneath the Thousand Pockets Tongue increase in thickness as the tongue thins and pinches out near the Paunsaugunt fault. At Meadow Creek, in the western part of Kane County, the Carmel is almost 700 feet thick with the Dakota Formation resting unconformably upon it. East of the Paunsaugunt fault the Carmel Formation is overlain by the Entrada Sandstone.

The lithology of the Thousand Pockets Tongue and Page Sandstone is mostly fine to medium grained quartzose sandstone, similar to that found in the Navajo Sandstone. It is lightly and calcareously cemented. Less than 5 percent of the grains are feldspar, mica, magnetite, and other minerals. Most of the grains are subrounded to rounded. The Page Sandstone, east of Glen Canyon Dam, is cliffy and irregularly underlain with reddish brown siltstone or silty, very fine grained pale reddish-brown sandstone. The sandstone color may be salmon or tan like the underlying Navajo, or slightly darker; moderate reddish-orange or gray orange. Like the Navajo it exhibits high angle crossbedding. Where there is no reddish-brown siltstone at the base it is difficult to separate from the Navajo and the unconformable contact may only be represented by an inconspicuous line like those separating crossbed sets (photos 24 and 25). The Page Sandstone was named by Peterson and Pipiringos (1979, p. 1979, p. B20-B30) after they discovered that the strata were separated from the Navajo Sandstone by the J-2 unconformity.

The composition and size of sand grains in the Thousand Pockets Tongue is comparable to that in the Page Sandstone and Navajo Sandstone. It is cliff-forming at most locations, even though it is friable and quite porous. High angle crossbeds are also evident in the tongue along outcrops extending from Glen Canyon Dam westward to the Cockscomb and into the Slickrock country near Kodachrome Basin State Reserve (photo 26). Here the color is generally gray white, light gray, or salmon. Occasional reddish-brown siltstone or silty, fine grained sandstone tongues of the Carmel Formation are found in the Thousand Pockets Tongue. A persistent Carmel 8 to 20 foot tongue is found along the Cockscomb about 50 to 60 feet above the base. In its westernmost exposures, before it pinches out, it is decidedly yellow in color and the crossbedding is much less pronounced. At these locations the tongue is often fractured, the breaks cemented with calcite or veinlets of gypsum. Gypsum veinlets are locally common.

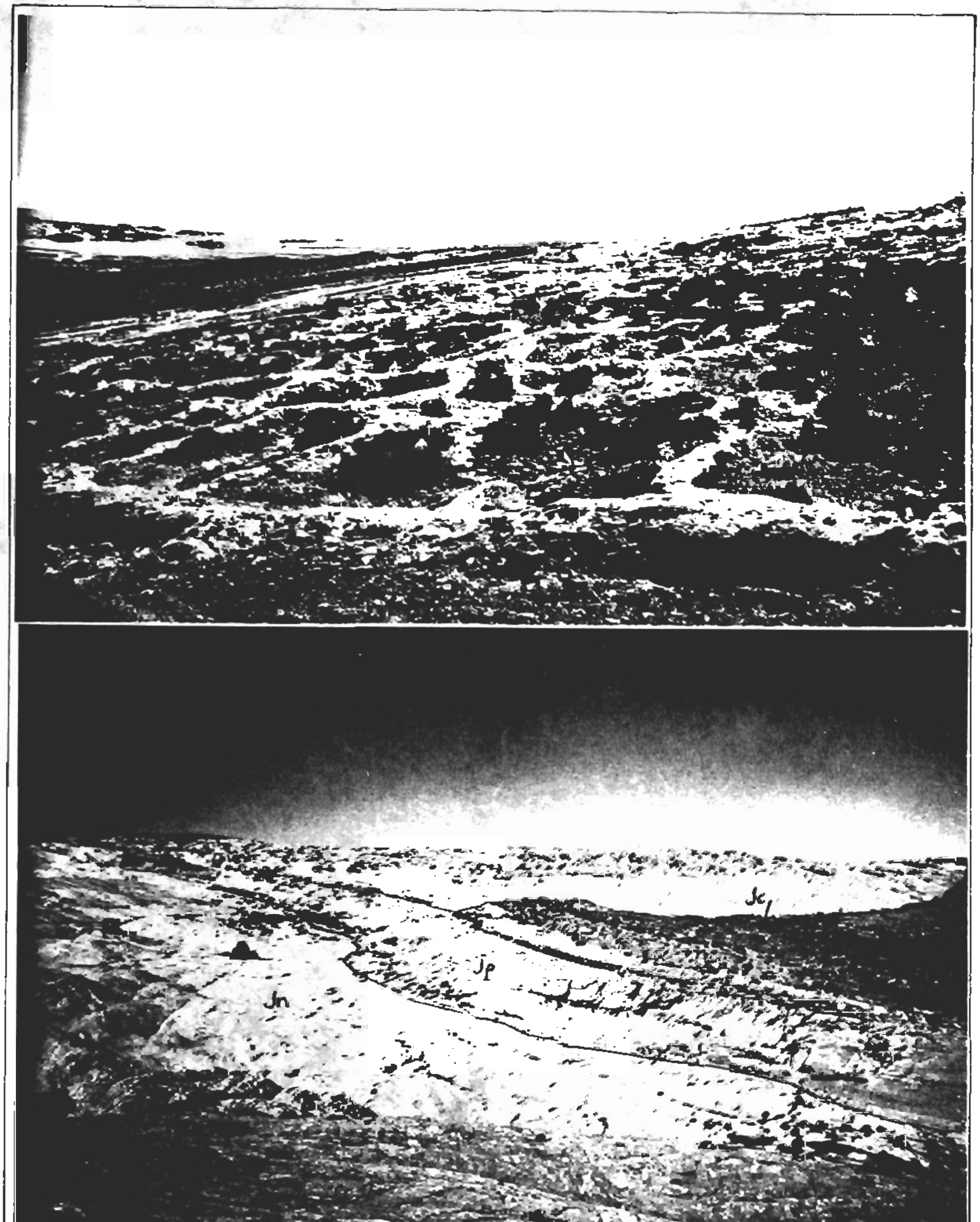


Photo 25. Upper photo shows large polygonal features developed at the top of the Page Sandstone on the west side of Halls Creek Bay. Lower photo shows contacts between the Navajo Sandstone and Page Sandstone and the contact between the Page Sandstone and Carmel Formation also on the west side of Halls Creek Bay.

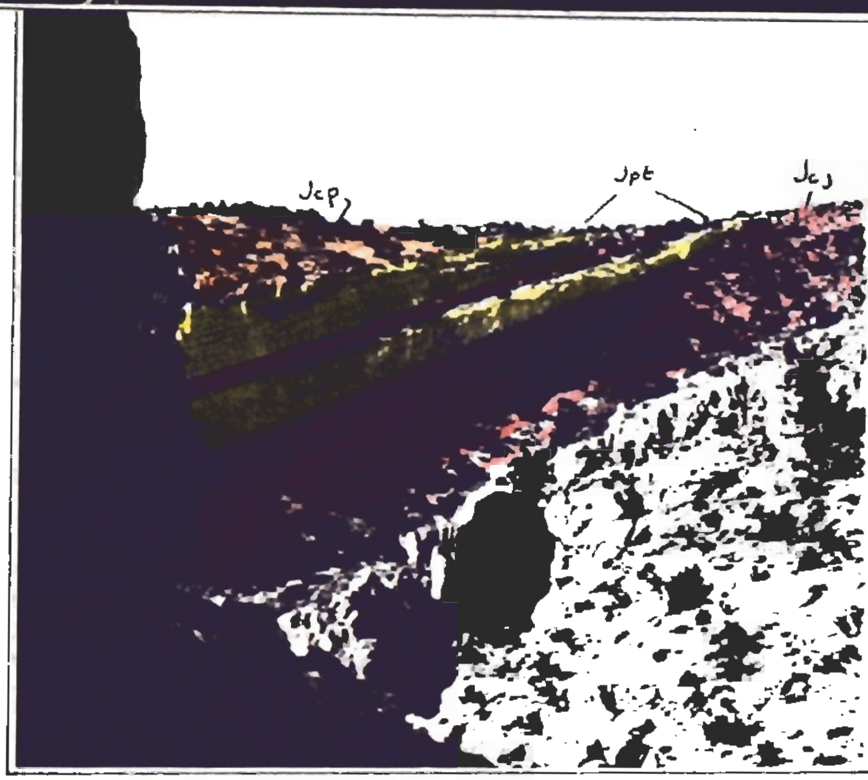


Photo 26. Upper photo shows Paria River Member of Carmel Formation (Jcp), Thousand Pockets Tongue of Page Sandstone (Jpt), Crystal Creek Member of Carmel Formation (Jcc), Kolob Limestone Member of Carmel Formation (Jck) and Navajo Sandstone (Jn) a few miles south of Butler Valley. The lower two Carmel members are grouped to form the Judd Hollow Tongue of the Carmel Formation. Lower photo shows Thousand Pockets Tongue between the Judd Hollow Tongue and Paria River Member near Catstairs Canyon. Note the additional thin tongue of the Carmel dividing the Thousand Pockets Tongue.

The lower contact of the Thousand Pockets Tongue is usually sharp, marked by the change from reddish-brown, earthy weathering sandstone or siltstone to the light colored, more resistant and cliffy sandstone of the tongue. Thompson and Stokes (1970, Fig. 3) indicate this lower contact to be an unconformity, but Peterson and Pipiringos (1979, p. B30) disagree. The upper contact is also usually sharp, so that an unconformity might be suspected. Peterson and Pipiringos (p. B14) indicate, that even though there is some relief and that a local mudchip conglomerate was found above the contact, they could find no evidence that any appreciable erosion or nondeposition occurred before the overlying member of the Carmel had been deposited.

Measurement of the Page Sandstone in Coyote Gulch, NENE Sec. 16, T. 39 S., R. 7 E., Kane County, Utah.

(place measurement of Page Sandstone here.)

Measurement of the Thousand Pockets Tongue near West Cove along a road cut on U. S. Highway 89, NWSW Sec. 19, T. 42 S., R. 1 W., Kane County, Utah.

(place measurement of Thousand Pockets Tongue here)

The Carmel Formation is a heterogeneous unit of sandstone, limestone, limestone shale, siltstone, gypsum, mudstone or claystone, and rare gritstone or conglomerate. Sandstone is one of the more common rock types in the Carmel Formation. The grain sizes range mostly from very fine to medium, although coarse grained and even gritty varieties can be found. The grains are mostly quartz, but mica, feldspar, zircon, magnetite, and chert are also present. The grains are generally subangular to angular and there is usually a fair amount of silt mixed with some of the beds. Cementation is poor to good, gypsiferous, calcareous, and with iron oxide. The bedding can be thin to thick to indistinct and even massive. Where the cementation is calcareous the sandstones form ledges, elsewhere the outcrops are earthy weathering or form steep slopes. Colors are varied and dependent upon the amount of iron oxide present. Colors include moderat reddish-orange, moderate reddish-brown, white, brown, tan, grayish-orange, grayish-brown, yellowish-white, pale yellowish-orange, and light gray. The colors often occur as bands and this is a trade mark of the Carmel Formation. Gypsum veinlets often crisscross through the sandstones. In some places the sandstones of the Carmel are crossbedded, both high angle and low angle varieties are present. The high angle varieties are often massive and reminiscent of the massive sandstones of the Navajo and Entrada.

True siltstones in the Carmel Formation are generally moderate brown, dark reddish-brown, greenish-yellow, or moderate orange pink in color. The bedding is usually indistinct. The siltstones are often interbedded with the sandstones. Mudstones and claystones are also interbedded with the siltstones and generally exhibit darker shades of the colors on fresh surfaces. All of these lithologies are usually poorly exposed except when protected by overlying overhanging ledges. Siltstones usually weather to earthy slopes.

The limestones are generally tan weathering, gray, grayish-tan, or grayish-green; dense, hard, and ledge forming. The beds are thin to thickbedded. They are often fossiliferous and a host of forms including Astarte, Camptonectes, Dosinia, Lima, Modiola, Neritina, Ostrea, Pentacrinus, Trigonia, and Volsella have been identified and fix the age as early Upper Jurassic (Reeside in Gregory, 1950, p. 93).

The limestones grade into limestone shale, which weathers gray, white or tan, and is mostly olive gray on fresh surfaces. Limestone shale forms steep slopes that are usually littered with chips and plates of limestone. The limestone shales are arenaceous, silty, and sometimes argillaceous. They are shaly to very thinbedded.

Bedded gypsum, mostly alabaster, is common in the Carmel Formation and occurs in very thin beds to beds as thick as 30 feet. The dominant color is white, but pale yellow, pale orange, pale green, and pale red are also present. Some is very pure, other gypsum is contaminated with abundant reddish silt or fine grained sand.

Of least abundance are the coarse-grained sandstones, gritstones, and conglomerates. The clasts are generally subangular and loosely cemented with calcite. The beds are generally thin to medium and lenticular. The most abundant grains and clasts are of quartz or quartzite, but considerable chert, sandstone, and claystone clasts are also present.

The Carmel Formation was deposited in a shallow seaway that extended from the north to a point near the Arizona line in Middle Jurassic time (Hintze, 1973, p. 64-66). The limestones were undoubtedly deposited offshore and most of the remaining rock types on broad tidal flats upon which occasional stream channels were scoured. Gypsum was deposited in the restricted arms of the seaway. If the high angle crossbedded sandstones are of eolian origin, then some beach deposits are also included. The finer grained rock types occasionally exhibit ripples and mudcracks and verify the above indicated depositional environments.

Although the Carmel is divided into members, the above listed rock types can be found in any of them. Usually a particular rock type dominates and is the basis for dividing the member. Color changes also assist in identifying the members. The Carmel Formation was named by Gilluly and Reeside (1926) and first described by Gregory and Moore (1931, p. 72-77) for rocks exposed near Mt. Carmel in Kane County. They included only part of the total formation present in that area in their measured stratigraphic sections. The members of the Carmel Formation are well developed in western Kane County so that Gregory (1950, p. 92-98) construed them to be correlatable to formations present in eastern Utah. The uppermost member did not resemble any of those units so he named it the Winsor Formation with the type section in Winsor Cove along Muddy Creek. In all he mapped four members which he called (in ascending order) Carmel Formation, Entrada Sandstone, Curtis Formation, and Winsor Formation (figure 19).

Insert

Gregory, 1950	*Cashion, 1967*	*Thompson & Stokes, 1970*	
WINSOR FM.	WINSOR MBR.	Wiggler Wash Mbr. WINSOR MBR.	Upper
CURTIS FM.	GYPSIFEROUS MBR.	PARIA RIVER MBR.	Lower
ENTRADA SS.	BANDED MBR.	CRYSTAL CREEK MBR.	Judd Hollow Tongue
CARMEL FM.	LIMESTONE MBR.	KOLOB LIMESTONE MBR.	

Figure 19. Carmel Formation nomenclature relationships. In eastern Kane County the lower two members thin to form the Judd Hollow Tongue before pinching out. The upper two members also thin and are often mapped as upper and lower members.

Cashion (1967), in mapping the south flank of the Markagunt Plateau, recognized that the two middle members were not the Entrada and Curtis Formations of the San Rafael Swell, and made members of the four formations. He used lithologic terms for the lower three (Limestone, Banded, Gypsiferous) and retained the name Winsor for the upper member. Thompson and Stokes (1970), in a study of the San Rafael Group in south-central Utah, renamed some of the members and added a fifth in the Paria Terrace area. These include the Kolob Limestone Member, Crystal Creek Member, Paria River Member, Winsor Member, and Wiggler Wash Member (figure 19). At present the members of Thompson and Stokes (1970) are not recognized by the U. S. Geological Survey, who retain the names proposed by Cashion. Additional information is available in a Professional Paper by Peterson and Pipiringos (1973).

The lower two members are recognizable eastward to the Cockscomb. East of the Paunsaugunt fault they are located under the Thousand Pockets Tongue of the Page Sandstone. Thereafter all the rocks under the Thousand Pockets Tongue are known as the Judd Hollow Tongue of the Carmel Formation as named by Phoenix (1963, p. 33). The upper two members at Mt. Carmel are recognized by Peterson and Pipiringos (1973, p. B12) as far east as the Cockscomb and then that part of the Carmel above the Thousand Pockets Tongue is known as the Upper Member (Peterson and Barnum 1973, Peterson 1975, and Bowers 1983). We continue to recognize the upper members all the way to Bullfrog Basin, certainly an upper and lower member can be differentiated. Even the Wiggler Wash Member can be identified along the Hole-in-the Rock road adjacent to the Straight Cliffs (figure 20).

One of the better sections of the Carmel Formation is found along Meadow Creek just south of the Coal Hill landslide (figure 20). The Limestone or Kolob Limestone Member is almost 250 feet thick and consists mostly of limestone and limestone shale. Just above its contact with the Temple Cap is about 10 feet of bright reddish-brown siltstone. Above this are about 35 feet of blocky and ledgy limestone followed by 170 feet of shaly limestone, followed by 35 feet of alternating ledgy and slope forming limestone.

The Crystal Creek or Banded Member is mostly banded in shades of brown or reddish-brown, and is earthy weathering sandstone (photo 27). Lesser amounts of siltstone and gypsum are also present. The unit is a little over 175 feet thick. The dominant portion of the Paria River or Gypsiferous Member is thickbedded to massive white rock gypsum (lower 45 feet). There are some thin interbeds of shale and siltstone in this lower part. Overlying the thick gypsum is sandstone, siltstone, and light gray limestone. The limestone is fossiliferous (casts and molds of pelecypods). Even though this limestone is very thin at Meadow Creek, it persists all the way across the county and is a fine marker. The entire Paria River Member is only 60 feet thick at Meadow Creek.

The Winsor Member is mostly sandstone at Meadow Creek, yellow or white in the upper 165 feet and reddish-brown or light brown in the lower 45 feet. Thin siltstone layers are also interbedded with the unit.

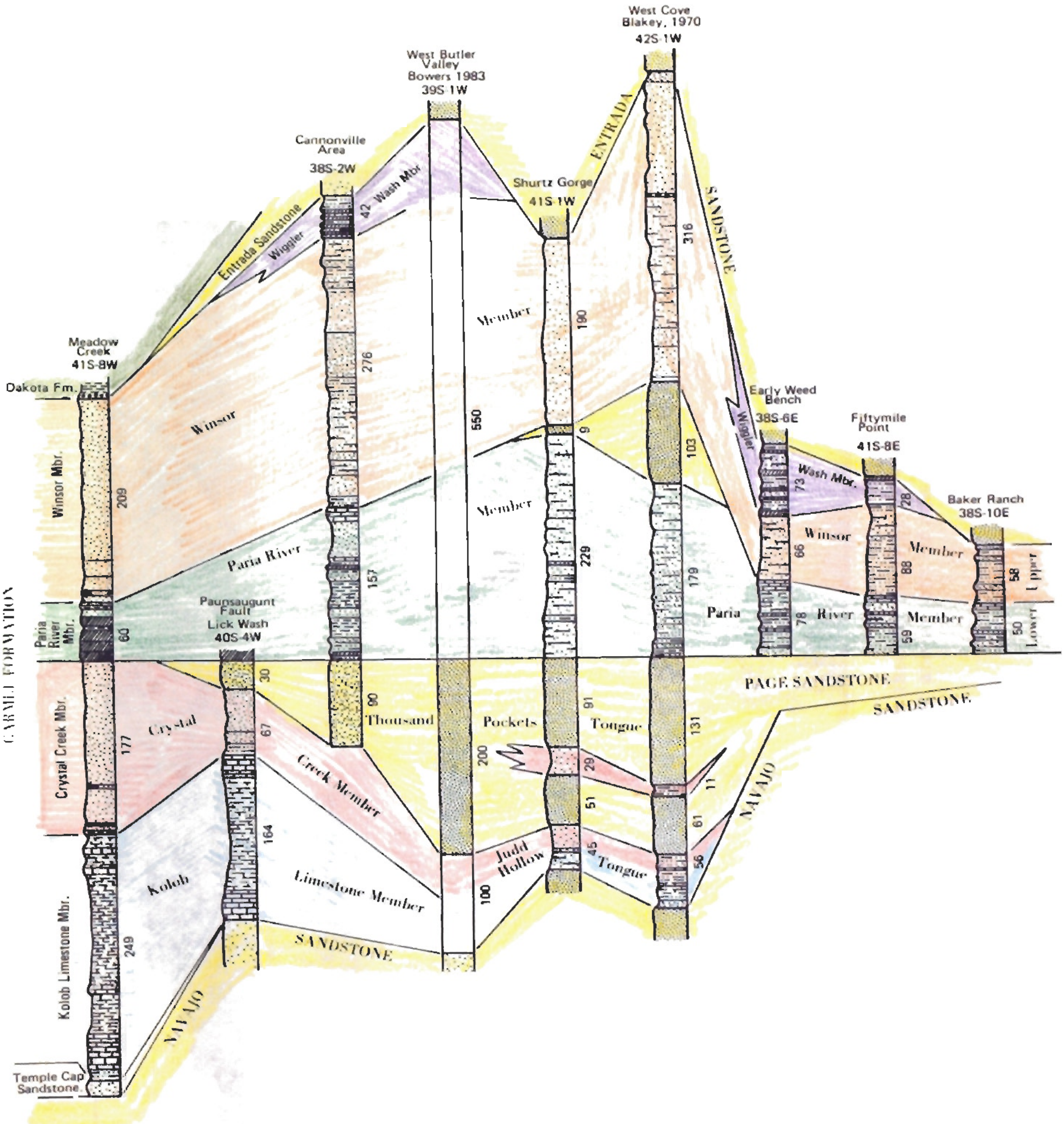


Figure 20. Correlations of Carmel Formation and Page Sandstone Members west to east across Kane County. Thicknesses are given in feet to the right hand of the columns.

Photo 27. Outcrops of the Crystal Creek (Banded Member) of the Carmel Formation near Mt. Carmel, Utah. The offsets are a part of the Sevier fault zone.

Measurement of the Carmel Formation at Meadow Creek (The Barracks quadrangle) in S 1/2 S 1/2, Sec. 7, T. 41 S., R. 8 W. (Winsor Member), NESW Sec. 18, T. 41 S., R. 8 W. (Paria River and Crystal Creek Members), and NWSW Sec. 18, T. 41 S., R. 8 W. (Kolob Limestone Member), Kane County, Utah.

(place Carmel Formation measurement here.)

In the Paria Terrace area, south of Cannonville, between the Paunsaugunt fault and the Cockscomb, all the members are present, but it is difficult to find a place where all can be measured together. At Lick Wash, at the Paunsaugunt fault, the Kolob Limestone Member is 164 feet and the Crystal Creek is 67 feet thick (figure 20). The two units are readily distinguishable. The Kolob Limestone still has a ledgy limestone near the bottom and top, but the middle shaly unit contains some silty red gypsum and reddish siltstone that forms a pale red band in the middle. The Crystal Creek is still mostly banded sandstone, but lighter bands, especially near the base, invade the dominant reddish-brown hues.

At Bull Valley Gorge, these lower members are similar to what they are at Lick Wash, the Kolob Limestone is a little over 100 feet thick and the Crystal Creek Member is only 35 feet thick. The Kolob Limestone contains several thin to medium gypsum beds here. The Paria River Member is 150 to 220 feet thick. Thick white rock gypsum is generally found at the base (up to 40 feet), followed by interbedded mudstone, reddish brown siltstone, or pale orange sandstone, and minor gypsum (photo 28). The middle part is generally earthy-weathering with a few ledges. At the top is the limestone "marker," that weathers to light shaly or chip-strewn surface. The upper limestone "marker" is 15 to 20 feet thick. Farther east the gypsum become discontinuous, and before reaching the Cockscomb, disappears completely.

At Big Dry Valley in Lower Slickrock, the Winsor Member is 175 feet thick and consists mostly of earthy weathering interbedded reddish or brown sandstone and siltstone. The Wiggler Wash Member is present above the Winsor and is 42 feet thick. It consists of thin to medium beds of banded or laminated gypsum interbedded with reddish-brown siltstone and fine grained sandstone. It makes an irregular contact with the Entrada Sandstone above.

Where the members become steeply tilted along the East Kaibab monocline (The Cockscomb), they all become decidedly reddish in color. Southward from Butler Valley, the Wiggler Wash Member disappears. The Paria River Member becomes very thin (part of the thinning may be attributed to folding attenuation). There is no gypsum at the base, but the upper chippy limestone "marker" persists until lost under the alluvium of Cottonwood Creek. The upper members are also usually incomplete along the Cockscomb, buried under the alluvium of the creek. The Judd Hollow Tongue is mostly reddish sandstone, but there usually is a lavender or gray limestone horizon in the middle. South of Hackberry Canyon, 24 feet of reddish-brown ledgy sandstone make up the Crystal Creek Member and 27

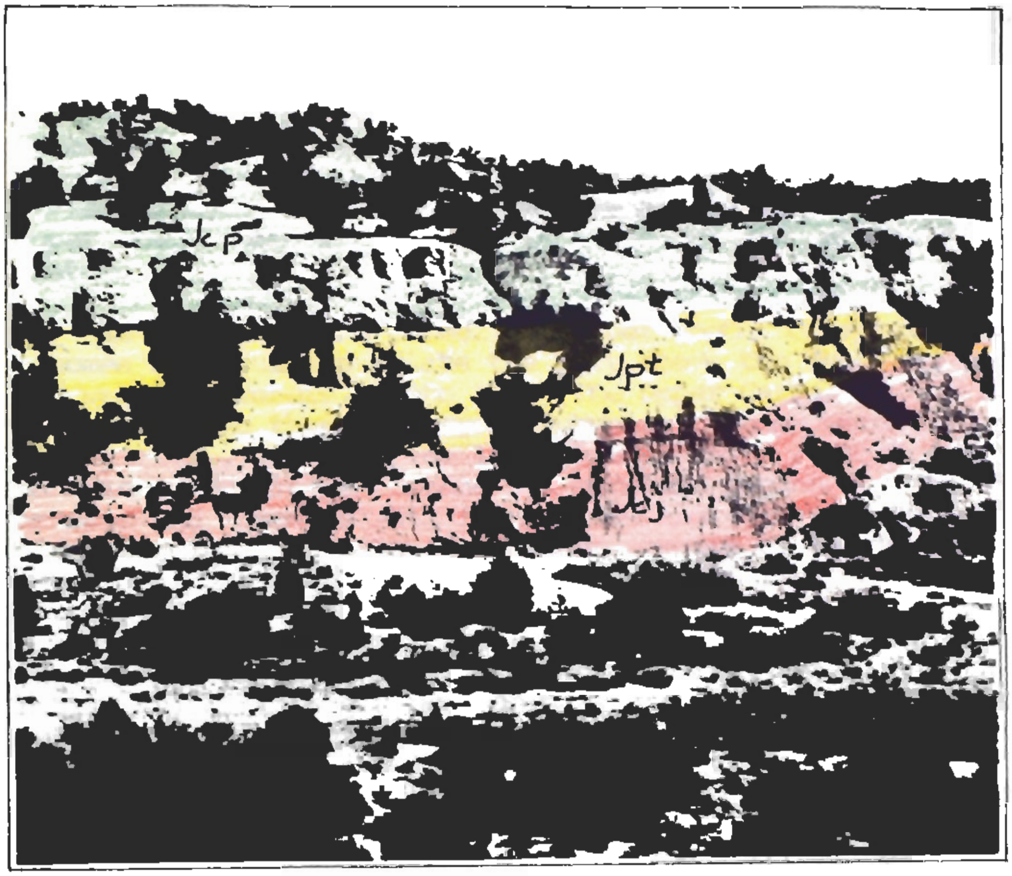


Photo 28. Judd Hollow (Crystal Creek) Member, Thousand Pockets Tongue, and gypsum of the Paria River Member near Willis Creek.

feet of ledgy limestones and sandstones with red siltstone partings make up the Kolob Limestone Member.

Only the Judd Hollow Tongue and upper member are mapped along the Cockscomb and eastward. The Judd Hollow Tongue is too thin to subdivide into members along the monocline and the upper members are not easily divisible along the southwest margin of the Kaiparowits Plateau. The upper member becomes too thin in exposures east of the Kaiparowits Plateau.

At West Cove the Carmel is rather anomalous in its appearance and it becomes difficult to relate the part above the Thousand Pockets Tongue to the western members (photo 29). The upper Carmel is 600 feet thick and divisible into three arbitrary subunits. These were also recognized by Blakey (1970, p. 77). The lower subunit is a reddish poorly sorted sandstone, reddish siltstone and mudstone sequence. The sandstone is arkosic and cemented with iron oxides and calcite. The unit is generally slope-forming, but with significant numbers of "soft" ledges; these ledges rarely being blocky. The unit is about 180 feet thick (it is steeply dipping along the monocline and may be as thick as 218 feet as claimed by Blakey, p. 77) in West Cove. This is overlain by a white highly crossbedded massive sandstone about 100 feet thick. It is composed of nearly white, fine grained, angular and frosted grains. It is somewhat calcareous and resistant. Above this sandstone are 320 feet of irregularly weathering light and dark brown banded sandstone. A small amount of dark brown, maroon, or green mudstone, and thin pebble conglomerate lenses are also present. It forms a steeply sloping outcrop supported by the massive major sandstone cliff of the Entrada Sandstone above. The upper contact is sharp, changing from the steep slope of the friable Carmel to the vertical massive and hard cliff of the Entrada.

Blakey (1970, p. 77, 79, and 81) called the three subdivisions the Paria River, White Sandstone facies, and Winsor Members. The white chippy limestone "marker" is not present at West Cove, but according to Blakey's system the White Sandstone facies has probably replaced it. A little limestone is locally found beneath it. In the highway roadcut at West Cove the Judd Hollow Tongue is a little over 55 feet thick. A 3 foot platy weathering, ledge-forming gray and lavender limestone is found 11 feet below the top. The 11 feet of Crystal Creek Member consists of reddish-brown, slope-forming siltstone. Gray, red, and tan sandstone, claystone, and siltstone make up the remainder of the Kolob Member.

At Fiftymile Point, at the southeast tip of the Kaiparowits Plateau, the Carmel Formation is 175 feet thick. The upper three members of Thompson and Stokes appear identifiable. The lower Paria River Member rests on the Page Sandstone. It is about 60 feet thick. It can roughly be divided into three subunits; a lower reddish-brown, earthy, slope-forming siltstone and sandstone, a middle light brown resistant ledge of fine grained calcareous sandstone, followed by a reddish brown siltstone capped by a pink, platy and chippy weathering limestone. These subunits are 43, 10, and 7 feet thick respectively. The Carmel above is mostly earthy weathering, poorly exposed reddish siltstone and sandstone,

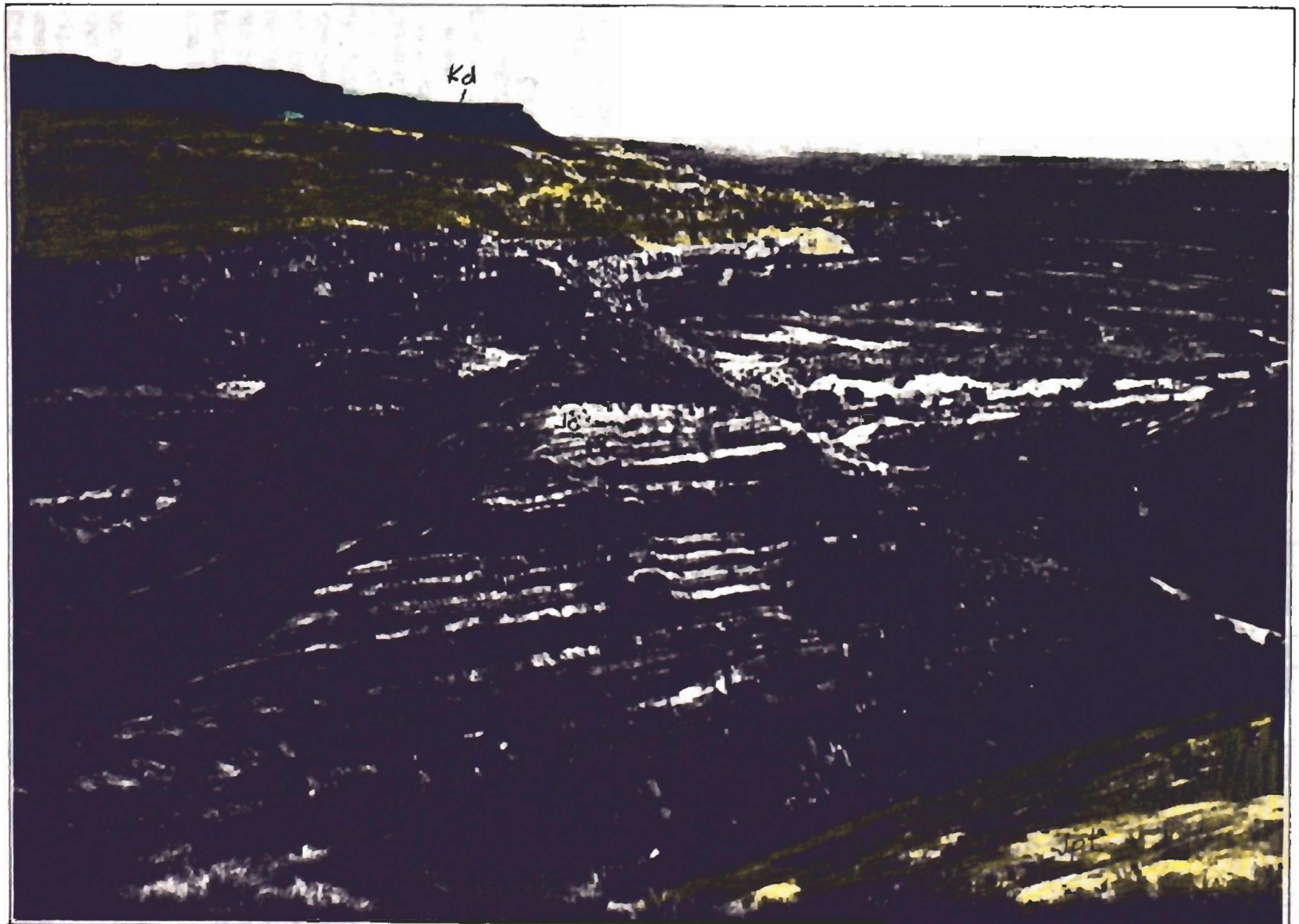


Photo 29. Outcrops of the Carmel Formation above the dip slope of the Thousand Pockets Tongue at West Cove. The massive sandstone and gray cliffs in the background are of the Entrada Sandstone and Dakota Formation. The exposures of the Carmel Formation in south-eastern Kane County were deposited in mostly tidal flat and beach environments.

interrupted by an occasional white sandstone ledge. The Winsor Member portion is nearly 90 feet thick. Finally, at the top, are 27 feet of interbedded siltstone, platy limestone, and silty sandstone that probably represent the Wiggler Wash Member.

At Early Weed Bench, also east of the Straight Cliffs, the Carmel above the Page Sandstone is about 215 feet thick. All three members can be identified. The Paria River Member is over 75 feet thick, again with 37 feet of reddish-brown slope-forming siltstone and sandstone, a 3 foot ledge of light brown, ledge-forming siltstone and sandstone and 35 feet of siltstone capped by platy or chippy weathering light limestone. The Winsor Member is only 66 feet thick and consists of earthy weathering, slope forming reddish-brown, siltstone with some fine grained sandstone. Above the Winsor are 73 feet of Wiggler Wash Member; blocky banded or laminated gypsum beds alternating with earthy weathering siltstone (photo 30). To the north the gypsum of the Wiggler Wash tongues lower into the Winsor Member so that in Garfield County the entire Winsor is eventually replaced by the Wiggler Wash. These were identified by Doelling (1975, p. 35-38) as an upper gypsiferous member (Wiggler Wash) and a lower limy unit (Paria River).

Finally, at the Baker Ranch across the bay from Bullfrog marina, the Carmel is nearly 110 feet thick. The upper Carmel can again be divided into two members. A lower Paria River Member is recognized consisting of reddish brown siltstone and sandstone capped by a pinkish gray, silty, platy and chippy weathering limestone (5 feet thick) (photo 31). The Paria River Member is about 50 feet thick. The upper part (Winsor) is mostly sandstone, reddish, fine grained, and silty, occasionally interrupted by a medium or thick white, fine grained sandstone ledge.

Carmel-Entrada contact. The Carmel-Entrada formational contact is thought to be conformable. In most places it is sharp and placed where the earthy weathering, usually reddish and gypsiferous upper units of the Carmel butt against the lower massive cliff of the "slickrim" or "slickrock" Entrada Sandstone. Locally this contact is very uneven, and probably a product of post-depositional deformation. At Early Weed Bench and at other locations just east of the Straight Cliffs, mounds of "slickrim" seem to have sunken deep into the Wiggler Wash and Winsor Members of the Carmel Formation. It seems reasonable to assume that some of the dunes of Entrada sand were deposited unevenly over locally water saturated and unconsolidated upper Carmel sands. The thicker and dry dunes of the Entrada then sank and distorted the saturated beds beneath them. These local areas of deformation along the Entrada-Carmel contact are known over a wide area of the Utah Colorado Plateaus.

Entrada Sandstone. The Entrada Sandstone (Gilluly and Reeside, 1928) is a prominent formation in eastern Kane County. It overlies the Carmel and terminates at the top of the J-3 (sub-Curtis) unconformity of Pipiringos and O'Sullivan (1978, p. A12, Fig. 2). From the Paria Terrace westward the K-0 unconformity progressively truncates the J-3 and the Entrada Sandstone. The formation is finally cut out at Coal and Slide

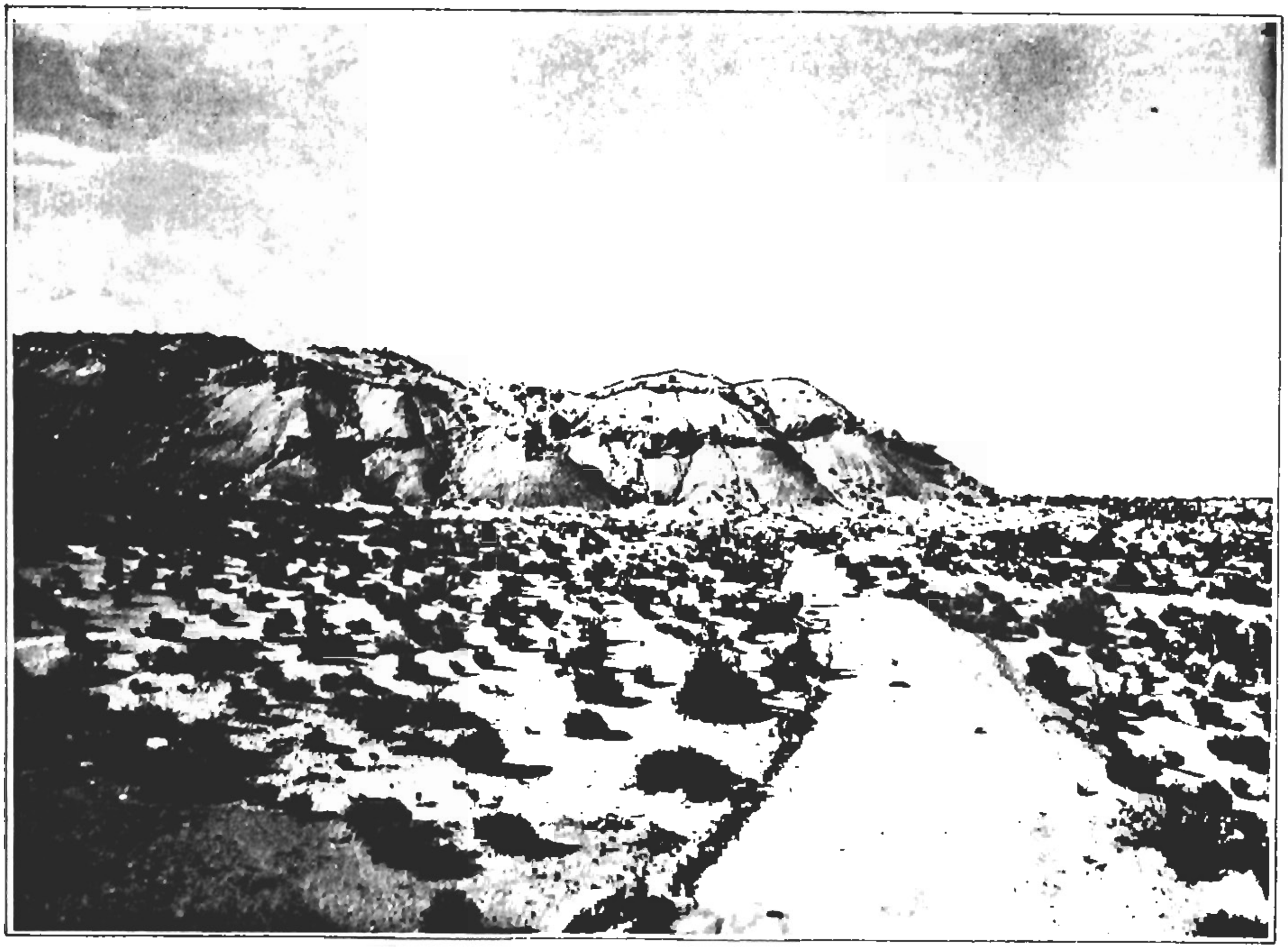


Photo 30. Early Weed Bench exposing the Winsor and Wiggler Wash Members of the Carmel Formation. The light outcrop at road level is the top of the Paria River Member, a white chippy weathering limestone. The rough ledges are gypsum beds in the Wiggler Wash Member.

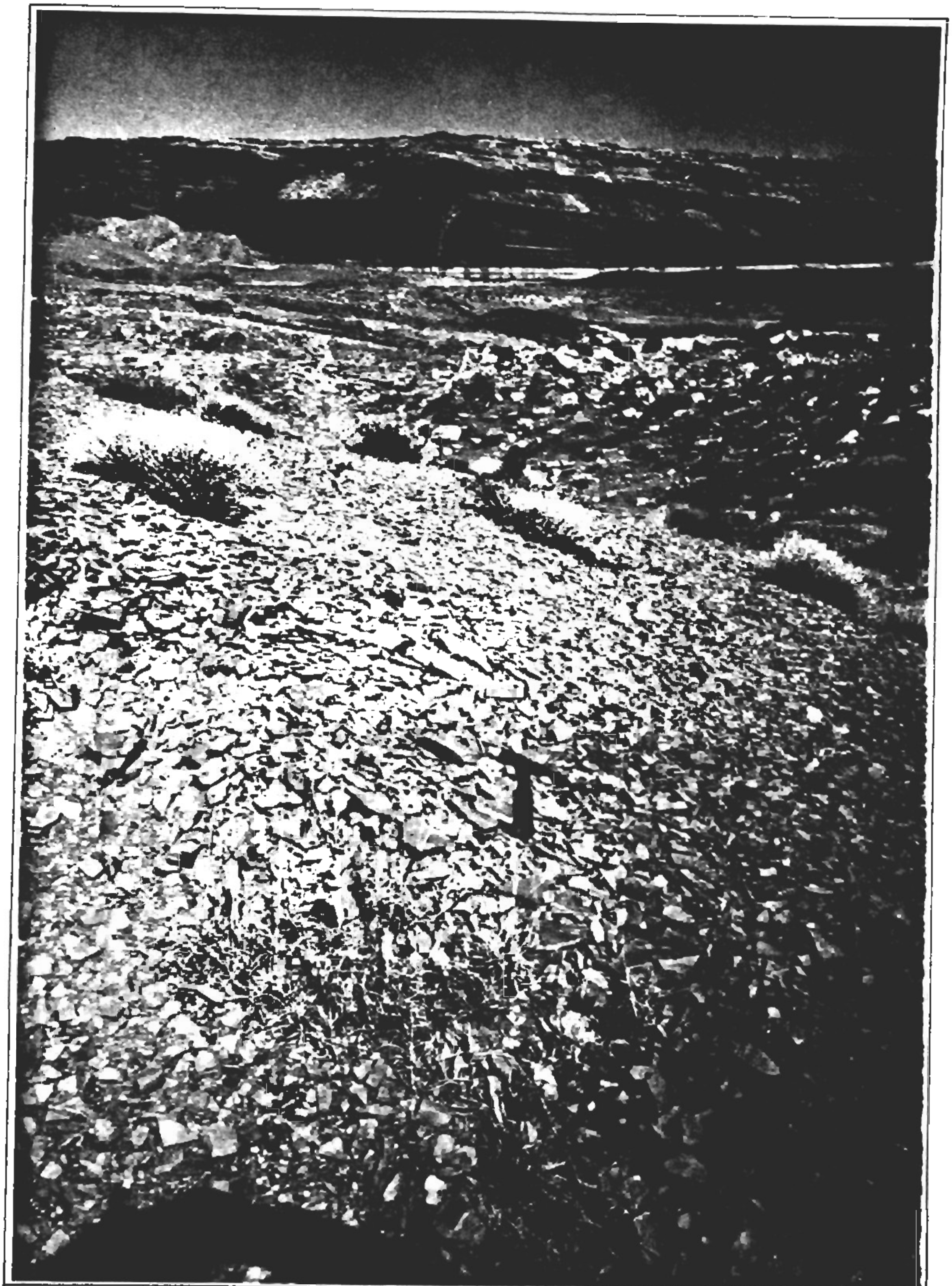


Photo 31. Chippy sandy limestone marking the top of the Paria River Member of the Carmel Formation near the mouth of Halls Creek in extreme eastern Kane County. The overlying Winsor Member consists of reddish-brown silty sandstone and ledges of white calcareous sandstone at this location. The entire Carmel Formation is only 108 feet thick here.

Canyons on the southeast margin of the Paunsaugunt Plateau (Secs. 17 and 18, T. 40 S., R. 4 W.).

In Kane County the Entrada ranges in thickness from 0 to over 950 feet, the thicker sections being located to the north and east. It is about 850 feet thick near Bullfrog to the east; 950 (north) to 800 (south) feet along the east margin of the Straight Cliffs; 800 (east) to 300 (west) feet along the southern end of the Kaiparowits Plateau; 300 (south) to 600 (north) feet along the Cockscomb or East Kaibab monocline; and 600 (east) to 0 (west) around the Paria Terrace to the south margin of the Paunsaugunt Plateau.

The Entrada is mostly sandstone, very fine to fine grained, and quartzose. Small quantities of orange, pink, and black accessory grains are also present. The grains are mostly rounded or subrounded and moderately to well sorted. Siltstone and claystone or shale make up the remainder of the rock types. Colors range mostly from white to red. Orange, reddish-brown, and white are the most common colors. The reddish and orange hues dominate to the north and east, whitish shades dominate to the south and west. The finer rock types are generally darker. A few of the thin claystones are bentonitic and a bright purple.

Much of the sandstone is crossbedded, medium and large scale wedging planar sets are present. In other places the sandstones are irregularly flatbedded or indistinctly bedded. Cementation is poor to good; calcareous, siliceous, or with iron oxides. The Entrada weathers to form vertical cliffs, rounded hard "slickrims," or to steep earthy slopes. The earthy weathering parts are often covered with sandy alluvium, sandy mixes of alluvial and eolian origin, or sand dunes. The sandy areas of the Flats (east of the Straight Cliffs) and on Clark Bench are partly developed on softer Entrada horizons and the Carmel Formation. The Entrada was deposited in environments similar to those that deposited the Carmel Formation; as shallow marine, tidal flat, sebka, and beach deposits.

Differences in weathering characteristics and color have led some workers to divide the formation into members. These are not shown on the county geologic map. The member divisions are locally useful and some 7.5 minute mappers have been able to plot them. The easiest division is into upper, middle, and lower members. The "lower member" is generally cliffy, well cemented, and forms the "slickrim" outcrops or vertical cliffs. It is usually highly crossbedded. The "middle member' contains more silt, is less well cemented and more earthy weathering, forming steep earthy slopes, sand covered benches and flats, or rough cliffs. Flatbedded sandstone, indistinctly bedded strata are more likely to occur in this unit. The "upper member" varies from place to place and occasionally causes confusion when correlations are attempted.

Thompson and Stokes (1970) named these divisions the Gunsight Butte, Cannonville, and Escalante Members. These names have not been accepted by the U. S. Geological Survey workers (Zeller and Stephens 1973, Peterson 1975, and Bowers 1983) who prefer to call these Lower, Middle, and Upper.

The Entrada Sandstone is exposed around Bullfrog and Halls Creek Bays in eastern Kane County. Wright and Dickey measured a section in 1956 (Baker Ranch section in Wright, Dickey, and Snyder, 1979), dividing the unit into three informal members; lower, middle, and upper sandy members (total 849 feet). The lower member consists of about 355 feet of "slickrim" type orange or reddish-orange sandstone. Above is a reddish, poorly cemented unit that is rather poorly exposed and estimated to be 255 feet thick. The upper sandy member forms a rough cliff, is better cemented than the middle member, but less well cemented than the lower member. It forms a cliff, is irregularly bedded, and 239 feet thick.

Zeller and Stephens (1973), east of the Straight Cliffs at the north margin of the county (Seep Flat quadrangle), indicate the Entrada Sandstone to be at least 940 feet thick and divisible into three members; lower, middle, and upper. The lower is described as reddish-brown, silty, and crossbedded. It represents the "slickrim" type of Entrada and probably correlates directly with Wright and Dickey's Baker Ranch lower member. The Entrada has been eroded from the Circle Cliffs anticline between these two locations. It is about 380 feet thick, the middle member is 280 feet thick, and the upper member is also 280 feet thick in the Seep Flat quadrangle. The middle member is reddish-orange and forms banded slopes. It is often covered by sandy Quaternary deposits and probably correlates with at least part of the middle member of the Baker Ranch section. The upper member consists of light-gray to white, fine grained, high angle crossbedded (eolian?), and massive unit. It does not resemble the upper sandy member of the Baker Ranch section.

Peterson (1973, 1975, etc.), in mapping the Entrada on several quadrangles between Sooner Bench and Gunsight Butte (southeast margin of the Kaiparowits Plateau) recognizes the presence of only the lower and middle members of Zeller and Stephens, the upper member pinching out or undergoing a facies change southward. Near Fiftymile Point the Entrada is 822 feet thick with a 453 foot lower "slickrim" type member (photos 32 and 33). Peterson's middle member is 369 feet thick, very thin to thickbedded and thinly to thickly crossbedded, appearing mostly in a steep cliff. Most is reddish-brown to reddish-orange. Toward the top the sandstone appears to be banded red and white or is completely white (upper 100 feet). Between Seep Flat and Fiftymile Point the "softer" middle member changes its outcrop habit, the upper part becoming cliffy and increasingly thick at the expense of a "softer" lower part.

Farther west along the south flank of the Kaiparowits Plateau and along the shores of Lake Powell, the Entrada forms nearly vertical cliffs which cannot be measured directly. Near Gunsight Butte, Peterson (1973) measured the lower member "slickrim" sandstone by alidade and obtained 570 feet. His middle member was less than 70 feet thick and consists of white and red banded steep slopes or cliffs. The top of the middle member is marked by an unconformity above which is the Romana Mesa Sandstone. Thompson and Stokes (1970, p. 36-38) scaled the thickness of units from photographs and record 475 feet of Gunsight Butte Member and 198 feet of Cannonville Member at the same location. The total thickness of the two

Photo 32. Fiftymile Point near the southern end of the Straight Cliffs and Fiftymile Bench. The Navajo Sandstone and Page Sandstone make up the bare rock outcrops at the foot of the cliff. The dark line at the foot is the Carmel Formation and the Entrada Sandstone extends up to the top of the white band, mid-cliff. The remainder of the "smooth" part of the cliff is the Romana Mesa Sandstone and the top is the Morrison Formation.

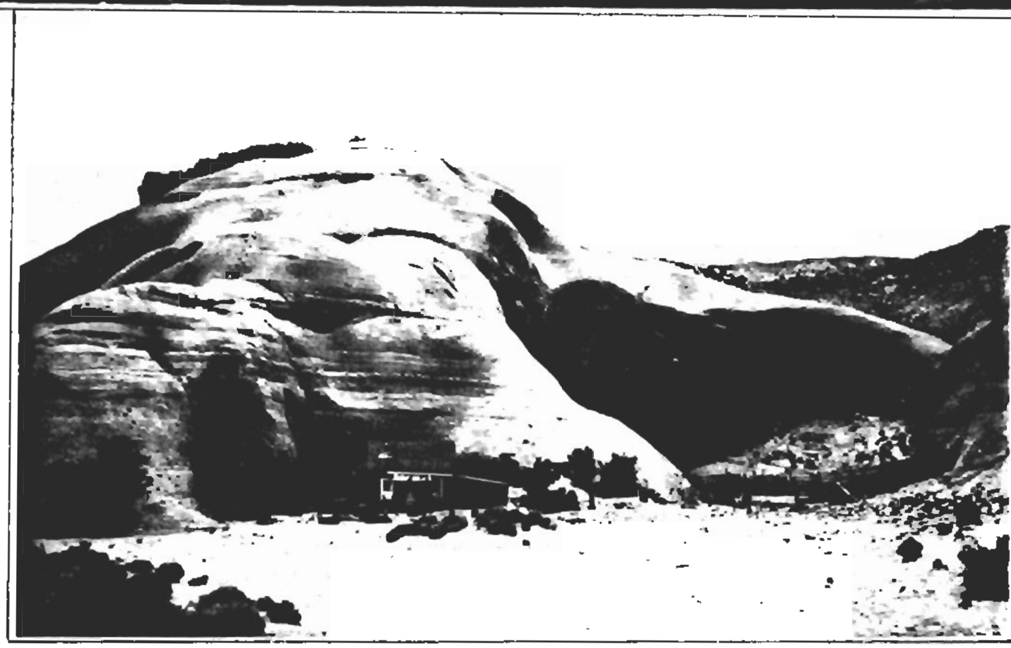


Photo ~~32~~ 33. Entrada Sandstone outcrops. Upper photo shows the Cannonville Member near the Cockscomb capped by the Cretaceous Dakota Formation. The Cannonville Member is also known as the upper member. The lower photo is of the lower "slickrim" member or Gunsight Butte Member as seen near Fortymile Point.

member measurements show the Entrada to be 640 and 673 feet respectively and compare favorably. Thompson and Stokes indicate the Escalante Member to be 137 feet thick and lying above an intraformational unconformity. Peterson records 70 feet of Romana Mesa Sandstone above the J-3 (sub-Curtis) unconformity, but measurements were probably taken at separate localities.

At West Cove the Entrada is a bit over 300 feet thick. It is mostly white or nearly white, very fine grained sandstone with a few reddish bands. It can roughly be divided into four units. There is a lower cliff 30 to 45 feet thick, a softer unit with a red band 50 feet thick, an upper cliff 160 to 220 feet thick and an upper slope-forming unit with pale red bands 60 to 80 feet thick. The upper unit is terminated by the K-0 unconformity and is overlain by a claystone in the Dakota Formation. A thin coal bed is present 1 foot above the contact. Blakey (1970, p. 160-161) assigned the 30 to 45 foot lower cliff to the Gunsight Butte Member; the soft unit and upper cliff to the Cannonville Member and the upper slope-forming unit to the Escalante Member.

The present writers believe these assignments to be in error, and that only the lower two members are present. We traced these units northward into the Cockscomb and found that all units except the upper slope former become the Gunsight Butte Member as portrayed in Thompson and Stokes' (1970, p. 17, Fig. 30, and p. 19, Figs. 36 and 37) photographs. Therefore only the upper 60 to 80 foot unit is the middle member or Cannonville Member and there is no Escalante Member present.

In a section measured just north of the mouth of Hackberry Canyon along Cottonwood Creek, the Entrada is 524 feet thick. The Gunsight Butte is mostly white and weathering yellow tan. It is crossbedded, massive, and weathers to monolithic cliffs. It is 158 feet thick. The remainder of the Entrada is earthy weathering, lightly banded sandstone that forms steep slopes (photo 33). It is 366 feet thick. The upper 20 to 30 feet is a little darker and is the Escalante Member of Thompson and Stokes (1970, p. 19, Figs. 36 and 37).

At Butler Valley, Bowers (1983) indicates the presence of 700 feet of Entrada Sandstone. He describes three divisions not differentiated on his map. These include a lower 200 to 300 feet of reddish-brown, fine grained, low to high angle cross-stratified sandstone that corresponds to the lower or Gunsight Butte Member. Then there is a 200 to 300 foot middle member (Cannonville) of white to light gray, fine grained, low angle crossbedded silty sandstone that is softer, containing pale reddish bands. The uppermost 80 to 100 feet are white to yellowish-brown sandstone, fine to coarse grained with high angle crossbeds that form a massive cliff. At least part, if not all, of this upper unit is Thompson and Stokes'(1970) Henrieville Sandstone and part of this may be their Escalante Member.

At Kodachrome Flat, the Entrada Sandstone, as defined by Thompson and Stokes (1970) is a little over 560 feet thick. The typical "slickrim" color and characteristic of the lower or Gunsight Butte Member returns just west of Butler Valley. At Kodachrome Flat this lower member is 290 feet thick. The Escalante and Cannonville Members (middle member) are difficult to separate and together are 270 feet thick. This unit forms steep earthy slopes with light reddish bands. Toward the top the bands disappear and the sandstone becomes more yellow or light greenish-gray and may be the Escalante Member (about the upper 75 feet of the middle member). Overlying the combined Cannonville and Escalante Members is the Henrieville Sandstone, about 92 feet thick. The Henrieville has been mapped as part of the Entrada by Bowers (1975 and 1983).

Thompson and Stokes (1970, p. 38) offer a stratigraphic section measured at Lick Wash, Sec. 25, T. 39 S., R. 4 W., only 4 or 5 miles from the place where the Entrada is truncated along the outcrop (Secs. 17 and 18, T. 40 S., R. 4 W.) by the K-0 unconformity. The typical "slickrim" appearance of the lower member is no longer present. The entire Entrada is light greenish-yellow or greenish-gray, very fine to fine grained sandstone or coarse siltstone, forming earthy weathering steep slopes or mud-plastered cliffs. Thompson and Stokes were able to trace a local key bed at this location that grades eastward into the typical "slickrim" Entrada. Therefore the Gunsight Butte Member is 165 feet thick and the undivided Cannonville and Escalante Members is 135 feet thick, for a total of 300 feet.

Measurement of the Entrada Sandstone along the west and north sides of Kodachrome Flat in Sec. 3, T. 38 S., R. 2 W. (Henrieville quadrangle), Kane County, Utah by Mark E. Jensen.

(place Entrada Sandstone measurement here).

<u>Summerville Formation, Romana Mesa Sandstone, and Henrieville Sandstone</u>. A relatively thin layer of rocks persists between the Entrada Sandstone and Morrison Formation (or Dakota Formation to the west) around the margin of the Kaiparowits Plateau. Positive correlations and relations have not been made as yet. These rocks are probably correlative to the Summerville Formation of eastern Utah. Outcrops of true Summerville just reach into Kane County at the north end of Halls Creek Bay, to the northeast. They are separated from the Kaiparowits Plateau rocks by the Circle Cliff anticline or uplift (from which they have been eroded).

At the Halls Creek Bay location the Summerville is typical for eastern Utah. It is composed of alternating thin to medium even beds of fine grained sandstone, siltstone, shale, and mudstone, mostly brown in color, but with occasional white layers. It is 143 feet thick and rests on the J-3 unconformity above the Entrada Sandstone and lies beneath the J-5 unconformity at the base of the Morrison Formation (photo 34).

Individual sandstone beds range from a few inches to three feet in thickness and form evenly spaced ribs between the softer units. The soft lithologies vary from thin partings to about six inches in thickness. Occasional beds are crisscrossed with gypsum veinlets, and a few thin beds of gypsum may be found near the top.

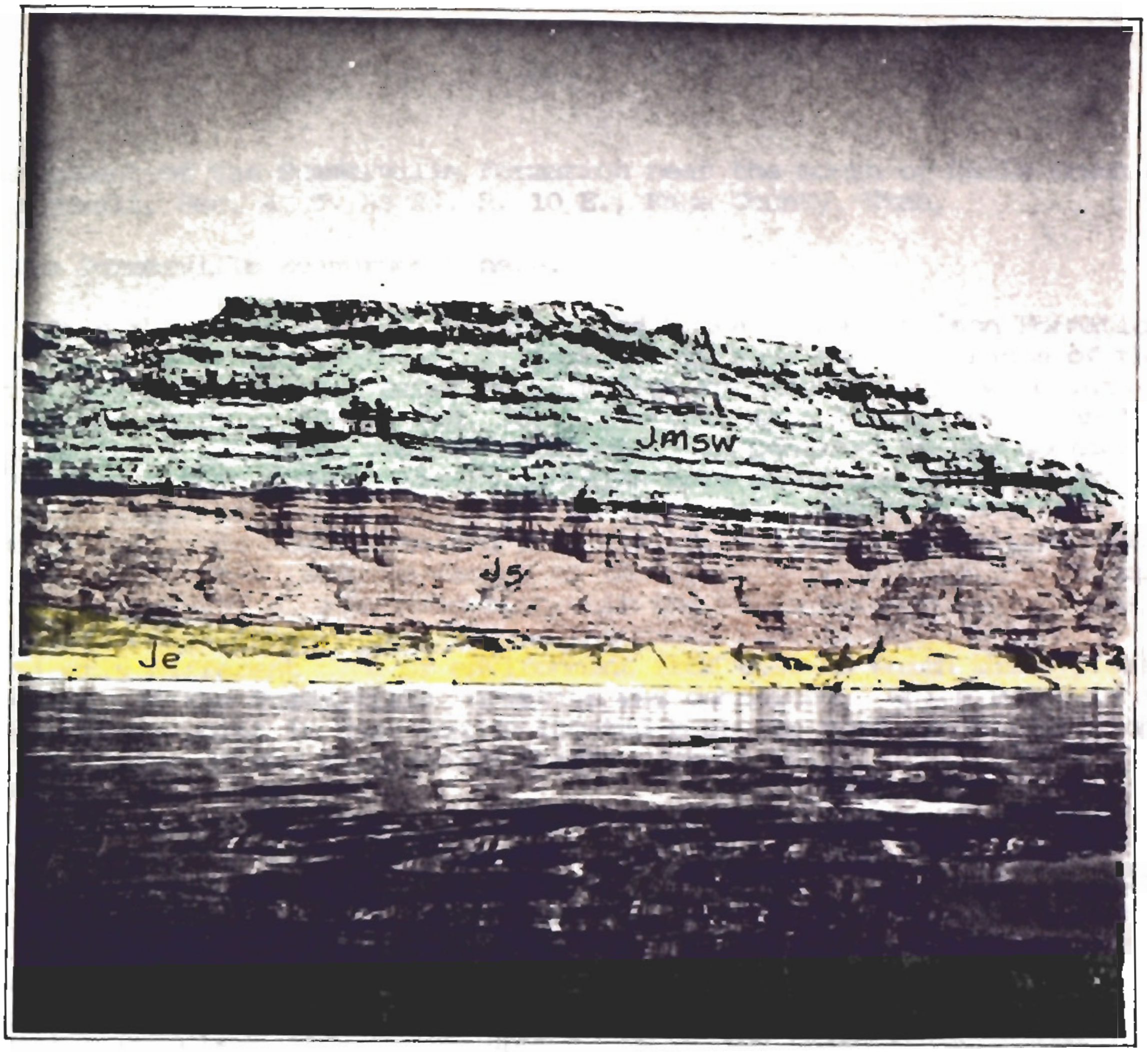


Photo 34. The Summerville Formation as exposed in Halls Creek Bay. The top of the Entrada Sandstone is exposed just above water level and the top of the mesa exposes the Salt Wash Member of the Morrison Formation.

Measurement of the Summerville Formation near the mouth of Halls Creek on Lake Powell, Sec. 4, T. 38 S., R. 10 E., Kane County, Utah.

(place Summerville measurement here.)

Beds above the Entrada Sandstone and beneath the Morrison Formation near the town of Escalante in Garfield County have the appearance of the Summerville, but are dominated by a reddish rather than a brown color (Doelling, 1975, p. 40-41, Fig. 30). The unit is a little less than 120 feet thick, 1 1/2 miles west of Escalante. In contrast to the section farther east this Summerville(?) contains more sandstone and thicker, more white or light colored sandstones. No gypsum is present. In addition some of the sands are course and even gritty, and somewhat crossbedded. It may represent a landward facies of the Summerville Formation. Thompson and Stokes (1970, p. 25) named this unit the White Point Member of the Summerville Formation, justified on the basis that it represents a distinctly different type of environment from that in which the typical or main body of the Summerville Formation was deposited. White Point is a geographical point in Kane County located near its northern border along the east edge of the Kaiparowits Plateau (photo 35).

From Escalante southward to White Point, the 84 ft. member retains its appearance as in Garfield County, but thins to [redacted] feet. Zeller and Stephens (1973), in mapping the Seep Flat quadrangle, combined the White Point with the lower beds in the Morrison and labelled the combination the "lower member" of the Morrison Formation. To the south of White Point a new character begins to develop for this horizon. The middle part becomes dominantly sandy and massive and only the upper and lower margins retain the thin even beds and reddish appearance of the White Point Member. At Cat Pasture the unit is only 40 feet thick. Thompson and Stokes (1970, p. 26) believe the White Point is finally cut out south of Soda Springs Canyon by the J-5 or sub-Morrison unconformity (figure 21).

Measurement of the White Point Member of the Summerville? Formation at White Point, 26 miles southeast of Escalante City along Hole-in-the-Rock road, SWSW Sec. 11, T. 38 S., R. 5 E., Kane County, Utah.

(place White Point Member measurement here.)

Contrarily Peterson (1975) believes this horizon becomes the Romana Mesa Sandstone as exposed along the south margin of the Kaiparowits Plateau. He indicates the unit to be only 22 feet at one locality on the Sooner Bench quadrangle, which then thickens to as much as 105 feet in the Cummings Mesa (15 minute) quadrangle (Peterson and Barnum, 1973). A thinbedded reddish "Summerville band" is found in the basal two feet. The rest of the Romana Mesa is described as grayish-yellow green to yellowish-gray, very fine to fine grained sandstone. It normally stands in a cliff between the Entrada and Morrison cliffs. Unconformities continue to be recognized at the base and top of the unit. Thompson and Stokes (1970, p. 23) indicate that this horizon was previously called the Cow Springs by Peterson and Waldrop (1965, p. 55-56), an Arizona unit defined by

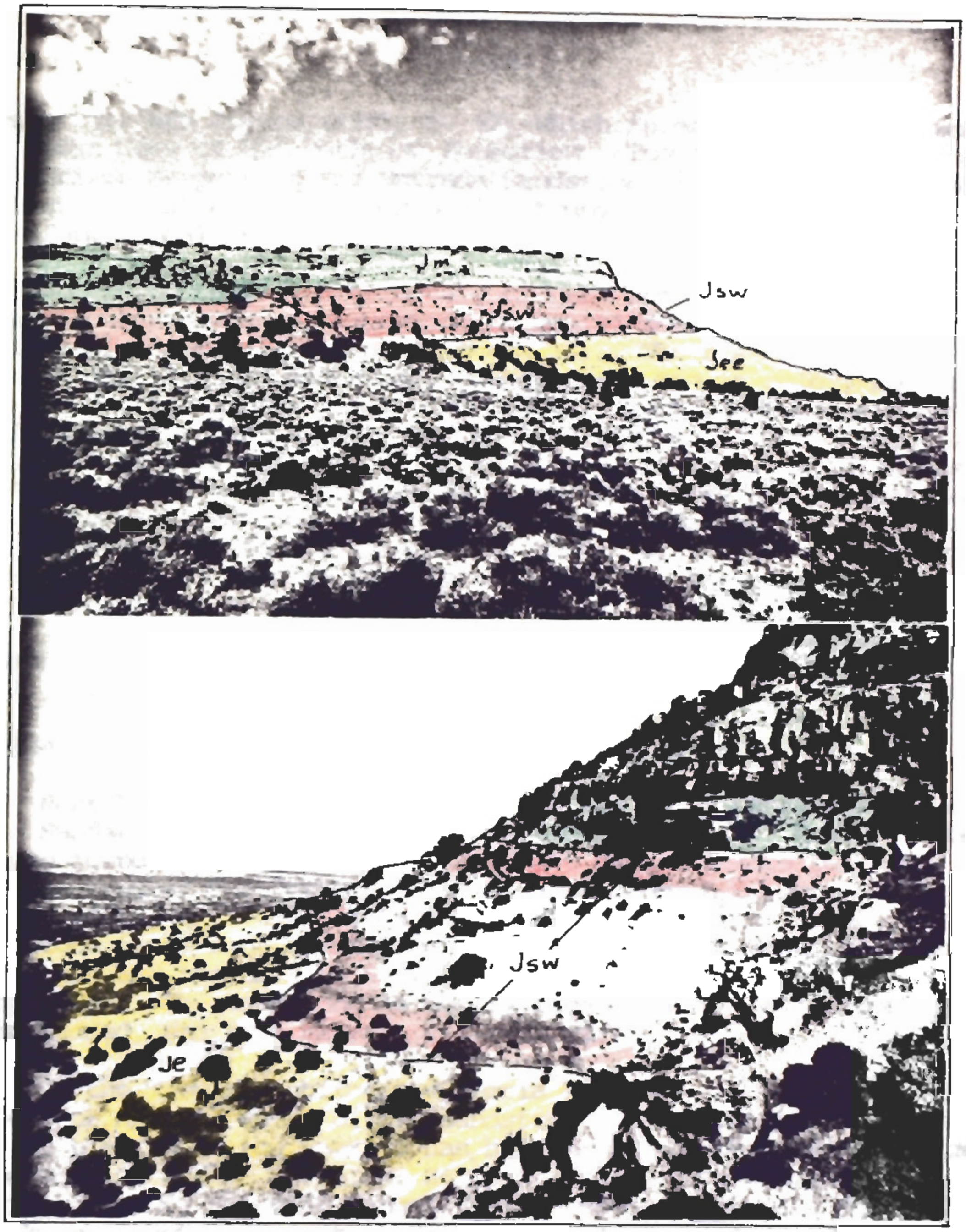


Photo 35. White Point Member of Summerville? Formation. Upper view shows the unit sandwiched between the Escalante Member (upper) of the Entrada Sandstone (white) and the cliffy capping conglomeratic sandstones of the Morrison Formation near White Point. Lower view shows earthy weathering White Point Member at the base of the cliffy Morrison Formation. The White Point outcrop includes the two dark bands and the white horizon between (abt 40 ft). The location of the lower view is below "Triangle Point" near Cat Pasture.

Harshbarger and others (1951, p. 97) which intertongues with Summerville and lower beds of the Morrison Formation. Thompson and Stokes included the horizon as part of the Entrada Sandstone, i.e., the Escalante Member, indicating that a basal unconformity found at its base was intraformational (p. 37).

At Crosby Canyon, a tributary of Warm Creek, we measured the Romana Mesa (Escalante Member) Sandstone to be 134 feet thick. At the base are 35 feet of "Summerville bands" (photo 36). The rest of the unit is very fine to fine grained sandstone, mostly light tan in color, medium bedded to massive, that forms cliffs and ledges. Forty feet beneath the top is a 25 foot massive unit displaying "eolian" high angle cross beds (single set) with some relief between it and the upper beds. It also displays some streaks of coarse grained sand and worm tubes are present near the top. The basal contact of the Romana Mesa Sandstone at this locality is an unconformity with the Cannonville Member of the Entrada Sandstone. The upper contact is also an unconformity with the Morrison Formation, and locally displays a relief of 15 to 20 feet.

Measurement of the Romana Mesa Sandstone in Crosby Canyon, SW Sec. 9, T. 43 S., R. 4 E., Kane County, Utah.

(place Romana Mesa Sandstone measured section here.)

Near Lone Rock, not far from Big Water (Glen Canyon City), the Romana Mesa Sandstone is truncated by the K-0 unconformity. However, the unit may be found farther to the west as rare discontinuous patches. At the southern end of the Cockscomb (about a mile north of West Cove), SWNE Sec. 18, T. 41 S., R. 1 W., a relatively thin 26 foot lens of nearly white sandstone is present between conglomerate at the base of the Dakota Formation and the Entrada Sandstone. Unconformities are found at the top and bottom. The sandstone is mostly fine grained, calcareous, crossbedded, and is a massive cliff-former.

In the Tropic Amphitheatre (Paria Terrace) and extending east to Grosvenor Arch, a white cliffy sandstone unit below the K-0 unconformity and at the top of the Entrada has been named the Henrieville Sandstone by Thompson and Stokes (1970, p. 26). In Kane County and parts of adjacent Garfield County the unit ranges from a feather edge to 234 feet in thickness (photo 37). It is divisible into 2 informal members; a lower flatbedded sandstone, siltstone, claystone,m and shale unit of fluvial origin and an upper massive crossbedded fine to medium grained sandstone of eolian deposition. The upper unit is poorly sorted and contains many coarse grains. The lower contact appears conformable with flatbeds resting on massive silty sandstone without any indication of relief. Bower (1975 and 1983) describes the unit as the upper part of the Entrada Sandstone. At Kodachrome Basin (Sec. 3, T. 38 S., R. 2 W.) the Henrieville Sandstone is 92 feet thick. It is truncated by the K-0 unconformity to the west in the vicinity of Cannonville.

Measurement of the Henrieville Sandstone on the north side of Kodachrome Flat, Sec. 3, T. 38 S., R. 2 W., Kane County, Utah by Mark E. Jensen.

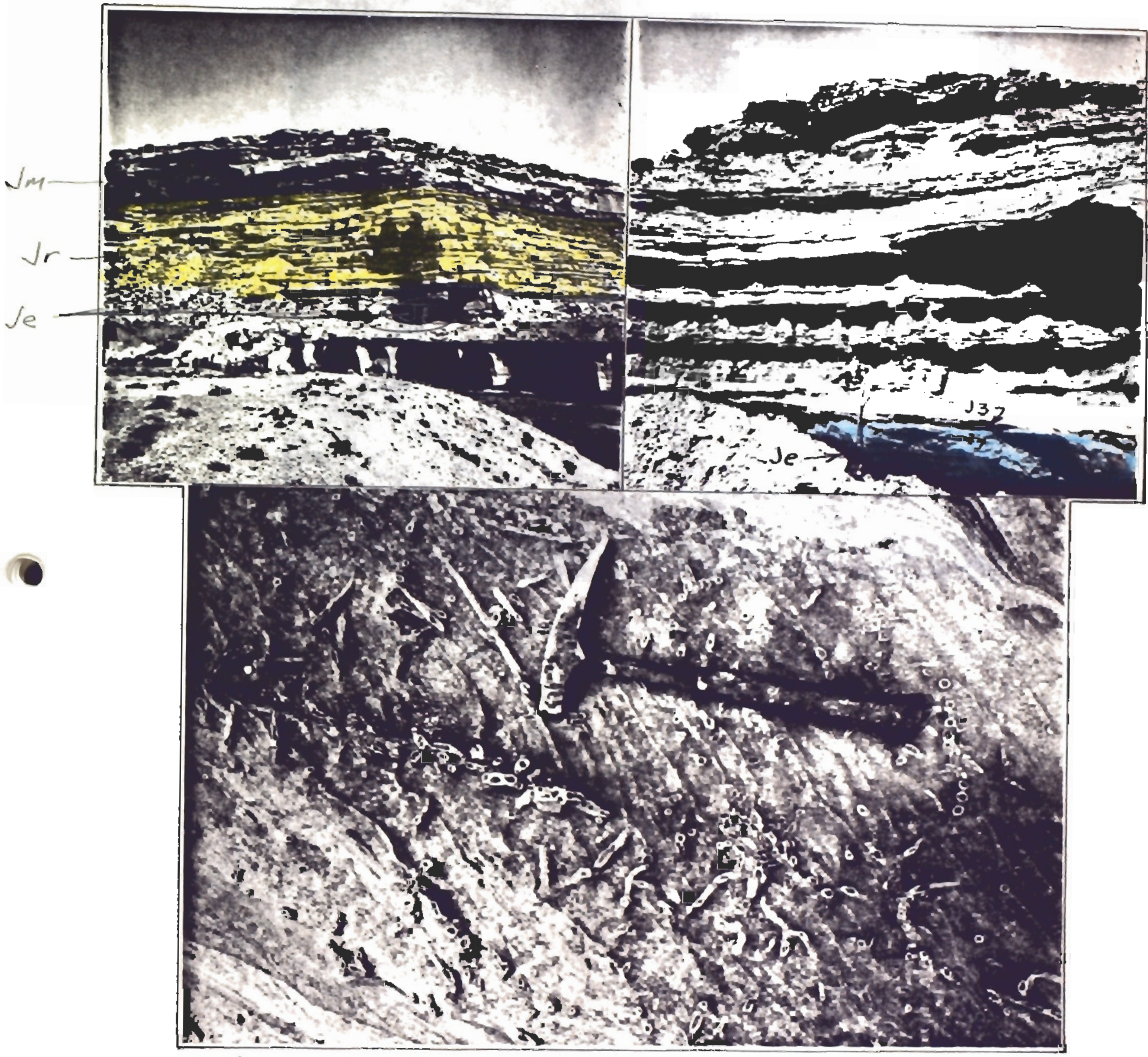


Photo 36. Romana Mesa Sandstone in Crosby Canyon. Upper left shows the entire unit between the dark band above the terrace in the Entrada Sandstone and the capping darker conglomeratic sandstones of the Morrison Formation at the top. Upper right shows "White Point"like beds just above the J-3 unconformity at the top of the Entrada Sandstone. Lower photo shows worm burrows at the top of a beach sand within the Formation.

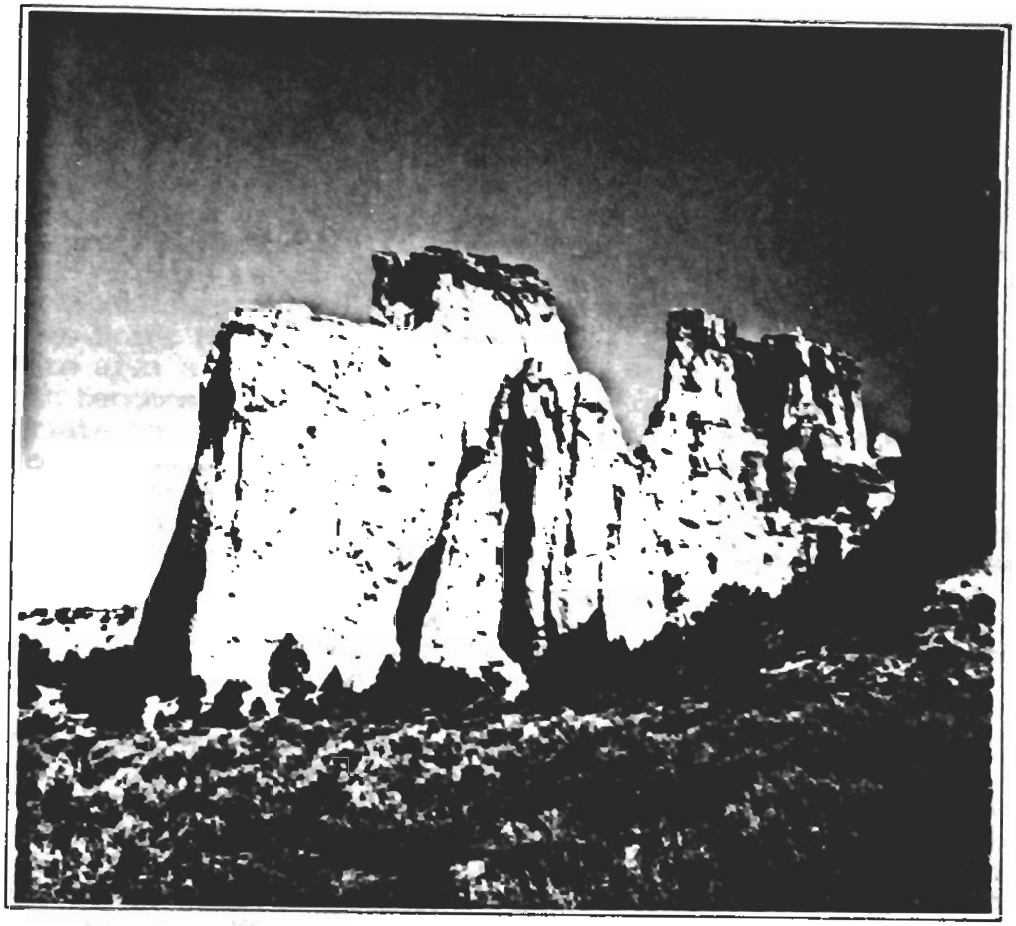


Photo 37. View of the Henrieville Sandstone near Grosvenor Arch. The darker caprock is the sub-Dakota Conglomerate.

(place measurement of Henrieville Sandstone here)

Figure 21 represents the interpretations of the various above-mentioned authors as we understand them. Our interpretation is also presented and suggestions are given for nomenclature usage. We believe the White Point Member of the Summerville Formation can be used in the Escalante area and as far south as Cat Pasture ("Triangle Point"), where the unit becomes dominantly non-red sandstone. Romana Mesa Sandstone is appropriate for the remainder of the exposures along the east and southern sides of the Kaiparowits Plateau, and the Henrieville Sandstone is appropriate for the Cannonville-Grosvenor Arch area. We believe the three are correlatable although definite proof or laboratory investigations are lacking; there are no fossils and no traceable key beds. We base our assumption on stratigraphic relationships and subtle lithologic similarities. They include the persistence of White Point-like flatbeds at the base (although they are not red in the case of the Henrieville), and the presence of coarse sands in many of the beds.

Morrison Formation. This formation is present only in eastern Kane County. It is incompletely exposed in a cliff at the north end of Halls Creek Bay (photo 34). Additional exposures extend around the eastern and southern margins of the Kaiparowits Plateau. Westward it is eliminated by the K-0 unconformity and is cut out near Lone Rock east of Big Water (Glen Canyon City). Over much of eastern Utah the Morrison is divided into two members; an upper Brushy Basin Member and a lower Salt Wash Member. The upper is dominated by varicolored slope-forming mudstone, the lower is dominated by lenticular, cliff and ledge forming channel type conglomeratic sandstone and sandstone. At the north end of Halls Creek Bay only the lower Salt Wash Member is present, the upper having been eroded from the top of the mesa. The complete Salt Wash Member in the southern Henry Mountains area, may be as much as 550 feet thick (Doelling, 1975, p. 42). The Brushy Basin Member is probably not present in Kane County.

At Escalante, in Garfield County, both members are present, but the upper Brushy Basin thins and disappears southward in outcrop before the Kane County line is reached. In the Kane County outcrops the Morrison Formation ranges from 0 to an assumed maximum of 700 feet. The formation is about 350 feet thick near Twentymile Wash, at the north end of the county, 415 feet thick below Cat Pasture ("Triangle Point"), Sec. 4, T. 39 S., R. 6 E.; 475 feet thick near West End Point, Sec. 24, T. 39 S., R. 6 E.; 681 feet thick at the head of Soda Springs Canyon, Sec. 11, T. 41 S., R. 8 E. (Peterson and Barnum, 1973); 188 feet thick in Crosby Canyon, Sec. 8, T. 43 S., R. 4 E.; and 72 feet thick near Lone Rock Canyon, Sec. 24, T. 43 S., R. 3 E. Zeller (1973) reports westward thinning of the Morrison Formation under the Kaiparowits Plateau in the northern part of the county. In the Death Ridge quadrangle he estimates the unit to be only 30 to 150 feet thick.

fig 62 (white)
Discarded

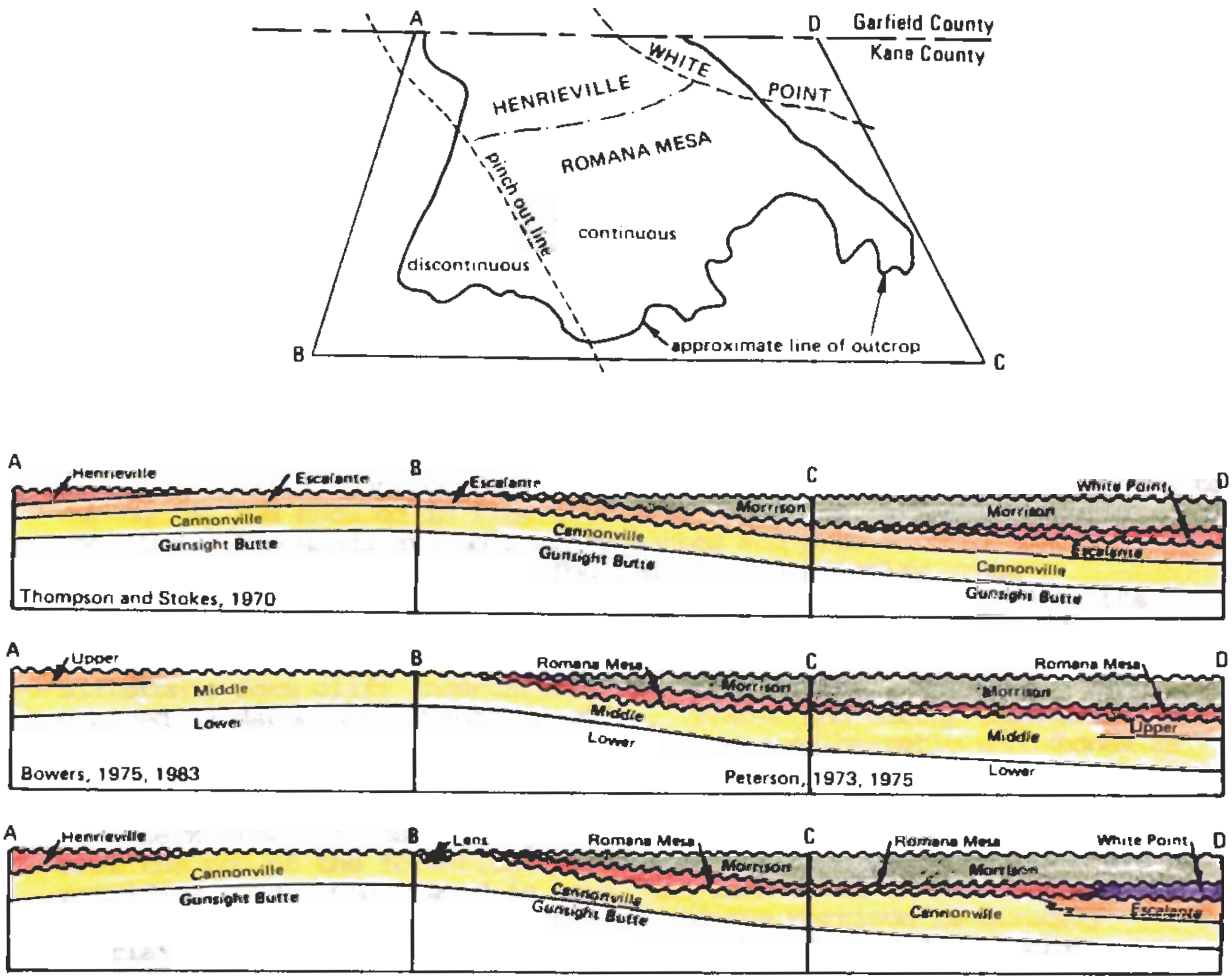


Figure 21. Upper San Rafael Group correlations around the Kaiparowits Plateau. Cross sections and map are diagrammatic, no vertical or horizontal scales are intended. Upper diagram is suggested White Point-Romana Mesa-Henrieville facies map. Upper cross section indicates correlations as visualized by Thompson and Stokes, 1970. Middle cross section indicates correlations suggested by Bowers and Peterson. The lower cross section represents our interpretation.

Peterson (1975) has divided the Morrison Formation in Kane County into upper and lower members, calling his lower member the Salt Wash. The Brushy Basin Member near Escalante may intertongue in part with this upper member to the south. Peterson's Salt Wash consists of up to 350 feet of fine to medium grained crossbedded sandstones, conglomeratic sandstone, conglomerate, and lesser amounts of thinbedded mudstone and siltstone that form cliffs. The upper member interfingers with the lower and is composed of the same rock types, but generally has whiter sandstones and more mudstone and siltstone. The upper member is more likely to form ledgy slopes than cliffs. The upper member ranges to 365 feet in thickness.

The Morrison Formation is a fluvial deposit and is built mostly of superimposed river channels. Near "Triangle Point" (triangular shaped prominence along the Straight Cliffs near Cat Pasture) the unit is composed of 75 percent conglomeratic sandstone, 20 percent fine grained sandstone, 3 percent mudstone and siltstone, and 2 percent conglomerate (photo 38). The colors of the conglomeratic sandstones include yellow gray, gray, tan white, yellow, and light brown. The clasts are dominated by pebbles averaging 1/2 inch in diameter, composed of quartzite, silicified limestone, chert, and minor sandstone and siltstone. Clasts are occasionally found up to 4 inches in diameter. They are subrounded to subangular and encased in fine to coarse sandstone, all calcareously cemented. The sands are moderately sorted and size sorting occurs along the various crossbed laminae. The lenses often display cross-stratification that dip in the direction the old rivers flowed in the channels, are thin to massive, and are separated by partings and thin beds of mudstone and siltstone. The maroon or greenish-gray mudstones and siltstones form cliff indentations or earthy slopes. The mostly fine grained sandstones are light in color, friable and earthy weathering, and form slopes. They are interbedded with the conglomeratic sandstones as are the conglomerates.

Dark brown pieces and logs of petrified wood are locally plentiful near the top of the formation. sometimes the conglomerate clasts are of petrified wood. Coaly wood is rare, and when found is radioactive. The upper contact is the K-0 unconformity and the Morrison is directly overlain by either the Dakota Formation or sub-Dakota Conglomerate.

Measurement of the Morrison Formation below "Triangle Point", E 1/2, Sec. 4, T. 39 S., R. 6 E., Kane County, Utah.

(place measurement of Morrison Formation here.)

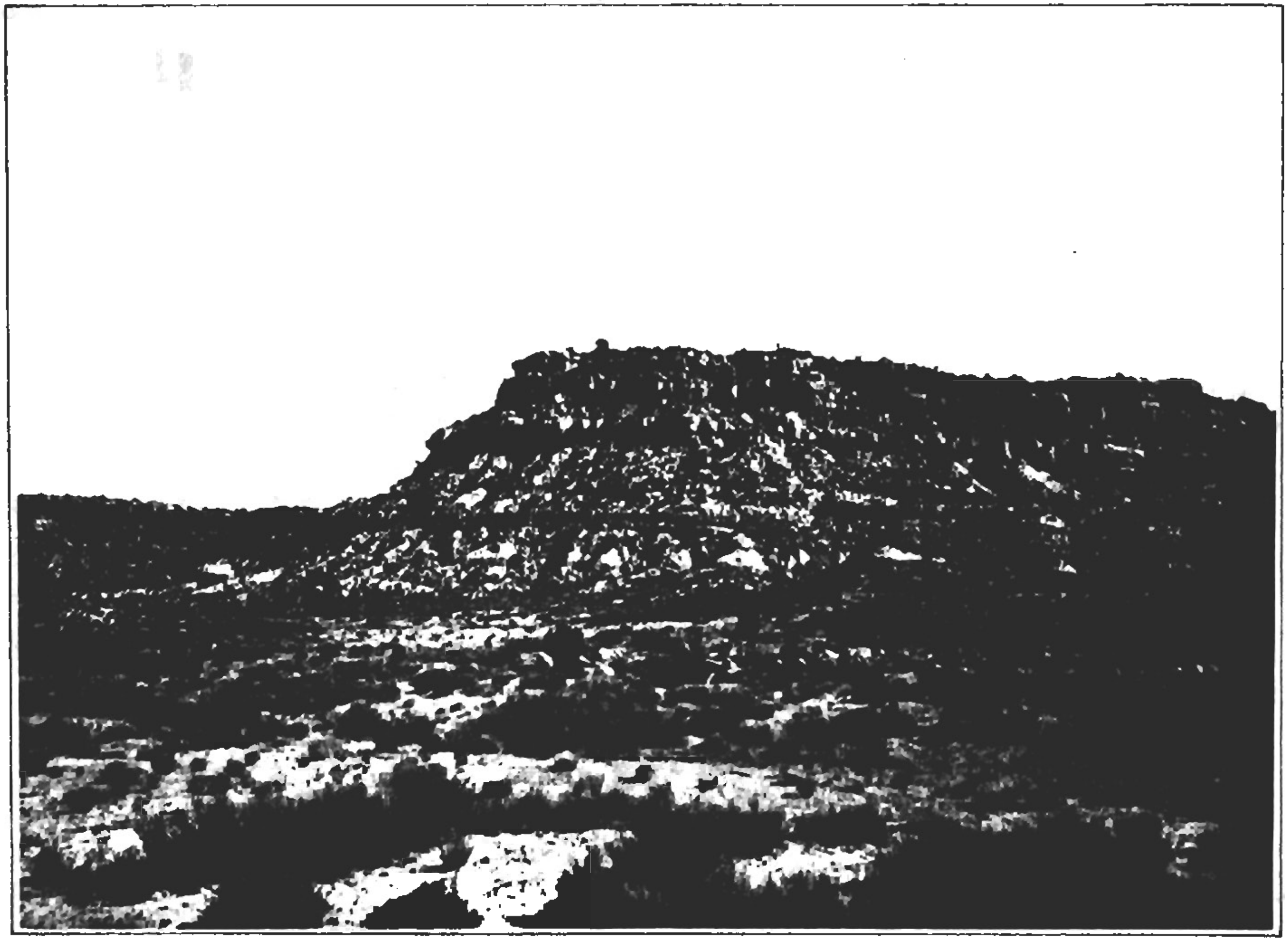


Photo 38. Morrison Formation outcrops at the foot of "Triangle Point" near Cat Pasture.

Cretaceous Formations

The Cretaceous System is relatively thick in Kane County and variable in thickness, perhaps 2500-6000 feet. The thickest section is found in the Kaiparowits Basin where it ranges from 4,500 to 6,000 feet. The Cretaceous prism in the Podunk Terrace area ranges from less than 2000 feet to over 3000 feet and in the Kolob Terrace area from 2300 to 4400 feet, thickening westward. Five formations crop out in Kane County (figure 22), some of which are subdivided into several members: Dakota Formation, Tropic Shale, Straight Cliffs Formation, Wahweap Formation, and Kaiparowits Formation (ascending order).

The rocks portray the deposition in advance, during, and after the incursion of the Cretaceous sea from the east. Valuable coal deposits, titanium and zirconium deposits, were created during this time. Sediments reached the area primarily from the west, from the area of the Sevier Orogenic Belt. The relationships between the Cretaceous formations of Kane County is shown diagrammatically in figure 23.

Dakota Formation and sub-Dakota Conglomerate. The Dakota Formation as portrayed on the Kane County geologic map is the oldest unit thought to be of Cretaceous age. The unit has been mapped as redefined by Lawrence (1965, p. 75-78) and includes all rocks above the K unconformity and below the base of a thick gray marine shale (Tropic Shale). Peterson (1969, p. 14-34) divided the Dakota Formation into three members; lower, middle, and upper. The lower member is a fluvial, mostly conglomeratic unit, the middle is a lagoonal interbedded sandstone, mudstone, and coal bearing unit, and the upper is mostly fossiliferous sandstone deposited in brackish to marine environments. The upper and lower members are discontinuous.

Gregory and Moore (1931, p. 95-100), in their study of the Kaiparowits region, named the lower conglomeratic member the Dakota(?) Sandstone and included the upper two members with the Tropic Shale. Gregory (1950, 1951) maintained this division in his studies of the Zion and Paunsaugunt regions. Cashion (1967), in mapping the southern Markagunt Plateau, also maintained the division, but divided the Tropic into a lower coal-bearing member and an upper shaly member. Lawrence's nomenclature has been adopted by Zeller (1973), Peterson (1969, 1975), Doelling (1972), Blakey (1970), and Bowers (1975). Most recently Bowers (1983) separated out at least some of the conglomerate of the lower member and named it the Conglomerate of Butler Valley and assigned it a Jurassic(?) age.

The base of the lower member is a regional unconformity, the K unconformity (basal Cretaceous unconformity). Bowers (1983) believes that the conglomerate in the Butler Valley area may be Jurassic in age and shows unconformities above and below. In the Zion Park region Gregory (1950, p. 102) reports that the conglomerate grades into the middle unit. Along the Cockscomb and the southwestern flank of the Kaiparowits Plateau the upper contact is an unconformity. Peterson (1969, p. 20-21), working in the southeastern Kaiparowits, indicates the upper contact is poorly

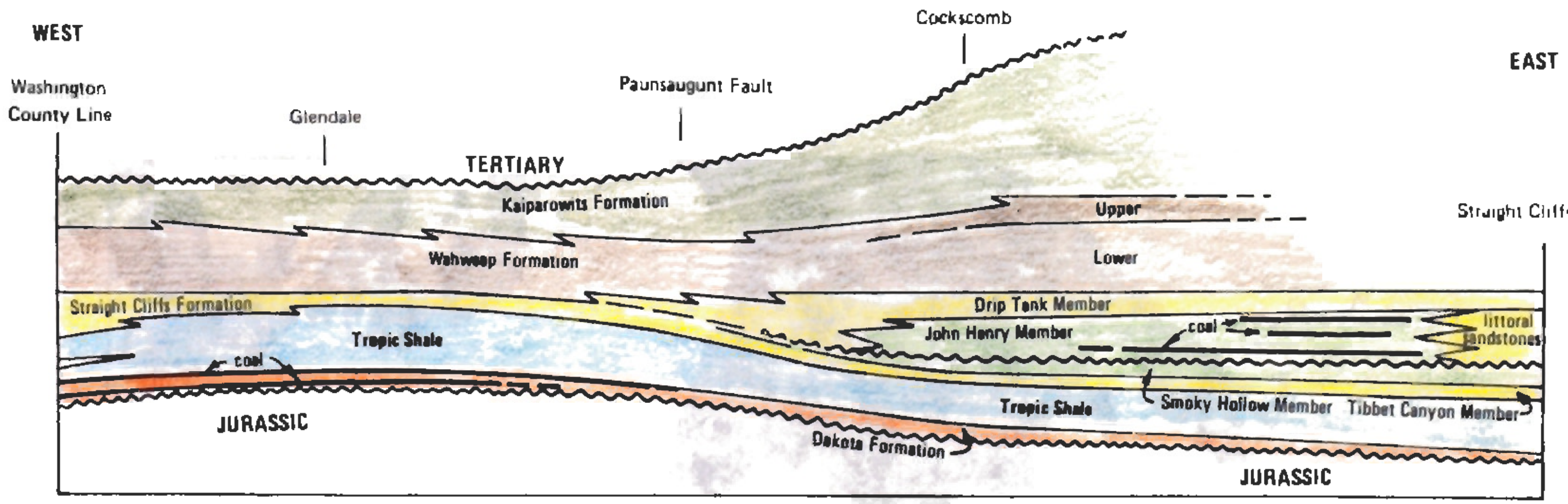


Figure 23. Diagrammatic west-east cross-profile showing relative thicknesses of the Cretaceous formations of Kane County.

Figure 22: Cretaceous outcrops of Kane County

exposed, but that the lighter colored sandstone and conglomerate of the lower member contrast sharply with the darker mudstone and sandstone of the middle member. He indicates the upper part of the lower (conglomeratic) member interfingers with the lower part of the middle member, but concedes that part or all of the lower member could be of late Early Cretaceous age. The upper contact might be an unconformity throughout eastern Kane County. In Crosby Canyon, Sec. 7, T. 43 S., R. 4 E., a "channel" of Dakota coal (middle member) effectively cuts out the conglomerate and rests on the Morrison Formation. Peterson (1969, p. 20) notes that fossils are rare in the lower member and reports only being able to find carapace fragments of a turtle. He states, "The lower member is probably about early Cenomanian in age on the basis of stratigraphic position beneath the middle member which is probably early to middle Cenomanian in age. We assume the conglomeratic member to be upper Lower Cretaceous, perhaps Albian in age. If the upper contact is an unconformity then considerable time may have lapsed before deposition of the coal bearing middle member began.

The sub-Dakota Conglomerate consists of interbedded conglomerate, pebbly sandstone, and sandstone with lesser amounts of siltstone, mudstone, and coal. Not all the lithologies are everywhere present and locally the unit is altogether missing. The unit generally forms ledges and often is found in cliffs with cliffy underlying and overlying neighbors (photo 39). The clasts are generally of chert, quartzite, silicified limestone, feldspathic sandstone, and petrified wood, they are subround to subangular, and average 1/2 to 1 inch in diameter. They are encased in a poorly sorted matrix of sand, silt, and clay, and are poorly to moderately cemented with calcium carbonate. Occasionally logs of petrified wood are incorporated in the lenses of conglomerate or sandstone. The lenses range from thin to massive and are usually shared with the sandstones and pebbly sandstones, evenso contacts between conglomerates and sandstones are generally sharp within the lenses. The sandstones are mostly poorly sorted, fine to coarse grained, friable, usually lightly cemented with calcium carbonate or silica. The conglomerate-sandstone lenses are cross stratified with laminae dipping down the axis of channels. In most places the siltstone, mudstone, and coal are minor constituents and form thin partings or beds between the lenses. The coal is generally fregmentary or present as vegetative trash, and rarely in very thin beds. The lenses have commonly been stained by mineralizing solution fronts, coloring the lenses with yellows, purples, oranges, and reds (iron oxide mineralization). Locally the sub-Dakota Conglomerate is uraniferous (western part of county), especially at the base. The overall color is light yellow-gray, light gray, white, or chalky pink. The sub-Dakota Conglomerate ranges from 0 to 120 feet in thickness, but at most localities it is less than 50 feet thick. The thicker sections are mostly found to the west, although thin and missing sections are also known there.

The middle member of the Dakota Formation is a coal bearing unit deposited in transitional terrestrial and marine environments (lagoonal). It consists of interbedded mudstone and shale, sandstone, carbonaceous mudstone, claystone, coal, and conglomerate (photo 40). The unit thickens

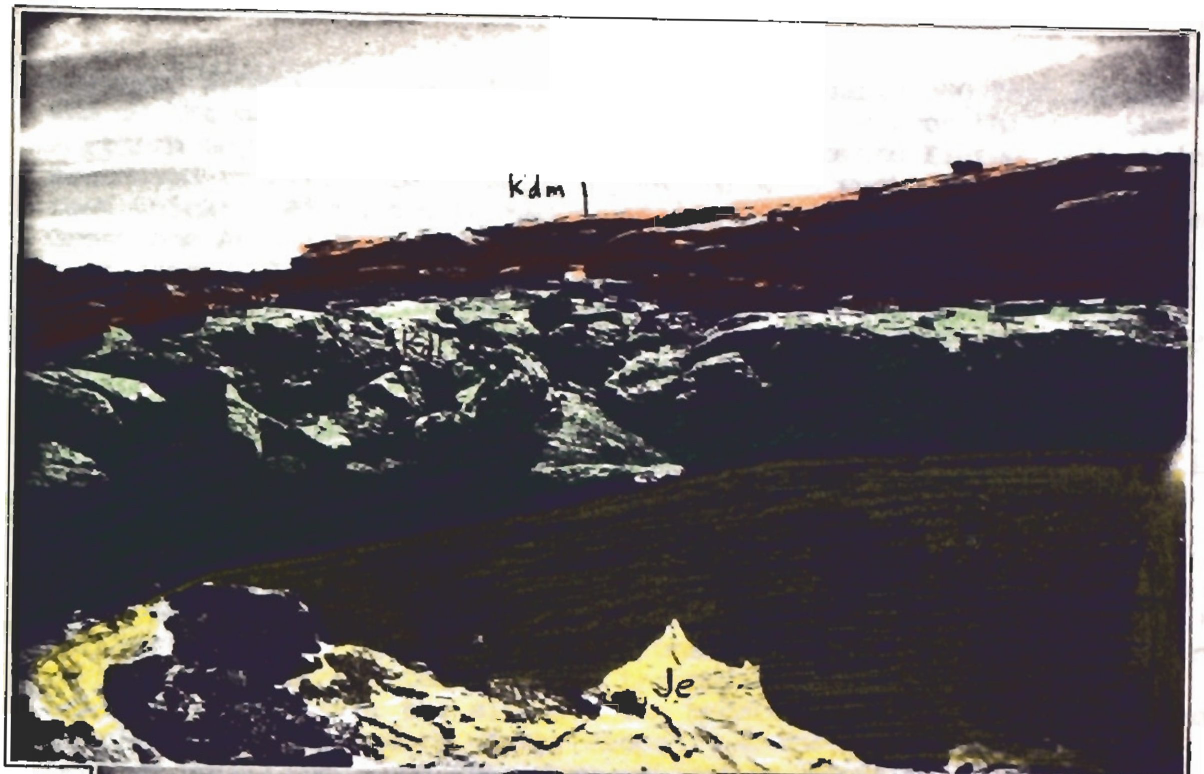


Photo 39. Upper view shows Entrada Sandstone, K unconformity, sub-Dakota Conglomerate and middle member of Dakota Formation a few miles west of Wahweap Creek. Lower view shows Winsor Member of Carmel Formation, K unconformity, sub-Dakota Conglomerate and lower part of Dakota Formation along Little Meadow Creek just below the Zion mine.

westward from 3 feet near Fiftymile Point to nearly 380 feet at the west end of the county. The middle member is 35 to 40 feet thick at the northern edge of the county east of the Kaiparowits Plateau. It thins southward to Fiftymile Point and then thickens westward to West Cove (150 feet thick). Along the Cockscomb it is 75 to 150 feet thick and from Grosvenor Arch (about 100 feet thick) it thickens westward to nearly 200 feet near Yellow Creek in Garfield County (south of Cannonville, Sec. 22, T. 37 S., R. 3 W.). Around the Paunsaugunt Plateau it is 140 to 240 feet thick and around the southern flank of the Markagunt Plateau it is 180 to nearly 400 feet thick, thickening westward.

The mudstones and shales are gray to nearly black, brown, and olive gray in color. Fresh exposures are shaly to laminated and the rock is non-calcareous. The mudstone is composed of clay with some silts and even sand. Peterson (1969, p. 24) reports the mudstone in the southern Kaiparowits Plateau to consist of 20 to 30 percent quartz and 52 to 67 percent clay minerals, the remaining portion including calcite, feldspar, and gypsum. The identified clays reported are kaolinite, illite, and montmorillonite. Sideritic concretions or thin rusty siliceous layers are occasionally found interbedded in the mudstones. When present they conspicuously litter the slopes. The mudstones and shales form undercuts in cliffs or form smooth earthy slopes. Westward the middle member becomes more clayey and therefore subject to landsliding or the development of colluvium. This characteristic is best developed in the Orderville Canyon area.

The sandstones are mostly orange or yellow gray to light gray on fresh surfaces, although light browns are also occasionally present. Weathered colors are in various shades of brown and orange gray. They are generally ver fine to fine grained, with less common medium and coarse grained beds. The subround to subangular grains are moderately sorted. Peterson (1969, p. 23) determined the mineralogy of the grains; about 75 percent siliceous (quartz, chert, or quartzite), dolomite and feldspar 9 percent, accessory grains about 1 percent, and matrix 15 percent. The sandstones are moderately to well cemented with calcite. The beds are thin to thick bedded, lenticular and cross-stratified. The beds are resistant and generally form ledges between the slope forming mudstones. The percentage of mudstone to sandstone generally increases westward across the county.

Carbonaceous mudstone is dark gray to dark brown to mearly black and is similar in composition and other characteristics to the non-carbonaceous mudstone. The amount and type of carbonaceous material defines the color. Most are confined to the zones around the coal beds. Claystones are less common, but make good local marker beds. Peterson (1969, p. 25) reports of one between his 1 and 2 coal beds at the top of the lower third of the member at the south end of the Kaiparowits Plateau. It ranges in thickness to 2 feet. A persistent dark gray claystone "marker," up to 11 feet in thickness, is found near the base of the member in outcrops between Grosvenor Arch and Willis Creek. The bentonite "marker" weathers to a typical "popcorn" surface and

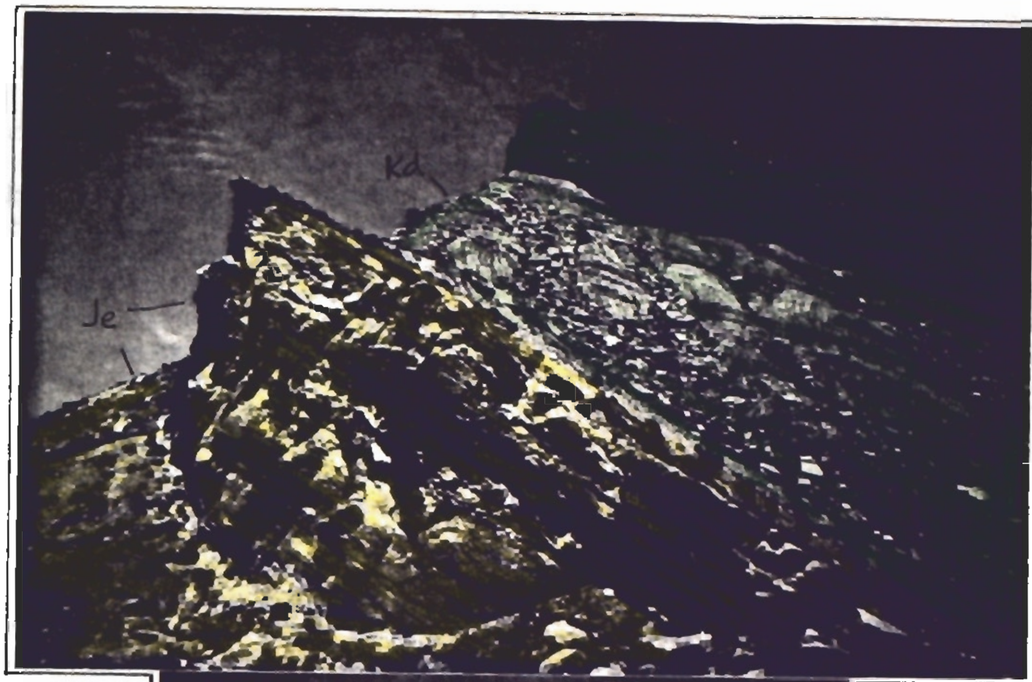


Photo 40. Upper view shows Entrada Sandstone overlain by the **middle** member of the Dakota Formation along the **East Kaibab monocline.** Lower view shows thin middle member coal beds in Crosby Canyon.

occasionally reappears at the southern margins of the Paunsaugunt and Markagunt Plateaus. When found it is usually thin and discontinuous.

Coal in the middle Dakota is generally subcommercial around the Kaiparowits Plateau, but a few small mines have operated in them at favorable locations. The coals reach minable thicknesses along the southern margins of the Paunsaugunt and Markagunt Plateaus (see coal in Economic Geology section). The coal along the east side of the Kaiparowits Plateau is highly lenticular and discontinuous reaching a maximum of a little over 4 feet in thickness (average less than 2 feet). As many as two beds may be identified, the most prominent at the top of the member. Peterson (1969, p. 25-26) indicates 4 correlatable coal beds, most less than 2 feet thick and rarely reaching 4 feet along the southern Kaiparowits Plateau. Again the most prominent bed is the upper. All are discontinuous. West of Wahweap Creek the beds continue to be thin, but contain logs of flattened petrified wood with long diameters to 3 feet and lengths of 6 feet or more (Doelling, 1977, p. 29-34). Along the Cockscomb (East Kaibab monocline) there are three persistent coal beds in the middle Dakota; one near the base, one near the middle, and one at the top. They range to more than 5 feet in thickness, but are mostly under 2 feet thick. The middle and upper coals are more persistent. The upper bed probably correlates across the county, but the relationships of the others is unknown. The thickness of the coals increases south of Cannonville and around the southern margins of the Paunsaugunt and Markagunt Plateaus. There are two persistent zones, one at the top and another within 50 feet of the base (above the bentonitic clay marker). These contain coal beds up to 18 feet in thickness, generally the upper is thicker and contains less ash (but more sulfur). Dakota coals are generally of subbituminous rank, some to the east may be high volatile bituminous in rank.

Conglomerates and coarser sandstones are generally uncommon in the middle Dakota and mostly found at or near the base, just above the sub-Dakota Conglomerate (lower member). These conglomerates may represent a reworking of the unit below.

Fossils are not common and poorly preserved in the middle member and include petrified wood, carbonaceous wood fragments in the mudstones and sandstones, and pollen and spores in the coals and shales. May (1972, p. 506-507) indicated the age on the basis of the palynomorphs as no older than upper Albian and no younger than upper Cenomanian (latest Lower Cretaceous and lower Upper Cretaceous). This is confirmed by Scott and Tschudy (in Peterson, 1969, p. 27).

The upper member of the Dakota Formation is mostly discontinuous fossiliferous marine sandstone and mudstone with minor shale, carbonaceous mudstone, and rare coal. Compositionally and texturally the sandstones do not differ from those of the middle member. They are yellow or orange gray to brown in color and ledgy, forming a hard cap on the Dakota Formation. This produces a prominent "dip slope" surface in many areas. Normally the upper member consists of one or two thick sandstone ledges (5 to 20 feet thick) separated by mudstone. The sandstones may be thinbedded to massive and may contain thin lenses of coquinoid masses of oysters, especially Exogyra, Gryphaea, and Ostrea. Some scattered pebbles and cobbles are occasionally found in the upper Dakota. Lawrence (1965, p. 85) indicates that the upper sandstones interfinger with mudstone to the west of the Kaiparowits Plateau and disappear. Nevertheless between Willis Creek and Coal Canyon (southeast Paunsaugunt Plateau) the Smirl (upper) coal zone is capped by a bed of oysters (Doelling, 1972, p. 6). Major fossil zones continue to be found just above the Smirl or upper coal zone of Cashion (1967) around the southern margin of the Markagunt Plateau as well. The upper member probably interfingers with the overlying Tropic Shale and the time line dividing the two units varies from place to place. Peterson (1969, p. 26-34) identified the Dunveganoceras pondi and Dunveganoceras conditum zones in this upper member. He notes that the Dunveganoceras albertense zone is present in the upper part of the upper member in the southwestern Kaiparowits region, but is found in the Tropic Shale to the north. The Sciponoceras gracilis zone is always near the base of the Tropic Shale in Kane County.

Tropic Shale. This unit overlies the Dakota Formation at all Kane County locations (photo 41). The base of the unit interfingers with the sandstones in the upper Dakota. It was originally named by Gregory and Moore (1931, p. 98-99), but they included the coal bearing strata of the Dakota Formation. Lawrence (1965, p. 71-78) restricted the usage of the term Tropic Shale to the upper marine shales.

The Tropic Shale is a drab gray slope former that ranges from less than 500 to more than 1000 feet in thickness. Along the east edge of the Kaiparowits Plateau it ranges from 600 to 750 feet, apparently thickening southeasterly. At the southern margin of the Plateau it ranges from 600 to 700 feet and along the Cockscomb most measurements indicate a thickness ranging from 500 to 600 feet (photo 42). A few drillholes penetrating the Tropic in the western Kaiparowits show it to be 510 to 530 feet thick. Few reliable measurements are available for the southern margin of the Paunsaugunt Plateau. The outcrops are wide and usually covered and estimates range from 700 to 1000 feet. Measurements of the Tropic from the southern margin of the Markagunt Plateau indicate the formation to be 500 to over 1000 feet thick. Included are measurements from several drill holes.

The formation is usually found in some shade of drab gray. The upper parts usually become silty or sandy and the color consequently changes to yellow gray or light olive gray. Lawrence (1965, p. 86-87) reports that a distinctive color change takes place 300 feet below the top of the Tropic, from light silvery gray mudstone claystone in the lower part to medium brown in the upper part. The gray color varies and is dependent on the carbon content in the shales. Where the carbon content is highest the formation is a very dark gray, where it is low the color is light, almost silvery.

The Tropic is a thinly laminated to thinbedded mudstone and shale unit with lesser amounts of sandstone, bentonitic claystone, siltstone, and limestone. The mudstone and claystone are often nodular and chunky when fresh, but are shaly and earthy when weathered. The mineral matter

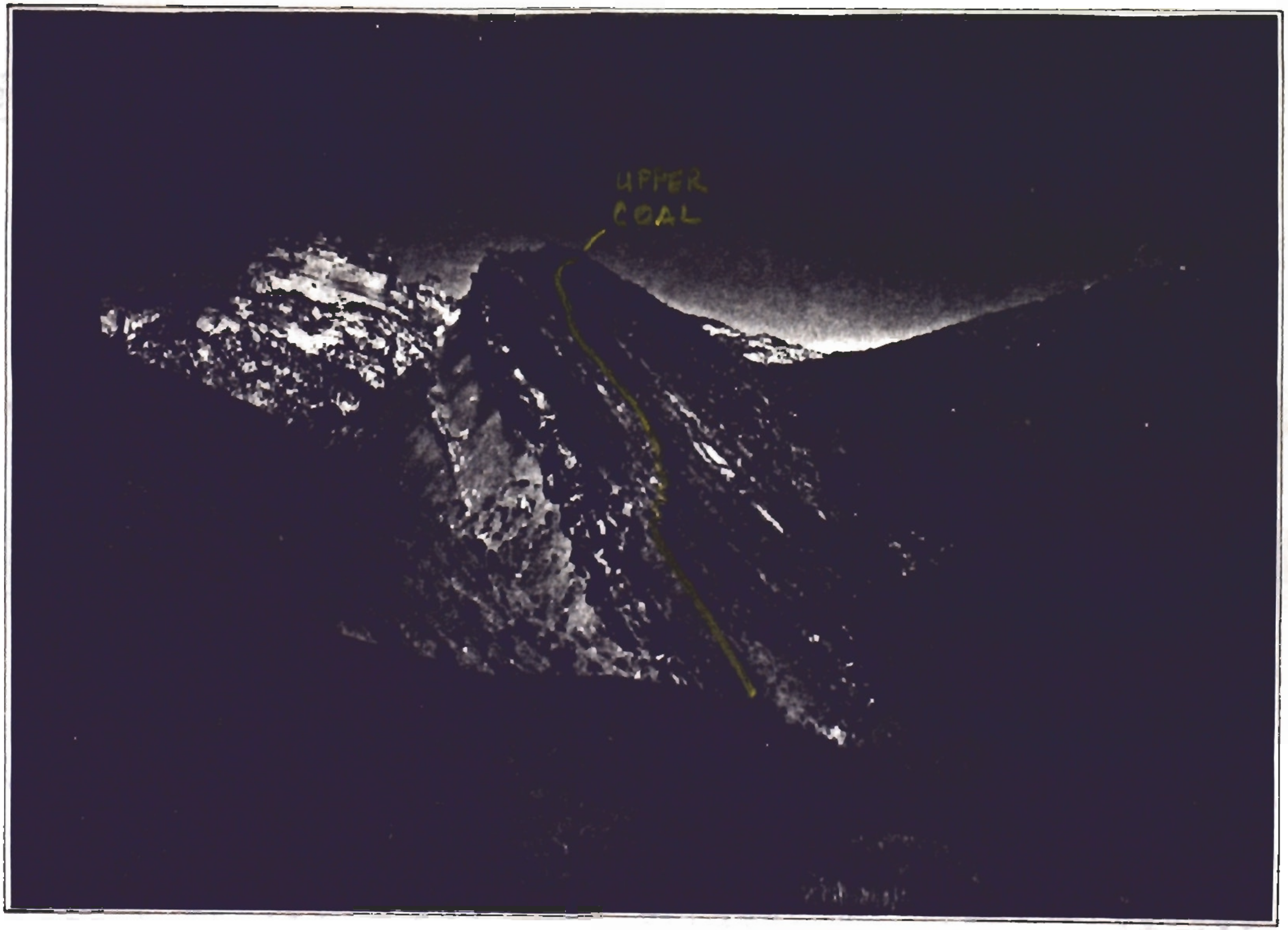


Photo 41. Dakota-Tropic contact along the East Kaibab monocline (Cockscomb). The highest coal in the Dakota Formation, at this location, is just below the contact. A few fossiliferous sandstone beds overlie the coal before reaching the drab gray Tropic Shale.

in the shale has been analyzed by both Peterson (1969, p. 39) and Lawrence (1965, p. 87). The prominent minerals are clays, quartz, calcite, and dolomite (97 percent of the rock). The remainder consists primarily of feldspars and gypsum. Deviations from the typical shaly lithology are more likely to be found near the top and bottom of the unit. Peterson, p. 41) notes that thin beds of mudstone, siltstone, and sandstone occur mainly in the lower and upper parts of the Tropic. Lawrence (p. 87) reports that three or more relatively continuous beds of bentonite are near the base of the formation. Apparently the mineralogy and texture of the clays and muds change from place to place as is reflected by the tendency of the formation to participate in mass-wasting phenomena. The formation has "flowed" over cliffy units below along the southeastern edges of the Kaiparowits Plateau during wet cycles in prehistoric times, but there is no evidence for similar mudflows in the western part of the county.

The sandstones are generally very fine to fine grained with low angle crossbeds in mostly thin to medium beds. The sandstones are calcareously cemented and weather into slabs. The uppermost 10 to 20 feet are transitional with the overlying Straight Cliffs Formation and contain numerous resistant beds of calcareous yellow gray sandstone. Trace fossils have been noted in these sandstones. In the western part of the county, west of Muddy Creek, at least one cliffy littoral sandstone tongue divides the unit. This tongue is known as the Sugarledge Sandstone (Cashion, 1961) and ranges from a feather edge to more than 60 feet in thickness. It is found 175 to 220 feet above the Tropic-Dakota contact. The sandstone beds are thick, the sand grains are quartzose, well sorted, and calcareously cemented. Some are bioturbated, rounded to elongate limestone concretions are found locally along certain horizons and include septarian types with their interiors filled with yellow or white calcite spar. Some contain fossils and well preserved mollusks, crabs, fish, and bones of marine reptiles. Many of these localities have been claimed for commercial purposes and the concretions are sold to tourists and collectors. The Tropic Shale weathers into rounded hills, slopes, and broad gently undulating flats, or, when found under the Straight Cliffs, forms a steep curtain-like slope (photo 42).

The Tropic Shale contains a host of marine fossils that have allowed for the identification of specific fossil zones. These were identified and correlated by Peterson (1965, p. 61 and 1969, p. 40). These include (in ascending order) the zone of Dunveganoceras pondi (Haas), Dunveganoceras conditum (Haas), Dunveganoceras albertense (Warren), Sciponoceras gracilis (Shumard), Inoceramus labiatus (Schlotheim), Collignoniceras woollgari (Mantell), and Collignoniceras hyatti (Stanton). The first two are found in the upper member of the Dakota Formation where it is present (in the Tropic Shale elsewhere). The first four are found in the lower part of the Tropic, the Inoceramus labiatus and Collignoniceras woollgari zones take in most of the Tropic thickness. Collignoniceras hyatti zone fossils have only been found in the Tibbet Canyon Member of the Straight Cliffs Formation, but the Tibbet Canyon interfingers with the upper part of the Tropic Shale. The lower part of

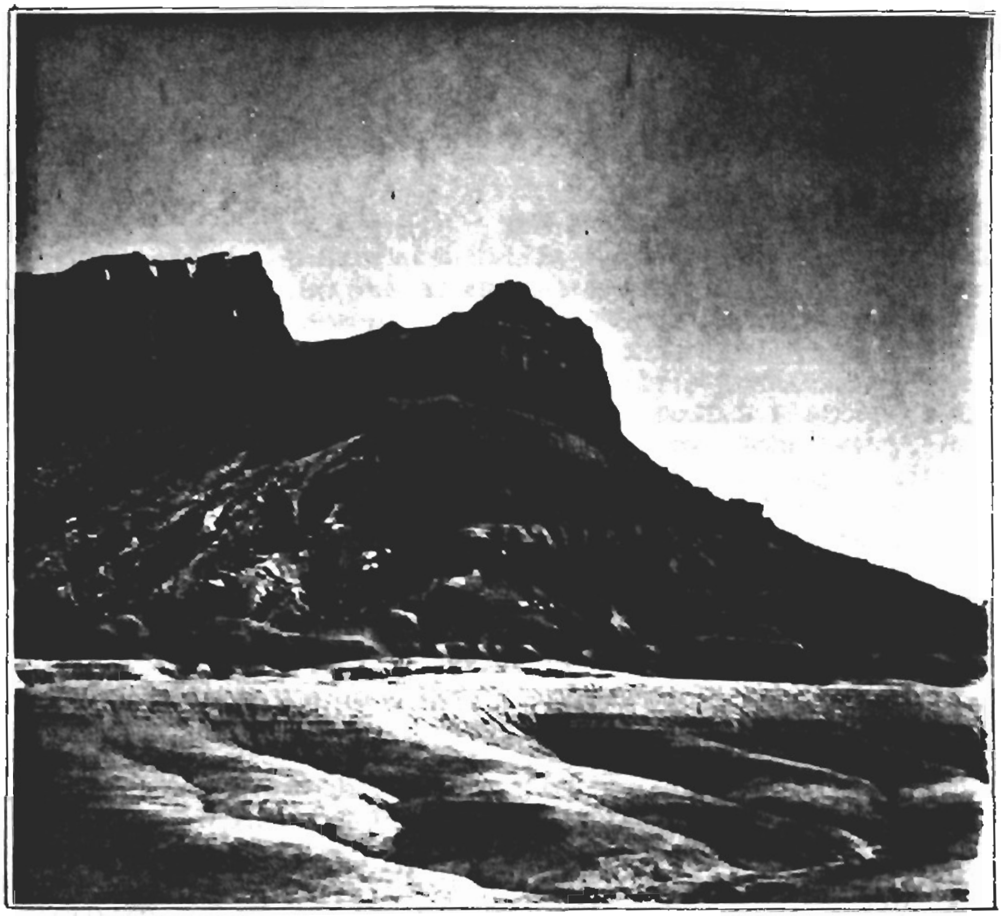


Photo 42. Typical Tropic Shale outcrops along the south margin of the Kaiparowits Plateau. Very little vegetation can establish itself on its outcrops at this location.

the Tropic is therefore upper Cenomanian and the major part of the unit is Turonian in age.

Straight Cliffs Formation. The Straight Cliffs Formation was originally termed the Straight Cliffs Sandstone by Gregory and Moore (1931, p. 91) for exposures along the Straight Cliffs on the eastern side of the Kaiparowits Plateau. Inasmuch as the unit contains several lithologies other than sandstone, Peterson and Waldrop (1965, p. 62-63) suggested naming the unit the Straight Cliffs Formation. The formation was divided into four members in the Kaiparowits Plateau (Peterson 1969a, p. 49 and 1969b); Tibbet Canyon, Smoky Hollow, John Henry, and Drip Tank (ascending), named after canyons in the southern Kaiparowits region in which the members are well exposed. The Tibbet Canyon is mostly a cliffy littoral sandstone; the Smoky Hollow is ledge and slope forming sandstone, mudstone, carbonaceous mudstone, and minor coal; the John Henry is a slope and ledge forming unit like the Smoky Hollow containing thick coal beds; and the Drip Tank Member is mostly a fluvial cliff forming sandstone. Peterson (1969b, p. J10-J14) noted an unconformity dividing the Smoky Hollow Member from the John Henry Member.

The formation averages about 1400 feet in thickness near the mouth of Collet Canyon and probably varies from 1300 to 1500 feet. In the southeastern Kaiparowits Plateau the formation is over 1200 feet thick, but the Drip Tank Member and the uppermost portion of the John Henry Member have been eroded. In the Smoky Mountain and Warm Creek areas, at the southern end of the Kaiparowits Plateau, Peterson (1969b, p. J5) reports the complete Straight Cliffs Formation to be a little over 1200 feet thick. Blakey (1970) reports the formation to be about 1275 feet thick to the southwest in the Brigham Plains area. The formation is 1280 feet thick near Grosvenor Arch and Butler Valley. Lawrence, in Robison (1966, p. 17), has a section in Garfield Country where he measured almost 1500 feet, 6 miles north of the Grosvenor Arch section (photo 43).

To the west, in the Paunsaugunt and Markagunt regions, the Straight Cliffs Formation is much thinner and may be confined to the rocks beneath the sub-John Henry unconformity. This thinning occurs near the Paunsaugunt fault or along the eastern margin of the Paunsaugunt Plateau. The upper two members of the Straight Cliffs Formation either intertongue with the Wahweap Formation or pinch out. Along the southern margin of the Paunsaugunt Plateau the Straight Cliffs ranges from 200 to 450 feet in thickness, thinning westward. In a side canyon branching north from Broad Hollow and about 5/8 mile southwest of the first trout pond in Meadow Canyon, NW Sec. 29, T. 39 S., R. 4 W., the formation is 331 feet thick. Goode (1973a, 1973b) reports the Straight Cliffs to be 200 to 250 feet thick in the Skutumpah Creek and Bald Knoll quadrangles.

Cashion (1967) indicates the Straight Cliffs Formation to thicken westward along the southern flank of the Markagunt Plateau. In a scaled figure, "Diagrammatic restored section of rocks in the mapped area," he indicates the thickness to increase from about 110 feet at the Sevier fault to about 580 feet near the Kane-Washington county line, the lower part of the formation intertonguing with the Tropic Shale. In a measured

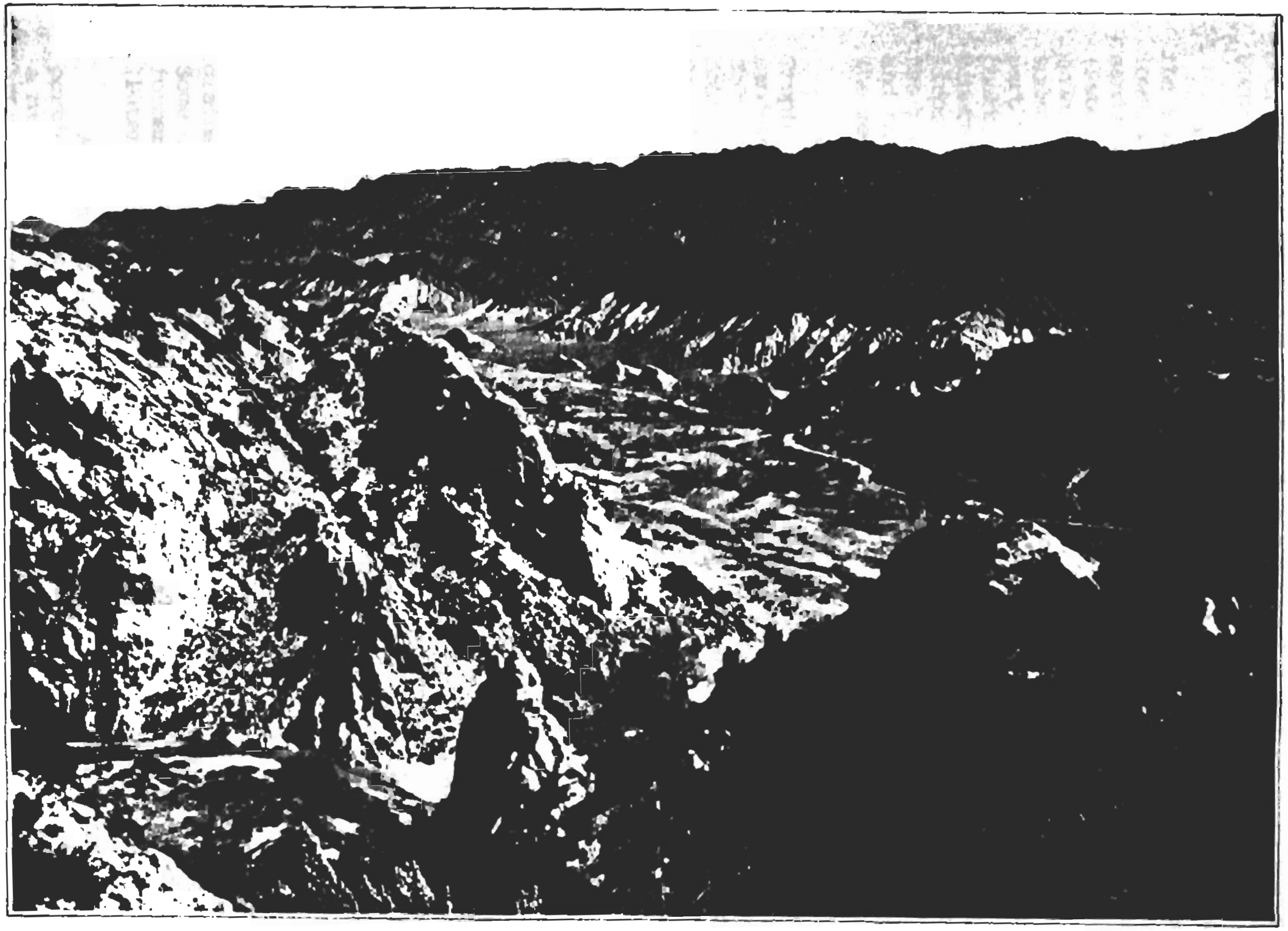


Photo 43. View across the East Kaibab monocline (Cockscomb) south of Hackberry Canyon. In the foreground the Jurassic Navajo, Judd Hollow Tongue, and Thousand Pockets Tongue are exposed. Across the valley of Cottonwood Creek the light outcrops are of the Entrada Sandstone. The upper formations are all Cretaceous in age. The top of the first hogback is the Dakota Formation. The hogback nearly hides the Tropic Shale which overlies it. The hogback which rises to the skyline exposes the entire Straight Cliffs Formation, the hard rim being the Drip Tank Member.

section along U. S. Highway 89 just north of Glendale the Straight Cliffs Formation is only 85 feet thick (photo 44).

All four members of the Straight Cliffs Formation are well exposed in the Smoky Mountain area of the southern Kaiparowits Plateau. The lowermost Tibbet Canyon Member is mostly yellowish-gray to moderate brown sandstone that coarsens upward from very fine grained to medium grained (Peterson, 1969a). In the lower part of the member the sorting is poor to moderate and in the upper part it is moderate to well. Partings of gray mudstone and siltstone divide the sandstone beds, especially in the lower part where thin beds occur. The grains are mostly of quartz (quartz, chert, quartzite), followed by feldspar, dolomite, and calcite. Accessory minerals include biotite, garnet, glauconite, muscovite, tourmaline, and zircon (Peterson, 1969a, p. 53). The cement is primarily calcareous and the rock is moderately to well cemented. The member displays crossbedding and thin to thick bedding, becoming more thickly bedded toward the top. The member is a cliff forming unit.

The lower contact is gradational and probably intertonguing with the Tropic Shale. The contact is placed at the base of the first prominent sandstone or where the lithology becomes dominantly sandstone. The upper contact is usually sharp and placed at the base of the first mudstone or coal bed in the overlying Smoky Hollow Member. The Tibbet Canyon was deposited in beach or shallow marine environments. Fossils include pelecypods (Inoceramus, Ostrea, etc.), gastropods (Gyrodes, Cryptorhytus, etc.), cephalopods, shark teeth, and trace fossils (Ophiomorpha). The index fossil Inoceramus howelli (White) indicates the member to be middle Turonian in age. In the Kaiparowits region the Tibbet Canyon ranges from 70 to 185 feet in thickness.

The Smoky Hollow Member consists of interbedded sandstone, mudstone, carbonaceous mudstone, and coal in ledge and slope forming beds. Peterson (1969a, p. 56) divides the unit into three informal subdivisions: a basal coal zone, a middle barren zone, and a "Calico" bed at the top. The coal zone contains much dark gray carbonaceous mudstone, thin coal beds, and very thinbedded sandstone. The coal beds rarely exceed 2 feet in thickness, but are locally quite persistent. The coal zone is 0 to 30 feet thick, a slope former, and is missing over the anticlinal axes.

The barren zone consists of yellow gray to white sandstone beds and gray shale or mudstone. The sandstones are very fine to medium grained, poorly to moderately sorted, crossbedded, and ledge forming. The sand grains are mineralogically the same as those in the Tibbet Canyon Member. Some of the mudstones are bentonitic, olive gray, and all are slope formers. The barren zone ranges from 13 to 110 feet in thickness (Peterson 1969a, p. 58) in the Kane County Kaiparowits region.

At the top is the "Calico" bed which intertongues with the upper portions of the barren zone. It averages 25 feet in thickness and attains a maximum of 51 feet. It is fine to coarse grained, poorly sorted, and often pebbly sandstone. It is white or light gray and crossbedded. The upper contact of the Smoky Hollow Member is a regional unconformity that

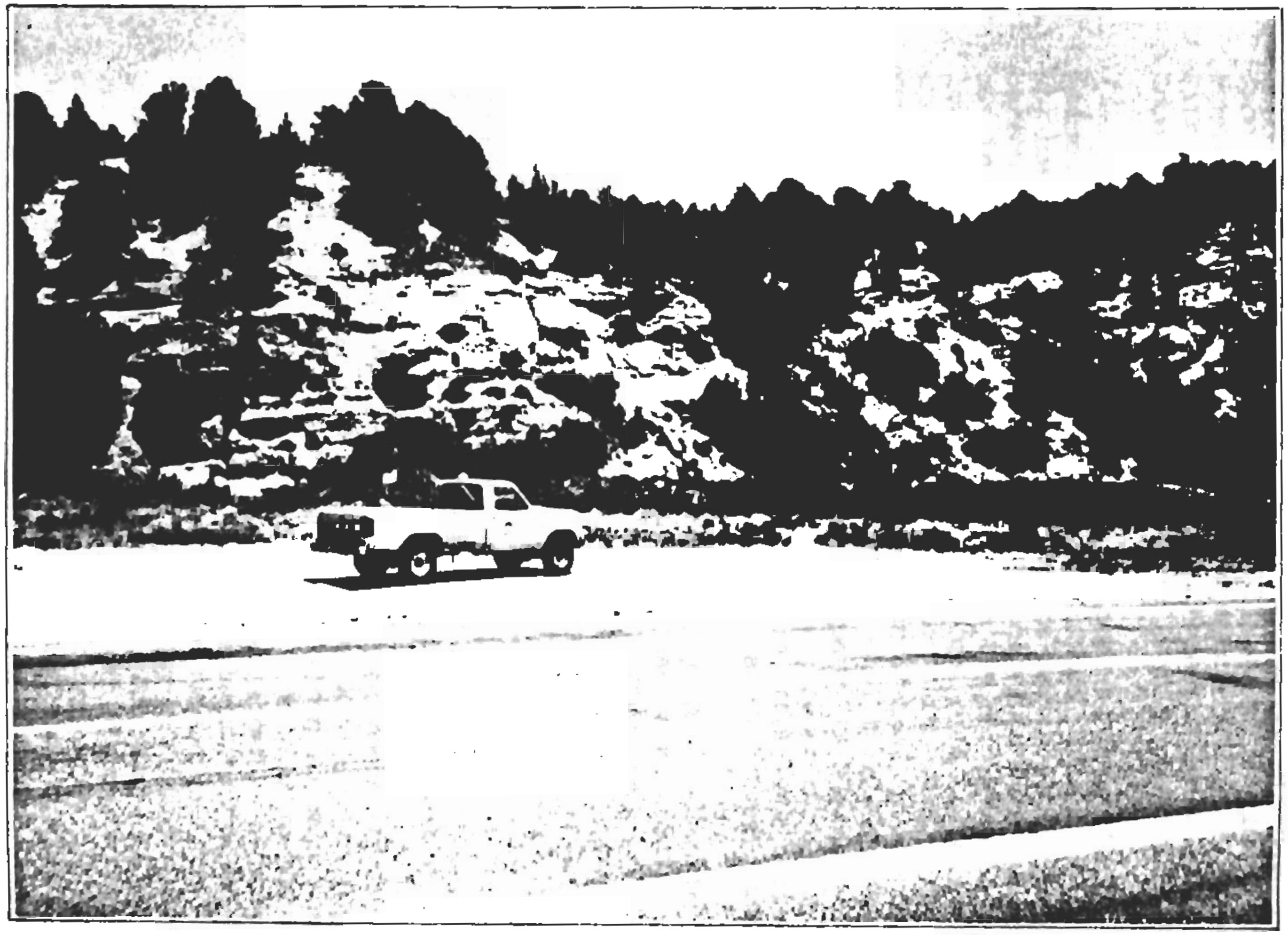


Photo 44. Outcrops of the Straight Cliffs Formation along U. S. Highway 89 just north of Glendale. This formation has its thinnest exposure at this location (see figure 23).

cuts out the upper Turonian stage and lower and middle parts of the Coniacian stage (Peterson, 1969a, p. 61). The full Smoky Hollow Member ranges from 24 to 230 feet in thickness.

The Tibbet Canyon and Smoky Hollow Members have been combined on the Kane County geologic map and are listed as the lower Straight Cliffs Formation. It is difficult to separate the two members along the Fiftymile Mountain front, but in the south and west margins of the Kane County Kaiparowits region they are readily discernible.

The John Henry Member is a slope and ledge forming unit of sandstone, mudstone, carbonaceous mudstone, and coal (photo 45). Peterson (1969b, p. J5) has subdivided the member of the central Kaiparowits Plateau into barren zones and coal zones. The coal zones are not everywhere present, but in ascending order the subunits are as follows: a lower coal zone, a lower barren zone, the Christensen coal zone, middle barren zone, Rees coal zone, upper barren zone, and the Alvey coal zone. From the southwestern part of the Kaiparowits Plateau to the east, the John Henry beds change from terrestrial to lagoonal to marine in depositional environments. From the central Kaiparowits Plateau southwestward, the coal zones thin and pinch out at the expense of the barren zones. Eastward along the Fiftymile Mountain front both barren and coal zones are replaced by thick or massive marine sandstone and mudstone tongues.

The barren zones are dominated by thickbedded to massive cliff forming yellow gray to yellow brown sandstones with interbeds of gray mudstone, thin friable to blocky sandstone beds and thin limestone beds. The cliffy sandstone is fine to medium grained, poorly to moderately sorted, and poorly to moderately cemented with calcite. It is usually crossbedded and locally contains nodules of pyrite up to 6 inches in diameter. Some of the pyrite has been converted to limonite or siderite. The mineralogic composition of the sand grains is similar to those in the Tibbet Canyon Member. The mudstones are less commonly carbonaceous, but occasionally they become so, and even thin seamlets of coal may be found.

The coal zones are dominated by mudstones, carbonaceous mudstones and shales, claystones, and relatively thick coal beds (up to 20 feet or more). The coal zones are generally slope formers and not as well exposed as the barren zones or marine rocks. The thin sandstones are generally fine grained and occasionally produce ledges. In many areas, such as in the Burning Hills, the coal beds have been extensively burned along the outcrops (some are still burning) and have baked the clays and muds to a natural brick. The brick exhibits many brilliant colors (coal bloom), especially reds, yellows, and black. The sands of the overlying barren zones are often reddened as well. The coal zones, especially in the carbonaceous shales, contain fragments of woody plants: twigs, bits of leaves, pollen and spores, and even jetified branches. Occasional coquinas of mollusks are also found associated with the sandstones. When burned the fossil material is preserved as black impressions on the red or yellow brick. The burned material weathers as clinkery rubble, some pieces show that it became hot enough to melt the rock.

Photo 45. Views of the Straight Cliffs Formation in and around the Kaiparowits Plateau. Upper left is along th west margin (Cockscomb). Lower cliffy rocks are of the Tibbet Canyon-Smoky Hollow Members. Upper less resi rocks are John Henry Member and the Drip Tank Member is at the top. Upper right

Mostly exposures of the John Henry Member. The top of the plateau is supported by the harder Drip Tank Member. Lower left is a view across the Kaiparowits Plateau from the Rees anticline at the north end of the Burning Hills. There are two well developed benches, one at the top of the Drip Tank Member (point from where photo was taken), and one at the top of the Wahweap Formation (making the cliff line in the distance). Lower right is a view in Left Hand Collet Canyon showing the Straight Cliffs Formation. The light massive sandstone in the middle of the cliffs marks the top of the Smoky Hollow Member.

Fires are a natural phenomena in coal fields and are more prevalent in semi-arid areas where coal beds are relatively close to the surface, soil development and vegetation is sparse, fracture systems in the rocks are open, and deep drainages are regularly present. All of these conditions are present in the John Henry rocks between Warm Creek and Croton Canyon in the southern Kaiparowits Plateau. At this location the coal under entire "points" have been burned out and the overlying rock has collapsed and fractured all the way to the top because of the uneven loss of support formerly furnished by the coal (photo 46). Coal beds, once near the surface, can burn anywhere. The fires start spontaneously as oxygen bearing rain water trickles to the coal through the open fractures and starts the heat generating oxidation process. The insulating rocks do not allow the heat to escape and temperatures build to those necessary for combustion. Additional coal information is provided in the Economic Geology section.

The thick to massive beach or marine sandstones of the eastern Kaiparowits Plateau are generally fine grained and well sorted. Peterson (1969, p. 71) has identified seven key beds. The mineralogic composition of the grains shows the percentage of quartz to be somewhat higher than in the Tibbet Canyon or barren zone sandstones, and the percentage of feldspar and other unstable grains to be less. These key beds are occasionally high in magnetite, zirconium, and titanium (fossil beach placers). Peterson's key beds are commonly 50 to 100 feet thick and can be traced long distances along the Fiftymile Mountain front.

Less prominent slope forming lithologies interrupt the thick to massive bedded key cliff forming sandstones along the Fiftymile Mountain front. These are comprised of interbedded gray mudstone and yellow gray to brown thin to medium bedded well sorted fine grained sandstone. Thin conglomerate lenses are often found at the base of these slope forming lithologies. The marine beds, cliff formers as well as slope formers, contain poorly preserved, but identifiable fossils, generally pelecypods and shark teeth along with occasional gastropods, cephalopods, and trace fossils. The age of the John Henry is dated as late Coniacian to early Campanian (middle Upper Cretaceous)(Peterson, 1969a, p. 83-84).

The thickness of the John Henry Member is variable in the Kaiparowits Plateau, ranging from 590 to 1100 feet, generally thickening to the east. It appears to be thinner over the anticlines. The average thickness is 650 to 750 feet in the better coal areas. The upper contact is with the cliff forming Drip Tank Member, with which it interfingers. The contact is usually placed at the top of the highest significant slope former or mudstone unit.

The Drip Tank Member is a cliff forming and a prominent bench forming unit on the Kaiparowits Plateau. The member is mostly yellow brown to yellow gray, fine to medium grained, poorly sorted, lenticular sandstone in medium to thick beds. The sandstone is interlensed with minor mudstone and pebble conglomerate. The latter lithology becomes more prevalent tgo the north and west. The Drip Tank represents deposition in a fluvial environment.

Photo 46. Two views of fractures in the Drip Tank Member of the Straight Cliffs Formation which opened as support was removed when coal burned naturally in the John Henry Member below.

Iron staining, and iron oxide nodules, concretions, or bands are common in the Drip Tank Member, and occasional pieces and even logs of petrified wood along with vertebrate bone fragments are contained in the rock. The member is 140 to 160 feet thick in the Smoky Mountain area, but it is thicker to the west and along the Cockscomb. Blakey (1970, p. 164) reports the Drip Tank to be 380 feet thick. Near Grosvenor Arch, to the northwest, measurements indicate the member to be 485 to 550 feet thick. The upper part interfingers with the lower part of the Wahweap Formation, which is a slope former. Diagnostic fossils are not present in the member, which is thought to be only slightly younger than the underlying John Henry Member (early Campanian).

The Straight Cliffs Formation of the Paunsaugunt and Markagunt Plateaus has not been divided into members. In the Paunsaugunt Plateau the formation is mostly very fine to fine grained, poorly sorted, crossbedded sandstone, which is medium to very thickbedded, generally well cemented with calcite, argillaceous material, or iron oxides. The mostly cliffy or ledge forming rock is yellow brown, gray orange or yellow gray in color. These sandstone beds are interbedded with subordinate thinbedded, dark yellow brown and less resistant sandstones; gray, olive gray to brown shales or mudstones, conglomerates, and rare thin coal seamlets. Most of these less prominent lithologies are slope formers and are more common in the lower half of the formation.

The sand grains are dominated by quartz, the remainder are represented by chert, quartzite, feldspar, calcite, and accessories. Conglomerate clasts are mostly chert, silicified (black) limestone, or quartzite. Sometimes mudballs up to 3/4 inch are present. Carbonaceous material is present mostly as fragments, chips of charcoal, carbonized twigs, branches, and leaves. Indications of both terrestrial and marine features are present in the rocks (Gregory, 1951, p. 39) so that a specific and accurate depositional environment cannot be determined without additional study. In our opinion the Paunsaugunt Plateau Straight Cliffs Formation section is mostly lagoonal and terrestrial in nature. In most areas the Straight Cliffs Formation deposits bridge the transition between marine and terrestrial environments. This regressive transitional zone rises stratigraphically eastward so that the western outcrops are older than those to the east (see figure 23). The marine strata below are represented by the Tropic Shale and the terrestrial strata above are represented by the Wahweap Formation. Tectonic activity, the unconformity in the Kaiparowits Plateau Straight Cliffs section, and the differences in thickness across the county, all serve to complicate the relationships.

The thinnest section of Straight Cliffs Formation is along U. S. Highway 89 just north of Glendale. The unit may be less than 85 feet thick (photo 44). Here it is practically all sandstone, which is pale yellowish-orange, very fine to fine grained, with subrounded, well sorted, mostly clear quartz grains. The exposure forms a cliff. The rock is mostly low angle crossbedded except near the top where high angles appear along with calcareous plates that may be shell fragments. The environments of deposition are surmised to be littoral (near shore marine) for the lower part and beach for the upper part.

The formation in the westernmost reaches of the county thickens and takes on the appearance and description of Peterson's (1969a) key beds as exposed along the Fiftymile Mountain front in the Kaiparowits Plateau. The sandstone beds range to more than 80 feet in thickness, but beds 10 to 40 feet thick are most common. Cashion (1961) indicates these beds are dominantly littoral as are the key beds of the Kaiparowits region. There is some evidence, however, which points to an older date of deposition (different assemblages of fossils) and a greater terrestrial influence. Sandballs, conglomerate lenses, petrified wood, vertebrate bones, along with carbon trash (twigs, bits of leaves, etc.) have been found in some of the rocks. Gregory (1950, p. 107) further notes that brackish and fresh water species of fossils become progressively more numerous west of the Kaiparowits Plateau.

Wahweap Formation. The Wahweap Formation overlies the Straight Cliffs Formation conformably and is an interbedded sandstone mudstone unit. In the Kaiparowits Plateau it is divisible into informal members, lower and upper, based on topographic expression. Essentially the lower member is dominated by slope formers and the upper member by cliff formers. At the top a bench is formed similar to that on top of the Drip Tank Member of the Straight Cliffs Formation. The lower member, in most places, has been eroded or has receded from the cliffy edge of the Drip Tank and forms a steep slope to the cliffy upper member (photo 47). The two members intertongue irregularly so that in some places the upper member appears exceptionally thick, in others exceptionally thin.

No such division is possible in the Markagunt or Paunsaugunt Plateau where the Wahweap is ledge and slope forming throughout. It is less resistant than the Straight Cliffs below, but more resistant than the Kaiparowits Formation above.

In the Petes Cove quadrangle (northeast Kaiparowits Plateau) the Wahweap Formation is 1100 to 1500 feet thick. The basal contact is usually placed at the top of the last massive unit of the Drip Tank above which the less resistant sandstones, shales, siltstones, and claystones of the Wahweap persist. Picking the contact is at times difficult inasmuch as the Wahweap locally has some massive or thickbedded sandstones near the base. The lower member is dominated by alternating shaly sandstones and siltstone and brown to tan or olive gray claystones. The uppermost 200 to 400 feet make up the upper member and consist mostly of medium to coarse grained, generally subangular, gray, tan, yellow, and brown, partly crossbedded, lenticular sandstones. Some conglomerate is also present as well as ironstone concretions. The sandstones are generally quartzose, but contain a slightly larger percentage of unstable grains, primarily feldspar.

The sandstones are somewhat fossiliferous, locally containing fragments of dinosaur bones, petrified wood, ostracodes, and mollusks. The Wahweap is thought to be deposited in a fluvial environment. The

Photo 47. Wahweap Formation outcrops in the Kaiparowits Plateau. The formation rises above benches developed on the Drip Tank Member of the Straight Cliffs Formation often veneered with the lowermost beds of the Wahweap. The upper cliff of the Wahweap also forms a bench.

fossils indicate a Late Cretaceous age for the Wahweap (Peterson, 1969a, p. 94), probably early to middle Campanian in age.

Measurements of the Wahweap along the southern margins of the Paunsaugunt and Markagunt Plateaus are difficult to take and few good ones are recorded in the literature. The strata are exposed at higher elevations and are irregularly covered with more vegetation and colluvium than in the Kaiparowits Plateau. The beds dip very gently, stretching the descriptive interval over 2 to 3 miles. Subtle changes in dip or small faults in the poorly exposed interval can easily be overlooked and cast doubt on the value of the measurement. Unfortunately no drill holes are available as yet. The problem is compounded by the intertonguing nature of the upper Wahweap and the overlying Wahweap Formation. However, scaling on topographic maps indicates the Washweap to be 400 to 700 feet thick along most rims of the Paunsaugunt Plateau and 1100 to 1700 feet thick around the south edge of the Markagunt Plateau.

Around the Paunsaugunt Plateau rims the Wahweap Formation is mostly sandstone and highly arenaceous shales (Gregory, 1951, p. 39). The sandstones are generally yellow-gray to light brown and are dominated by fine to medium quartzose grains. The cementing material is mostly calcite. The beds are even and lenticular and the sandy shales and sandstone beds form steep slopes and ledges. Claystones and conglomerates are also occasionally present. Gastropod shells, vertebrate bones, and fossilized wood have been found in the rocks along with iron oxide bands and nodules.

South of the Markagunt Plateau the Wahweap is also mostly sandstone and highly arenaceous shale. The sands are mostly fine to medium grained, but some beds and lenses are coarse grained and even gritty. Others are bimodal, with both fine and coarse grains. The sands are mostly subangular to angular, poor to well sorted and are cemented with calcite or calcite mixed with iron oxides. In some places the cementation is uneven, and upon weathering produces odd shapes, some concretionary. These weather into lime balls and iron concretions. The grains are dominantly quartz, but chert, quartzite, feldspar, and calcite grains are also common. In coarser varieties bits of sandstone, limestone, and hard claystone can be identified.

The Wahweap Formation beds of the Markagunt range in thickness to 25 feet, but better exposed ledges of yellow gray to light brown sandstones average 5 to 10 feet. Locally the thicker Wahweap beds combine to form vertically walled cliffs. The bedding is even to irregular, and appear as flat beds or lenses. Crossbedding is a common feature. Fossil material is locally found, but mostly poorly preserved, broken into bits and pieces. These include charcoal fragments, leaf casts, shell fragments, bits of petrified wood, and vertebrate bone fragments. The Wahweap thickens westward and was fluvially deposited, presumably from a high western source. Although no definitive fossils were found in western sections of Kane County, it is presumed that most of the unit is Campanian (upper Late Cretaceous) in age.

The upper contact of the Wahweap Formation at the south flanks of the Paunsaugunt and Markagunt Plateaus is difficult to place. Gregory (1950, p. 108-109) described the contact as an erosional interval: "Everywhere observed, the upper surface of the Wahweap is uneven. In places it is merely scoured and roughly striated, but commonly it is dissected into broad swales, rounded ridges, and narrow, even canyonlike trenches."

On the other hand Cashion (1961, 1967) indicated that the Wahweap Formation and overlying Kaiparowits Formation were very similar in lithology and that no satisfactory basis for separating the two could be found. The scope of the present study precluded searching for a "suitable" contact and mapping the two units was based on topographic expression, the line drawn where the steeper slope of the lower unit changed to the less steep slope of the upper. Above the mapped contact lithologic characteristics expected for the Kaiparowits Formation gradually become more prominent.

Kaiparowits Formation. The Kaiparowits Formation is the youngest Cretaceous unit in Kane County and the youngest unit (excepting Quaternary units) deposited in the Kaiparowits Plateau region. It consists mostly of drab gray, olive gray, brownish-gray or greenish-gray slope forming and badlands forming sandstone. Lesser amounts of thin light gray mudstone and light yellowish-gray calcareous siltstone beds are also present. The sandstone is mostly quartz, with orthoclase, albite, biotite, calcite, gypsum, clay, iron, and bits of coal or charcoal. The sand is generally very fine to fine grained, and in detail, are poorly sorted and exhibit a "salt and pepper" coloration. The sands are weakly cemented with calcite. Thin lignitic layers are often associated with the mudstones.

The bedding is usually poorly defined and lenticular, the lenses are generally thin, rarely exceeding 5 feet in thickness. Crossbedding is recognized in many of the lenses. Occasionally a better cemented thin to medium brown bed of sandstone or hardened calcareous siltstone forms a ledge and interrupts the slope. A complete Kaiparowits Formation is 2600 to 3000 ft thick (Bowers, 1983) in the Kaiparowits Plateau region, of which up to 2200 ft may be exposed in the Kane County portion. In Garfield County the Kaiparowits Formation is unconformably overlain by the Canaan Peak Formation (Bowers, 1972), which consists of interbedded sandstone, conglomeratic sandstone, and conglomerate, with some mudstone beds in the lower part. The conglomerates are multicolored well rounded pebbles and cobbles of quartzite, chert, igneous rocks, and gray limestone. Bowers discovered Late Cretaceous (Campanian?) palynomorphs in the lower mudstones and indicates a Late Cretaceous to Paleocene age for the Canaan Peak Formation. Therefore the Kaiparowits Formation must also be Campanian in age. Mostly non-definitive molluscan fossils have been collected in the Kaiparowits Formation of the Kaiparowits Plateau along with some dinosaur and turtle bone fragments (Gregory and Moore, 1931, p. 108).

To the west, under the Pink Cliffs of the Paunsaugunt and Markagunt Plateaus, the Kaiparowits Formation is imilar in description, but contain many Wahweap-like sandstone beds in the lower part indicating a gradational or intertonguing boundary. These Wahweap-like beds extend quite high into the formation making it very difficult to establish a map boundary between the two formations. Occasional conglomeratic beds make their appearance westward as do lavender, yellow, and pink zones in the slope-forming units (photo 48). The conglomerates consist of well rounded pebbles and cobbles of quartzite, chert, and limestone. Some contain Pennsylvanian and Permian fossils. Western fossil assemblages found in the Kaiparowits Formation generally include freshwater mollusks, vertebrate bones, and plant fossils (mostly dicotyledons and cycads) indicating a terrestrial (fluviolacustrine) depositional environment.

The thickness of the Kaiparowits Formation in western sections is less than that of the Kaiparowits Plateau and quite variable. Available stratigraphic measurements and scaling on topographic maps indicates the formation to range from 400 to 750 feet in thickness. The upper contact in western sections is also an unconformity, but the overlying unit is the Claron Formation. This unconformity is plainly marked in outcrop placing the drab gray and yellow gray colors of the Kaiparowits Formation beneath the pink or white limestones of the Claron Formation. The contact also marks the line between Cretaceous and Tertiary rocks.

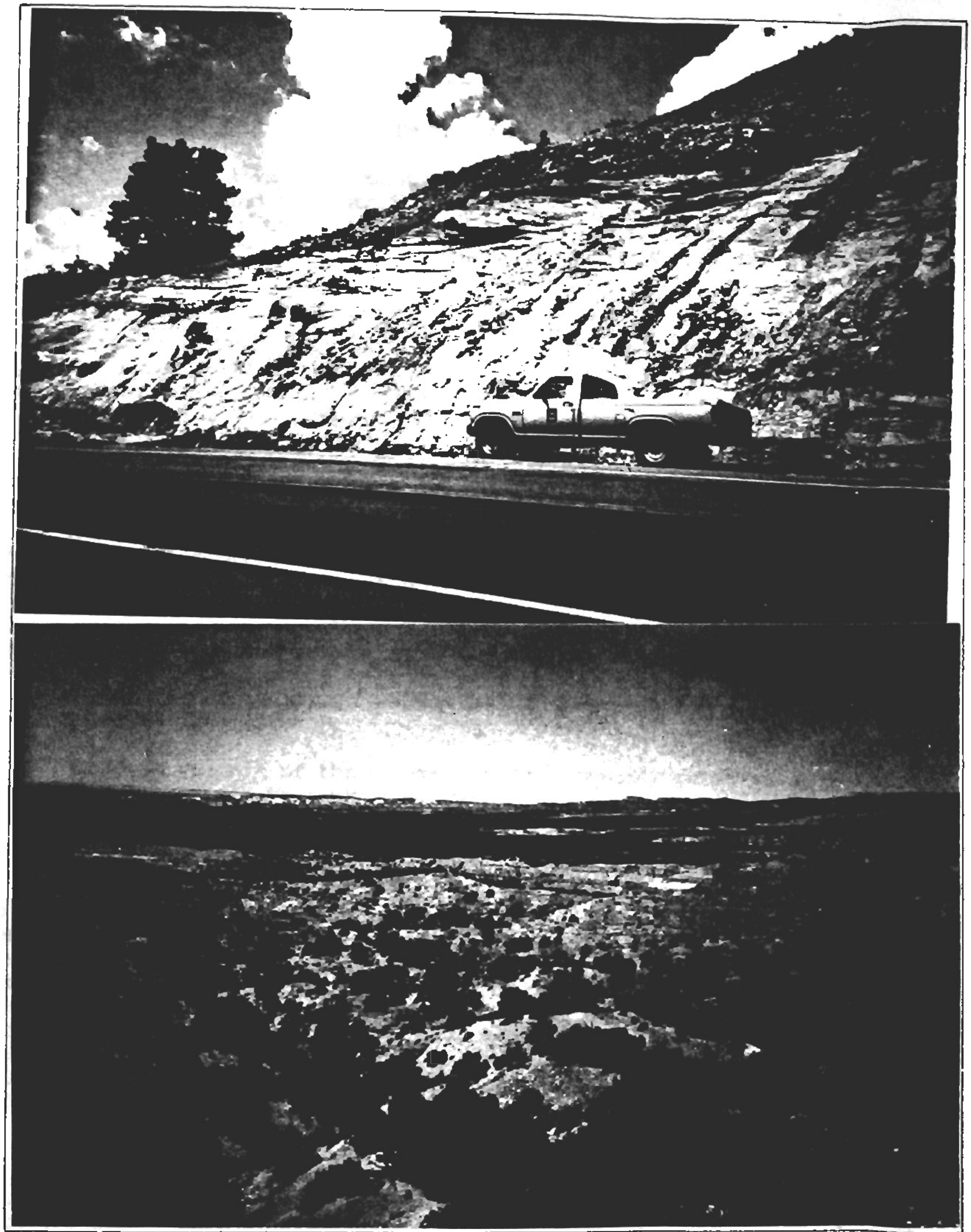


Photo 48. Views of the Kaiparowits Formation. The upper location is along U. S. Highway 89 near the Sevier fault. The lower location is in the Kaiparowits Plateau. The Kaiparowits Formation is mostly drab gray "salt and pepper" sandstone that weathers into slopes and badlands.

Tertiary Rocks

Tertiary rocks in Kane County are limited to one formation, the Claron Formation, and its outcrops are indicated on figure 24. The formation is thought to be Paleocene-Eocene in age. The outcrop area is limited to the northwest part of the county on the top of the Paunsaugunt and Markagunt Plateaus.

Claron Formation. The Claron Formation caps the top of the Markagunt and Paunsaugunt Plateaus in Kane County and is responsible for the uppermost riser of the Grand Staircase, the Pink Cliffs. The Claron Formation is also known as the Wasatch Formation (Gregory, 1950, 1951, Gregory and Moore, 1931, Bowers, 1972, and Cashion, 1961, 1967), Cedar Breaks Formation (Hintze, 1973), and informally as the "Pink Cliffs" or "Bryce Canyon" Formation. To the north, in Garfield County, the Claron Formation can be divided into two or three subunits (ascending order): (1) red or pink limestone, usually with some conglomerate lenses at the base, (2) white or gray limestone or dolomite, and (3) white to variegated pyroclastics, limestone, and sandstone. Gregory (1949, 1950) regarded the lower unit as his Wasatch Formation (Claron) and assigned the other two to his Brian Head Formation, but Anderson and Rowley (1975) returned the middle unit to the Claron (Wasatch) Formation, abandoned the term Brian Head Formation and divided the upper into several new units. In Kane County the lower unit is present and part of the second. The Claron is the youngest formation in the county excluding Quaternary lava flows and unconsolidated deposits.

The lower subunit of the Claron usually consists of a basal conglomerate overlain by pink and pink-stained limestone, sandstone, and conglomerate that weathers into cliffs, pinnacles, minarets, natural bridges, arches, and other forms that delight tourists at Bryce Canyon National Park and elsewhere along the rims of the Paunsaugunt and Markagunt Plateaus (photo 49). From a distance the Claron strata appear to be rather uniform, but lithologies, bedding characteristics, and other features vary widely under close inspection. The basal 100 or so feet consist of pink massive limestone containing scattered pebbles or cobbles along with lenses of thick calcareous and iron oxide cemented pebble and cobble conglomerate. The well rounded cobbles and pebbles of the conglomerates are identifiable as having come from Precambrian and Paleozoic sources. They are mostly varicolored quartzite, but chert, silicified limestone, limestone, well cemented sandstone and rare hard siltstones and shales are also present.

The remainder of the lower subunit consists of irregularly bedded pink and red limestone, conglomerates, sandstone, sandy limestones and breccias up to 800 feet thick. The limestones are generally argillaceous. The limestone occurs in thick to massive beds of pink, pale red, or gray color, occasionally nearly white. Staining, produced by weathering, colors the cliffs a more uniform pink color. Weathering produces a rough surface to the rock, presumably by solution and enhanced by close-spaced vertical jointing that cuts the unit vertically. The combination of differential weathering, jointing, and color are

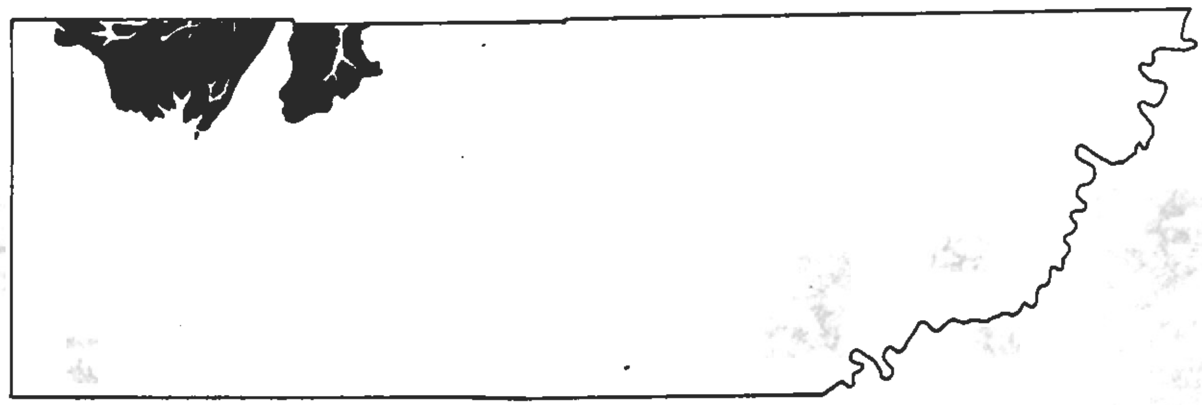


Figure24: Tertiary outcrops of Kane County

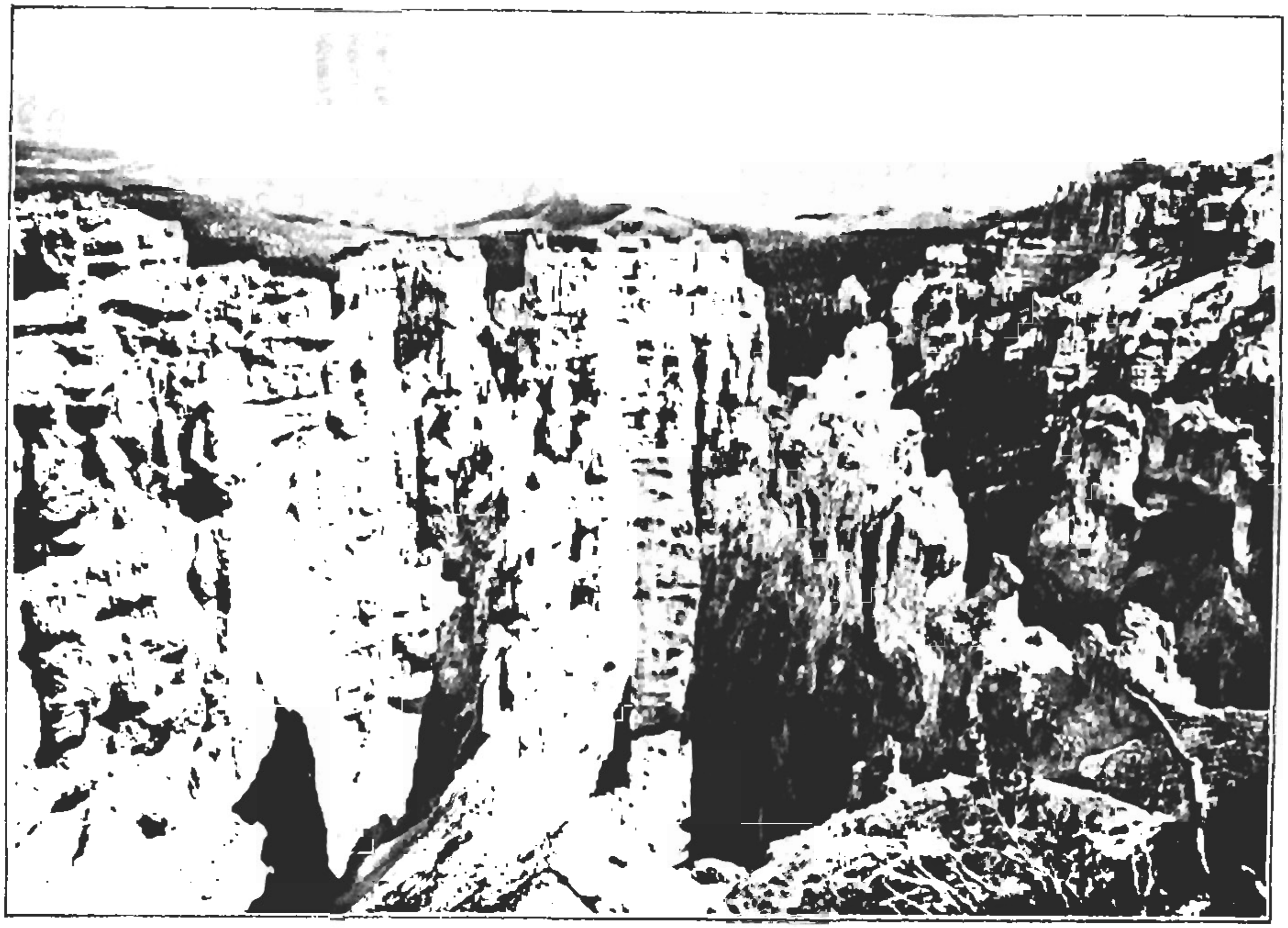


Photo 49. The Pink Cliffs (Claron Formation) along the south flank of the Paunsaugunt Plateau. Closely spaced jointing coupled with unequal weathering of the bedding governs the erosion that develops the beautifully sculptured forms along the cliffs. The Claron Formation provides the "main attraction" at Bryce Canyon National Park.

responsible for the spectacular scenery that the formation exhibits. The unit is especially prone to solution along joints, often developing underground conduits for groundwater. At several locations large springs issue at the base of the cliffs.

Calcareous sandstones, conglomerate lenses, sandy limestones, and limestone breccias are abundant in the remainder of the lower subunit. These are irregularly bedded, fine to coarse grained, comprised of quartz or chert grains and less common feldspar and calcite grains. The thickness of the lower subunit probably varies from 800 to 1000 feet in the Paunsaugunt an Markagunt Plateaus.

The white subunit overlies the lower Pink subunit, the contact placed at the base of a conspicuous, massive, resistant white limestone bed above which the rocks are mostly white or varied in color. At some locations the white limestone bed is not present and the division is made where the rocks generally change color. The white subunit is present as remnants at the top of the Markagunt and Paunsaugunt Plateaus. It is 300 to 500 feet thick in Garfield County (Doelling, 1975), but incomplete in Kane County. The thickest exposures are located on the downthrown side of the Sevier fault along U. S. Highway 89 from Long Valley Junction northward. The rocks are more varied in color, lithology, resistance to erosion, and textures. The white unit becomes more tuffaceous in its upper portion (Anderson and Rowley, 1975, p. 11). Included are white limestones and dolomites, yellow gray loosely cemented sandstones, tuffaceous sandstones, calcareous gray and reddish shales, and gray conglomerate.

The Claron Formation is thought to be of lacustrine and fluvial origin. Much is thought to have been deposited in the southern part of Paleocene-Eocene Lake Flagstaff (Hintze, 1973, p. 79) which covered a large part of central and southwestern Utah. Definitive fossils are rare in the Claron Formation of southwestern Utah and the crushed and worn fragments identified in Gregory (1950, p. 112, and 1951, p. 52) led him to believe the unit was entirely Eocene in age and correlatable with the Wasatch Formation of northern and eastern Utah. Spieker (1946), in the Wasatch Plateau of central Utah, found a freshwater molluscan fauna in the Flagstaff Formation which indicated a Paleocene age. Gill (1950), however, found Eocene mollusks in the upper part of the Flagstaff. From the above information the Claron of Kane County is probably both Paleocene and Eocene in age. A further discussion on the age of the Claron can be found in Anderson and Rowley, 1975, p. 12-13.

Quaternary System

One volcanic unit and 5 unconsolidated units are differentiated on the Kane County map. The volcanic unit includes cinder cones and blocky lavas of olivine basalt. The variety of unconsolidated rocks in Kane County is much greater than 5 and in many places the mapped units could further be subdivided on the basis of age and other characteristics. The most abundant types are reflected in the mapped units. The contained materials reflect bedrock units exposed in the county and are their erosional and weathered products on the way to the sea via the transportational forces operative in the area. The dominant forces include water, wind, and gravity. The dominant material in most of these deposits is sand, also reflective of the dominant bedrock types. The five depositional types grade into another and boundaries are often difficult to place. Mapping decisions were based on dominant features. Although Quaternary deposits are scattered everywhere across the county the dominant areas are highlighted in figure 25.

Olivine basalt. Olivine basalt is present in cinder cones, dikes, and blocky lava flows on the Markagunt Plateau, Kolob Terrace, and Skutumpah Terrace. The rock itself is generally gray to black and dense and vesicular. In thin section the rock shows aprse olivine phenocrysts along with titaniferous augite, labradorite, and very small phenocrysts of iron-titanium oxides set in a groundmass of the same minerals. Technically some of the Kane County flows are hawaiites (Best, Mckee, and Damon, 1980, Fig. 1).

At least 14 cinder cones are present in Kane County (photo 50). The conical features rise to 300 feet over the surrounding landscape and most have craters tens of feet deep and hundreds of feet in diameter. In cross-section the cones are crudely stratified at angles of 30 degrees or more. The material is sized mostly as lapilli or ash, but a significant amount of blocks, bombs, and dust are also incorporated.

The flows stretch out up to 5 or 6 miles from the cones and consist of piles of blocky lava that fill low spots, valleys, or canyons on the plateau and terraces (photo 51). These flows range to 60 or more feet in thickness and spread out to a width of two or more miles. In some places the upper surfaces are "crusty" and lava tubes have developed beneath them. Generally upper surfaces of the rock are more vesicular than the interiors.

The exposures of the lava flows are so rough and the cinder cones so little modified by erosion that they give the appearance of being very young. In fact little vegetation is established on most of the flows. Where the lava has been flowed in narrow channelways the streams have only been able to erode around them. On some the filled channel now stands in relief. K-Ar ages of two Kane County flows indicate they were erupted 500,000 to 1,100,000 years ago (Best, McKee, and Damon, 1980).

Mass wasting deposits. Many varieties of mass wasting deposits (Qms) are found in Kane County. These include landslides, talus, colluvium, toreva blocks, debris flows, and rock falls, and some are of relatively large areal extent. The deposit types grade into one another and some have been reworked by alluvial processes. The largest deposits are related to incompetent and pliable bedrock formations, notably the Cretaceous Tropic Shale and Dakota Formation, and the Triassic Petrified Forest Member of the Chinle Formation. They are more prone to mass wasting when the bedrock contains swelling clay beds. Therefore the Tropic breaks down particularly around the southeast margins of the Kaiparowits Plateau and the Dakota Formation west of the Sevier fault. Swelling clays are especially present in the Petrified Forest Member from

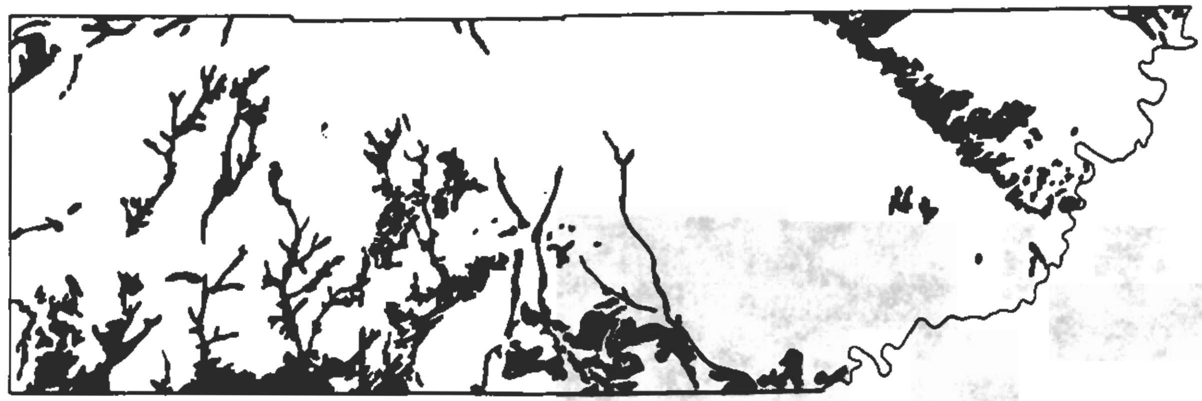


Figure 25 : Quaternary outcrops of Kane County

Photo 50. At least 14 cinder cones dot the landscape in northwestern Kane County. This is Black Knoll, located 4 or 5 miles east of Glendale.

Photo 51. Blocky lava flow on the Markagunt Plateau north of Navajo Lake.

Johnson Canyon eastward. More competent overlying formations break up and are transported by the moving slippery mudstones and claystones of the culprit formations beneath.

The Kolob Terrace-Gray Cliffs mass wasting zone involves the Dakota Formation. Large fragments of sandstone and shale bedrock as well as boulder and cobble sized clasts appear to float in mudstone and are found in areally large hummocky masses. The mapped areas average 1x2 miles and the debris is found up to 80 feet in thickness. Some have moved down the mountainsides covering much of the underlying Carmel Formation. The lower parts of these colluvium-landslide-debris flow masses are commonly saturated with water. It is presumed that this mass wasting zone was most active during Pleistocene time when climatic conditions were more humid. Nevertheless, some mass wasting deposits are still active (see Geologic Hazards section).

Another large mass wasting zone extends around the southeastern edges of the Kaiparowits Plateau on the Grand and Fiftymile Benches (Kaiparowits Plateau landslide zone). The zone extends along 38 miles of Tropic Shale outcrops and the deposits cover most of them. The width of the zone ranges to more than 2 miles and averages 1 to 1.5 miles. In places, especially between Fortymile and Fiftymile Washes, the debris has flowed or slid over cliffs of underlying formations (photo 52). Huge boulders, cliff fragments, and all categories of smaller clast sized particles from the overlying Straight Cliffs Formation "swim, float," or are otherwise suspended so thickly in the gray dried mud of the Tropic that it is often difficult to climb or hike about. Most of these mass wasting deposits appear to be presently stabilized and some are undergoing erosion. Presently active sliding areas are mostly small and local. The water saturation in the lower parts of the deposits, characteristic of active slides and debris flows and common with the Dakota Formation mass wasting deposits to the west, is far less pronounced.

A mass wasting deposit can be observed at Lake Powell opposite the Rincon. A large hummocky mass of the Petrified Forest Member of the Chinle Formation is littered with sandstone boulders and debris from the overlying sandier portions of the Chinle and the Wingate and Kayenta Formations.

Two types of mass wasting deposits are prevalent between Paria and the Paunsaugunt fault at the north end of the Kaibab Uplift. Both involve the incompetent beds of the Chinle Formation. The first type are blankets or sheets of sandstone debris that rest on the slopes of the Petrified Forest Member and dip away from the overlying cliffs at 7-15 degree angles. The base of the deposit is usually flat, the basal surface dipping up to 10-12 degrees. Many such surfaces are found in which the slopes are much gentler and nearly horizontal. Chinle materials are often incorporated into the lower parts of the mass wasting deposit. The deposit itself is sandstone fragment supported rather than mud supported. The incorporated materials are mostly derived from the overlying Moenave Formation and include all sizes of sandstone chunks, from fine grains to great angular boulder sized cliff fragments. The average size diminishes

Photo 52. Mass wasting deposits around the Kaiparowits Plateau. Upper photo shows debris flow that cascaded from Fiftymile Bench between the Morrison Formation cliffs. These debris flows are believed to have been most active in Pleistocene time. Lower left shows the poorly sorted angular consistency of the deposits. Lower right shows a deposit presently being eroded with a big boulder protecting the material below to form a damosel.

away from the cliff fronts. The nearly flat basal surfaces are probably shear zones developed in the Chinle by the weight of the overlying cliffs. Even though the upper few inches of Chinle get very muddy and "slick" when wetted, the formation is so tight that it is doubtful that any moisture can penetrate it. The incompetent unconfined Chinle fails, however, when stresses such as loading are directed on it.

The second type affects landforms on a grander scale. The overlying Moenave and Kayenta Formations have been jointed by tectonic activity stresses. These joints are only partially transmitted into the incompetent Chinle Formation. In the erosional process the joint zones generally erode more quickly and detached cliffs along the Vermilion Cliffs apply pressure on the underlying incompetent and unconfined Chinle Formation. The weights of these cliff segments cause stresses in the Chinle that are relieved through shearing into an unoccupied canyon where some upward buckling takes care of the space requirement. Upward buckling has not been directly observed in the Chinle, but erosion may have destroyed all such evidence. Upward buckling has been observed in the underlying Moenkopi Formation, however, especially in the Paria-Calico Peak area. The joints thus allow movement, become faults, and drop large blocks at points and salients along the Vermilion Cliffs. Shear zones have been observed in the Chinle, often in unexplained angles and configuration. It is difficult to classify or draw cross-sectional diagrams of these movements, a cross between mass wasting and gravity tectonics. The mass wasting deposits of this type have been mapped as blocks of parent material. Perhaps the most spectacular example is found just south of the Manganese King mine, Sec. 2, T. 42 S., R. 3 W., where horizontal Chinle beds are abutted against vertical Kayenta and Moenave strata. A well drilled into the vertical beds reached sandy clays (Chinle Formation?) at a depth of 65 feet and encountered some water along the shear zone.

Mixed eolian and alluvial deposits. By far the most widespread group of unconsolidated deposits in Kane County can be classed as mixed eolian and alluvial deposits (Qeas). They are mostly composed of fine grained sand, but usually contain subordinate silt, gravel, clay, and other clastics that arrived by fluvial processes. Sand is accumulated on benches or protected places as sheets by the wind and as weathering products. These are then reworked by sheetwash during torrential rains and flooding ephemeral streams. Occasional floods spread over the banks of the streams depositing fine material over the eolian sand. The deposits often grade into "pure" eolian deposits and "pure" alluvial deposits. The deposits are generally thin, rarely exceeding 30 feet in thickness. The map fields incorporate smaller areas of "pure" alluvial deposits and "pure" eolian deposits.

Eolian sand deposits. Kane County has many deposits of eolian sand (Qes). Most are quite limited in aerial extent and have not been marked on the geologic map. There are, however, several large mappable areas of sand dunes that are significant. Of the many sandstone units exposed in the county, the Navajo and Entrada Sandstones and the Thousand Pockets Tongue of the Page Sandstone are especially productive in supplying sand for dunes. Friable and poorly cemented horizons are best. The middle pink unit of the Navajo, best developed west of Johnson Canyon, has probably provided the sand for the Coral Pink sand dunes and other large sandy areas in the vicinity. The Coral Pink sand dune area is about 8 miles in length and 1 mile wide, half on the upthrown block of the Sevier fault, the other half on the lower block. The dunes on the lower block are better protected and are somewhat larger, the largest rising to 45 feet from the surface of non-dune sand. The sand dunes provide the basis for a popular state park recreational area (photo 53). Lower dunes connected by sheet sand deposits form the Sand Hills that extend across U. S. Highway 89 between Kanab Creek and the Sevier fault. This area of sand is about 2x6 miles in area. Many smaller, but thick accumulations of sand develop on the lee sides of ridges and cliffs. Some rise more than 100 feet on the cliffsides. Still other small areas consist of thin veneers of sheet sand with regularly spaced very low longitudinal dunes.

Alluvium. Alluvium (Qa) was mapped wherever alluvial processes have dominated. It has usually collected along the active and semi-active stream courses, their valleys, and as small fans, slope covers, terraces and pediments, and all sizes of clasts can be found in it. The occasional ephemeral pond, playa, or small lake deposits are included in this unit. The sorting is poor to good and the coarsest materials are generally restricted to the stream channels. In pediments the coarsest materials are closest to cliff and mountain fronts. The thickness of such deposits can vary from a very thin veneer to more than 100 feet. Alluvial deposits in Kane County that cover or are found downstream from the Tropic Shale and other Cretaceous rocks usually contain much gray mud. Those downstream from the Claron and Kaiparowits Formations usually contain rounded cobbles and pebbles from the conglomerate lenses of those units. Claron Formation derived limestone gravel maintains the pink and white color of the original formation and has often been carried a considerable distance from the source. These gravels resist abrasion and deterioration so that they are identifiable many miles downstream. Elsewhere sand and sandstone debris dominates, the color often indicating the source formation.

Along some stream courses rather thick well-stratified accumulations are present, such as in the lower stretches of Kanab and Johnson Canyon Creeks (photo 54). The varying hues of the sandstone layers indicate that the flooding that brought the sand came from local areas (due to torrential type rainfall) in the upstream watershed; reddish layers from canyons eroding reddish sandstones and yellow or white layers from canyons eroding yellow, tan, or white sandstones. Deep gullies have been cut into some of these relatively thick alluvial deposits and show how temporary even the thickest of these deposits are with respect to geologic time (photo 55). In some Kane County locations plant regimes requiring a long time to develop are present on the deposits, indicating that stream action has been minimal or is temporarily inactive. Most of these deposits are believed to be Holocene in age.

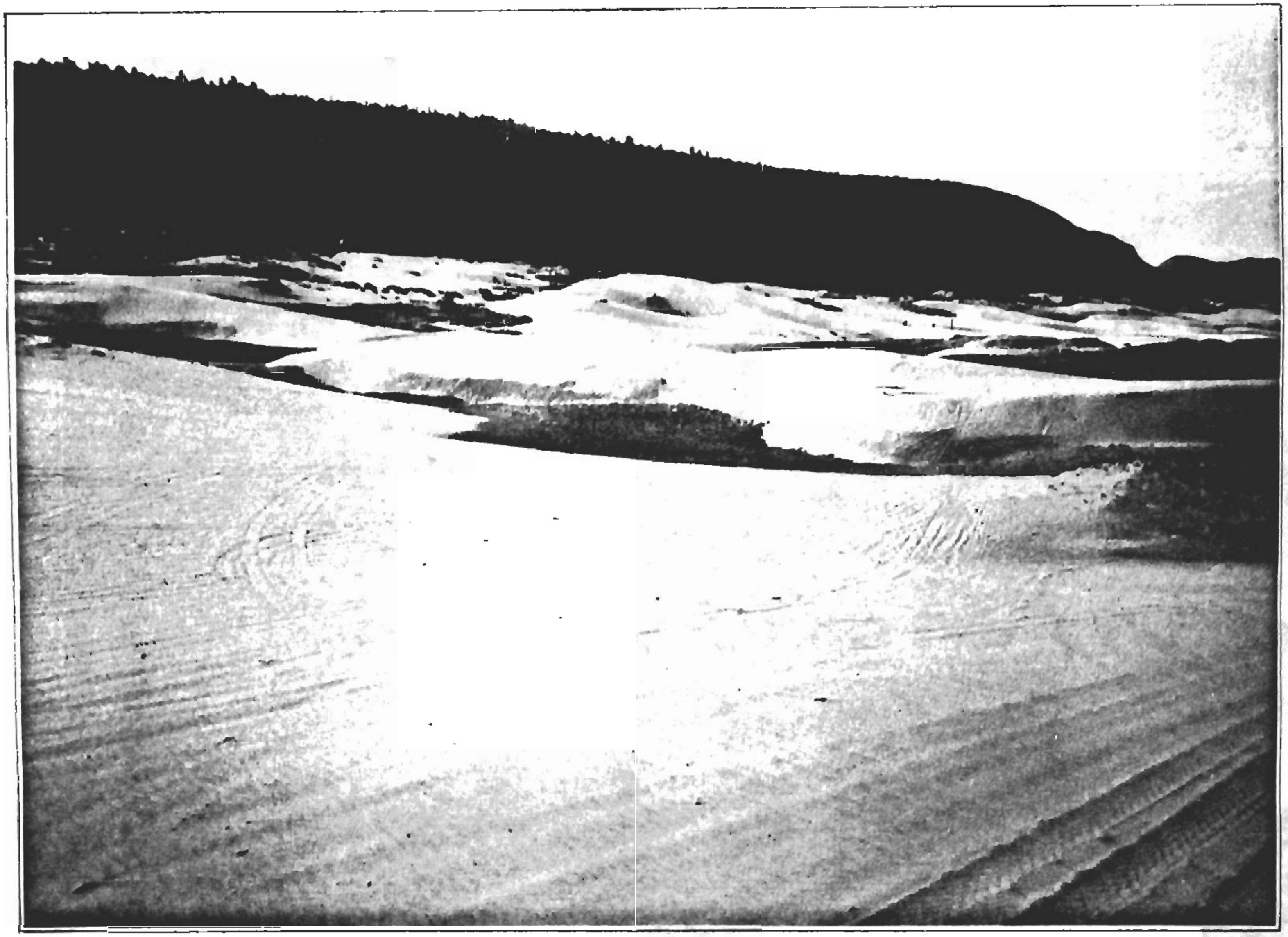


Photo 53. Coral Pink sand dune area in western Kane County. The pink sands were probably mostly derived from the "red" Navajo and are piled up in front of the escarpment along the Sevier fault. *The* southwesterly prevailing winds have piled the sand along the escarpment and at a low spot have covered it and deposited on the upthrown block.

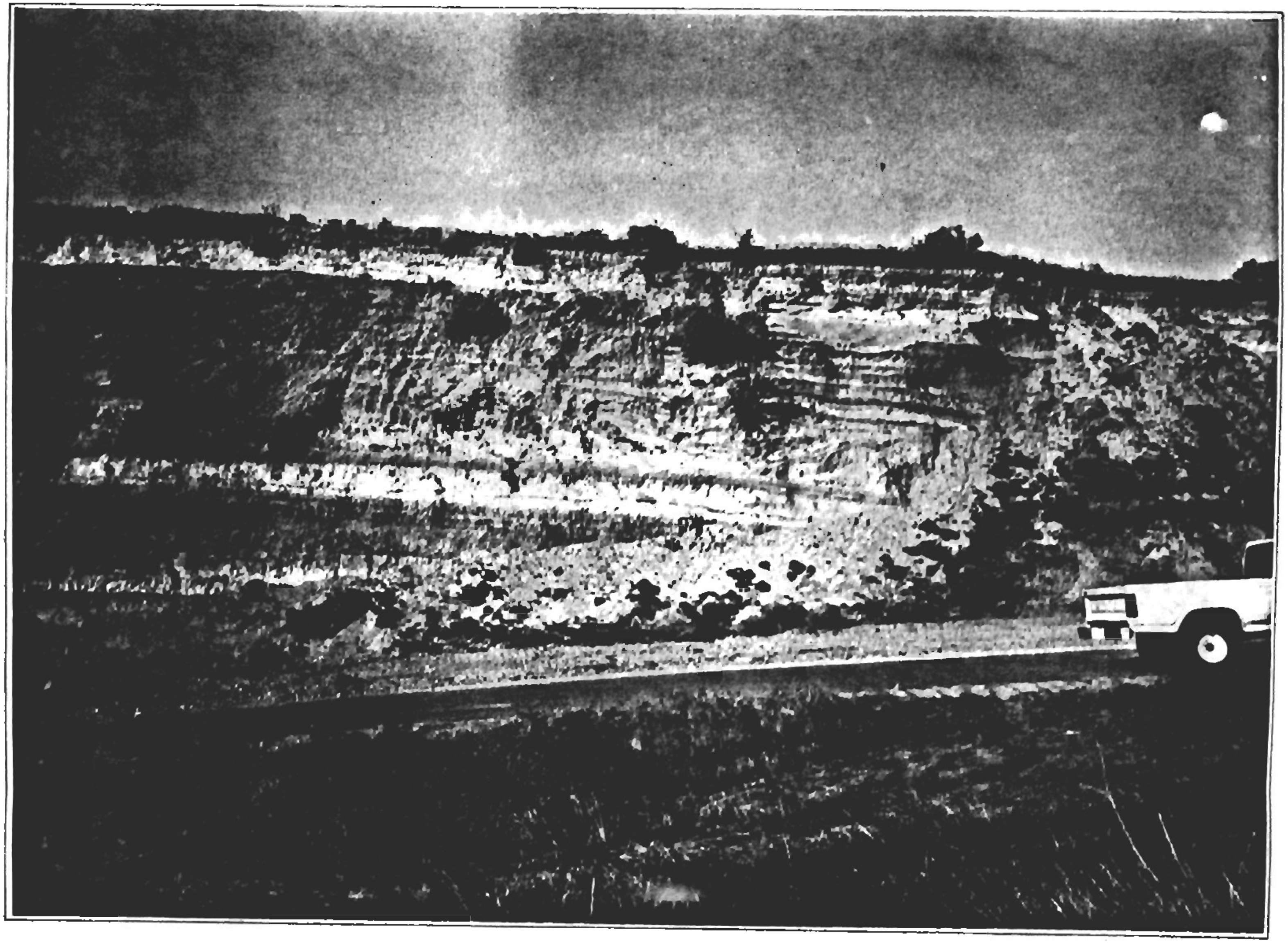


Photo 54. Banded layers of thick sandy alluvium along Kanab Creek near Kanab. Each band represents a deposit brought down by an individual flood. The alluvium was probably deposited 10,000 to 1,000 years ago.

Photo 55. An alluvium filled valley (Kitchen Corral Wash) now being deeply gullied. The amount of alluvial fill may exceed 100 feet along the more important drainages. In some places the gullying is reaching the bedrock.

A sample of charcoal was obtained from an unconsolidated alluvial bed along Kanab Creek in NWNW Sec. 28, T 43 S, R 6 W that is 65 feet above the creek bed. The charcoal was found in a 5-inch thick, calcareous, greenish-gray, clayey silt bed that was 35.3 feet below the top of the bluff. The charcoal had a radiocarbon age of 4790 ± 275 years B.P. (Geochron Lab sample number GX 11703). This indicates that much, if not all of the Kanab Creek bluff is Holocene in age.

Alluvial gravel. Larger areas of predominantly gravel deposits were mapped separately (Qag). Interlayers of silt, mud, and other materials are often present. These are usually pediment or terrace deposits or similar types where coarser materials have accumulated, usually in well developed landforms or geomorphic features (photo 56). Not all such deposits would provide suitable aggregate for road metal. Many are dominated by angular sandstone pebbles, cobbles, and larger fragments with no inherent strength. Some of the gravels are remnant terraces, located far above the present stream course, and are relatively old (photo 57). Some are partly cemented by thick white caliche affecting up to 4 feet of the deposit (Bullfrog Basin). Many of these deposits are believed to be Pleistocene in age and a very few may be even older.

Photo 56. Pediment surface developed adjacent to the whaleback of Buckskin Mountain. Angular gravelly limestone and chert debris cover the upturned edges of the Triassic Moenkopi Formation.

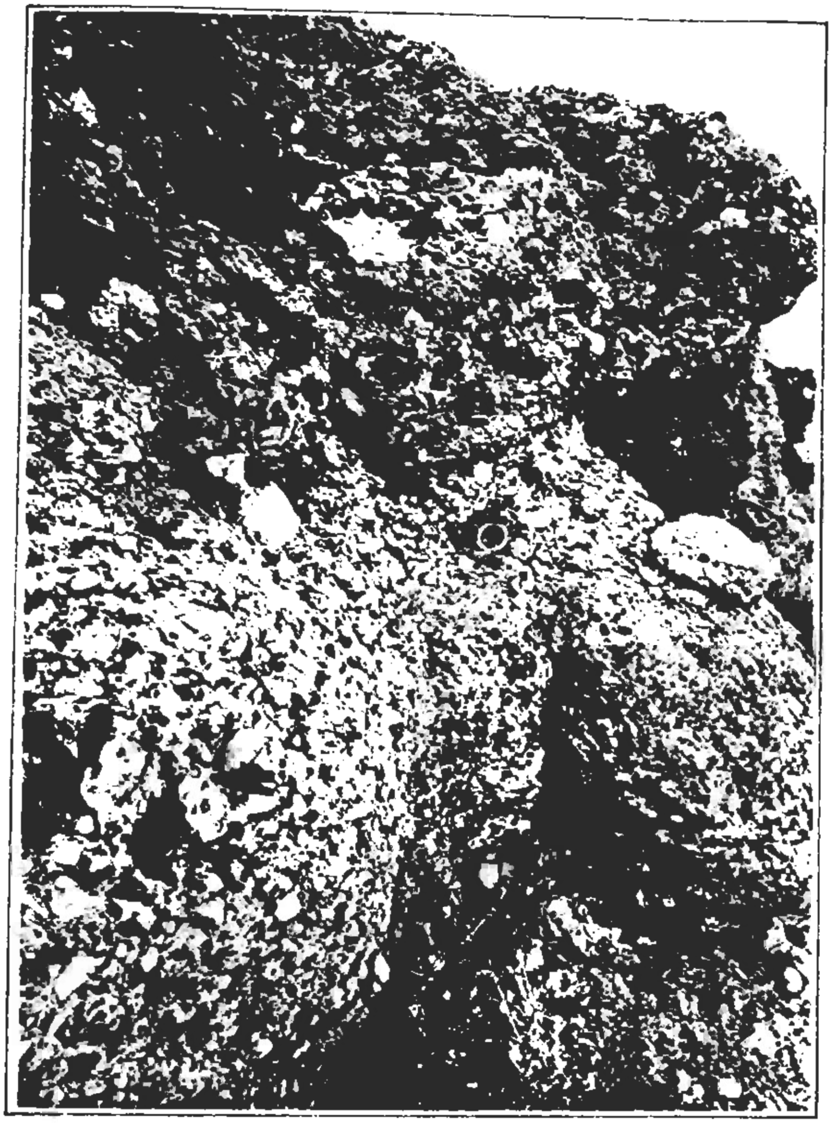


Photo 57. Partly cemented terrace gravel along Kitchen Corral Wash. The thickness of the calichified zone can exceed 5 feet. Terrace gravels can be found several hundred feet above the present drainage levels in Kane County.

Structure and Geomorphology

Kane County is a typical Colorado Plateaus area and reflects this structurally and geomorphologically. In essence all strata dip gently northward in a homocline that is warped and faulted. The oldest rocks are generally exposed to the south while the younger beds cap plateaus to the north. The mostly gentle northward dip of the beds is often overshadowed by the axes and trends of the warps (folds), faults, and joint systems, of which most trend N 20-45° W and N 15-30° E.

Structurally the county can be divided in half at the East Kaibab monocline. The the west of the monocline the northward dipping homocline is well developed into the "Grand Staircase." Northeast trending faults are the most prominent structural features. The folds are generally broad and shallow (there are a few exceptions). To the east of the monocline the strata are regularly folded, mostly along northwest trending axes. The beds drop into the relatively deep Kaiparowits Basin from the monocline and then gradually rise easterly to the Circle Cliffs anticline. The steep east limb of the anticline is known as the Waterpocket Fold. East of this fold the beds drop into the southern part of the Henry Mountains Basin and then gradually begin to rise on the west flank of the Monument Upwarp.

The dominant streams of Kane County are mostly obsequent and flow southward into the Colorado River. Most of the county is in the Colorado River drainage. A small portion, consisting of the tops of the Paunsaugunt and Markagunt Plateaus, in the northwestern parts, drain into the Great Basin. The principal Great Basin streams are consequent. The Colorado River drainages are more vigorous and steep and the cliffs are gradually (quite rapidly considering relative geologic time) retreating northward.

Western Kane County

Structurally western Kane County is dominated by the northward dipping homocline. The rocks dip generally northward into a large basin in central Utah (Central Utah Basin) filled with Cretaceous and Tertiary sedimentary and volcanic rocks. Structurally western Kane County can further be subdivided into three blocks by two major NNE striking faults. Both are high angle normal faults, both are complex in that each forms a fault zone. The downthrown block is on the west side in both cases. These are known as the Sevier and Paunsaugunt faults of which the westernmost Sevier fault has the greatest displacement.

Sevier fault. The Sevier fault zone extends far to the north and far to the south of Kane County and is about 300 miles long. To the south it begins about 35 miles south of the Grand Canyon and to the north its affects are noticeable well into central Utah. The zone, in Kane County, consists of many closely spaced splinter faults that together account for the 1000-2000 foot displacement. An escarpment with up to 800 feet of relief has developed along this zone. In most places, however, this escarpment displays only several hundreds of feet of relief. The blocks between the splinters are often moderately tilted and dips up to 60 degrees have been measured. At Coral Pink Sand Dunes State Reserve the "red" Navajo is abutted against the Moenave Formation rocks (1000+ feet of displacement). The sand dunes deposit has collected at the foot of the escarpment where it is high to the south and has drifted across and over a low point in the escarpment to the north. The prevailing winds are from the southwest. Near Orderville the Cretaceous Tropic Shale is abutted against the cliff forming white Navajo Sandstone (about 1800 feet of displacement).

<u>Paunsaugunt fault</u>. Escarpments are less prominent and intermittent along the Paunsaugunt fault, which has a lower order of displacement. Like the Sevier fault it is a long fault zone that extends from Arizona into central Utah. The fault plane(s) dips at various angles from 45° E (reverse fault) to 45° W (normal fault). The displacement decreases to the south from about 800 feet near Willis Creek to less than 100 feet near Deer Spring Point. Then from Deer Spring Point southward to the Arizona border it increases again to approximately 500 feet. In areas where the displacement is less, the rocks on the upthrown block dip sharply toward the fault. The total displacement effect along the entire Paunsaugunt fault in Kane County is therefore estimated to average 500 feet. It is interesting to note that escarpments are mostly posed on the downthrown block (reverse topography). Some escarpments, however, have developed on the upthrown block and the relief is totally dependent on the differences of hard and soft strata. Along Willis Creek the Entrada abuts against the Straight Cliffs Formation. Along Seaman Wash (to the south) the Chinle abuts against the Moenave Formation. In many places the fault line is obscured or covered by alluvium and other Quaternary deposits.

<u>Kolob Region</u>. The block located west of the Sevier fault (Kolob Region) is structurally simple and divided geomorphologically into four physiographic subdivisions. These include Long Valley, Markagunt Plateau, Kolob Terrace, and Coral Pink Bench and Canyonlands (figure 3). Long Valley carries the south-flowing East Fork of the Virgin River south of the Colorado River Basin-Great Basin divide. The divide crosses the Long Valley physiographic subdivision at Long Valley Junction. North of the divide is another valley containing the headwaters of the north flowing Sevier River. Both rivers flow in alluvium filled valleys that are entrenched into the bedrock. The rivers flow parallel one to three miles to the west of the Sevier fault. The valley itself is usually west of the zone of splinter faults, but several splays cross it, especially near Glendale and Mt. Carmel Junction. The rivers usually bend where a fault crosses the valley. Some of these splay faults have displacements of several hundred feet. The alluvium filled valleys vary from several hundred feet to 1/2 mile in width. The rivers meander across and are slightly entrenched in the alluvium. The alluvium itself is relatively thick, ranging to 40 or 50 feet above the bedrock. Terrace gravels are plastered or lodged at several levels on valley walls that rise on both sides indicating that the river has been in this area for a long time.

With the exception of a few areas the structure of the other three physiographic subdivisions of the Kolob Region is simple. The structure contours indicate that the average dip is less than two degrees. A broad rise to the west has skewed the strata so that the homocline dips northeasterly rather than directly northward. Otherwise the "Grand Staircase" is typically displayed.

The northernmost Markagunt Plateau is divided from the Kolob Terrace along the Pink Cliffs. North of the Pink Cliffs all drainages flow into the Great Basin and most flow northeastward. The principal drainages are found in shallow alluvium filled valleys between which paralleling ridges rising to 500 feet above the valleys have developed. Several volcanic cinder cones are present along the Garfield County line which are surrounded by very fresh appearing blocky lava fields. These Pleistocene lavas have blocked at least one principal drainage and created Navajo Lake behind it. Some of the drainages flow into caves in the Claron and emerge as large springs or disappear as "lost rivers." Scattered relatively short faults with displacements are occasionally found on the plateau surface. These are probably parallel and related to the closely spaced joint systems found in the Claron Formation. Inasmuch as the Markagunt Plateau is capped by the Claron Formation, which is mostly limestone, some karst features have developed. There are a few shallow caves and sinkholes on the ridges and at least one drainage is known to flow in a cave system (Cascade Falls). Claron karst activity is largely controlled by the joint system. The Pink Cliffs rise 400 to 600 feet all along the southern boundary of the Markagunt Plateau. Bare cliffs are not present continuously along the escarpment, parts are mantled with thin colluvium. It is thought that the colluvial cover was continuous during the Pleistocene and is gradually being removed during the Holocene epoch.

The Kolob Terrace does not take on the form of a true terrace. It is found between the Pink Cliffs and Gray Cliffs and consists of a series of ridges between the principal obsequent streams. Along the south and east margins the ridges terminate as a series of points along an intermediate cliff forming unit (Straight Cliffs Formation). Below the Straight Cliffs Formation is a convex slope developed on the Tropic Shale and then a concave slope developed on the Dakota Formation. The concave slope of the Dakota is often mantled with colluvium and landslide debris and the Gray Cliffs are not well developed. Faults are not abundant on the Kolob Terrace except to the northwest (Ts. 38 and 39 S., R. 9 W.). A series of normal faults with displacements up to 200 feet are present that trend N 50° E to N 88° E. The lengths of these faults ranges from 2 to 4 miles and they are spaced 1/2 to 1 mile apart. In 9 larger faults the downthrown side is to the northwest along four of them and on the southeast side on the remainder, so as to form horsts and grabens. In the same area lava flows are present, similar to those found on the Markagunt Plateau. The lava erupted from vents and volcanos below the Pink Cliffs and flowed into canyons, partially filling them. The aforementioned faults apparently cut some of the lava flows. Several obsequent streams originate below the Pink Cliffs and cross the Kolob Terrace in alluvium filled valleys. These include the North Fork of the Virgin River, Orderville Canyon Creek, Meadow Creek, Muddy Creek, Lydias Creek, and Stout Canyon Creek.

The Coral Pink Bench and Canyonlands physiographic subdivision covers the remaining area of the Kolob Region in Kane County. It extends southward from the Gray Cliffs (Dakota Formation) to the Vermilion Cliffs in Arizona. The White Cliffs usually divide this area into two subdivisions, but there is little area between them and the Gray Cliffs and no significant terrace has developed. Several deep canyons have been incised into the White Cliffs and the overlying Kolob Limestone Member in this northern part (where the terrace should have been developed) and these units have been dissected to form mesas and buttes. The "red" Navajo makes up most of the surface below the mesas and buttes and is differentially eroded into rounded knolls and ridges. The Navajo Sandstone is strongly jointed with joint sets trending N 30° E and N 20° W. Some vertical displacement can be demonstrated along the most prominent of the joints. The drainages have cut their valleys and canyons along these joint trends. The Harris Mountain anticline is present just west of the Sevier fault zone. Several splay faults from the Sevier fault zone cut and displace the rocks in the anticline. The anticlinal axis parallels the fault zone (about N 30° E), and the west flank is the more gentle. Dips on the west flank range to 3 or 4 degrees while dips on the east flank range to 7 or 8 degrees. In the fault slivers near the zone the dips are occasionally as steep as 45 degrees. The East Fork of the Virgin River is deflected westward near the nose of this anticline. It has incised a deep canyon into the Navajo Sandstone and the Kayenta Formation is exposed at the head of Parunuweap Canyon. Earlier in its history the river meandered across the softer "red" Navajo and some of the meanders are now entrenched. The principal streams from the north all flow into the Virgin River so that the area to the south has no permanent streams.

<u>Johnson Canyon Region</u>. The area between the Sevier and Paunsaugunt fault zones (Johnson Canyon Region) includes the Paunsaugunt Plateau, Podunk Terrace, Skumtumpah Terrace, Wygaret Terrace, and Shinarump Flats physiographic subdivisions (figure 3). The northward dips of the entire region are very gentle and rarely exceed 3 or 4 degrees. Locally, especially along the margins of the Paunsaugunt and Sevier fault zones, the beds are tilted at somewhat steeper angles. A very shallow and broad syncline (Paunsaugunt syncline) is present on the Paunsaugunt Plateau that plunges gently northward. South of the Pink Cliffs the structure contours broaden and flatten out. Several clusters of faults are present in the region that offset the broad northward dipping homocline. Perhaps the most important is the Bald Knoll fault zone. The zone starts near the White Cliffs at Brown Canyon and Cutler Point and extends northward about N 20° E to Bald Knoll where the fault trace is covered by alluvium and lava. Then it continues almost directly northward along the west side of the Pink Cliffs. An en echelon branch, 1 1/2 miles to the east continues northward from Rush Canyon into Garfield County. Many branch and splay faults are present in the zone to the south of Bald Knoll. Here the zone is 2 to 3 miles wide and most of the branch faults parallel the main fault (N 20° E) or lie conjugately at N 20° W. The displacements on individual

faults ranges to 200 feet or more. The branch north of Bald Knoll places the Wahweap Formation against the upper part of the Tropic Shale for a minimum of 500 feet of displacement. Farther north, in the en echelon branch, the Kaiparowits Formation is brought against the lower part of the Claron Formation for a maximum of 200 feet of displacement. The downthrown block along the fault zone lies to the east so that the area between the Bald Knoll and Sevier fault zones forms a wide horst-like block.

Several faults are found to the west of the Bald Knoll zone including the rather prominent Skutumpah Terrace fault that extends across the Skutumpah and Podunk Terrace from Timber Mountain approximately N 20-30° W to the southernmost point of the Pink Cliffs. It appears to be offset in a few places by northeasterly trending faults. The trends of faults in the Bald Knoll zone and along the Skutumpah Terrace fault appear to be controlled by the regional joint patterns. The offset on the Skutumpah Terrace fault is in excess of 100 feet.

Two relatively short fault zones parallel Kanab Creek and Johnson Canyon Wash. They also subparallel the regional joint trends. Most have the downthrown blocks positioned toward the canyons and this feature is best developed along Kanab Creek. The faults are relatively short and have displacements ranging to 100 feet. These fault zones are active (see geologic hazards) and at least some of the stresses are thought due to unequal loading between plateaus and canyons. Many short faults are observable along the Vermilion and White Cliffs that allow points to slump downward.

The Paunsaugunt Plateau is similar to the Markagunt except that there are no volcanic flows. The consequent streams of the upper surface are tributaries of the East Fork of the Sevier River, the flow is north northeast into the Great Basin. The streams flow in shallow alluvium filled valleys that are up to 1000 feet wide. The principal stream course is nearly coincident with the very shallow and broad Paunsaugunt syncline that trends about N 30° E. The Pink Cliffs are usually 400 to 600 feet high and are partially mantled with a thin veneer of colluvium that is presently being removed by erosive processes. The southern part of Bryce Canyon National Park extends along the Pink Cliffs on the east side of the Paunsaugunt Plateau where the process of removing the colluvium is more complete. The picturesque minarets, castle forms, arches, and other characteristics of the Pink Cliffs are the result of differential erosional along closely and evenly spaced vertical joints and slight differences in the hardness (horizontal) of the Claron Formation beds.

The Podunk Terrace extends from the Pink Cliffs to the Gray Cliffs and the Skutumpah Terrace from the Gray Cliffs to the White Cliffs. In the Podunk Terrace area the interfluves are largely paralleling ridges. Well developed ledge or cliff lines are developed on the Straight Cliffs and Dakota (Gray Cliffs) outcrops. The Straight Cliffs Formation usually forms a cliff to 150 feet in height, whereas the Gray Cliffs are 200 to 400 feet high. Where the Gray Cliffs are highest the upper parts of the Entrada or Carmel Formation form the lower part. Interfluve areas in the

Skutumpah Terrace are similar to those in the Podunk Terrace in the northern part, but broad benches have developed on the top of the White Cliffs on the Kolob Limestone Member of the Carmel Formation. The upper surfaces of these benches are generally veneered with fine brown sand of mixed alluvial and eolian origin.

The White Cliffs form an imposing erosional escarpment across the region with an average rise of 800 feet above the Wygaret Terrace. The softer, more pinkish Navajo Sandstone below ("red" Navajo) is partly covered by sheet sand and erodes to low knolls, ridges, low cliffs, and other projections. The major streams and washes that cut through the White Cliffs form deep steep-walled canyons. Only a few major washes cross the Wygaret Terrace and Shinarump Flats and these flow in alluvial filled valleys. The alluvial fill in these valleys in places exceeds 50 feet and the streams are deeply entrenched in this alluvium. Farther south on the Wygaret Terrace are alternating benches and cliffs formed by hard and soft units (lower main body Navajo [hard], Tenney Canyon Tongue [soft], Lamb Point Tongue [hard], and Kayenta Formation [ledgy and soft]). The Vermilion Cliffs mark the southern boundary of the Wygaret Terrace and they are formed from the ledgy Kayenta above and the cliff-forming blocky Moenave Formation. The Shinarump Flats are found below the Vermilion Cliffs and extend southward to the Kaibab Uplift. They are broken by the Shinarump Cliffs along the Arizona border in this region. In the Utah portion the Flats consist of a gentle alluvial slope covering the Petrified Forest Member of the Chinle Formation. The Shinarump outcrops form a 2-5° north sloping dip-slope along the state line.

<u>Paria Region</u>. The area between the Paunsaugunt fault and the East Kaibab monocline (Cockscomb) is a block that is structurally higher than blocks (regions) on either side. Several faults and north trending folds alter the principally north-dipping Paria Region. The principal feature is the Kaibab anticline which enters Utah from Arizona trending N 45° W. The axis may join with the Tropic anticline in Garfield County. The plunge is steadily northward except for a sag as the axis crosses Kaibab Gulch. The sag allows for some closure on Fivemile Mountain. Along Buckskin Mountain the east flank coincides with the East Kaibab monocline. On the east flank of the mountain, where the upper surface reflects the anticlinal form, dips range from 10-15° before steepening further along the monocline. Locally, as along the sag at Kaibab Gulch, dips decrease to as little as 4 or 5 degrees.

The anticline is more symmetrical to the north and flanking dips usually range from 2 to 4 degrees. Other folds are present between the Kaibab anticlinal axis and the East Kaibab monocline, the axes of the Hackberry Canyon syncline and the Butler Valley anticline. The dips of beds between these folds are relatively gentle (2-6°) except for the east side of the Butler Valley anticline and the east side of the Kaibab anticline near Wiggler Bench. The east side of the Butler Valley anticline is coincident with the East Kaibab monocline. The dips between the Kaibab anticline and the Hackberry Canyon syncline near Wiggler Bench (T 38 S) steepen to 10-15 degrees (photo 58). The axis of the Hackberry

Photo 58. East flank of Kaibab anticline near Wiggler Bench. The folds in the Paria Region are relatively subtle except at a few locations, such as at this location. The beds dip 10-15 degrees into the Hackberry Canyon syncline.

Canyon fold is rather sinuous and there is some closure along the doubly plunging axis of the Butler Valley anticline.

Between the Kaibab anticline and the Paunsaugunt fault, in the northern part of the Paria Region, the strata are only gently warped and the folds are poorly defined. Roughly paralleling the sourse of the Paria River is the Paria River syncline. To the west and trending northwesterly are the Deer Range anticline and Nipple Lake syncline. The Deer Range anticline has a relatively steep west limb with dips to 15°. The limb is cut off by the Paunsaugunt fault and the Swallow Park fault zone. The Deer Range anticline probably has some closure between Deer Range Point and the Paria River. The dips on the flanks on this part of the anticline range to 7 degrees.

There are several fault groups or zones on Buckskin Mountain. One zone, trending N 70-80° E, subparallels Pine Hollow Canyon (near the Arizona border) on the east flank of the Kaibab anticline. The displacement reaches a maximum of about 250 feet and the downthrown block is to the south. There are at least three pairs of paralleling faults which drop narrow intervening blocks between them into grabens. The displacements range to about 100 feet and the trends are dominantly north. Another fault is paired with a short anticline. Strata rise gently southwestward from the sag of Kaibab Gulch and after reaching the anticlinal axis, collapse sharply to the fault, which is downthrown to the southwest. The trace of the fault is covered with alluvium in a narrow paralleling valley. On the downthrown block, across the valley, the beds rise sharply at first and then gently, suggesting collapse between the anticlinal axis and the southwest side of the total structure.

A fault marks the west side of the Kaibab anticline and Buckskin Mountain. It trends N 15° E and the displacement seems to increase southward. Near the T 43-44 S boundary, the Lower Red Member of the Moenkopi Formation is brought against the Kaibab Formation indicating 250 feet of displacement. Additional displacement is present in splay faults that project northward, but their traces are covered by alluvium. The trends of most faults on Buckskin Mountain (excepting the Pine Hollow Canyon faults) range from N 30° W to N 15° E. An extension of one of the graben forming faults extends north, crosses Kaibab Gulch and is lost under the alluvium of Kimball Valley (Shinarump Flats). It is downthrown to the east and there is some downward drag in the beds on the downthrown block adjacent to the fault. Middle Red Member beds of the Moenkopi Formation are brought adjacent to the Lower Red Member beds suggesting about 200 feet of displacement.

The Swallow Park fault zone trends N 70-45° N and is a series of faults which downthrow strata to the north between No Mans Mesa and Deer Range. The northwest extension of these faults extend and bend into the Paunsaugunt fault. It is difficult to estimate the true displacement inasmuch as only the Navajo Sandstone strata are involved, but a minimum of 200 feet is indicated. The beds rise quickly to the north of the zone on the steep flank of the Deer Range anticline.

Of the remaining faults in the northern part of the Paria Region, most trend parallel to the dominant joint pattern, N 15-35° W. The joints with offsets are concentrated along the major stream courses (Hackberry Canyon, Paria River, and Kitchen Corral Wash). The most impressive set is along the Paria River north of Paria. There are two major faults, one on each side of the river, that are 3/4 to 1/4 mile apart. Each downdrops strata into the canyon and each exhibits a maximum displacement of about 250 feet. On the east side fault the deformation starts at the south end as a riverward dipping fold, then the fault appears and drops the strata flatly or with a small amount of reverse dip. Still farther north the fault breaks into several branches some of which cross the river. The western fault starts south of Paria where it seems to join splay faults from faults attendant to the East Kaibab monocline. The downdropped block has been lowered uniformly or exhibits a small reverse dip angle. The fault planes dip steeply toward the river or are nearly vertical. Between these major faults there are additional ones with less offset, some of which cross bends in the river. These faults appear to cut and displace high river terrace gravels. Detailed examination of Chinle Formation outcrops north of Paria indicates the presence of some nearly horizontal slippage planes above which the strata are imbricated (photos 59 and 60). To the north of the fault zone the strata rise somewhat before returning to the gentle northward dip. This is probably because the area to the north of the fault zone has not been collapsed into a graben. It may also be due to the axis of the Deer Range anticline swinging eastward across the area. It is thought that collapse has occurred along the regional joint systems due to unequal loading between the river valley and the high cliffs that bound it. The sinking blocks probably displace incompetent strata beneath (Chinle and Moenkopi Formations) which move riverward along shear planes and buckle up under the valley floor. Indications are that this process was more active during Pleistocene time.

Similar collapse appears to have occurred on many of the points along the Vermilion Cliffs. An outstanding example is evident near the Manganese King mine (see figure xx, p. zzz). Kayenta, Moenave, and Chinle beds slipped over the Chinle and Moenkopi beds on an old surface rotating into nearly vertical position. The Moenkopi beds immediately in front of the slide plane dip more steeply than in unaffected areas.

The Paria Region is divided into at least four physiographic subdivisions (figure 3) that generally contain the geomorphic patterns of counterparts in the Johnson Canyon and Kolob Regions. In addition small remnants of a "Podunk or Kolob Terrace" extend into the region in the north. They physiographic subdivisions include the Paria Terrace, the eastward extensions of the Wygaret Terrace and Shinarump Flats, and Buckskin Mountain. Each has some unique characteristics worthy of discussion.

The northern part of the Paria Terrace exposes the members of the Entrada and Carmel Formation. The area consists of mesa ridges and buttes built of these units, between which rather large valleys have developed which are covered with alluvium. To the west, and to a lesser degree in the east, the tops of the mesa ridges are veneered with pediment gravel.

Photo 59. Deformation in the Chinle Formation, west of the Paria River across from the abandoned townsite of Paria. The faults are thought to have been created because of differential loading of sediments on the incompetent Chinle Formation. Bed A is correlated with Bed A on the opposite side of the high angle fault. The dip below the low angle fault is represented by the dashed line. Another high angle fault is found just to the right (east) of the picture which is upthrown to the east beyond which the beds have nearly horizontal attitudes (see photo 60).

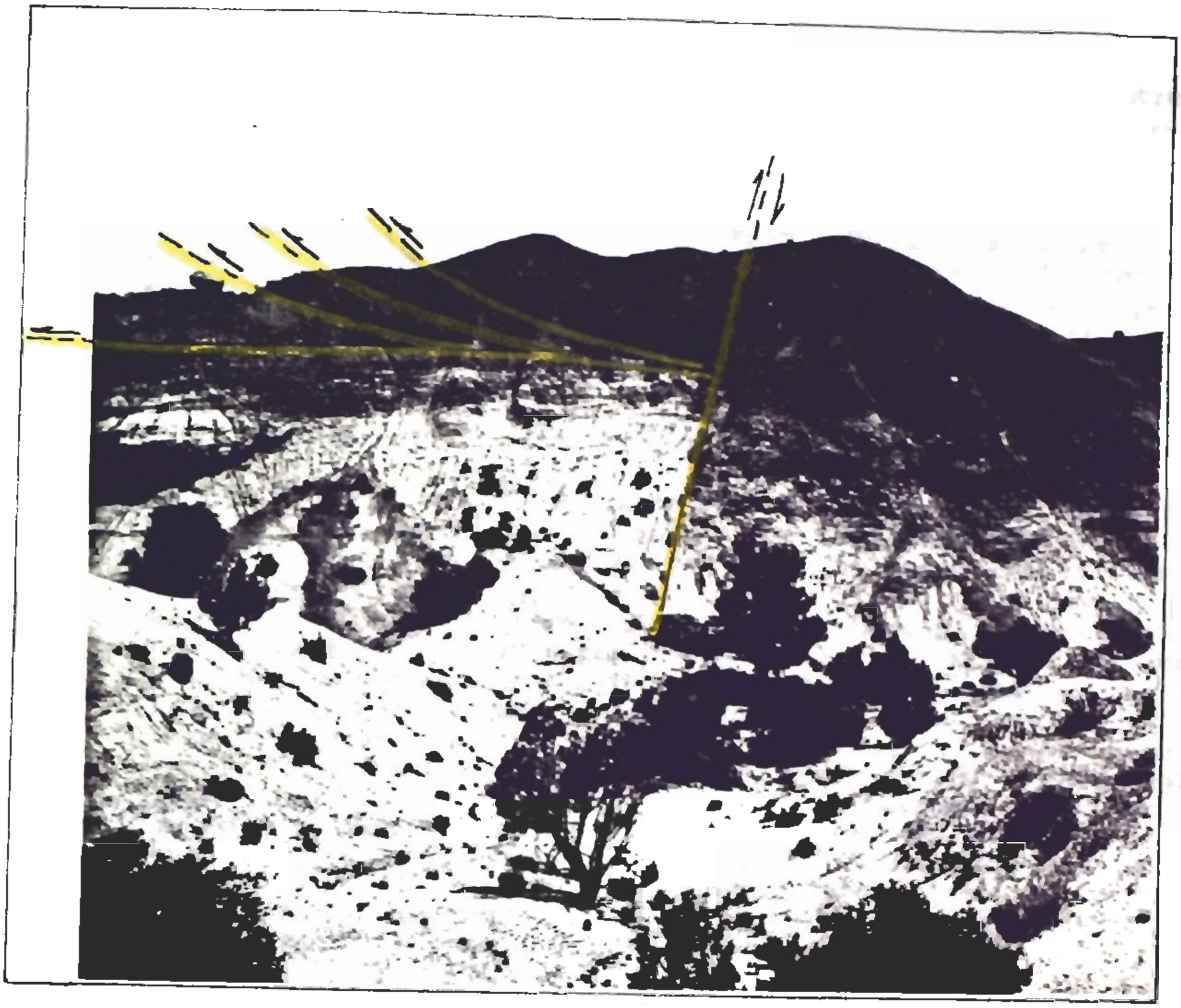


Photo 60. Fault deformation just west of Paria River and abandoned townsite of Paria. Photo taken just east of photo 59, but looking south. Notice the shear fault imbrications to the east of the high angle fault.

Principal streams and washes, all tributaries of the Paria River, generally flow in valleys filled with alluvium. Most of the streams are cutting into the alluvium and reach patches of bedrock along the bottom. Vertical and rounded pipes have shattered and deformed the beds of the San Rafael Group in T 38 S, in Rs 1 and 2 W. The pipes range in diameter to 40 feet (photos 61 and 62). Some have been recemented and are more resistant than the rock that encases them. These form columns and other monuments that add to the interest in the Kodachrome Basin State Reserve. Some are bleached and others are mineralized with lead and copper (see Economic Geology, p. zzz). These features have been discussed by Hornbacher (1984). The southern part of the Paria Terrace consists of northward dipping benches developed on the Kolob Member of the Carmel Formation that rest on top of the White Cliffs. These benches are generally veneered with fine sand of mixed alluvial and eolian origin.

The Wygaret Terrace is mainly built on outcrops of the Navajo Sandstone. The upper 400 feet of the Navajo stand as the White Cliffs at the northern boundary of the subdivision. Drainages have cut many deep canyons into the White Cliffs in this region. There are several impressive buttes at the ends of points and there are some large mesas isolated from Paria Terrace benches to the north. Most of the remainder of the Wygaret Terrace is built on the softer middle part of the Navajo Sandstone. The landforms consist of bare rock domes, swales, and slopes. Between the bare rock forms are numerous hollows filled with sand. The lower part of the Navajo (lower 50 feet) forms cliffs, towers, and even arches. In the south, along the edges of the terrace, the upper surface exposed the ledgy Kayenta Formation. In places the principal drainages and their tributaries have cut deep canyons into the terrace and canyon walls are generally unscalable (Hackberry Canyon, Paria River Canyon, and Kitchen Corral Wash Canyon). Most principal streams and washes flow over alluvium, but in places flow over bedrock.

The Shinarump Flats physiographic subdivision exposes outcrops of the relatively softer Triassic units and large connecting areas of alluvium covered Flats (Telegraph Flat and Kimball Valley). Harder beds form discontinuous cuestas (Virgin Limestone, Shinarump Member, etc). The exposed bedrock areas are rough and eroded into badlands. This is especially developed around the Kaibab anticlinal axis. Around the base of the Vermilion Cliffs, which form the north boundary of the subdivision, mass wasting deposits form pediment like benches on the Chinle Formation. In places, where short obsequent washes have been able to cut deep canyons into the Moenkopi, the difference in loading causes the rock to buckle the canyon floors (photo 63). This can be observed in almost every canyon south of Pilot Ridge and Calico Peak.

Buckskin Mountain is a large anticlinal whaleback, the upper surface of which consists mostly of the tough Timpoweap Member of the Moenkopi Formation (photo 64). On the gentle west slope the drainages are all shallow and most have not been able to cut through the member into the underlying Kaibab Formation, which is also quite resistant to erosion. On the steep east side nearly every consequent wash has cut relatively straight canyons into the Kaibab. They flow perpendicular to the

Photo 61. Pipe in the Winsor Member of the Carmel Formation at Shepherd Point in northern Paria Region.

Photo 62. Pipe in the Gunsight Butte Member of the Entrada Sandstone at Kodachrome Basin State Reserve. Some of the pipes have been recemented and are more resistant to erosion than the host formations. There are at least 60 pipes in and around the reserve.

Photo 63. The Moenkopi Formation is extremely sensitive to unequal loading of sediments. Nearly every small canyon south of Pilot Ridge and Calico Peak shows the unit buckling "up" to relieve the stress. Occasionally the strata from one side of the canyon have thrusted over those from the other.

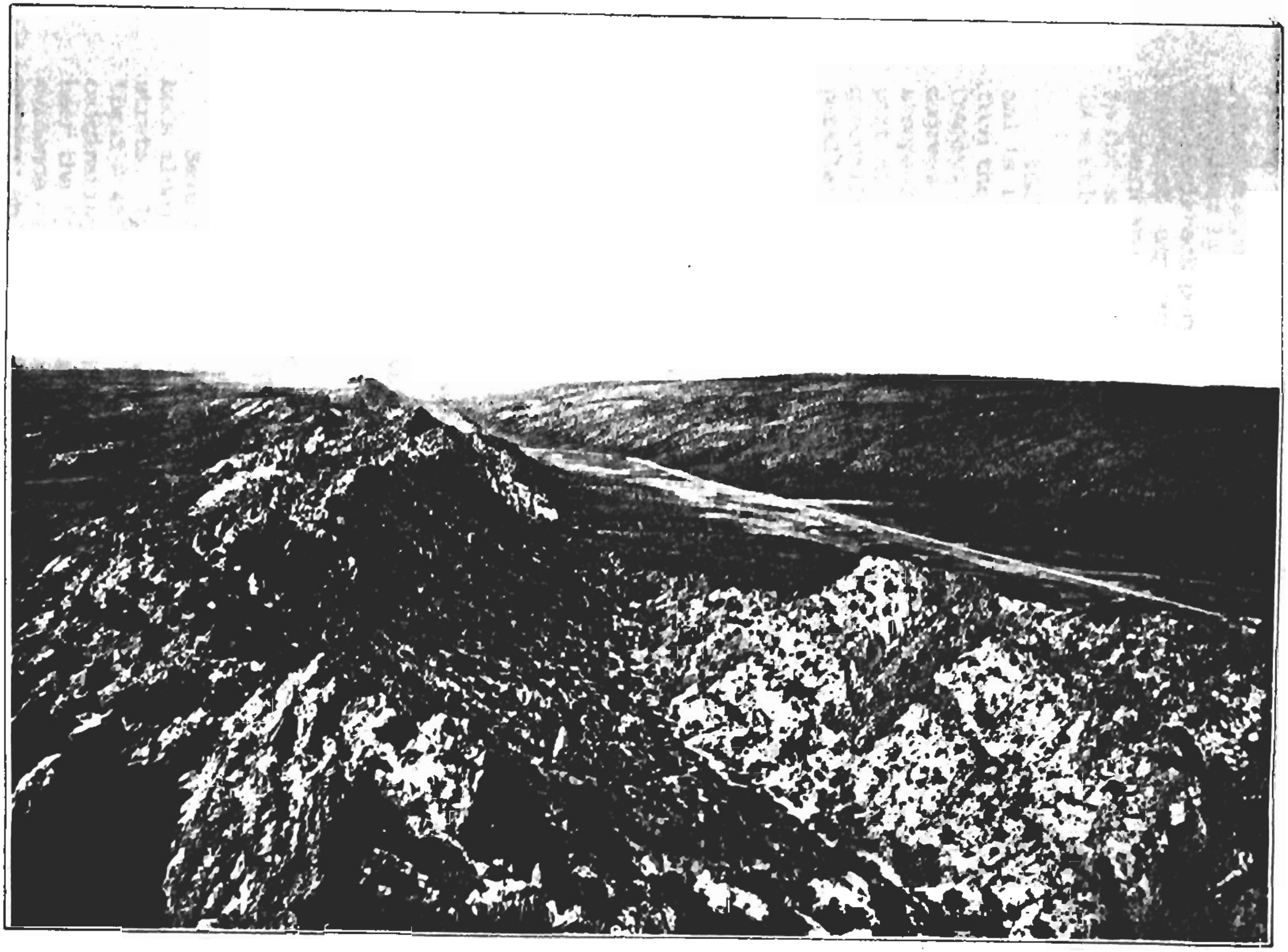


Photo 64. View southward along the East Kaibab monocline (Cockscomb) from the Hattie Green copper mine. The whaleback of Buckskin Mountain appears to the right. Fivemile Valley is the strike valley that parallels the monocline in this area.

structure contours in most cases. Some of their courses have been deflected by faults. Sand Gulch and Kaibab Gulch are washes that cross the whaleback perpendicularly (superposed washes). The latter has cut a 550 foot deep canyon through the whaleback. The exposed units on Buckskin Mountain are mostly limestone and there has been some karst activity. It is not extensive and mostly found along the faults. The surface evidence is mostly in the form of deep sinkholes.

East Kaibab monocline. This sharp flexure divides the county in half and is its most outstanding structural feature. The structure extends from the Colorado River in Arizona northward to Canaan Peak in Garfield County. The rock strata drop sharply eastward at angles ranging from 15 degrees to slightly overturned, with an average of 40 to 60 degrees in the steepest part of the flexure. The structural displacement in the southern part of Kane County is about 5,000 feet. This displacement decreases gradually northward to Butler Valley and then rapidly dies out. Its parallelism with the Sevier and Paunsaugunt faults suggests that it too could be a fault at depth. Since soft and hard units are involved the landforms consist principally of a series of hogbacks and strike valleys. There is usually one strike valley that is filled with alluvium up to 40 or 50 feet thick. The present drainages have usually cut a deep channel in this alluvium and some have reached patches of bedrock beneath. In addition there are patches of pediment along the edges high above the present drainage levels. These are especially well displayed south of Kaibab Gulch.

The principal trend of the monocline is N 20° E, but a N 35° E trending "jog" appears each 5 to 8 miles. In the vicinity of these "jogs" the structure becomes more complex. "Jogs" appear in the vicinity of Kaibab Gulch, Shurtz Gorge, Pump Springs, and at the Gut. South of Kaibab Gulch the steepest part of the fold involves the Moenkopi, Chinle, and Moenave Formations. Between Kaibab Gulch and Shurtz Gorge the steepest involvement with the fold is gradually shifted from the Kayenta-Navajo Formations to the Navajo-Carmel. North of Shurtz Gorge the steepest dips are found in a zone involving strata from the Judd Hollow Tongue to the Dakota Formation. In the next segment the sharpest flexure extends to the Tropic and lower Straight Cliffs Formation, but the Judd Hollow and Thousand Pockets Tongues remain relatively steep. From the Gut northward the steepest part of the flexure involves the Straight Cliffs and Wahweap Formations.

Several faults can usually be found paralleling the strike of the beds along the East Kaibab monocline which usually serve to cut out strata. In a few places strata are repeated. Splay faults, most of which trend N 45° W extend out from the fold in both directions, mostly originating in the vicinity of the "jogs." The number of faults increases near the "jogs" and dips change rapidly. In a few instances there is evidence of back-thrusting (photo 65). In the section between Pump Springs and the Gut there are numerous closely spaced perpendicular offsetting faults. Several faults extend into the Navajo Formation on the west side of the fold, which have recemented fault traces that are more

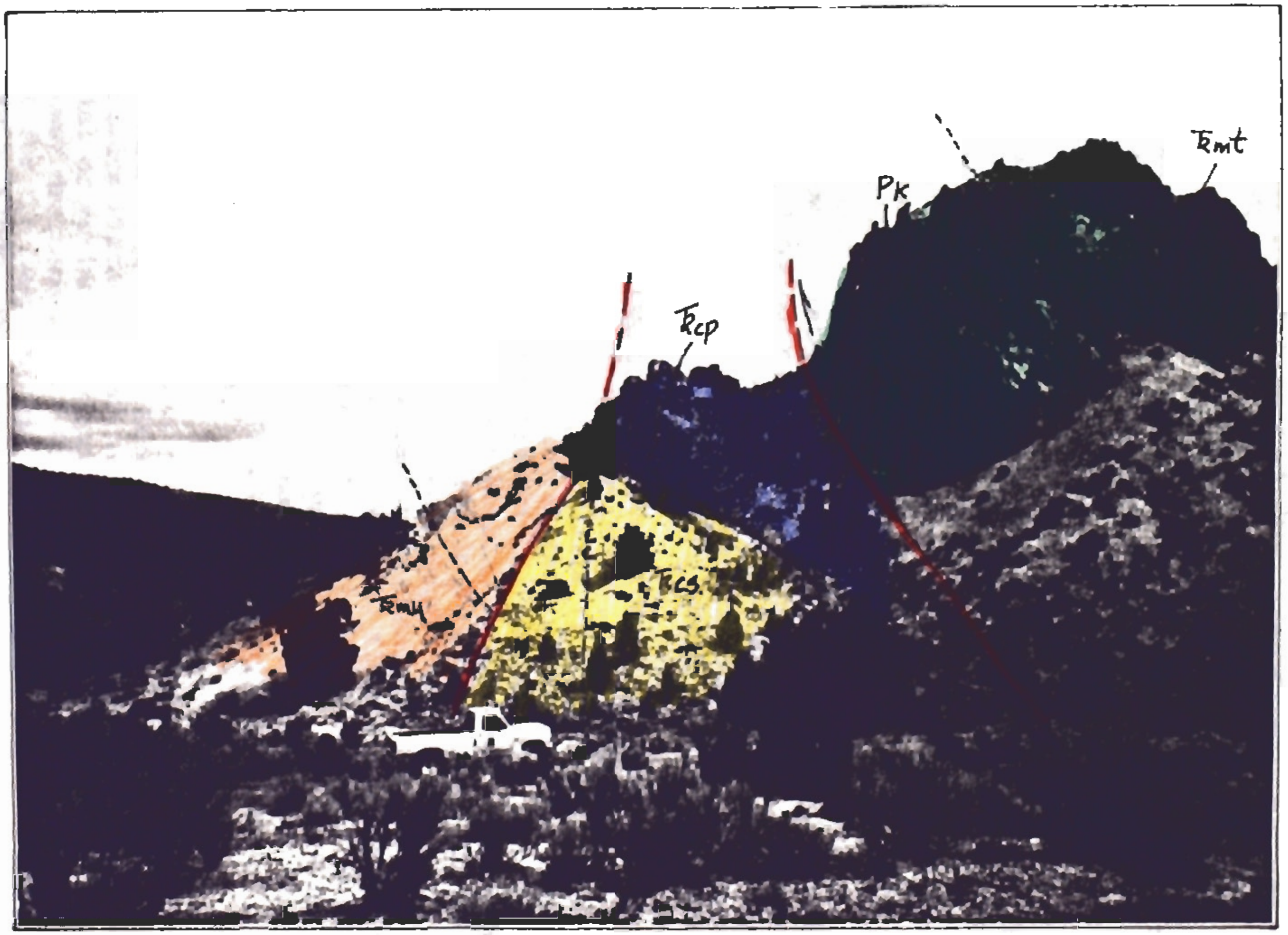


Photo 65. Complex faulting along the Cockscomb near Kaibab Gulch. Several faults subparallel the bedding along the East Kaibab monocline and cut out strata or repeat strata. In this case the Kaibab Formation has backthrusted over the Triassic Chinle Formation. The dashed lines are aligned with the dip of strata. Trmu = Upper Red Member of Moenkopi Formation, Trcs = Shinarump Member of Chinle Formation, Trcp = Petrified Forest Member of Chinle Formation, Pk = Kaibab Formation, and Trmt = Timpoweap Member of Moenkopi Formation. See also figure .

resistant and form very narrow linear dike-like or wall-like ridges (photo 66).

In the central part of the monocline, notably between Shurtz Gorge and the Gut, the west side of Cottonwood Creek, which occupies the principal strike valley, consists of a steep dip slope of the Navajo Sandstone, Judd Hollow Tongue, or Thousand Pockets Tongue of the Page Sandstone. In places the relatively thinbedded Judd Hollow limestones have sheared away from the Navajo and have slid out over themselves and the Thousand Pockets Tongue near the bottom of the slope.

Eastern Kane County

It is also convenient to divide eastern Kane County into three regions. The first (Kaiparowits Region) involves the deepest part of the Kaiparowits Basin and extends from the Cockscomb (East Kaibab monocline) to the Straight Cliffs. The second is the Escalante River Region which extends from the Straight Cliffs to the Waterpocket Fold. The third region (Bullfrog Region) has the smallest area and involves that part of the county east of the Waterpocket Fold. The Kaiparowits Region includes the Kaiparowits Plateau, Clark Bench, and Glen Canyon Bench and Canyonlands physiographic subdivisions (figure 3). The Escalante River Region includes the Flats, Escalante Bench and Canyonlands, and Waterpocket Fold physiographic subdivisions. The Bullfrog Region includes only one physiographic subdivision, the Cane Springs Desert.

Kaiparowits Region. The Kaiparowits Plateau dominates the region and is areally the largest in Kane County. It is difficult of access and is bounded on all sides by steep cliffs (Tropic and Straight Cliff Formations). It is a typical plateau with two major benches built on the Drip Tank Member of the Straight Cliffs formation and on the hard sandstones at the top of the Wahweap Formation. Deep canyons have been cut into the plateau by the principal drainages and their tributaries: Wahweap Creek, Last Chance Creek, Rogers Canyon Wash, and Left Hand Collet Canyon Wash. All but the last named drainage flow south toward the Colorado River. Left Hand Collet Wash flows easterly to the Escalante River. The east boundary of the Kaiparowits Plateau is marked by the famous Straight Cliffs or Fiftymile Mountain. In Kane County this line of cliffs is unbroken from Left Hand Collet Canyon (near the Garfield County line) to Navajo Point (just north of the Colorado River), a distance of about 35 miles (photo 4).

The Clark Bench physiographic subdivision lies between the East Kaibab monocline and the Echo monocline south of the western part of the Kaiparowits Plateau. Much of the bench area is covered by Quaternary alluvial or eolian sand deposits. These deposits even fill in the shallower drainage ways. In most places canyons are not conspicuous, except for the deep canyons of Kaibab Gulch and the Paria River cutting the Navajo Sandstone.

Photo 66. Fault line in the Navajo Sandstone near the Cockscomb expressed as a "wall." Fault shattered sandstone was recemented and hardened to become more resistant than the normal bedrock that stand in relief as "walls". Calico Peak quadrangle.

The Glen Canyon Bench and Canyonlands physiographic subdivision differs from Clark Bench in that almost every drainage cuts a deep canyon. The most important benches (Grand Bench, Sit Down Bench) are developed on the Morrison Formation which is missing in the Clark Bench subdivision. Mesas and buttes are common in the Glen Canyon Bench and Canyonlands area.

Structurally the Kaiparowits Region is a gently warped table land. Anticlinal and synclinal axes alternate each one to six miles and dips range to about 7 degrees. Most of the axes trend northerly or northwesterly and most plunge northerly. A few have steeper limbs and have been called monoclines. The Echo monocline forms the boundary between the Clark Bench and Glen Canyon Bench and Canyonlands subdivisions and is found just west of Big Water (Glen Canyon City). It is the limb between the Tommy Canyon-Cedar Mountain anticline (west) and the Wahweap syncline (east). It is steepest near the Arizona border where the structural relief between the fold axes approaches 1500 feet (across 3 miles). Several subparalleling short faults are present in the area of steepest flexure. The Dutton monocline extends into Kane County from the north between the Upper Valley anticline and the Table Cliff-Last Chance syncline. The structural relief at the county line is over 2000 feet, but the monocline diminishes into a gentle limb 8 or 9 miles to the south. The Grand Bench monocline is a local steepening between the Rock Creek anticline and the Glen Canyon syncline and is located in the southeast part of the region. The dips on each of these monoclines increases to a maximum of 20 degrees. Faults are not common or are short and of relatively small displacement. More have been mapped in the southern part of the region.

Escalante River Region. This region lies between the Straight Cliffs on the west to the Waterpocket Fold on the east. The principal drainage is the Escalante River which has cut a deep canyon into the exposed sandstones. It flows into the Colorado River which forms the south boundary of the region. The Colorado River has also cut a deep canyon (now inundated by Lake Powell). The rivers have meanders incised into the rock indicating superposition. In the central part of the region (Escalante Bench and Canyonlands) and the Waterpocket Fold, surfaces are dominated by bare bedrock with infilled scattered hollows of sand. Along the west margin flats or benches have developed consisting of pediments of sand and gravel. These have developed on the Entrada and Carmel Formations. Below the Straight Cliffs a line of lower cliffs built on the Morrison Formation is present. The bench (Fiftymile Bench) between the two sets of cliffs is mainly covered with colluvium and landslide debris. Here and there windows of the underlying Tropic Shale or Dakota Formation can be noticed. The bench is a very rugged boulder-strewn area. In places the mass wasting deposits have flowed (debris flows) over the lower cliff to the flats below. These debris flows are presently mostly inactive and undergoing erosion. The importance of rainfall in the present erosional process is evident from the numerous damoisselles that have developed on the debris flows.

Structurally the western edge of the region is similar to that of the Kaiparowits Plateau. Several closely spaced, generally north trending fold axes with gentle flanks are present. These die out easterly as the strata gently rise to the axis of the north trending, south plunging Circle Cliffs anticline (photo 13), the steep easterly limb of which is the Waterpocket Fold. Dips on the gentle limb of the Circle Cliffs anticline rarely exceed 4 degrees. The dips on the Waterpocket Fold in Kane County are not overly steep, the fold diminishing southward. The dips rarely exceed 15 degrees. Faulting is not significant in the Escalante Reiver Region, most are short and of small displacement. The most significant faulting is located along the Waterpocket Fold just north of the Colorado River. The downthrown blocks are easterly, as is the structural displacement of the fold. The displacements are not great, but the belt of joints and faults is at least 12 miles long.

Bullfrog Region. This region is partly inundated by Lake Powell. The remainder consists of rough bare rock surfaces, gravel or sand-capped mesas and buttes, and large low sandy areas. Cliffs are built on the Navajo, Entgrada, and Morrison Formations. Northwest trending and plunging fold axes extend into the region from the south. The most prominent fold is the Rock Spring syncline which subparallels Halls Creek Bay. One fault zone is present to the south that trends east-west (T 39 S) and extends from the Waterpocket Fold faults across the Colorado River into San Juan County. The displacements affect only the Navajo Sandstone and are small.

ECONOMIC GEOLOGY:

A summary of the commodities and values produced in Kane County thus far and the history of mining development has been given on the initial pages of this report. Table 1 lists the commodities and their values in tabular form and figure 26 graphically describes their importance.

Currently there are no completely active mining, quarrying, or extractive operations in Kane County. Sand and gravel pits operate intermittently, but usually produce each year. Leases on coal, petroleum, and gem commodities are kept current as are mining claims for uranium, copper, silver, and other metals. Gem materials are mined according to demand. The material is intensively mined for a short period of time and stockpiled until inventories diminish. Each cycle may take several years. New areas are constantly being prospected. Coal has not been mined since 1972 and metals have not been shipped since shortly after World War II. Even then metal ores shipped from Kane County have not exceeded test lot sizes.

Coal

Resources, production, and history. Kane County's greatest potential for mining activity is coal. Parts of three coal fields are found within its boundaries and its tonnage potential (original coal resources) is higher than for any county in Utah. Kane County holds 28.9 percent of the Utah resource, with Carbon, Emery, and Garfield Counties following with 20.9, 18.0, and 15.2 percent respectively (Doelling 1972b, p. 553)(figure 27). The estimate of in place coal, in beds more than 4 feet in thickness, is more than 7 billion short tons. In resources estimates of this type it is presumed that about 1/3d can be recovered as indicated by the experience of mined out areas in Utah. Although the results of most coal drilling in the county is still being held confidential, indications are that the above estimate is reasonably sure and may be larger.

Coal production figures for Kane County that accompany the large resource are extremely low. Through 1986 about 90,000 short tons have been mined. The last regularly producing mine closed in 1970 (Alton mine). In 1971 an experimental mine (Warm Creek mine) produced 12,000 tons to test mining cost estimates and was shut down. Kane County coal deposits are distant from cheap rail transportation, making them non-competitive for transport to distant markets. The local market has always been small, the permanent county population limited to a few thousand people.

Several mines were opened as wagon mines around Glendale, Mt. Carmel, and Alton in the early 1900s. Some closed after only one or two years as a few were able to supply the market. Some were opened in fault blocks adjacent to the Sevier fault and experienced structural problems or quickly ran out of minable coal. Prospecting was directed westward as far as Meadow Creek, a haul of about 10 miles to Mt. Carmel and 26 miles to Kanab. The King Cannel mine opened in 1907, and being quite distant from the market was able to struggle along on the basis of its cannel coal, a

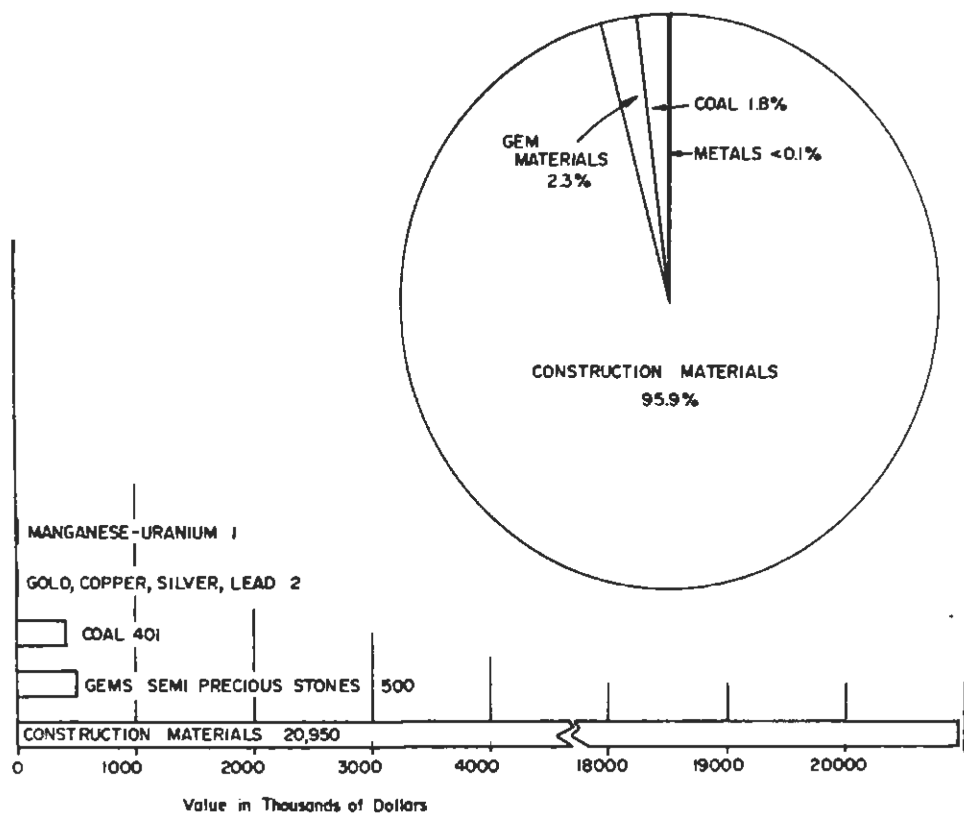


Fig. 26

Values of the principal mineral commodities produced in Kane County through 1985
Pie chart indicates percentage of total value.

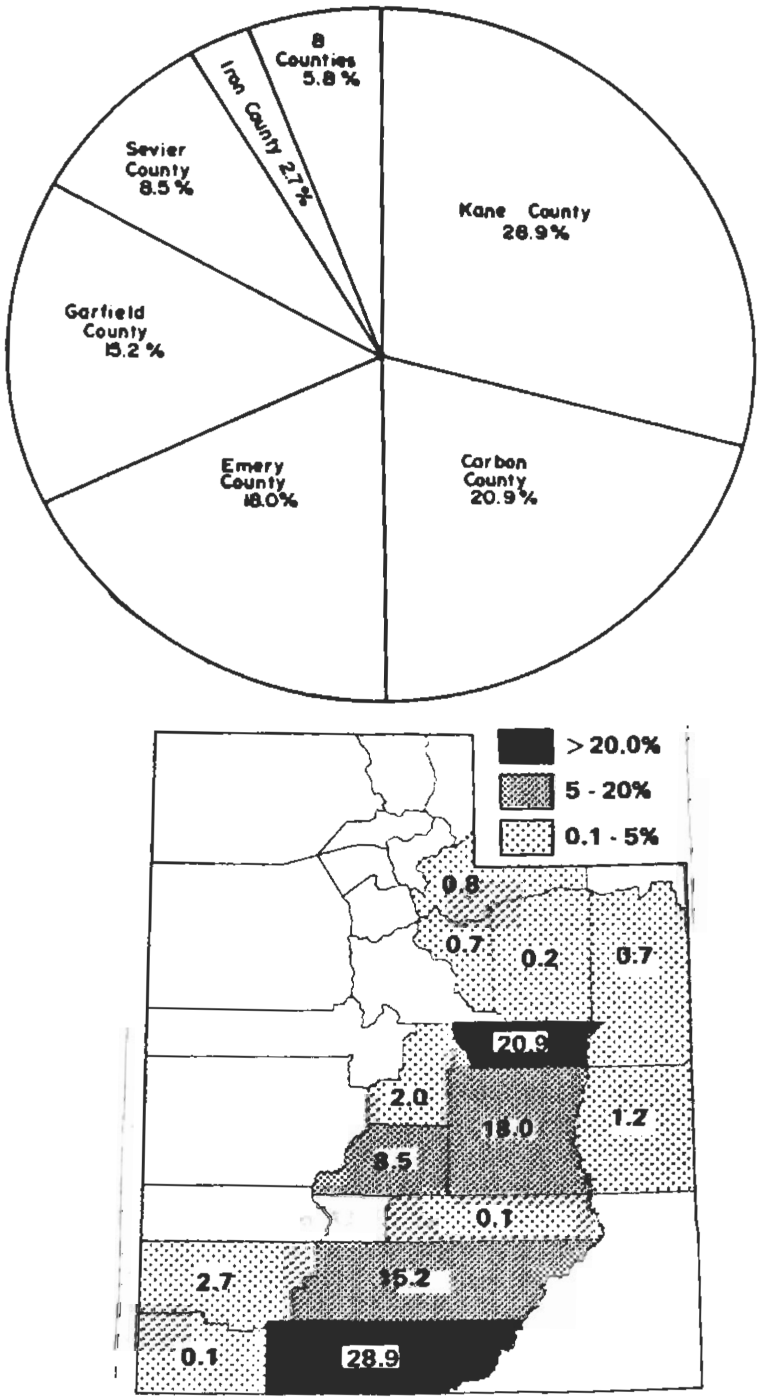


Figure 27. Distribution of Utah's coal resources, by county.

specialty fireplace fuel. Production from any of these mines rarely exceed a few hundred tons annually. By 1930 roads and trucks had improved to the extent that hauls within the county added little to the cost. All the coal could be supplied by one efficient mine, and that was the Smirl mine near Alton. The depression speeded up the demise of any remaining competitors.

Coal was the available fuel during World War II and a few additional mines were opened in outlying areas for local ranchers in order to save gasoline. These soon closed after the war. Low petroleum prices in the 1950s and 1960s caused many Kane County coal users to switch to oil and propane for heating. Eventually even the school system switched. However, some local users continued to enjoy burning coal in their fireplaces. Nevertheless, production dropped and the Alton mine, now the only producer, worked only a few months of the year. Shortly before 1970, new stringent mine safety regulations were imposed on the U. S. coal mining industry, which the "shoestring" Alton operation could not afford, and its entryway was closed for good.

In the 1960s, energy companies, foreseeing shortages in petroleum fuels, instigated by a steady increase in U. S. per capita consumption, investigated, leased, and drilled Kane County coal lands and proved many hundreds of millions of tons of minable coal reserve, even large tonnages of surface minable coal. Attempts to open viable mines were thwarted by (1) pressure by environmentalist groups to keep the rugged lands of eastern Kane County preserved in their natural pristine state, (2) the fear that an electric generating plant, that would be needed to burn the coal, would deter from the air quality and visibility on Lake Powell, (3) the fear that the view from Bryce Canyon National Park would be marred by a deterioration of air quality (dust) and by the visibility of the strip-mining operations, (4) by the predicted high costs (due to natural barriers) to transport coal out of the area to market, and (5) by the reduction in per capita energy consumption in the late 1970s and early 1980s brought on by the 1973 Arab oil embargo. In 1986 the world was experiencing a glut in petroleum; the cheap price of oil damaging the coal market everywhere.

Seams of coal thick enough to be mined commercially occur in the Cretaceous Dakota and Straight Cliffs Formations of Kane County. Occasional stringers and lenses of coal have been observed in Triassic and Jurassic rocks as well, but are non-commercial occurrences. The Triassic Chinle Formation contains a thin coal bed (up to 14 inches thick) in a deposit of several hundred acres, and is probably the only bed occurrence of coal in non-Cretaceous units (photo 67). This Chinle coal bed has a low heat value relating to a lignite B coal rank. Three surface samples were analyzed and are related in table 9. Some of the high moisture content would be expected to diminish if a deep sample could be obtained. Considering the areal extent of the coal bed and the degree to which it has been eroded, this would probably be impossible.

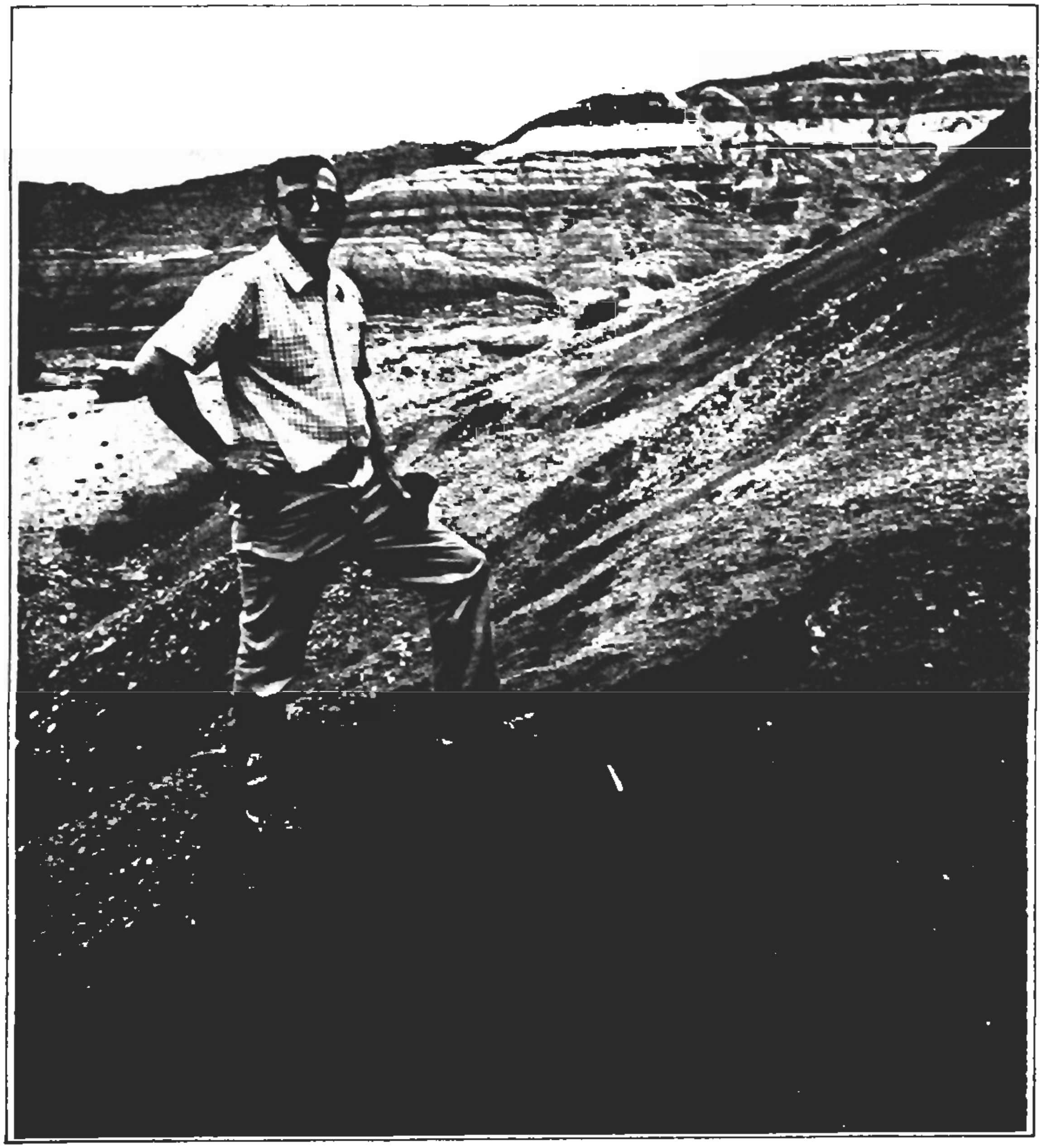


Photo 67. Thin bed of coal in the Chinle Formation near Paria. Palynological specimens found in the coal date it as Carnian.

Table 9. Analyses of Chinle coal seam, NENE Sec 13, T 41 S, R 1 W.

Proximate Analysis	Sample 1	Sample 2	Sample 3
Moisture	36.4%	31.0%	30.9%
Volatile matter	28.7	41.5	40.0
Fixed carbon	25.2	13.7	15.2
Ash	9.8	13.8	13.8
Btu/lb.	4,951	4,884	4,767
Sulfur	4.2	2.6	2.7

Parts of three coal fields extend into Kane County: Kaiparowits Plateau coal field, Alton coal field, and Kolob coal field. Straight Cliffs Formation coal beds are the most important in the Kaiparowits Plateau coal field and the Dakota Formation coal beds are most important in the Alton and Kolob coal fields (figure 28).

Kaiparowits Plateau Coal Field. The area of the coal field coincides with that of the Kaiparowits Plateau. It is limited by the edges of the Cretaceous outcrops, i.e., the base of the lowermost coal is the Dakota Formation. The plateau is about 54 miles across east-west to the south and 30 miles east-west along the Garfield County line. It has a maximum length of 33 miles north-south in Kane County. Three units contain coal zones: the middle member of the Dakota Formation and the Smoky Hollow and John Henry Members of the Straight Cliffs Formation (figure 29).

The coal beds in the Dakota Formation are mostly thin in the Kaiparowits Plateau. There are usually 2 or 3 horizons or beds of coal, one near the base, one in the middle, and another at the top of the middle member. At local places a fourth bed is occasionally seen between the lower and middle beds. The most persistent and thickest is the upper seam, the least persistent is the middle seam(s). The thickness of coal beds ranges to 5.6 feet and in most places there is at least one bed 1 foot or more in thickness. In a few places all beds are missing. The thickest known bed is 5.6 feet at the Bryce Canyon Coal & Coke mine, SWNE Sec. 21, T 42 S, R 1 W. This bed quickly thins laterally to less than 3 feet along outcrop from the mine. Other places where beds reach 4 feet are in Sec. 4, T 38 S, R 1 W, near Wiggler Wash and in Sec. 25, T 41 S, R 8 E, near Fiftymile Point.

The coal beds are encased in mudstones and sandstones. The mudstones are often carbonaceous or coaly, especially above or below the coal beds, the black color giving a false impression that very thick beds are present. At most locations around the Kaiparowits Plateau the Dakota middle member coal beds dip gently into the Kaiparowits Basin, rarely exceeding 7 or 8 degrees. Along the Cockscomb (East Kaibab monocline), however, dips may reach 70 degrees. Occasional faults cut the Dakota Formation at wide intervals except along the northern part of the Cockscomb, where transverse faults occur at closely spaced intervals (especially in Ts 39 and 40 S).

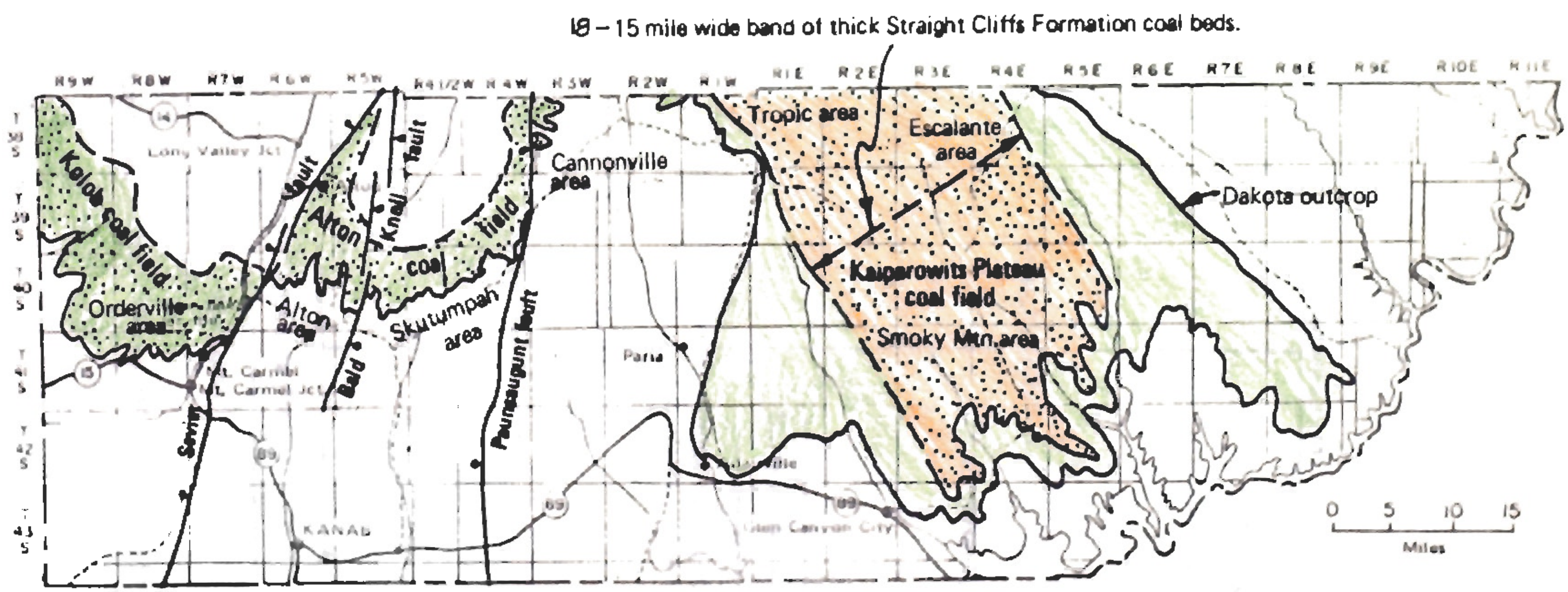


Figure 28. Kane County coal fields and areas

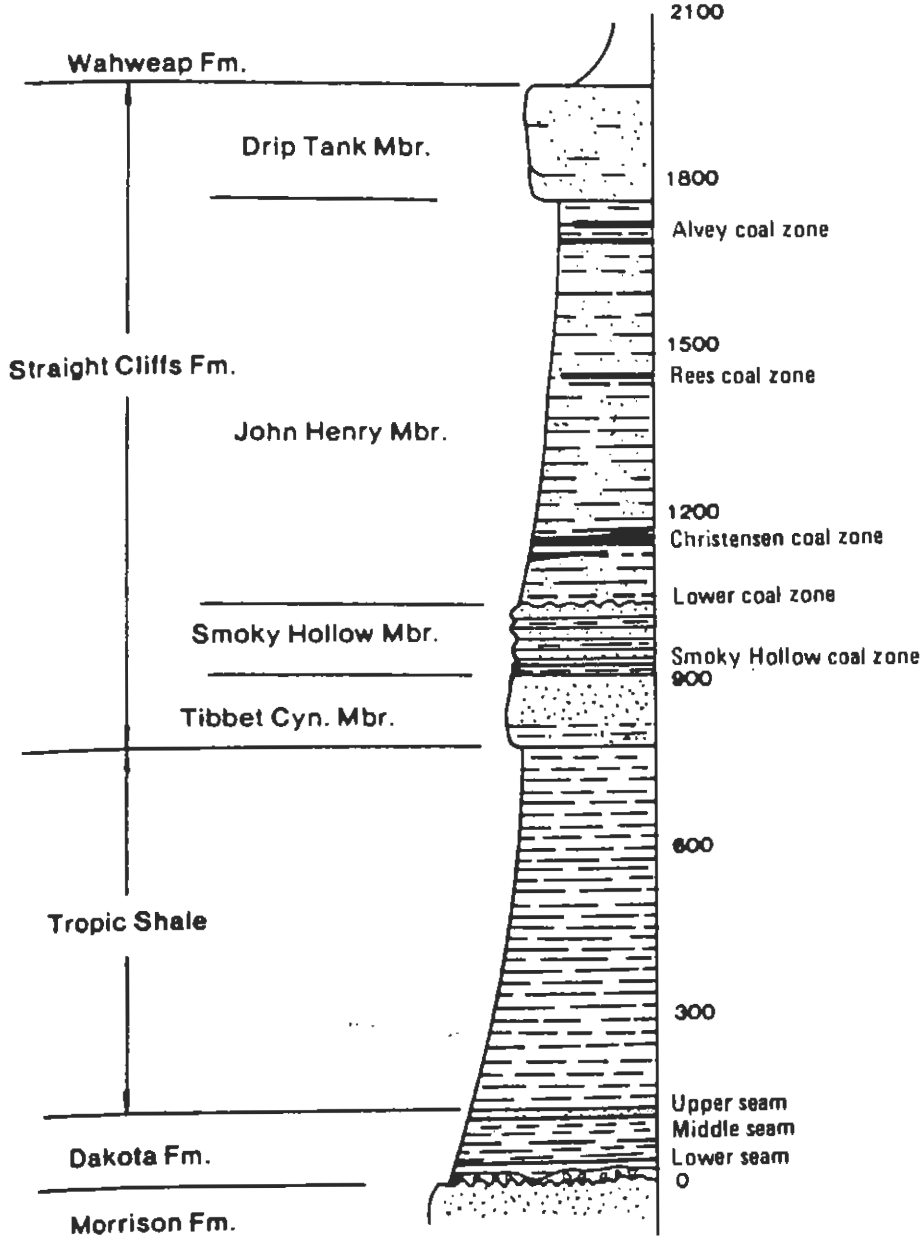


Figure 29. Coal zones of the Kaiparowits Plateau coal field.

As far as is known only two mines have been opened in the Dakota Formation coal seams of the Kaiparowits Plateau coal field. The first is the aforementioned Bryce Canyon Coal & Coke Co. mine, SWNE Sec. 21, T 42 S, R 1 W at the southwest corner of the plateau. The other is the "Dakota" mine, NESW Sec 7, T 43 S, R 4 E, in Crosby Canyon, a tributary of Warm Creek. The coal bed mined is less than 2 feet thick. Five adits were opened and about 456 tons of coal were removed (volumetrically calculated). Production from the Bryce Canyon Coal & Coke mine is unknown, but presumed to be no more than 1,000 tons.

The Smoky Hollow coal zone is found at the base of the Smoky Hollow Member of the Straight Cliffs Formation and is as much as 30 feet thick. It contains several thin, rather lenticular coal beds generally less than 2 feet thick. In a few places (Wahweap and Warm Creek synclines) the coal beds reach nearly to 5 feet in thickness. Most Smoky Hollow coal zone beds are replete with splits and partings. The whole coal zone is missing locally, especially over the anticlines and along the northern portion of the Straight Cliffs (Fiftymile Mountain). The remainder of the zone consists of carbonaceous mudstone, bentonitic and gray mudstones, and yellow brown sandstone. As far as is known there has been no development of Smoky Hollow coals.

The John Henry Member contains the thick and commercial coal beds of the Kaiparowits Plateau coal field. Four coal zones have been identified and three, possibly all four, contain commercial coals. The thickest beds often exceed 20 feet, Peterson (1969a, p. 68) reports one measuring 29.6 feet in the Christensen zone on the northeast side of the Last Chance anticline. In ascending order the John Henry Member is subdivided into a lower coal zone, lower barren zone, Christensen-Henderson coal zone, middle barren zone, Rees coal zone, upper barren zone, and Alvey coal zone. The thicknesses of both barren and coal zones vary greatly from one part of the plateau to another so that it may be difficult to separate them. To the east the coal zones pinch out against marine littoral sandstone tongues so that no thick coals persist under most of Fiftymile Mountain. The coal zones also thin and disappear southwestward. Therefore the important part of the coal field is a 15 to 18 mile wide band that trends about N 35° E through the center of the plateau. In this 18 mile wide band the coals are thickest in the synclines and often pinch out over the anticlines.

The lower coal zone beds of the John Henry Member are usually thin, but are best developed in the synclines. Peterson (1969a, p. 215) reports that the thickest bed found in the lower coal zone is 12.6 feet on the northeast side of the Last Chance syncline in the Smoky Mountain area. The coal zone is probably not present in the Tropic area. In the Escalante area the zone is lenticular and not everywhere present. When coal beds are found they are generally less than 2 feet thick.

The Christensen coal zone contains the thickes and most continuous coal beds in Kane County. The coal zone is the most extensive and is probably valuable throughout the 18 mile wide band. In the Tropic area the zone is known as the Henderson coal zone. It may contain up to four thick coal beds and in the synclinal areas it is rare to find less than two. Individual coal beds within the zone are extensive. The coal beds vary in thickness, acquire partings and splits and divide into benches. The average Kaiparowits Plateau coal bed may be continuously minable over 4 to 5 square miles, beyond which the coal either becomes too thin or develops too many partings (too much ash). In many places an overlying or underlying coal improves and a new mine must be developed or rock must be mined to make a connecting link to continue an established mine (figure 30). The seams often have little separation, some will need to be sacrificed because of mine safety considerations. The roof or floor rock may be too weak to support itself after removal of the coal. As the extent of a commercial coal bed covers an area of 4 to 5 square miles, the average good roof or floor rock is usually limited to the same areal extent, but in most cases will not coincide with that of the "good" coal. With proper mining practices, however, all of these problems can be overcome, and the coal can be produced. To the east, the Christensen coal beds rapidly thin and pinch out along the east edge of the basin. In the Escalante area, at the confluence of Trail Canyon and Left Hand Collet Canyon (photo 68), there are three coal beds in the zone, the lower two each over 7 feet thick separated by about 2 feet of rock, the other over 5 feet thick and separated from the others by 8 to 15 feet of rock (figure 31). Within a mile and a half northeastward, along the canyon walls, the coal zone thins and disappears.

The Christensen coals achieve their greatest development in the Smoky Mountain area. As previously indicated the thickest sections occur in the synclines. The coal beds are extensively burned along the outcrop and the red color of coal bloom is everywhere evident. The coal may be completely burned out at the ends of points and salients where fracturing has allowed the oxidation to continue far behind the outcrop. This is especially true in the southeastern part of the area, notably along the Rees anticline and Croton syncline. The most extensively burned area is known as the Burning Hills. Indeed some coal bed fires still continue. Most attempts at putting them out have failed. The least burning has occurred where most of the upper portion of the Straight Cliffs Formation has not been intensively dissected by erosion, mostly along the west side of the 18 mile band.

Toward the southwest the Christensen coal zone eventually thins, its coal beds splitting, increasing in ash, and finally pinching out altogether. From the Echo monocline westward only thin or discontinuous seams are to be expected in the coal zone. About 3 mines and a few prospects have been developed in the Christensen coal zone in Kane County, all in the Smoky Mountain area. The total tonnage produced is probably less than 14,000 short tons, most having come from the Warm Creek experimental mine (about 12,000 tons). All are presently inactive or abandoned (table 10).

The coal beds in the Henderson coal zone of the Tropic area appear in outcrop along the Cockscomb (East Kaibab monocline) in Ts 38 and 39. A measured section of the zone is shown in figure 31 and is found along the road from Grosvenor Arch through the Gut to the Kaiparowits Plateau. Nine

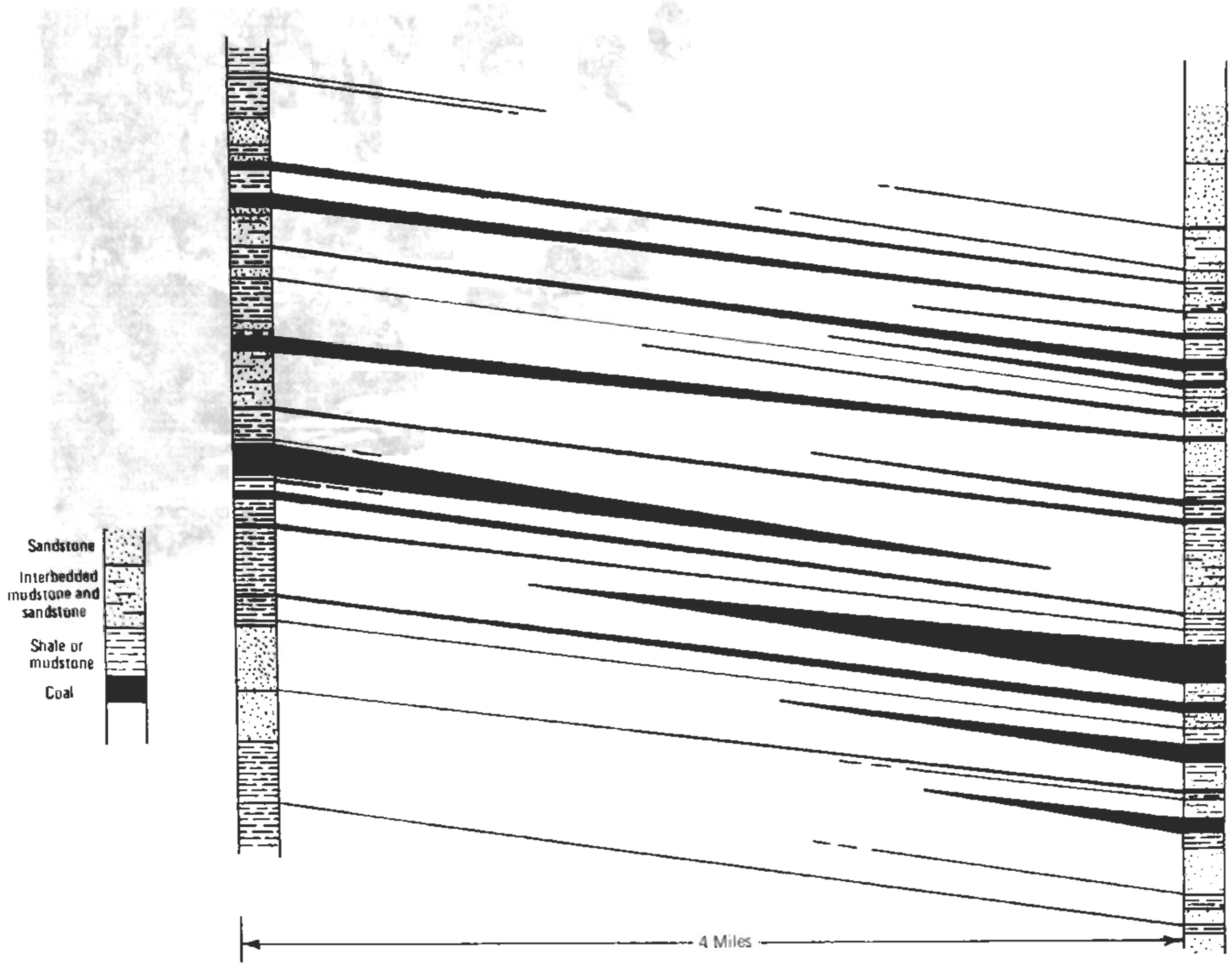


Figure 30 Diagram illustrating correlations between drillholes and the lenticular nature of coal beds within coal zones, Smoky Mountain area, Kaiparowits Plateau coal field. Vertical scale: 1 inch = 100 feet. The thicker coals of the Smoky Mountain area *are principally in* the Christensen coal zone.

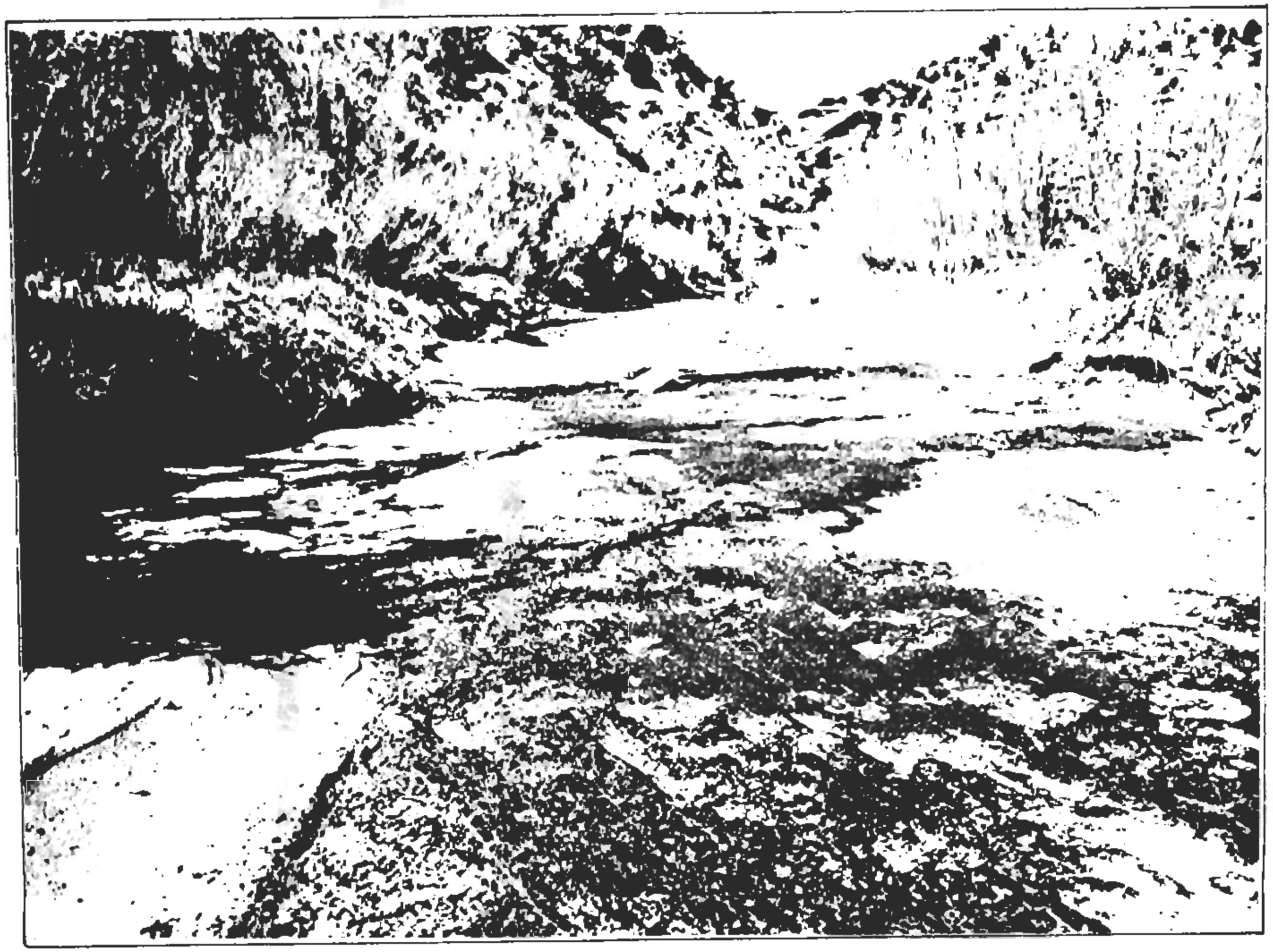


Photo 68. Right Hand Collet Wash above Trail Canyon. The floor of the wash is paved with coal from the Christensen zone in the Straight Cliffs Formation.

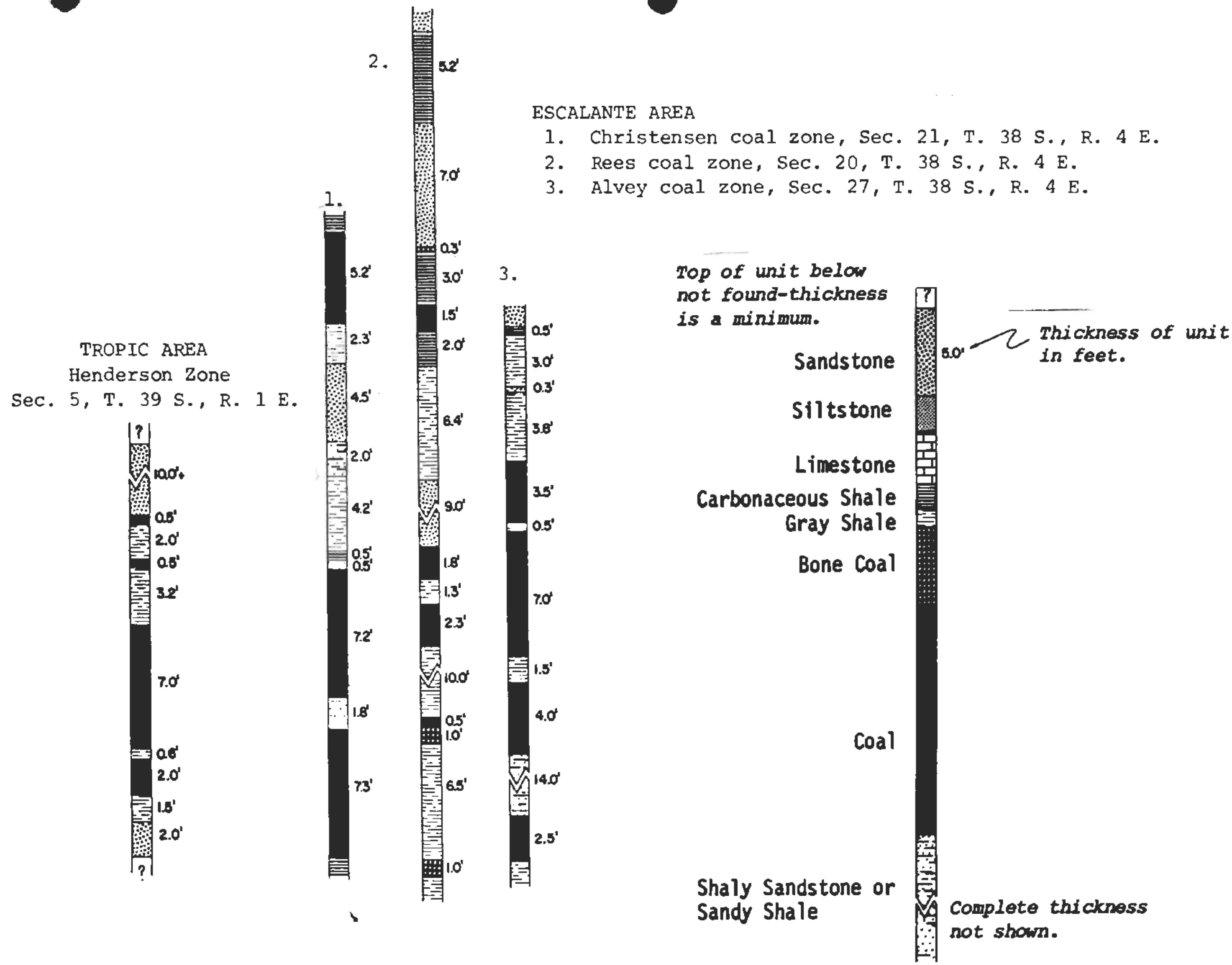


Figure 31 Stratigraphic measured sections of coal zones in the Tropic and Escalante areas, *Kaiparowits Plateau coal field in Kane County.*

Table 10. List of mines in the Straight Cliffs Formation, Kaiparowits Plateau coal field, Kane County, Utah.

Mine	Location
Warm Creek experimental mine	N 1/2 N1/2, Sec 36, T 41 S, R 3 E
Spencer No. 1 mine	SWSW Sec 3, T 42 S, R 3 E
Spencer No. 2 mine	SWSW Sec 3, T 42 S, R 3 E
"John Henry" prospect	NWSW Sec 12, T 42 S, R 3 E
Prospect	NENE Sec 33, T 40 S, R 4 E

feet coal are exposed, but split in the lower portion. To the south the bed thins, to the north it is mostly 2 to 5 feet thick, often contaminated with several thin partings of shale or bone. The bed dips moderately to steeply, increasing southward. At the 9 foot location the dip is about 17 degrees toward the basin. Although the outcrop dip is not favorable toward coal development, the dip quickly diminishes eastward and coal thicknesses are expected to improve.

The Rees coal zone is present in the east part of the 18 mile wide band. The zone is absent in the Tropic area. In the Escalante area the zone is thin and hard to define. It is found in the middle of the John Henry Member between two thick sandy barren zones. The coal beds of the zone are generally thin, occasionally reaching 3 feet. A sample measurement of the Rees coal zone in the Escalante area is given in figure 31. The best zone development is in the Smoky Mountain area. There the intervening barren zone becomes very thin so that the zone nearly merges with the Christensen zone, if indeed the zone is continuous between the two areas. Peterson (1969a, p. 216) has noted that there are as many as three beds 4 or more feet thick, with the thickest measured being 9.5 feet. He limits the commercial possibilities of the zone to the Last Chance syncline.

Commercial coal beds in the Alvey coal zone are limited to the northeast part of the basin, in the Escalante area. There the zone is reasonably wide and stretches across the entire outcrop width of the John Henry Member. A 4 to 8 foot coal bed is usually to be expected at most locations in the Kane County part of the area (figure 31). The zone persists a considerable distance to the south into the Smoky Mountain area, but is limited to the very eastern margin of the 18 mile wide band. The thickest coal bed in the zone is about 12 feet thick.

The total overburden over the Christensen coal zone in the Kaiparowits Basin does not exceed 3000 feet in Kane County. It approaches 3000 feet under the Table Cliff syncline in T 38 S, R 1 E and part of T 38 S, R 2 E. Mining in the Kaiparowits Plateau will generally be underground because the cliffs supported by the Drip Tank Member erode by cliff retreat, not allowing larger bench areas to develop on the John Henry Member. The bench formed at the top of the Drip Tank Member is usually 400 to 700 feet above the lowest bed in the Christensen coal zone. Augering and rim-stripping may be possible in some areas.

Alton coal field. The Alton coal field is based on Dakota Formation coal beds and corresponds closely to the Podunk Terrace with the coal beds exposed along the Gray Cliffs. Some coal is also found in the Straight Cliffs Formation, but the seams are very thin and discontinuous. Most of the field is found in Kane County, but part extends into Garfield County. A convenient eastern boundary is the north-south trending Tropic syncline, which has its axis about 1 1/2 miles east of the Paria River in Garfield County. At that location the coals are thin and subcommercial. From that line westward the Dakota coals gradually thicken.

In the Alton coal field the Dakota Formation is 140 to 240 feet thick, generally thickening toward the west. There are two coal zones in the Dakota, one near the base and one near the top. These are known as the Bald Knoll and Smirl zones respectively , and are named for the principal mines which operated in them.

Three convenient area subdivisions can be made on the basis of location, geology, and geography: Cannonville, Skutumpah, and Alton. The Cannonville coal area is that part of the Alton coal field lying between the Tropic synclinal axis and the Paunsaugunt fault. Most of the Cannonville area is in Garfield County, the Kane County portion consists of Horse Mountain and two other benches to the north. The displacement on the Paunsaugunt fault is about 500 feet near Bryce Point and diminishes to the south. The coal outcrops and the Dakota Formation exposures are projected southward well into Kane County on the west side of the fault.

The remainder of the coal field lies between the Paunsaugunt fault and the Sevier fault, the latter structure making an effective west boundary with its 1000 to 2000 foot displacement. The outcrop length between the two faults is about 20 miles. Structurally the beds dip 1-3 degrees into a northward plunging Paunsaugunt Plateau syncline. Northward the overlying formations add overburden and the 3,000 foot cover line is roughly coincident with the base of the Claron Formation. The band between the coal outcrops and the cover line averages 5 to 6 miles in width.

Another important north-south trending fault or fault zone cuts the strata one third of the distance from the Sevier fault to the Paunsaugunt fault. This is the Bald Knoll fault which has a maximum displacement of about 500 feet. It makes an effective boundary between the Alton area on the west and the Skutumpah area on the east.

In the Alton area both coal zones are well developed. The Smirl zone coal bed averages 12 feet in most places; but averages 7.5 feet in the Sevier fault zone area near Glendale and 9.3 feet to the southwest against the Bald Knoll fault. The thickest exposure is about 18 feet. The Bald Knoll zone coal consists of several closely spaced seams or one that is badly split. The coal averages 5.5 feet in thickness in which 1.2 feet of waste would have to be mined. Near the Sevier fault zone the Bald Knoll coal thins and becomes subcommercial. The thickest known exposure of the Bald Knoll coal is at the Bald Knoll mine and is 18 feet. At the mine the bed contains at least one split, a foot in thickness. The mine is thought to have produced little coal, possibly because of the irregular quality brought on by the lateral addition of partings and splits.

Almost all of the coal production recorded for the Alton coal field has come from the Alton area and two mines have produced the bulk (Smirl and Alton mines)(table 11). The total production for the field, and hence the area, is no more than 50,000 short tons.

Table 11. Mines and prospects of the Alton area, Alton coal field in Kane County.

Mine	Location	Coal zone
Alton mine	NE Sec 24, T 39 S, R 6 W	Smirl
Bald Knoll mine	SWSW Sec 21, T 40 S, R 5 W	Bald Knoll
Foote mine	C Sec 26, T 40 S, R 7 W	Smirl
Glendale mine	NENW Sec 24, T 40 S, R 7 W	Smirl
Johnson mine	SENE Sec 26, T 39 S, R 6 W	Bald Knoll
Levanger mine	NE Sec 26, T 40 S, R 7 W	Smirl
Seaman mine	NE Sec 14, T 39 S, R 6 W	Smirl
Silver mine	SWSE Sec 25, T 39 S, R 6 W	Smirl
Smirl mine	SESE Sec 13, T 39 S, R 6 W	Smirl
Prospect	SESE Sec 25, T 39 S, R 6 W	Smirl
Prospect	NWNW Sec 19, T 39 S, R 5 W	Smirl
Prospect	SW Sec 16, T 40 S, R 5 W	Bald Knoll
Prospect	SWSW Sec 5, T 40 S, R 5 W	Smirl?
Prospect	SW Sec 26, T 40 S, R 7 W	Smirl

Inasmuch as the thicker and better Smirl zone bed is near the top of the Dakota Formation and the soft overlying Tropic Shale has eroded back leaving wide benches at the top of the Dakota, some of the coal is minable by surface mining methods. The Alton area is considered one of the premier potential coal surface mine areas of Utah. Roof and floor conditions vary, but in most places the immediate roof and floor rock is shale or mudstone. Resistant sandstone ledges are sometimes found above the shales or mudstones of the Smirl zone roof and would need to be removed in a strip-mine operation. Development of the coal, other than in the mines, consists of exploratory and mine development drillholes, and several cuts to expose the coal bed.

The Skutumpah coal area is the largest areally. Both coal zones are present, but the upper is decidedly more important. The Smirl zone averages 9 feet in thickness from the Bald Knoll fault to Slide Canyon and then thins considerably. It is only 3 to 4 feet thick along the Paunsaugunt fault. More than half the measured coal sections show the immediate roof and floor material to be mudstone or shale. The Bald Knoll zone coal bed averages 4 feet in the west and 3 feet in the east half of the area. It is split in many places. It thickens again to 4 feet along the east edge of the Skutumpah area. The rocks that encase the coal in the Skutumpah area are similar to those for all Dakota Formation areas; interbedded mudstone, sandstone, with a small amount of siltstone.

An example of a drillhole log of the Dakota Formation in the Skutumpah area is given in figure 32. As in the Alton area there are several surface minable benches, although they are not as wide or extensive. There are no mines and no production is known. Development work has consisted of drilling and several surface prospecting cuts have been made to expose the coal.

The total coal area of the Cannonville area in Kane County is small, perhaps 4 square miles, located on benches between Sheep Creek and Willis Creek, and south of Willis Creek on Horse Mountain; all east of the Paunsaugunt fault. A larger area of buried coal is probably present between Bryce Canyon National Park and the fault with a width of two to three miles. The depth to the Bald Knoll zone, the more important in the Cannonville area, will be 1000 to 2500 feet.

Between Sheep Creek and Willis Creek the Bald Knoll zone coal bed (minable portion) averages 7 to 9 feet. The maximum amount of coal found in any one section is 27.8 feet, split five times with a total of 7.3 feet of waste. Some sections contain considerable bone coal. On Horse Mountain the minable coal is 7 to 10 feet thick and seems to contain a smaller amount of parting material. Several thin coal seams lie above the Bald Knoll zone, bunched together near the middle and near the top (Smirl zone) of the formation. Only a few exceed 2 feet in thickness and are quite lenticular and discontinuous. At Horse Mountain the Smirl zone coal is 3 1/2 feet thick, but the lower foot is bone. Drillhole data is available by Bowers (1977) for the Cannonville area.

<u>Kolob coal field</u>. The Kolob coal field extends westward from the Sevier fault zone and incorporates parts of Kane, Iron, and Washington Counties. The field coincides with the Kolob Plateau or Terrace. The Gray Cliff coal outcrops extend westward from Long Valley near Mt. Carmel to Clear Creek Mountain and then extend northward in the canyon of the North Fork of the Virgin River almost to the northwest corner of the county before crossing the line into Washington County. The part of the Kolob coal field that is in Kane County is known as the Orderville area.

As in the Alton coal field the important coal seams are found near the top and bottom of the Dakota Formation, which is 180 to 400 feet thick, thickening westward. Most of the development has been in the Cedar City area where facies changes show the Tropic Shale cut out be the overlying Straight Cliffs Formation (Lawrence, 1965, p. 81). There two coal zones are recognized; upper Culver and lower Culver (Averitt, 1962, p. 47-52). These zones are found near the top of the Dakota Formation not far beneath the Straight Cliffs contact. The upper Culver zone may correlate with the upper coal in the Orderville area, but direct evidence is lacking because of poor outcrops north of Zion National Park. Until such correlations are verified it is probably best to simply call the upper coal in the Orderville area as the "upper" zone and the lower coal

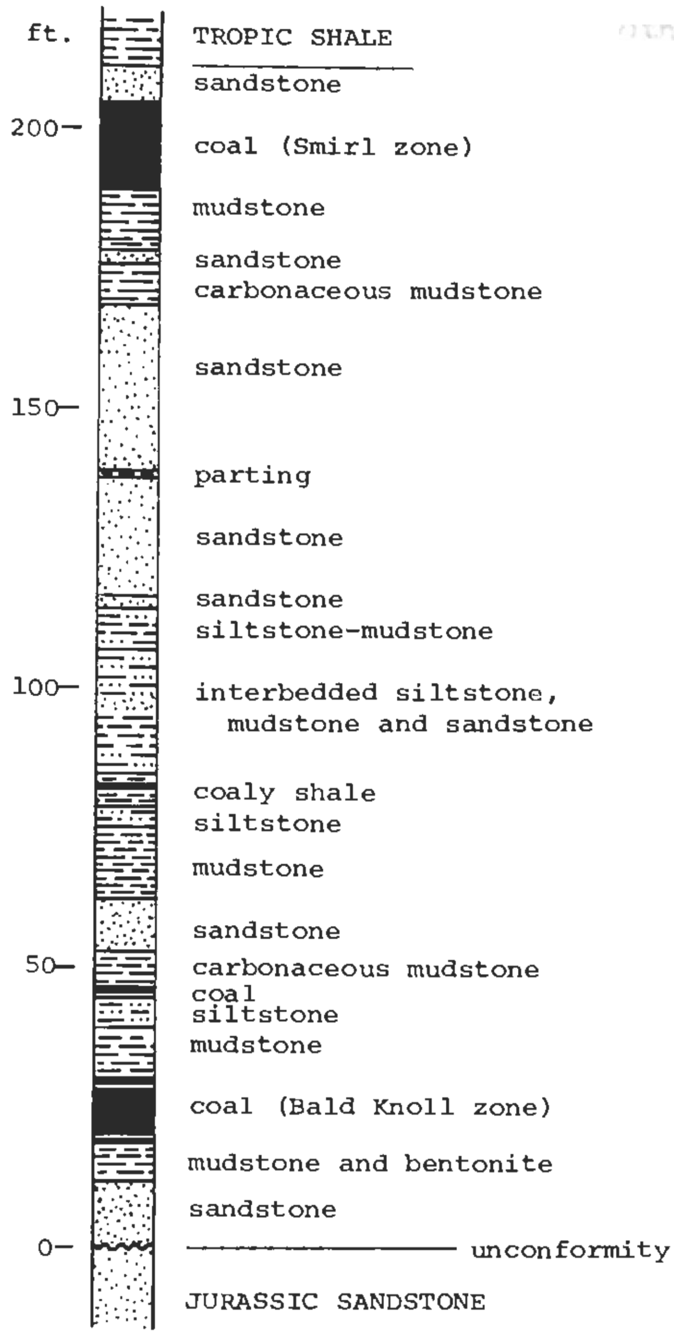


Figure 32. Representative column of Dakota Formation in the Alton coal field. Drillhole 104, NW Sec. 18, T 40 S, R 4 1/2 W; from BLM 1975 EMRIA Rept. No. 4. The Dakota Formation is about 211 feet thick at this location.

as the "lower" zone. These zones do correlate with the Smirl and Bald Knoll coal zones of the Alton coal field.

The U. S. Geological Survey drilled 14 holes on the Kolob Terrace to test the coal and these provide the most reliable information on the condition of the coal (Bowers and Strickland, 1978). Fourteen drillholes indicate an average 7.5 feet for the "upper" coal with the thickest bed intercepted at 11 feet. Eight drillholes reached the "lower" coal which averages 9.6 feet. It is present, however, in 3 to 5 benches with individual benches separated from the other by an average of 3.3 feet of rock. Usually individual benches are less than 4 feet, but locally a bed is found to 10 feet in thickness, which could be locally mined (photo 69).

At least 6 small mines have been opened in the Orderville area, all are inactive and the total production from all of them is probably less than 2,000 short tons (table 12 and photo 70). Unlike the Alton field, where much of the overlying Tropic Shale is stripped from the more resistant upper beds of the Dakota Formation, the overburden in the Orderville area build rapidly so that surface mining will not be economically feasible. Coal outcrops are poor, especially to the west where the Dakota is usually covered with colluvium and other mass wasting deposits.

Table 12. Mines and prospects of the Orderville area, Kolob coal field in Kane County.

Mine	Location	Zone
Adair mine (Meadow Brook)	SE Sec 32, T 40 S, R 8 W	"upper"
Cannel King mine	NE Sec 26, T 39 S, R 9 W	"upper"
Kroft mine	NW Sec 16, T 41 S, R 7 W	"upper"
Meeks-Carroll mine	NW Sec 5, T 41 S, R 7 W	"upper"
Mt. Carmel mine	NW Sec 16, T 41 S, R 7 W	"upper"
Muddy mine or prospect	SW Sec 7, T 41 S, R 7 W	(?)
Zion mine	SE Sec 1, T 41 S, R 9 W	"lower"

Coal resources. The resources of the county are divided among the three coal fields as indicated in table 13. They were determined (Doelling 1972b, p. 549-553) to include measured, indicated, and inferred coal as extrapolated up to 4 1/2 miles from a control point in reasonably continuous beds at least 4 feet in thickness and under less than 3000 feet of cover. Treatment of split coal beds followed the procedures outlined in Bass and others (1970). Since the calculation is one of coal in place, it cannot be considered a minable reserve, since the strict definition points out that the coal must be economically producible (Wood and others, 1983). Experience in other Utah areas with similar geologic circumstances shows that about 1/3d of the principal resource is usually recoverable in underground mining operations. The control points are mostly from outcrop measurements as most of the drillhole information is still held confidential by the energy companies that lease the land. Drillhole

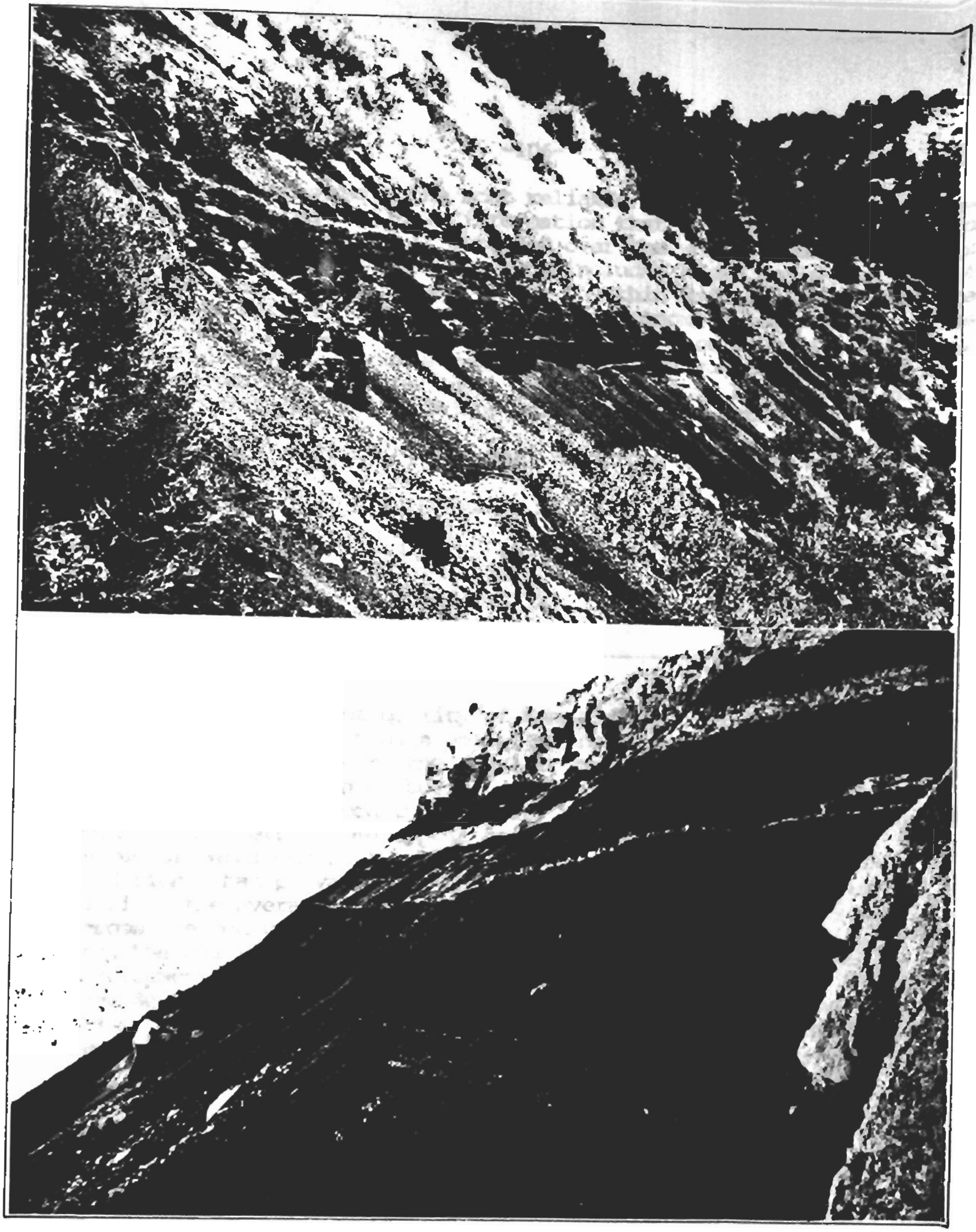


Photo 69. Good natural exposures of coal beds in the Kolob coal field near the Coal Hill slide. The lower photo is an exposure of the "lower" coal on Coal Hill.

information is considered the most reliable in making reserve or resource estimates. Limited drillhole information that has been released supports high tonnage figures, and if extended over the whole area would far exceed those shown. The identified resource includes known coals that are 14 inches to 4 feet in thickness. Since the thin beds of Kane County are presently considered to be marginal or subeconomic, less attention has been directed to them. If additional studies were made of the thinner beds the identified resource could be increased substantially. Some estimates indicate that the total coal resource of Kane County may be as high as 4 times that shown in the initial overall estimate.

Table 13. Kane County in-place coal resources (millions of short tons).

Coal field	Principal		Identified	
Kaiparowits Plateau	4,428.6	63.1%	4,959.9	61.6%
Alton	1,475.3	21.0%	1,492.1	18.6%
Kolob	1,113.0	15.9%	1,597.7	19.8%
Total	7,016.9	100.0%	8,049.7	100.0%

Coal quality. The quality of Kane County coal is variable and ranges from subbituminous C to high volatile bituminous C in rank. Part of the variability may be due to the physical conditions in which the coal is found, i.e., the depth of burial, altitude (which controls the precipitation in the county), density and depth of jointing in the host rocks, and others. Some appear to be regional, either related to the degree of metamorphism to which the coal was subjected or to the conditions that prevailed in that part of the depositional basin. Table 14 lists the average proximate analyses in a general east to west fashion across the county, paying no head to formation or coal zone. Most are from the available mines, but many are from fresh outcrops, as no development has occurred in many areas. Additional quality information is provided in tables 15 and 16. Information from Doelling and Graham (1972), Affolter and Hatch (1980), and Bur. Land Management (1975), or averaged from company files.

Photo 70. Portal of the abandoned Zion mine in Little Meadow Canyon. The mine developed the "lower" coal in the Dakota Formation in the Kolob coal field. All Kane County coal mines are presently abandoned.

Table 14. Representative analyses of coals in Kane County (as received and in percent).

East to West-->	1.	2.	3.	4.	5.	6.	7.
Moisture	10.5	9.6	19.5	15.8	19.3	17.0	12.1
Vol. Matter	40.6	38.4	35.7	31.9	35.2	33.4	40.1
Fixed carbon	41.9	44.1	33.7	35.0	37.7	41.8	36.0
Ash	7.0	7.9	11.1	17.3	7.8	7.8	11.5
Sulfur	0.88	0.68	0.79	0.73	0.86	1.1	2.2
Btu/lb.	10,349	11,211	9,022	7,182	8,204	10,018	10,492

1. Escalante area, Kaiparowits Plateau coal field, Straight Cliffs Formation coals, many samples from Garfield County.
2. Smoky Mountain area, John Henry Member, Straight Cliffs Formation coals.
3. Tropic area, Kaiparowits Plateau coal field, Straight Cliffs Formation coals, some from Garfield County.
4. Cannonville area, Alton coal field, Dakota Formation coals.
5. Skutumpah area, Alton coal field, Dakota Formation coals.
6. Alton area, Alton coal field, Dakota Formation coals.
7. Orderville area, Kolob coal field, Dakota Formation coals.

Table 15. Drillhole analyses (as received) from area locations in Kane County.

	Smoky Mtn Area	Skutumpah Area		Kolob Field
Type	15 samples	4 Smirl	1 Bald Knoll	7 samples
Proximate Analysis				
Moisture	9.47%	20.86%	16.20%	17.90%
Volatile matter	38.17	32.37	28.20	32.00
Fixed carbon	43.67	39.19	34.70	39.00
Ash	7.67	7.58	20.90	11.10
Btu/lb.	11,369	9,555	8,120	9,273
Ultimate Analysis				
Carbon	65.08	42.34	37.06	53.70
Oxygen	11.91	22.85	20.12	27.10
Hydrogen	4.48	4.70	4.21	5.80
Sulfur	0.47	0.79	0.80	1.20
Parr Formula Btu/lb.	11,837	10,436	9,914	10,547
ASTM Rank x	Hivol. C bituminous	Subbit. A or Subbit. B.	Subbit. B	Subbit. A or Subbit. B.

Table 16. Average ash analyses for 15 Smoky Hollow area samples, 8 Skutumpah, and 7 Orderville area samples (mostly drillhole samples).

Major oxides	Smoky Hollow	Skutumpah	Orderville
SiO_2	53.25	37.00	40.43
Fe_2O_3	5.08	7.65	7.99
Al_2O_3	18.35	22.62	16.00
TiO_2	0.90	0.93	0.83
CaO	10.52	8.77	8.36
Mgo	2.51	1.89	1.67
SO_3	6.98	16.32	n/t
P_2O_5	0.20	0.10	0.14
K_2O	0.63	0.25	0.40
Na_2O	1.19	2.35	3.27

Manganese King mine. This mine is located east of Kanab in the Kitchen Corral Wash drainage north of U. S. Highway 89 in Sec 2, T 42 S, R 3 W. Manganese nodules were discovered in 1908, but their source was not pinpointed until 1939. Through 1941 improvements were made on the property and 21 tons of manganese nodules were mined and stockpiled. In February of 1941 the property was subleased, development work continued, two tunnels were started, and ore washing facilities were installed along with housing, ore bins, and jiggers. Roads were improved and an intricate water supply system (6,000 feet of pipe from wells) was installed. Another 30 tons were produced and shipped with the previously stockpiled material. Work continued intermittently through 1944 and the records (Buranek, 1945, p. 10) indicate that at least 191 tons were shipped.

The deposit itself is contained somewhere in the middle of the Petrified Forest Member of the Triassic Chinle Formation. The outcrops are located in a cove just north of a spectacular landslide in which the Chinle, Moenave, and Kayenta Formations participated. The strata consist of a lower bentonitic mudstone which grades upward into dark manganese bearing mudstone. This is overlain by a light cream to greenish-gray altered calcareous tuff(?) that is 6 to 7 feet thick. Brown and Hannigan (1986, p. 17) indicate the tuff may be rhyolitic. The tuff(?) appears to contain altered lithic fragments or altered phenocrysts. The ore horizon is just below the lower contact of this tuff(?) in the dark shale or mudstone beneath it. Overlying the tuff(?) is a sandy limestone ledge rangin 0-12 feet in thickness. This ledge is tan gray to lavender gray, and breaks up into both thin and thick blocks, 2 inches to 4 feet in diameter, and is mineralized with specular hematite. The specular hematite occurs as thin lentils oriented subparallel to the bedding and spaced 1 to 4 inches apart. At the edges of the limestone lens, where it is thin (less than 3 feet in thickness), the limestone becomes nodular and contains little or no specular hematite.

Manganese nodules occur in the upper 8 to 10 feet of the dark mudstone, but are mostly concentrated in the upper 6 inches to 1 foot. The ore becomes rapidly lead below. In past mining practices only the upper foot apears to have been taken. The limestone lens does not occur everywhere over the manganese horizon (it is not directly superimposed over the interesting part). The tuff(?) horizon overlies the manganese horizon everywhere and extends beyond the area of interesting manganese.

Prospecting has extended to the east and west, along both the bottom and top of the tuff. To the east the ore horizon is first displaced by a fault? and the Chinle is mostly covered by colluvium. The light tuff horizon reappears in outcrop 400 to 500 yards to the east and has been prospected in at least 3 cuts. The dark mudstone is very bentonitic and there are small or no manganese nodules. There are lots of small limestone nodules present, however. To the west the outcrops are covered by bouldery alluvium and when they reappear there are no manganese nodules.

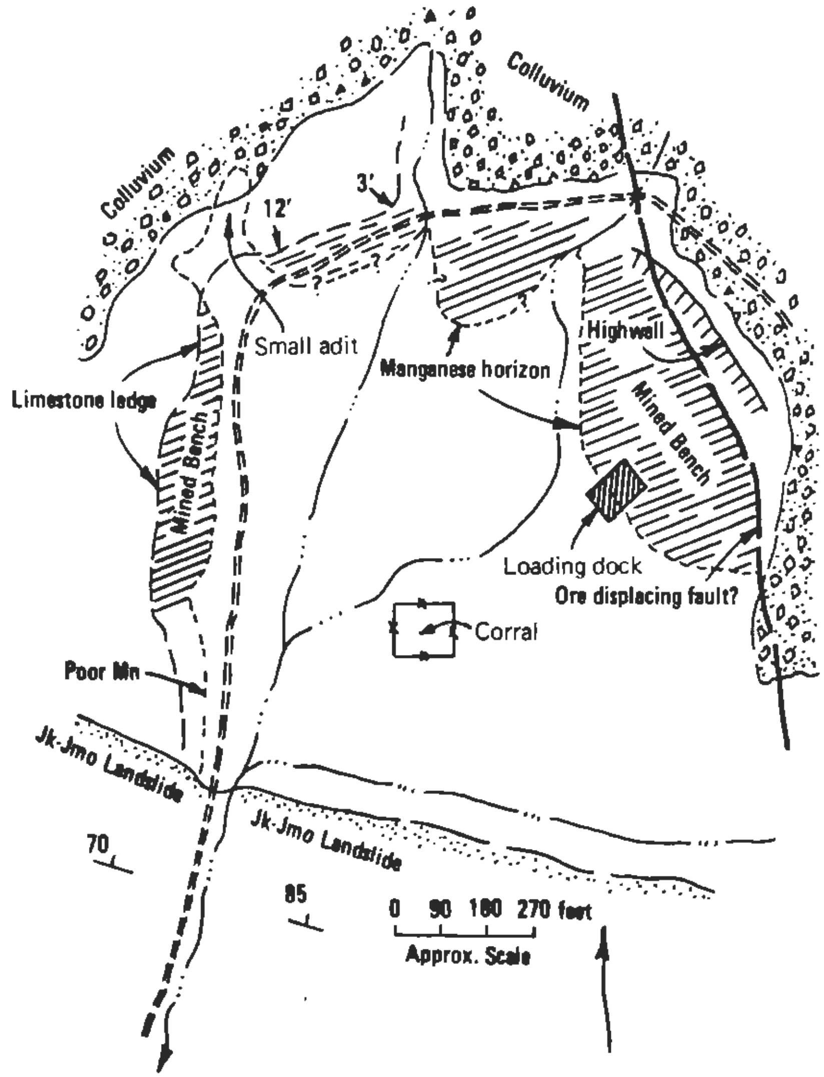


Figure 41.

Sketch map of Manganese King workings in Sec. 2, T. 42 S., R. 3 W. The manganese horizon is located somewhere in the middle of the Petrified Forest Member of the Chinle Formation.

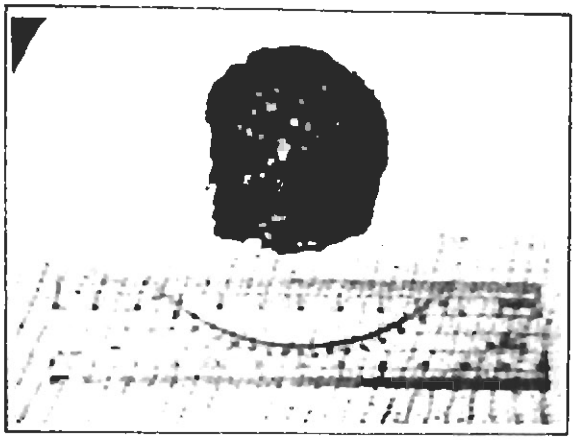


Photo 71. Manganese nodule 2 inches x 3 inches from the Manganese King mine in Kane County.

According to Buranek (1945, p. 6), the ore consists of nodular and irregular bodies of manganese oxides in shale. The manganese minerals include psilomelane, pyrolusite, and wad. Psilomelane predominates, especially in the nodules, and many show pyrolusite centers (Photo 71). The nodules seem concentrated along vertical openings in the shale just below the tuff(?) contact and range in size to 4 or 5 inches in diameter and average 1 or 2 inches. Many of the nodules have botryoidal surfaces.

In Triassic time the scene was probably a small lacustrine basin into which volcanic material was deposited. The source of the manganese is obscure but was probably leached from the volcanic materials in the deepest part of the lake.

Buranek (1945, p. 7) indicates that five tunnels were driven into the ore for distances of 140, 10, 110, 90, and 60 feet respectively. Presently only one underground working is evident with about 70 feet of underground tunnel length (see sketch map, figure 41). The remainder of the tunnels were probably destroyed by later surface mining (rim stripping).

It has been reported that the quality of ore was better at the tunnel faces than nearer the portals. Shipments made from the property reportedly assayed 48.94 percent manganese (Buranek, 1945, p. 11), but Havens and Agey (1949), U. S. Bureau of Mines, tested a 2 ton lot from the Manganese King (Black John) property which assayed about 40 percent after washing. According to Havens and Agey the ore consisted of crusts and nodules of high grade psilomelane and disseminated grains of pyrolusite distributed in a clayey gangue. The total ore assayed 7.1 percent Mn, 48.7 percent silica, 14.3 percent alumina, with 0.062 percent phosphorus. The samples were washed, eliminating slimes, and it was found that 62 percent of the Mn was contained in that part of the ore in the +10 mesh range. Buranek reports a probably ore reserve of 20,000 tons. All mining ceased when the ore buying of the Metals Reserve Corporation was discontinued after World War II. Good ores should contain 45 percent or more manganese. Manganese is essential to the steel industry, helpful to desulfurize and deoxidize the molten steel.

Uranium

The birth of the Atomic Age relegated importance to the metal uranium, which had previously been a by-product of Colorado Plateaus vanadium ore. After World War II the Federal government offered incentives to stimulate exploration and production, which reached a peak in the middle 1950s. Perhaps all of the outcrops of the principal uranium-vanadium bearing formations (Morrison and Chinle Formations) were claimed and explored, including those in Kane County. The amount of uranium discovered in the county was disappointingly small and did not compare with discoveries in San Juan , Grand, Emery, and Garfield Counties.

Three areas containing uranium are known in Kane County, each in separate host formations. To the west uranium has been found in the Sub-Dakota Conglomerate in channels cut into the Winsor Member of the Carmel

Formation. In and around Buckskin Mountain a few prospects have been opened in the Shinarump Member of the Chinle Formation. On the east side of the Kaiparowits Plateau uranium is present in the upper part of the Morrison Formation along Fiftymile Bench opposite Cat Pasture.

Bulloch Claims. The western area of uranium deposits are known collectively as the Bulloch Group of claims. These are located on both sides of Orderville Gulch at the Carmel-sub-Dakota Conglomerate contact. The sub-Dakota Conglomerate, which is 50 to 100 feet thick, cuts broad shallow channels into the yellowish friable slope-forming sandstone of the Winsor Member of the Carmel. The sub-Dakota Conglomerate, at this location, is mostly conglomerate in the lower part and grades upward into conglomeratic sandstone and crossbedded sandstone. The pebbles and cobbles are mostly quartz, quartzite, and chert, and range from grit to 3 or 4 inches in diameter. The color of the sub-Dakota Conglomerate ranges from light gray to yellow gray and brown. There are a few incorporated clay lenses or pods, especially near the base. Locally there are logs of petrified wood and fragments of carbonized wood. The crossbed directions (festoons) indicate that streams flowed northeasterly to northward.

The mineralization appears to be strongest at the contact, especially around the carbonized wood fragments and clay lenses and pods. Carbonized wood, petrified wood, and clay galls are generally surrounded by brown iron oxide halos, streaks, and mineralization fronts. Beroni and others (1953, p. 3) report that abnormal radioactivity extends along 4000 feet of outcrop. The concentrations within this zone are erratic. The three richest deposits are located on the Lynn No. 1, Lynn No.3, and Jeannie No. 3 claims. The better Lynn claims are located in the N 1/2 of Sec 21 and the S 1/2 of Sec. 16, T 40 S, R 9 W. The Jeannie No. 3 claim is located near the center of Sec. 8 of the same township. The better deposits range in length from 14 to 75 feet and are 1 to 7 feet in thickness. The average ore grades in these zones vary from 0.05 to 0.15 percent U_3O_8. There is much low grade ground between the richer deposits.

Identifiable minerals include carnotite, tyuyamunite, torbernite, and autunite. Much uranium is found as finely disseminated material in the clay or carbonized wood. Carnotite fracture coatings are also present. The ore was checked for other elements. The mineralogy indicates the presence of vanadium, some grab samples have yielded nearly 5 percent V_2O_5. In spectrographic analyses copper, molybdenum, lead, cobalt, nickel, yttrium, and germanium are present in higher than background quantities.

In June of 1950, 8 1/2 tons of 0.16% U_3O_8 ore was shipped and rejected by the U. S. Atomic Energy Commission. More was undoubtedly shipped as reported in Dasch (1967, p. 116). Apparently 100 to 1000 tons were shipped from the Lynn 3 claim, and less than 100 tons were shipped from School Section 16 and the Lynn No. 1 claim each. Records indicate a total of 689 pounds of U_3O_8 were produced from the Bulloch claims through 1973 (U. S. Bur. Mines MAS records). No production has occurred since. The most extensive workings occur on the Lynn No. 3 claim (figure 42).

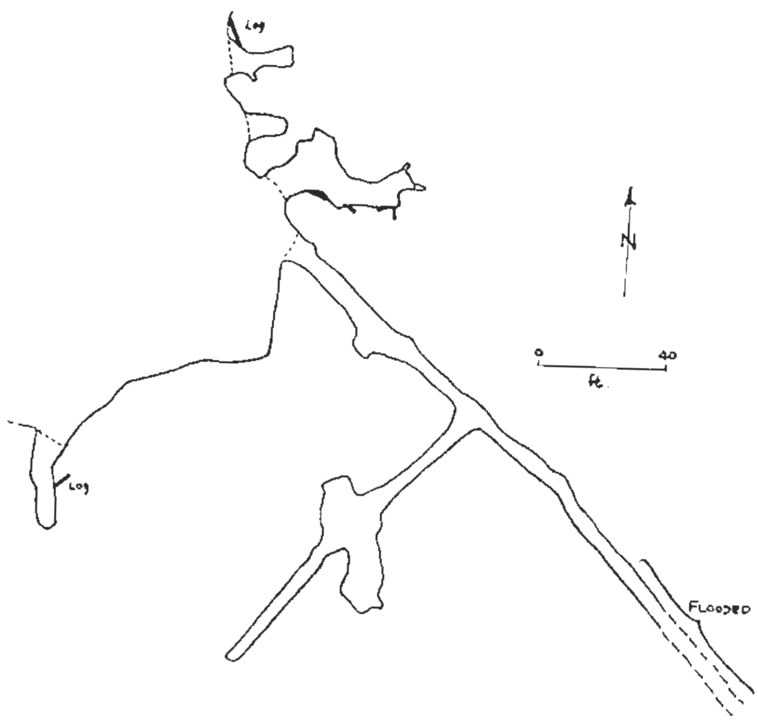


Figure 42.

Mine outline map of the Lynn #3 claim workings, SWSE Sec. 16, T 40 S, R 9 W. The mineralization is localized at the base of the sub-Dakota Conglomerate and at the top of the Winsor Member of the Carmel Formation (see text).

Radiance claims and Buckskin Mountain area deposits. The Shinarump Member of the Chinle Formation crops out discontinuously around the margins of Buckskin Mountain (Kaibab Uplift), which is cored in Permian rocks. The unit cuts channels in the Upper Red Member of the Moenkopi Formation and consists of gritty sandstones, conglomeratic sandstones, and conglomerate. The Shinarump grades upward into similar appearing rocks that are more friable and slope forming, that include sandy, carbonaceous, and bentonitic mudstones that probably correlate with the Monitor Butte Member. The Monitor Butte rocks are probably more continuous than the true Shinarump, but show little uranium mineralization. On the east side of the uplift, the Shinarump beds dip steeply eastward, are often faulted or cut out by attenuating faults. Uranium mineralization has also been identified along faults where the Shinarump has been cut out, and may be the result of a secondary uranium migration from that unit. As far as is known, there are only six prospects or groups of claims in this belt and most show only localized increases in radioactivity.

The best known deposit or occurrence is that of the Radiance or Cockscomb group of claims. They are apparently one and the same, the latter name evidently being the older. They are located on the east side of U. S. Highway 89 in Fivemile Valley, in Secs. 24 and 25, T 42 S, R 2 W. Several poorly defined paralleling faults, trending N 15° E cut out rocks along the west side of the Cockscomb between outcrops of the Moenkopi and Moenave or Kayenta Formations. A small sliver of Petrified Forest Member of the Chinle Formation is present between fault traces. There is no exposed Shinarump Member. The deposit consists of uranium mineralization that coats fractures in the Moenave or Kayenta Formation sandstones along the fault traces east of the sliver of Chinle Formation. The Moenave sandstones dip 30 to 65 degrees eastward. They appear to contain no carbon trash, clay galls, or other features characteristic of channel-type deposits in the Chinle and Morrison Formation of the Colorado Plateaus.

Buranek (1942, p. 5) reports that the property was developed by several small workings, including lower workings with a shallow inclined shaft (that was caved at the time), a small prospect hole, and upper workings (150 feet above the lower) of several small prospect pits. Presently there is only a long cut, indicating a later attempt to mine the occurrence by surface methods. Additional non-mining surface work was done by the Utah Department of Transportation when the big highway cut was constructed through the Cockscomb immediately to the south. At present there is a rimstripped zone about 1000 feet long and no underground working remain.

The mineralization of the Radiance Group occurrence was first discovered before World War I, apparently as part of the search for radium (Sanford and Stone, 1914; Schrader, Stone, and Sanford, 1916; and in Butler, 1920). Then little was done on the property until World War II, presumably to investigate the vanadium possibilities. Through 1973 about 173 lbs of U_3O_8 were produced (mostly in the middle 1950s) (U. S. Bur. Mines MAS files).

Scale North Arrow
Explanation of Units—

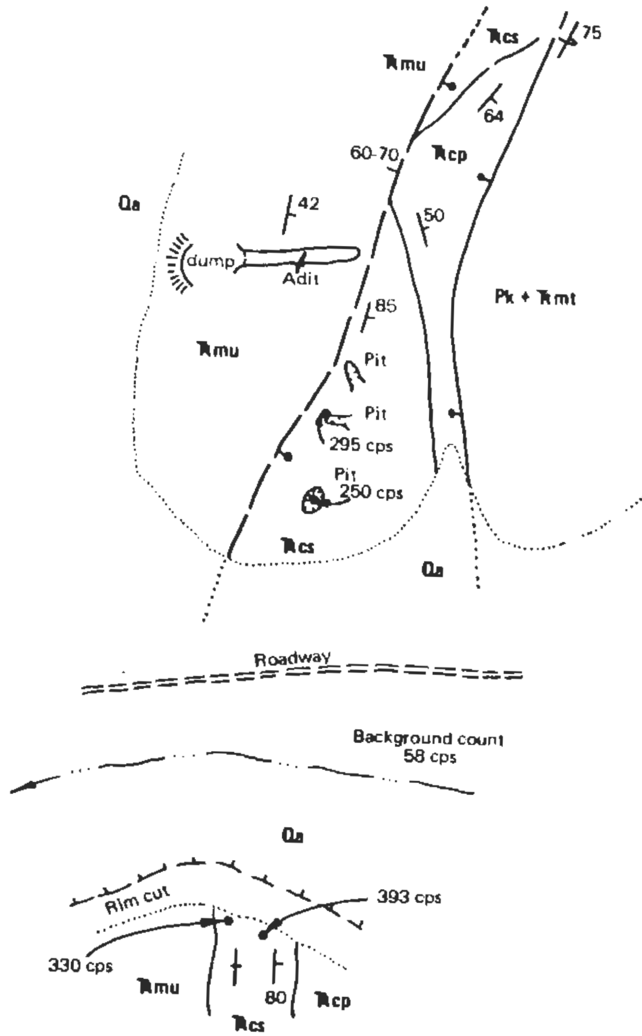


Figure 43. Sketch map of workings in the NWNW Sec. 14, T 43 S, R 2 W, along the Cockscomb, developed to find uranium (see also photo 65).

Fig

The mineralization is of the uranium-copper type and there is little vanadium. Identified minerals include yellow autunite, green metatorbernite, torbernite, azurite, malachite, schroeckingerite(?), uranophane(?), wavellite, and jarosite. Uranospinite has also been reported. Grab samples have yielded up to 0.25% U_3O_8 and channel samples in the better part of the occurrence yield 0.03 to 0.18% U_3O_8. No estimate of the remaining resource has been made, but it is probably small. Background radiation in the area is low (50-100 cps total count), local "spots" along the disturbed ground often record over 3000 cps, a notable concentration of radioactivity.

The highest radiation count of any area removed from the Radiance Group occurrence is found in the S 1/2, Sec. 11, T 43 S, R 2 W. In a bleached zone between the Moenkopi and Chinle Formations, the Shinarump is not well developed and is probably missing. The strike of the rocks parallels the structure and the dip is very steep to the east or vertical. Faults that are coincident with bedding are also present. The mineralization appears to be localized in coarse grained sandstones between the gray shales of the Monitor Butte Member of the Chinle Formation. The count is highly variable ranging from 150 to 2200 cps total count. The best count comes from thin sandstones that contain red chert as a constituent. The bleached zone is about 1000 feet in length and 150 feet wide. Within the bleached zone normally red-colored rocks have been altered to yellow. The only identifiable minerals are iron oxides.

About 4 miles farther south are two exploration adits cut to intersect the Shinarump Member (or Monitor Butte Member?) or a fissure (mineralized zone paralleling a fault or fracture). They are both located in Sec 14, T 43 S, R 2 W. The first is easily visible from and east of the House Rock Valley road in the SWNW of the section, a half mile north of the Kaibab Gulch crossing. The dump is not far above the road level. The adit is approximately 60 feet in length and cut entirely in the Moenkopi Formation along a bearing of N 86° E. The strike of rocks in the adit is N 8° E and the dip is 42 degrees east. A gulch to the south has eroded perpendicularly through the Cockscomb strata and exposes a steeply eastward dipping outcrop of Shinarump Member. This was the target of the underground working, but was not reached (see figure 43). Crude surveying shows that if the fault separating the Upper Red Member of the Moenkopi Formation from the Shinarump Member is vertical, then it would have required only 7 feet to reach it. A dip measurement of the fault plane taken north of the mine shows a 60-70 degree inclination to the west. East of the Shinarump outcrops another fault breaks the normal sequence and brings a thick slice of Kaibab Limestone and Timpoweap Member of the Moenkopi Formation against the Chinle.

The Shinarump Member is mineralized with iron oxides and outcrops give radiation readings 4 or 5 times higher than background. A few shallow pits have been dug or blasted on the outcrop. It is assumed that the surface rock of the Shinarump Member is too low in grade and too irregular in the contained U_3O_8 to make ore grade. The adit was designed to intersect the member in hopes that the uranium might be enriched at depth. A cut crosses the Shinarump outcrop just south of the gulch. The vertical beds of the member are about 70 feet thick and the thin beds are radioactive, 6 to 7 times that of background. Some of the rocks are plainly bleached.

To the south of the gulch and higher on the hill in the NWSW part of Sec. 14, is a 300 foot adit known as the Copper Cliff (figure 44). It consists of one long tunnel with a bearing of S 37° E. The strike of the rocks in the adit are N 47° E and the dip ranges from 30 degrees east to vertical. The adit did not reach the mineralization or there was none at that level. Above the portal, higher and southeast, the Shinarump is exposed in which the rocks are slightly overturned and dip 70-80 degrees westward. Copper mineralization with a slightly higher than background radiation count is evident. The copper mineralization is quite obvious and may have been the primary target, rather than uranium. The mineralization parallels the bedding in a rather narrow zone, mostly less than a foot wide. The mineralization is probably localized by a bedding plane fault and has a length of at least 50 feet along strike. Several shallow pits have been dug along the fissure including one 52 foot shaft. Other than abundant iron oxides the mineralization consists of scales and coatings of malachite with black copper pitch, chrysocolla(?) and occasional blebs of cuprite. No uranium minerals could be identified. An analysis of a high-grade grab sample yielded 7.46 ounces of silver per ton, 0.001 ounces of gold per ton, 11.65 percent copper, 900 ppm lead, and 1650 ppm zinc.

Another occurrence has been reported in Sec 35, T 43 S, R 2 W (Lovering and Gross, 1958). These are known as the Virginia Park claims. They are certainly not located in Sec. 35 because that section is not located along the Cockscomb and the suitable geologic formations. The description of the mineralization is similar to that for the Copper Cliff area. The report indicates the radiation count to be 4 or 5 times that of background along an altered zone containing chalcopyrite, bornite(?), bentonite, and iron stains. The radioactivity apparently follows "the Shinarump horizon and overlies hard Moenkopi shales." The Virginia Park claims lie about a half mile north of another altered zone 2 to 8 feet thick and uyp to 150 feet wide that is irregular in shape.

East of the movie set, 3/4 mile southwest of the abandoned townsite of Paria, in SWSW Sec. 18, T 41 S, R 1 W, a small adit or "dig" has been cut into a 1 foot lens of gritty sandstone near the top of the Monitor Butte Member of the Chinle Formation. The "dig" is located about 100 feet above the Shinarump contact. No uranium minerals were evident and the radiation count is only slightly higher than background (about twice background). The bottom of the spectacular Shinarump Member channel in the drainage west of the movie set shows no abnormal radiation (photo 12). Brown and Hannigan (1986, p. 10) report sampling clayey material from prospect pits in the Chinle Formation around the Paria townsite. Their samples contained only 2.6 to 6.0 ppm uranium.

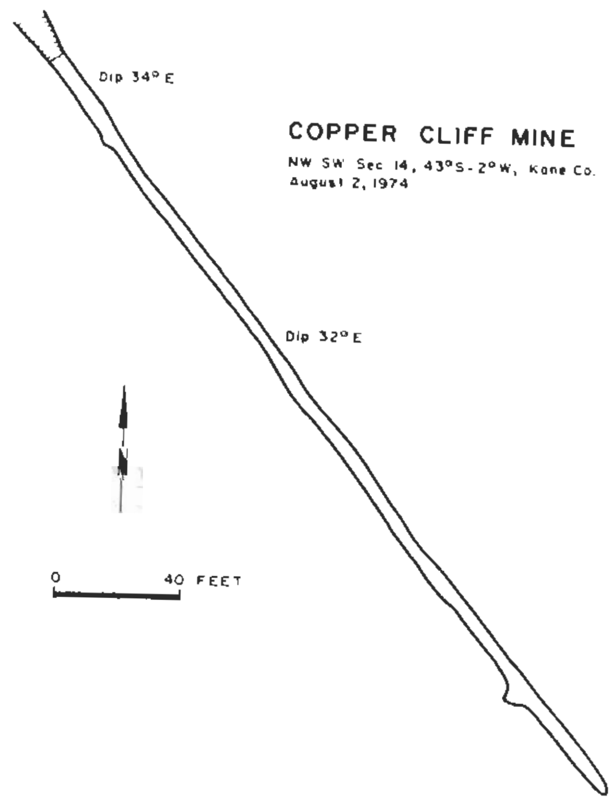


Figure 44. Mine outline map of the Copper Cliff workings, NWSW Sec. 14, T 43 S, R 2 W.

An outcrop of Shinarump Member is exposed along Kitchen Corral Wash in Sec. 3, T 42 S, R 3 W at White Rocks. The ruins of a loading dock are plainly evident just east of the main Kitchen Corral Wash road. A rim cut with a length of about 400 feet is the extent of development. The cut exposes the base of the Shinarump and its contact with Upper Red Member of the Moenkopi Formation. At the base there is a yellow green mudstone. The Shinarump consists of ledge coarse and gritty yellow tan crossbedded sandstone containing lenses of pebble conglomerate. The pebbles are mostly chert, quartzite, and sandstone. The sandstone contains many brown plant outlines, but there is little carbon trash. The unit is heavily stained and streaked with iron oxides, notably at the base. No uranium minerals can be recognized and the highest radiation count is about three times background. The Shinarump channel is about 20-25 feet thick at this location.

Another prospect consists of an open pit in the Shinarump Member just south of Pioneer Gap along the Shinarump Cliffs near the center of Sec. 32, T 43 S, R 4 W. The pit is 50x40 feet with the long axis trending N 32° E. The highwall is 14 feet , the dip of the rocks in the pit is gentle, perhaps 6 degrees to the northwest. There is a limonitized halo in the pit 12 feet long and 6 feet high. The rocks are fractured, but the fractures have not controlled the mineralization. A few local hotspots are present within the halo and are outlined by heavier concentrations of iron oxides that emit only twice the background radiation count. The Shinarump channel is 25 to 30 feet thick.

<u>Morrison Formation deposits</u>. The Morrison Formation also has uranium mineralization in Kane County. It is located on the east side of the Kaiparowits Plateau along Fiftymile Bench in the south of T 38 S, R 6 E, and in the north T 39 S, R 6 E. The Morrison Formation dips gently southwest and there are no faults of consequence at this location. The formation is about 415 feet thick and is mostly conglomeratic sandstone. The mineralization is in the upper half of the unit where individual sandstone channels are a bit thinner. About three channel sandstones, one lying above the other in a vertical interval of about 100 feet, emit radioactivity above background levels. The count drops to background over covered areas, but responds well in the immediate vicinity of the channels. On the average the radioactivity is 4 to 6 times background, but locally rises to 15 times background. The channels range to 15 feet in thickness. Evident on these sandstone channels are mineralization (iron oxide) fronts. These fronts are usually found in pairs and roughly parallel bedding, but commonly cross stratigraphic features. No organic or carbonaceous material seems to be present, the sands are usually calcite cemented. Along or within the boundaries of mineralization fronts are occasional lentils of coarse sandstone with a pinkish cast. The pink coloration is due to a pink or red chert and the lentils carry the highest radioactivity.

One short adit and some surface work comprise the total development work in the area. The highest radioactivity (400 to 1200 cps total count) are recorded here. Fresh exposures and areas within adits seem to magnify the count. The radioactivity has been followed in Secs. 32 and 33 in T 38

S, R 6 E, and in Secs. 4, 5, and 10 in T 39 S, R 6 E. Two samples were analyzed, the first was of a 1 foot lentil of pink chert-bearing sandstone and the second was a grab sample of heavily limonitized rock bearing a good count. The first sample yielded 0.033 percent U_3O_8, 0.002 percent V_2O_5 and the second 0.014 percent U_3O_8 and 0.005 percent V_2O_5. The area investigated is one with low-grade uranium values and the vanadium content is too small to recover. The area with anomalous radioactivity is comparatively large and may indicate a larger, better grade deposit down-dip. It is suspected that a large tonnage of low-grade (0.01 to 0.04 percent) material is present.

Precious and base metals

Most areas of the world have been extensively prospected for precious and base metals, and Kane County has not been overlooked. Although some production has been achieved it has been very small. Gold, copper, silver, and lead have been produced in relatively small quantities, but no such operations are presently active.

Colorado River gold. Gregory (1950, p. 188) speaks of the "futile" gold excitement of Kanab in 1876. Thereafter Cass Hite discovered gold in gravel bars along the Colorado River in the Garfield-San Juan County area (1883). Prospecting soon reached all the gravel bars along the river and it is assumed that production was achieved from the Klondike, Horse, and Meskin bars in Kane County. Most of this production occurred between 1886 and 1889. The recovered metal was in the form of flour gold and none was found as flakes and nuggets (Gregory and Moore, 1931, p. 147). The gold was accompanied by black sands consisting of magnetite, hematite, ilmenite, garnet, and small amounts of chromite, zircon, and rutile. One analysis indicated that the Colorado River gold contained a little platinum. At present all the Colorado River gravel bars are inundated by Lake Powell. Whatever production was achieved on the Kane County bars is probably credited with the San Juan County records.

Paria gold. Another period of gold "fever" occurred from 1910 to 1913 when gold was sought from the Chinle shales around the abandoned townsite of Paria. Lawson (1913, p. 446) reports trench sampling the lower half of the Petrified Forest Member and finding that this interval averaged 4 to 5 cents per ton in gold values. Individual assays ranged to 12 1/2 cents per ton. The price of gold at that time was $21 per ounce and presently (late 1986) stands at about $400 per ounce. This would equate to about a dollar in gold per ton at present prices. Lawson (p. 447-448) humorously summed up the situation by indicating the gold content of the Shinarump clay in Utah might be worth $1,500,000,000,000 (see the quote on page 1).

Lawson also indicates that the Moenkopi Formation in the same area was tested and found to average 4 cents per yard (80 cents at current prices). Ruins of construction designed to remove the gold from the Chinle Formation can still be observed at Paria.

Cockscomb copper and the Hattie Green mine. Copper mineralization is present in at least three areas of Kane County; in the southern one-third of the Cockscomb, south of Kodachrome Basin State Reserve south of Cannonville, and in the Montezuma area along the White Cliffs at the southern edge of the Skutumpah Terrace. The copper is usually associated with another metal or metals: uranium, silver, or lead.

Oxide copper minerals with a few blebs of sulfides are associated with fissures in the Navajo Sandstone, Moenave Formation, and Shinarump Member of the Chinle Formation along that part of the Cockscomb (East Kaibab monocline) starting 5 miles south of Paria and extending to the Arizona border. The fissures generally subparallel the strike of the monocline and, like the bedding, dip steeply eastward from 30 degrees to vertical. There are also some transverse or oblique fissures. Most occurrences of the mineralization appear small, extending only a few feet along strike, the largest extending several hundred feet. The width of the mineralization along the fissures is usually narrow, rarely exceeding 5 feet, but occasionally exceeding 30 feet.

The mineralization chiefly consists of iron oxide stains and fronts which pervade the sandstone. Along fracture faces or openings are encrustations, coatings, scales, and impregnations of malachite and copper pitch. Azurite is not common and some chrysocolla(?) and chalcanthite(?) is occasionally present. Tiny blebs of bornite stained chalcopyrite and chalcocite are occasionally found in the best areas. A few fissures also contain uranium or uranium-copper minerals (torbernite or metatorbernite). Most workings are very small and consist of shallow diggings or pits and short adits. The Copper Cliff workings were previously discussed (p. 114).

The largest workings are those of the Hattie Green mine, located along the crest of the Cockscomb in NW Sec. 18, T 42 S, R 1 W. The host is the Navajo Sandstone and several scattered fissures cut the rock both subparallel and normal to the bedding. The Hattie Green consists of workings scattered about a quarter mile of area and includes adits, shafts, and pits. According to Blakey (1970, p. 147) the main deposit is exposed in a pit about 20 feet in diameter and 10 feet deep. The fissure has additionally been worked by trenching over a length of 30 feet. The width of the pit corresponds to the width of the fissure which strikes N 50° W and dips 53 degrees to the northeast. A little ore has been stockpiled and it is thought that a few test lots were shipped to a smelter. A grab sample analysis yielded 0.55 ounces of silver, 0.001 ounces of gold per ton, 7.05 percent copper, 2800 ppm lead, and 260 ppm zinc. The handcobbed stockpileed ore probably contains 3 to 5 percent copper (visual observation). A channel across the best part of the fissure would probably yield less than 1/2 percent copper. Blakey also reports a 5 foot square adit, about 300 feet in length, cut to intersect the fissure. Copper minerals scattered on the dump seem to indicate that the fissure was reached. Blakey thinks the fissures are associated with a zone of shearing related to monoclinal folding as indicated by many outcrops of recemented crushed and fractured sandstone. Mahoney (1943) reports that the underground workings total approximately 1000 feet of drifting and crosscutting. He describes a lowermost 660 foot crosscut driven from the west slope of the east ridge. At a point 465 feet from the portal a northwest striking fissure was encountered with copper mineralization averaging 6 inches in width. A drift 40 feet in length was driven northwesterly and another 310 feet southeasterly to follow the fissure. This fissure was assayed and averaged 1/2 percent copper.

Another adit 138 feet in length was driven on a northwest fissure which may be the same one intersected by the lower crosscut. The mineralization is spotty and assayed 1.7 percent copper (16 inch channel) at the portal, 1.8 percent at a winze 80 feet into the adit (2.5 foot channel), and 0.95 percent copper at a fissure intersection 113 feet into the adit. In another assay taken from a 3 foot channel in the same mine northwest of the bottom of the winze the copper content was 0.7 percent and there was 0.1 percent lead.

Rock Springs lead deposit. The Thousand Pockets Tongue of the Page Sandstone is mineralized with copper and lead in the Rock Springs area, south of Kodachrome Basin. There are three principal areas: one in the NESE Sec. 22, another in the NESW Sec. 26, and the last in the SENW Sec. 35, all in T 38 S, R 2 W, and are known as the Rock Springs, Ridge Copper or Surprise, and Bullet shafts, respectively (figure 45).

The Rock Springs deposits was worked primarily for lead, but there is also some copper mineralization present. The mineralization is contained in elongated iron-stained pods in a thick yellow sandstone bed (Thousand Pockets Tongue). The beds are up to 8 feet in length and are rather irregular in shape and do not conform to the bedding. The lead is present as anglesite impregnations in the sandstone. In fresh exposures an occasional cubic grain of galena is also identifiable. Malachite is not abundant, but is the principal copper mineral. Some malachite coatings are also found in shale partings and in thin sandstone beds adjacent to the thick yellow sandstone bed.

The workings consist of a 10 foot shaft, some surface scrapings on the sandstone, and a 25 foot adit. The disturbed area is 100x200 feet. Apparently there has been some production and it occurred in the 1930s. The U. S. Bureau of Mines Minerals Yearbook series credits Garfield County with 850 pounds of lead production from an area near Cannonville. the Rock Springs deposit is the only one near Cannonville and is located in Kane County. The lead was valued at $34. The lead-bearing sandstone was ground to sand in a horse or mule operated arrastre and then panned to concentrate the galena and anglesite. The remains of the arrastre were still present along the Rock Springs road on the northwest side of the Rock Springs Creek crossing in 1980. Brown and Hannigan (1986, p. 15) took a chip sample of shale on massive sandstone showing minor malachite stains in the pit which showed the presence of 0.04 and 0.06 percent of copper and lead respectively. It is thought that most of a pod had been mined from the pit which had contained higher percentages of both metals.

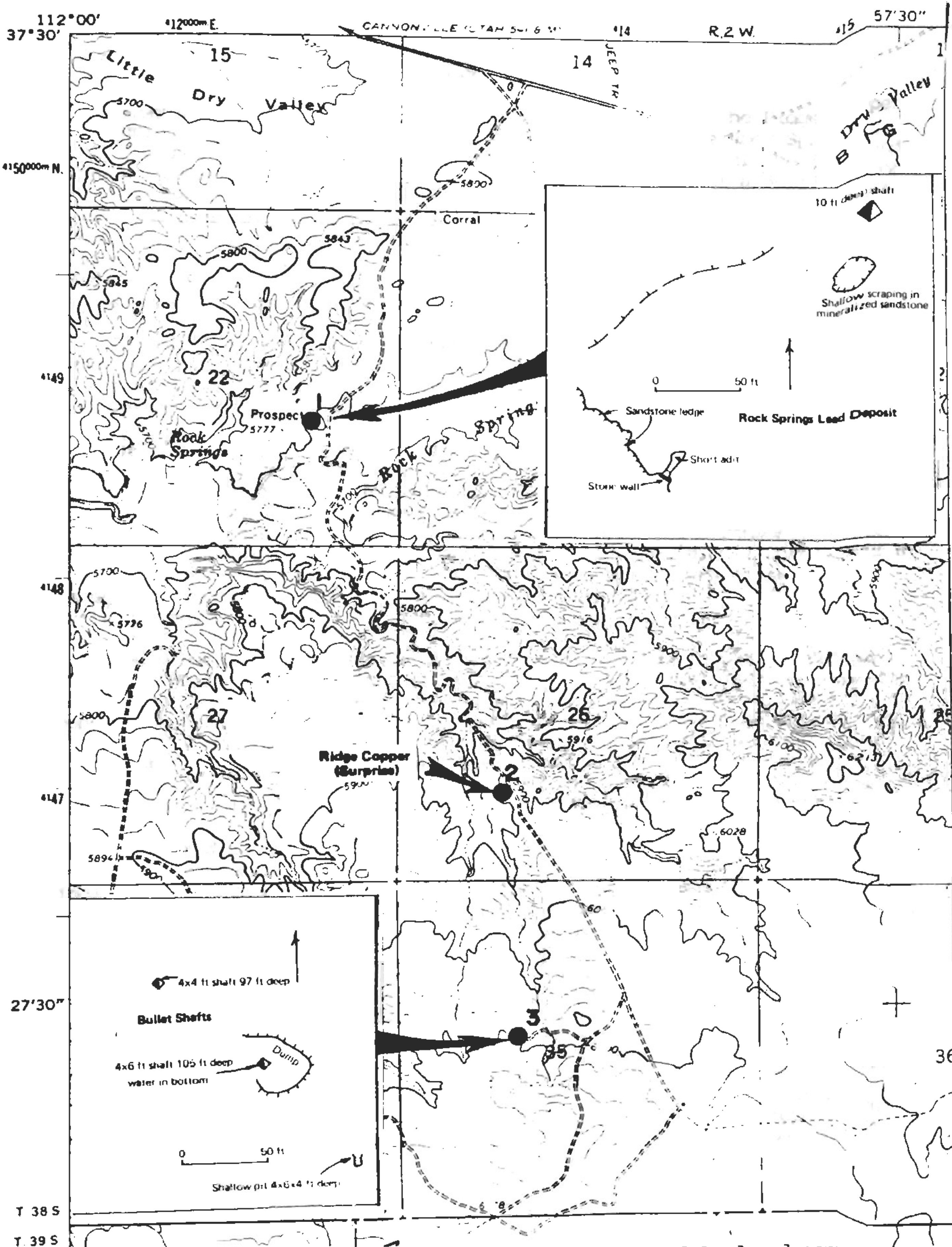


Figure 45. Map showing location and nature of workings of lead and copper occurrences south of Kodachrome Basin.

<u>Ridge Copper (Surprise) and Bullet Shafts deposits</u>. The Ridge copper or Surprise deposit is found about a mile southeast of the Rock Springs Creek crossing along the road which rises on the dip slope of the Thousand Pockets Tongue. Spotty mineralization affects 5 percent of a 50x1500 foot area that has its long axis paralleling the road. The "spots" consist of limonitized pods and small pipes in the sandstone. The copper oxides, chiefly malachite, occur as stains and scabs in iron concretions, iron nodules, or on fracture surfaces in the sandstone. Occasionally small patches of copper pitch and tiny blebs of cuprite are identifiable. Lead is also present as anglesite and is easily overlooked.

The workings are mostly shallow diggings, the largest of which is a 5x5x5 foot pit. Brown and Hannigan (1986, p. 15) analyzed a grab sample of a strongly mineralized nodule which yielded 10.4 percent copper and 1.1. percent lead. The sample also contained 5.3 ppm silver.

The Bullet deposits are located 3/4 mile south of the Ridge Copper deposit. The workings are found in a wooded area west of the principal road and consist of two relatively deep shafts and a shallow pit cut into mineralized pipes in the Thousand Pockets Tongue. Each working is about 80 to 85 feet apart along a N 45° W trending line. The northwesternmost working is a 4x4 foot shaft that is 97 feet deep. The middle working is a 4x6 foot shaft that is about 105 feet deep (the bottom was filled with water when examined), and the southeasternmost working is a 4x6x4 foot shallow digging or pit.

The mineralization is of copper and lead, but the copper is the most obvious. White anglesite is the lead mineral. The malachite, as coatings and scales, is sparsely scattered in pipes of iron oxide mineralized concretions, nodules, and irregular bodies that are present along the full depth of the shafts. Dump grab samples collected by Brown and Hannigan; the first of decomposed sandstone, the second from a small ore stockpile, yielded 0.08 and 6.3 percent copper respectively and 0.12 and 9.7 percent lead respectively. The latter sample also contained 5.9 ppm silver.

It should be noted that the area is one where a myriad of collapse features are present in San Rafael Group Formations. Unverified reports indicate many are mineralized, but prospecting was beyond the scope of this study (see Hornbacher, 1984). The collapse features are mostly vertical and generally circular in plan (see photos 61 and 62).

<u>Jodies Knoll deposit</u>. Copper-silver mineralization is found at the Jodies Knoll deposit near the south edge of the Skutumpah Terrace, NESWNW Sec 17, T 41 S, R 4 W. The host is the Thousand Pockets Tongue of the Page Sandstone. Spotty iron oxide and malachite stained and impregnated calcareous sandstone is exposed over 1 1/2 acres near the western pinchout of the tongue. Perhaps 5 percent of this area shows clearcut mineralization and most of this is weak. An analysis of a high-grade grab sample yielded 10.95 ounces silver per ton and 12.55 percent copper. The sample also contained 25 ppm lead and 875 ppm zinc. The workings consist of bulldozer scrapings and other surface disturbances (small pits).

Production from the deposit is not indicated, but some test lots may have been shipped.

Montezuma mines. A north-south trending belt, extending northward from Sec. 7, T 42 S, R 4 1/2 W to Sec. 20, T 41 S, R 4 1/2 W delimits an area of mineralization in the Navajo Sandstone main body that have been tested by numerous small workings. The upper parts of several crossbed sets are the most affected by the mineralization. Faults or fractures do not seem to be involved. The largest of these is in SE Sec. 30, T 41 S, R 4 1/2 W and is known as the Montezuma mine (photo 72). The mineralization consists of weak to moderate iron staining. No ore minerals are present. One analysis of the rusty sandstone yielded higher than normal concentrations of barium, chromium, and arsenic, but the precious and base metal content was very low. The mines may have been used to produce colored sand.

Titanium and zirconium

Titanium and zirconium minerals are found in several dark tan, reddish-brown, or dark purple sandstone lenses in the Straight Cliffs Formation in the southeastern Kaiparowits Plateau, notably in Ts 40 and 41 S, Rs 5 and 6 E. These sandstone lenses are fossil beach placers in the John Henry Member. So far, at least 14 individual deposits have been identified, although some may be parts of an originally single larger deposit. All are exposed at the surface and are undergoing erosion. The geometry of the lenses indicates that they are elongated and that the original beaches, in which the titanium and zirconium minerals were concentrated, were at least a mile in length. The identified deposits range to lengths of 1500 feet and widths of 400 feet. Observable thicknesses show most lenses to be 4 to 8 feet thick, although drilling in their central parts has indicated thicknesses to 15 feet (from a private report donated by Morris O. Rambo, 1986).

The sandstones vary considerably in color, resistance to erosion, and in heavy mineral concentrations. The sorting is moderate and fractions range from fine to coarse grained. Generally the zircon percentage improves in the finer grained fractions. Several of the deposits form benches and can be surface mined. Parts of others are covered with other strata.

Identified minerals include zircon, magnetite, ilmenite, rutile, quartz, calcite, monazite, garnet, sphene, hematite, and anatase. There appears to be no relationship between the amount of zircon present to the amount of titanium minerals present. A small amount of gold has also been detected (to 0.04 oz./ton). Peterson (1969, p. 73) reports on the mineralogical composition of 5 samples taken from one deposit and Bureau of Mines' investigators V. T. Dow and J. Vance Batty (1961, p. 11-14) examined the deposits and took several samples for analysis.

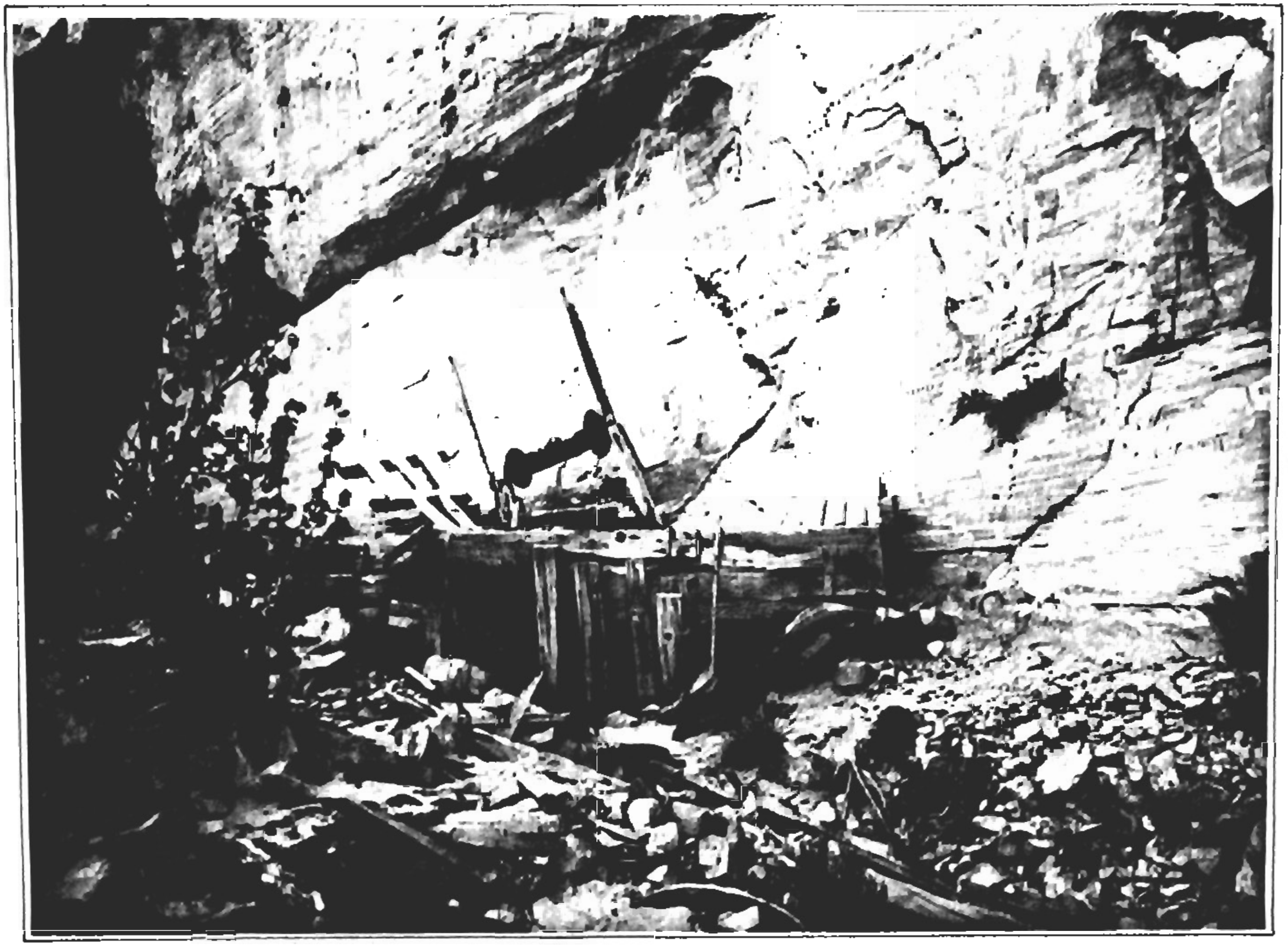


Photo 72. Abandoned mine shaft at the Montezuma mine near Johnson Canyon. Development occurs along rusty zones in the Navajo Sandstone.

Table 19. Various analyses of titanium-zirconium deposits in Kane County.

From Peterson (1969, p. 73):

Opaque minerals	73%	(magnetite and titanium minerals)
Zircon	22%	
Rutile	2%	
Garnet	2%	
Tourmaline	1%	
Staurolite	<0.5%	
Sphene	<0.5%	
Apatite	<0.5%	

From Dow and Batty (1961, p. 11-14):

	Sargent Dep. 5-40S-5E	U-249 Dep. 5-40S-5E	Mann Dep. 8-40S-5E	Croton, Sunday Cyns, several locations
TiO_2	9.5%	23.9%	22.5%	13.5%
ZrO_2	2.9%	7.0%	7.3%	3.7%
Fe	8.3%	16.2%	21.1%	12.7%
$eThO_2$	0.06%	0.09%	0.09%	0.08%

The best developed deposit(s) are those of the Long Shot claims, Mann claims, or TZ group claims. The deposit was drilled and analyzed and an estimate was made of the ore reserves. From a private report (Morris O. Rambo, 1986), this deposit contains from 450,000 to 550,000 tons average 11 percent zircon and 22 percent titanium minerals. Some of the other deposits may approach these concentrations, but many are known to be of lower grade.

Titanium is a metal whose chief ore minerals are ilmenite and rutile. Although both are found in the Kane County deposits, they are dominated by ilmenite. Ilmenite is used in the manufacture of titanium dioxide for pigments—for use in paint, enamel, lacquer, paper, rubber, floor coverings, and textile products. Titanium dioxide pigments have high opacity or covering power, are relatively light, and are chemically inert. Ilmenite contains titanium, iron, and oxygen ($FeO.TiO_2$), whereas rutile (TiO_2) is natural titanium dioxide. Therefore the price of rutile is generally about 6 times as high as that for ilmenite. The latter is therefore favored in the production of titanium metal, for steel alloys, and in fiberglass. The metal is relatively light, strong, and resistant to corrosion and its alloys are used in aircraft and jet engines.

Zirconium was called the "Cinderella" metal after World War II because of its high resistance to heat and entered the market place as a structural material for nuclear reactors. Zirconium minerals can be used with or without processing and zircon is the chief mineral. Zircon is an orthosilicate of zirconium ($ZrSiO_4$) and contains 1/2 to 2 percent Hafnium in its crystal lattices and is the most abundant source of this metal. Zircon is used as foundry sand (47%), as a refractory (22%), in ceramics (10%), as an abrasive (6%), with the remainder (15%) used in the manufacture of chemicals, zirconium metal and alloys, and for nuclear applications.

The Kane County deposits are located in a remote area and the ore must be upgraded and processed in place in order to compete in the market place. Processing will require a cheap source of electricity and water. The possibilities are favored by the presence of the Kaiparowits Plateau coal deposits (for electrical power generation) and that the possibilities of increasing the reserve through additional drilling and prospecting are great.

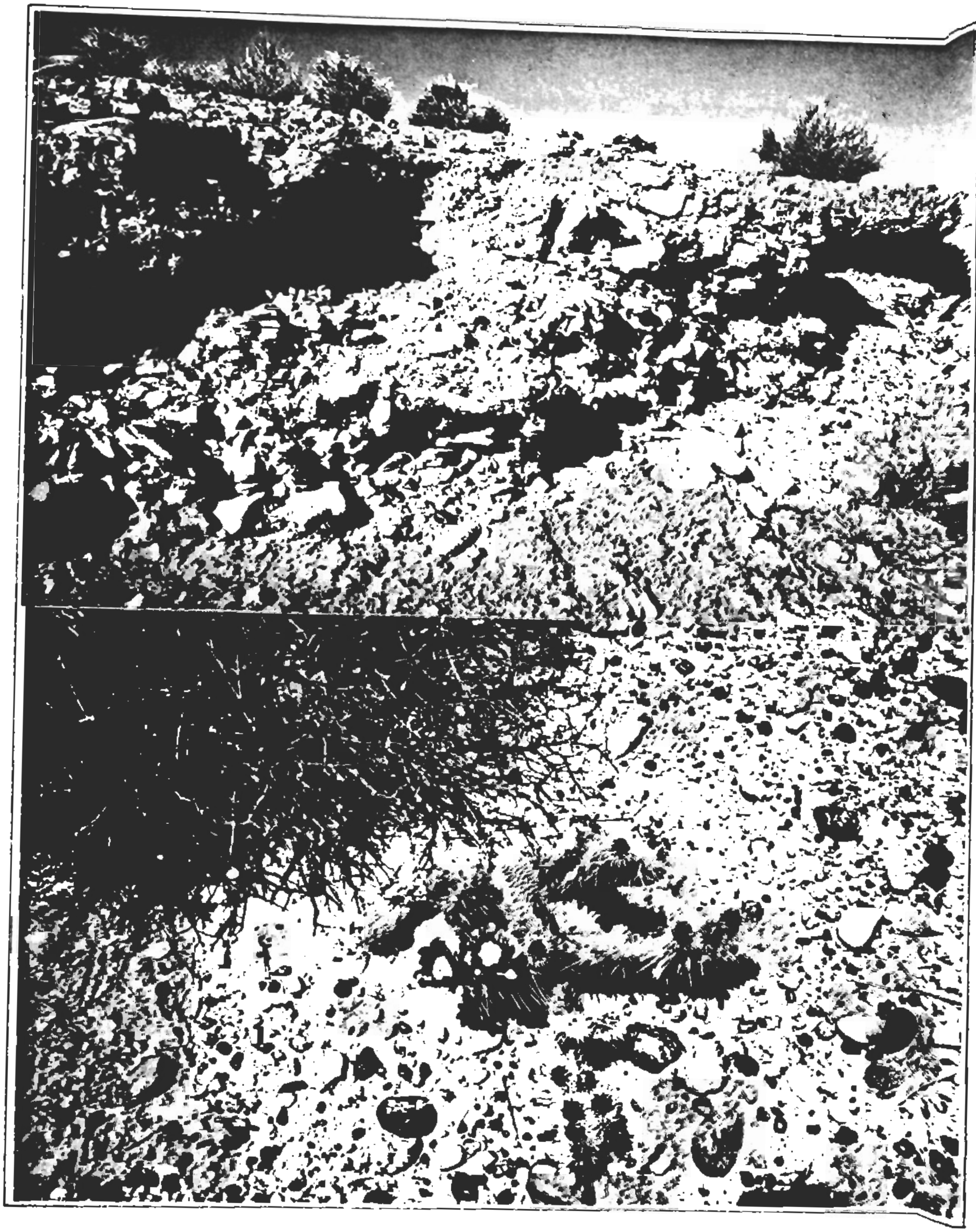


Photo 73. Sand and gravel for highway construction has been Kane County's most valuable commodity. The upper view shows partly calichified (partially cemented) gravels on benches near the Bullfrog marina.

Industrial and Construction Materials

Industrial and construction materials in Kane County include sand and gravel, limestone, gypsum, building stone, volcanic cinders, clays, and glass sand. Miscellaneous deposits, specifically those that fall in the gem materials classification, are included. The large deposits of gypsum, the various clay deposits, and limestone are resources that have not been mined as yet.

Sand and Gravel. Sand and gravel, by far, have been the greatest economic natural resources taken from the earth in Kane County (photo 73). Large tonnages have been used in concrete for home and building foundations, driveways, bridges, and in bituminous mixtures for highway pavements. The single greatest use has been for highway construction.

Many of the early homes were built of stone held together by mortar which required much sand. The population of the county slowly increased and during the late 1920s the gradual improvement and paving of the main roads began. In 1928, Bryce Canyon became a national park, and, in 1930 a tunnel and a highway was completed linking Zion National Park and Washington County to Kane County, opening a previously dead end drive with the other nearby national parks and monuments. In the 1950s tourism became important and more road miles were upgraded and paved. From 1961 to 1963 almost $19 million worth of sand and gravel were used in building U. S. Highway 89 between Kanab and Page, Arizona, and for the construction of the Glen Canyon dam.

Sand and gravel that meets construction specifications are not abundant in the county, however, there has been a fortunate distribution of excellent deposits that do. During 1967, geologists of the Utah Department of Transportion (U.D.O.T.) investigated and inventoried 27 material sites (table 20). Several reserve quantities, as expressed on this table, were increased because of additional mapping. Six of the sites were for rip-rap or borrow. The best sand and gravel sites occur in 6 areas: (1) southern Long Valley, (2) south of Mt. Carmel Junction, (3) Kitchen Corral Wash, (4) adjacent to the Paria River south of U. S. Highway 89, (5) adjacent to Wahweap Creek, and (6) the Bullfrog area. These deposits were mapped under the symbol Qag (alluvial gravel) on the geologic map. Not all the fields on the map marked Qag are suitable sand and gravel deposits for construction purposes, the best are the old stream terrace deposits. The ancient streams that deposited these gravels originated in the rocks on the Markagunt Plateau, Paunsaugunt Plateau, Canaan Mountain, and the Henry Mountains to the north. During transportation the softer rock types were disintegrated and carried away as sand and silt. Consequently, the deposits of these old streams contain an abundance of indurated, well rounded, hard-rock types, namely quartzite, quartz, limestone, and dense igneous rocks. It appears that the basal conglomerate beds of the Claron Formation supplied much of these gravels to the first 5 areas. Erosion of the Henry Mountains supplied the gravel to the Bullfrog area.

<u>Southern Long Valley</u>. These river terrace deposits are located south and southwest of Orderville in the SW Sec. 4 and the NW Sec. 9, T 41 S, R 7 W. The deposits contain bedded and graded sand and gravel that ranges to 50 feet in thickness. The gravel is mainly subangular to rounded gray quartzite and gray limestone and subordinate tan sandstone. Two pits have been opened in the deposit: one is U.D.O.T. pit 13003 (when all the counties of Utah are arranged in alphabetical order, Kane County is No. 13) and the other had not been opened before 1967. Material from these pits were used in upgrading U. S. Highway 89 in Long Valley as well as other construction uses. The samples from both pits have good test characteristics - low swell, low abrasion, low sodium sulfate loss, and a small amount of silt and clay (material passing the No. 200 sieve). These data substantiate that the sand and gravel is suitable for aggregate in concrete and bituminous mixtures. A substantial reserve remains in the area.

<u>South of Mt. Carmel Junction</u>. The largest pit area in the county is located 1.4 miles south of Mt. Carmel Junction and 0.3 miles east of present U. S. Highway 89. The gravel has been used by U.D.O.T. and others for many years. In October, 1985 there were 4 large pits at slightly different elevations in the N 1/2 Sec. 31, T. 41 S, R 7 W. Exposures reveal gravel to 14 feet in thickness and much of it is in well graded gravel lenses that gradually and laterally change into brown sand. Clasts are subrounded to round and consist of limestone, quartzite, and hard sandstone. In many place the upper 3 or 4 feet of gravel is a hardpan cemented by calcium carbonate.

This area includes U.D.O.T. pit No. 13010. Samples from several exposures were obtained and tested in 1964, 1967, and 1980. All test characteristics were good and the sand and gravel meets the specifications for concrete and bituminous aggregate. There is a large reserve in the area; the estimated 1 million cubic yards is a conservative figure.

<u>Kitchen Corral Wash</u>. An extensive old river terrace deposit is just east of and parallel to this wash near U. S. Highway 89. Two pits, one south of the highway and one north, have been opened in the deposit. The exposed gravel is 20 to 40 feet thick and it is well cemented in places. The gravel is graded and very few cobbles exceed 3 inches in diameter. The clasts are subrounded to round quartzite (60%), limestone (30%), and sandstone (about 10%) with a few scattered conglomerate boulders. The pit south of the highway was inventoried by the U.D.O.T. as site No. 13016, but that small area is almost mined out. By far, the largest reserve is in the old terrace north of the highway in the E 1/2 Sec. 23, T 42 S, R 3 W. The test data on material from both pits are good. The sand and gravel from this old river terrace deposit is suitable for use in concrete and bituminous mixtures.

<u>Adjacent to the Paria River south of U. S. Highway 89</u>. The Paria River also has an old river terrace along the east side in this area. Auger holes have proven at least 11 feet of gravel, mostly subrounded to rounded quartzite pebbles and cobbles. The U.D.O.T. inventoried one pit (13022) and three potential material sites (13019, 13020, and 13021) along

the river. Test data indicate that the sand and gravel meets specifications as aggregate in concrete and bituminous mixtures. The listed reserves at the 4 sites are very conservative; probably millions of cubic yards are present along the length of the old river terrace.

Farther north along the Paria River additional terrace gravels are available (especially SE Sec. 6 and NE Sec. 7, T 38 S, R 2 W), largely composed of quartzite materials, that should make excellent aggregate.

Adjacent to Wahweap Creek. An extensive old river terrace deposit is present on the bluffs that parallel Wahweap Creek on its southwest side. Several pits have been opened in the deposit east and northeast of Big Water (Glen Canyon City) in the E 1/2 Sec. 11, T 43 S, R 2 E. The U.D.O.T. listed one of these as pit 13024. The gravel is graded, is mainly quartzite, and is at least 12 feet thick throughout most of the deposit. It extends for several miles northwest and southeast of Big Water. Samples tested over the years show that the material meets specifications for concrete and bituminous aggregate. There are probably several millions of cubic yards remaining in the deposit. Its latest use was for highway construction in Arizona (highway repair south of Page).

Bullfrog area. Veneers of sand and gravel cap most ridges and knolls in this area. Small alluvial aprons, locally thick (to 30 feet), extend downslope from many of the caps. On some of the ridges and knolls a zone of hard, white caliche has formed that ranges from 1 to 4 feet in thickness. They were deposited by ancient rivers on a pediment which is now being removed by erosion. The sand in these deposits is fine grained, subrounded, and quartzose. The gravel is very hard and consists of angular to subrounded diorite (30%), gray, white, brown, and black quartzite (45%), gray and brown sandstone (10%), and tan, red, brown, and black chert (15%). The gravel is fairly well graded and 90 percent of the clasts are 0.25 to 1.0 inches in diameter.

A fairly large gravel pit is present about 2 miles ESE of Bullfrog marina in Stanton Canyon (SE Sec. 9, T 38 S, R 11 E). The excavation is about 500 feet north-south and 80 feet east-west. Thirty feet of well-graded, previously described gravel is exposed in a highwall. Presumably, material from this pit was used in construction of the highway near Bullfrog as well as other facilities near the marina. The U.D.O.T. did not inventory any material sites in the region; therefore no test data are available. However, judging from the hardness of the rock types, the apparent gradation, and other aspects, it quite likely makes good conrete and bituminous aggregate. The pit can be extended north at least 500 feet, west at least 60 feet, and south about 200 feet. This pit plust other Qag deposits should provide ample reserves for future construction use in the Bullfrog area.

Other sand and gravel areas. There are several other areas that might be exploited for sand and gravel. The previously discussed deposits cover areas that have been convenient for highway construction. The "other" areas have not been tested or prospected for their potential, but some are rather large. There are very large gravelly pediments that have developed on Cretaceous and Jurassic deposits on the Podunk and Skutumpah Terraces below the Pink Cliffs. Such gravelly pediments cover similar rocks in the northern part of the Paria Region. It is assumed that the source of the gravels is from the basal part of the Claron Formation and hence, should have the favorable characteristics necessary for good construction material. Another very large gravel deposit rests on Horse Mountain in the northern part of the Kaiparowits Plateau. The deposit is 7 or 8 miles long and averages 2 miles in width. Again the source must be the basal Claron Formation. The deposit rests on the Kaiparowits Formation and probably is 20 or more feet in thickness. Smaller gravel deposits parallel the streams and washes in the western Kaiparowits Plateau, and, in addition to Wahweap Creek, Warm Creek and Last Chance Creek are lined with them.

Volcanic cinders

There are 14 volcanic cinder cones in the western half of the county. All except four of these are on the Markagunt Plateau or Kolob Terrace. The remainder are found on the Skutumpah and Podunk Terraces. The pyroclastic cinders and ash that build up the cones all have fairly similar textures, composition, size ranges, and colors. The cinders and ash are cellular, frothy, lightweight, and mostly range in size from 1/4 inch to 2 inches in longest dimension. Larger pieces occasionally found usually are fractured and soon break up into the above noted size ranges. Comparatively little volcanic dust is present. Colors are reddish-brown through gray and black. The cinders are thought to be the last offshoots of a viscous, highly gaseous, olivine basalt magma.

Material from three volcanic cinder cones has been used for dirt road surfacing on the Markagunt Plateau (photo 74). These cinder pits are located in the (1) NWNW Sec. 11, T 38 S, R 9 W, (2) NENE Sec 9, T 38 S, R 8 W, and (3) SESW Sec 10, T 38 S, R 7 W (Strawberry Knolls). The U.D.O.T. inventoried (2) as pit number 13001 in the county. The reddish-brown to black cinders do not meet the abrasion requirements for base or surfacing aggregate on standard highways. However, on many dirt roads, the cinders get packed down and provide a good driving surface. The National Forest Service uses the material on their roads and such surfaced roads have the advantage of not getting as muddy during wet weather. An additional cinder pit was opened on the flank of Black Knoll, east of Glendale, but it is not known where the material was used. Use from this pit has been minimal and it may have been used by local ranchers to surface approach roads to fields and homes.

Possibly the best future use of the cinders would be as lightweight aggregate. The cinders from all the cones appear to be strong, durable, and to contain sufficient voids in their natural cellular condition. They are considerably lighter than the sand and gravel normally used in concrete. When larger buildings are contemplated for construction, some consideration might be given to using the cinders as lightweight aggregate to manufacture pre-stressed and pre-fabricated concrete items. This would reduce the total load on the reinforcing steel in the building as well as permitting lighter handling and transport.

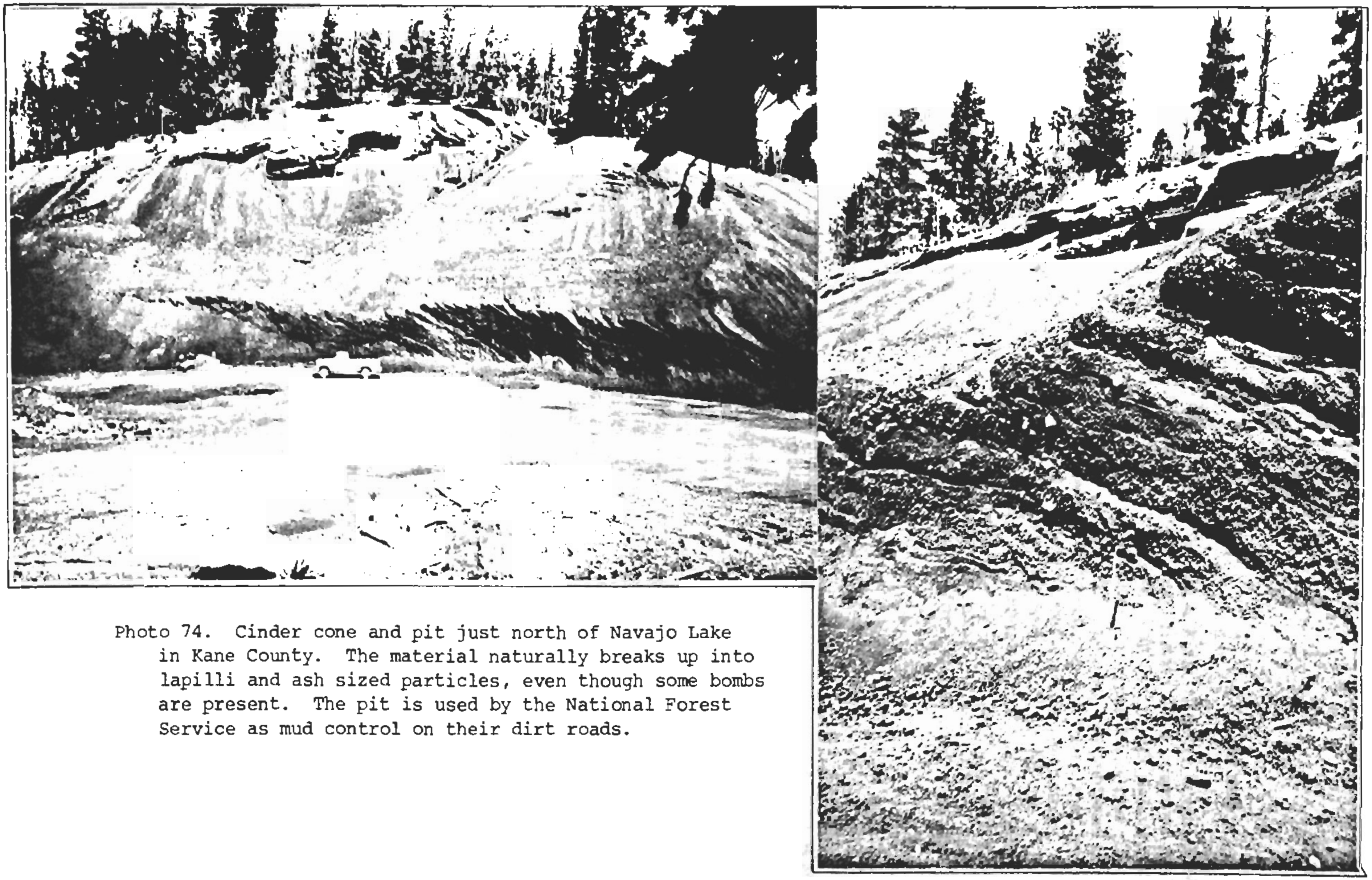


Photo 74. Cinder cone and pit just north of Navajo Lake in Kane County. The material naturally breaks up into lapilli and ash sized particles, even though some bombs are present. The pit is used by the National Forest Service as mud control on their dirt roads.

Glass sand

The major requirement for glass sand is a high silica content which is at least 93 percent for ordinary container glass, and over 99 percent for optical glass. Glass is made of a mixture of 52 to 65 percent quartz sand by weight plus soda ash (Na_2CO_3) and lime. Aside from the silica content the main concern in the glass industry is the percentage of impurities in the sand. Iron, chromium, cobalt, manganese, and several other elements are strong colorants, even in very small amounts. Alumina, however, is needed in the mix and may be present in sand up to 4 or 5 percent. Generally, grain sizes should be between 0.590 and 0.105 millimeters, but grain shapes do not seem to be important. Very few natural sands or sandstones meet the exact specifications and beneficiation becomes necessary, especially for removal of clay and iron oxides.

There are numerous sandstone formations in Kane County, but only the Navajo Sandstone and derived sand dunes have been tested specifically for use as glass sand. For the present four samples of Navajo sandstone and derived sand were tested: (1) one sample each from the lower and upper adits of an old glass sand mine about 4.5 miles north of Kanab (Lamb Point Tongue of the Navajo Sandstone), (2) a sample of dune sand in the Sand Hills area adjacent to U. S. Highway 89, (3) a sample of the Coral Pink sand dunes, and (4) the Navajo Sandstone in the Paria-Hackberry Wilderness Study area. The first three samples were submitted to a commercial laboratory in Salt Lake City for major oxides and selected elemental determinations. Brown and Hannigan (1986, p. 11), sampled and tested the fourth sample for suitability as glass sand. The test data, exact locations, and remarks are given in tables 21 and 22 (see also figure 46 and photos 75 and 53). Brown and Hannigan (p.11) state that the Navajo sand could be used in the manufacture of ordinary colored container glass.

From all indications Navajo sand probably could also be used for fracturing sand, foundry sand, filter sand, and abrasive sand (sandblasting, sandpaper, metal polishing, stone sawing, etc.), as well as industrial chemical uses.

Limestone and Dolomite

Limestone is mainly calcium carbonate ($CaCO_3$), and, in addition to being a precipitate, may also originate from the accumulation and cementation of fossil animal shells and plants. Dolomite contains considerable magnesium in the form of $(CaMg)CO_3$). Limestone is processed for use in the production of cement, refractories, fluxstone, lime products, filtration, poultry grit, coal mine rock dust, filler, calcium carbide, and other chemicals. Limestones containing more than 95 percent $CaCO_3$ are called "high-calcium limestones" and they are desirable for the manufacture of lime, cement, and chemicals.

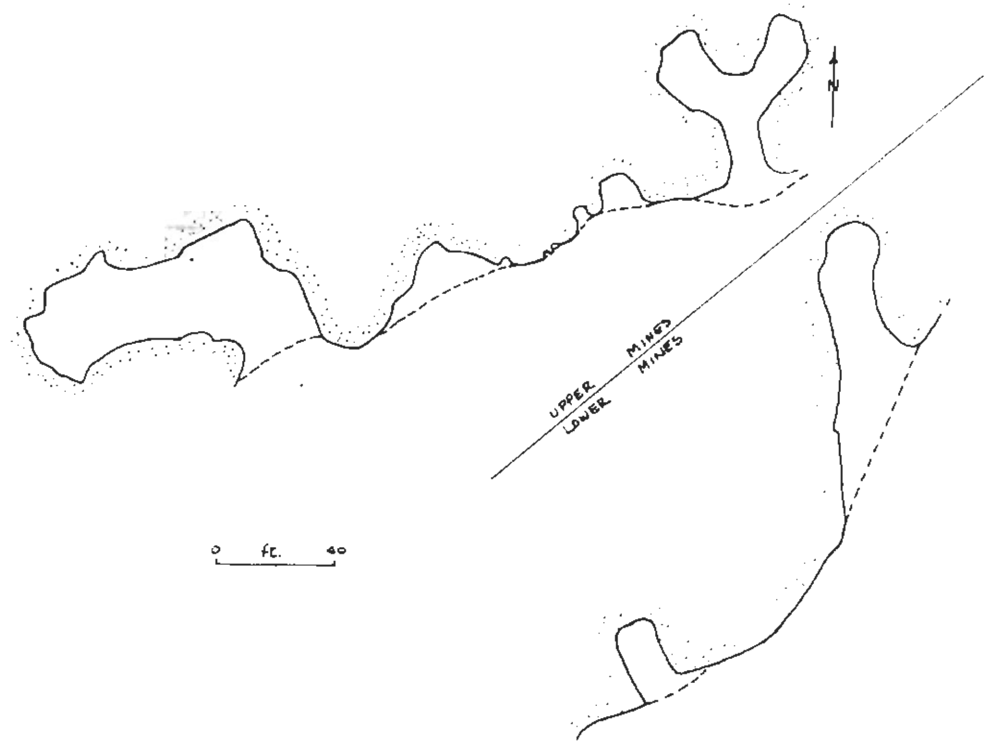
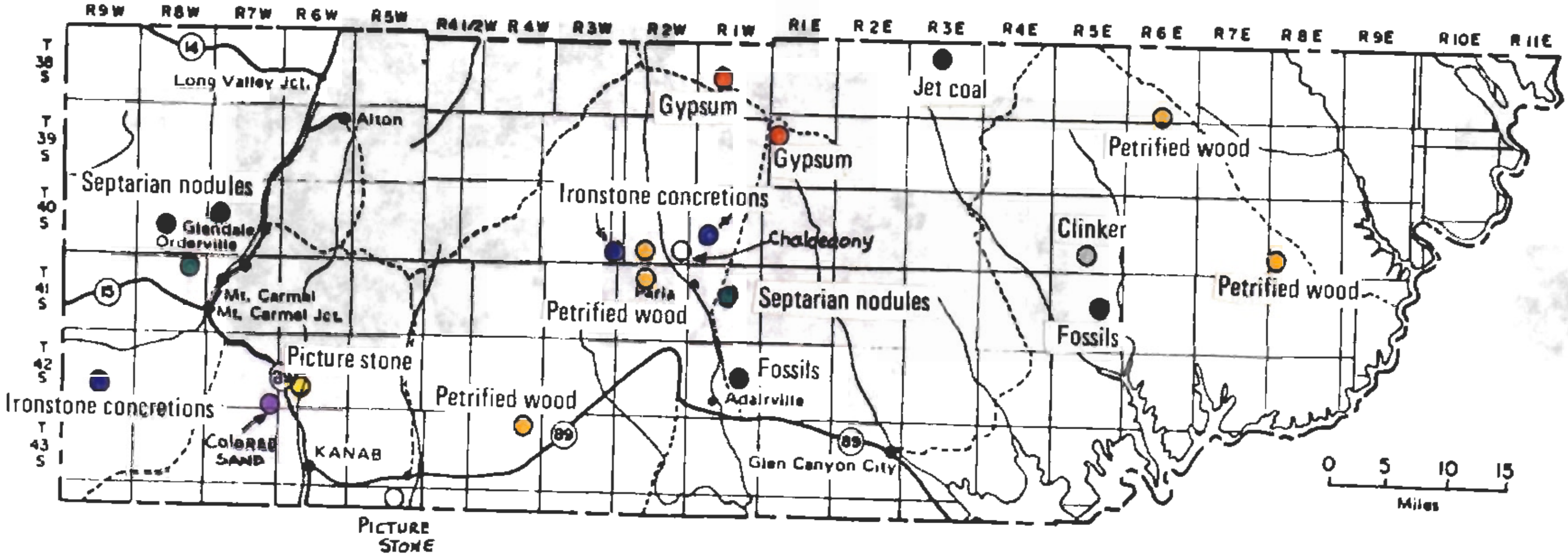


Figure 46. Mine outline maps of sand mines located near the confluence of Kanab Creek and Three Lakes Canyon, Sec. 32, T 42 S, R 6 W.


R9W
R8W
R7W
R6W
R5W
R4 1/2W
R4W
R3W
R2W
R1W
R1E
R2E
R3E
R4E
R5E
R6E
R7E
R8E
R9E
R10E
R11E
T 38 S
T 39 S
T 40 S
T 41 S
T 42 S
T 43 S
Long Valley Jct.
Alton
Gypsum
Jet coal
Petrified wood
Septarian nodules
Glendale
Orderville
Ironstone concretions
Chalcedony
Clinker
Mt. Carmel
Mt. Carmel Jct.
Paria
Petrified wood
Septarian nodules
Fossils
Picture stone
Petrified wood
Fossils
Adairville
Ironstone concretions
Colored Sand
Kanab
89
Glen Canyon City
Picture Stone
0 5 10 15
Miles

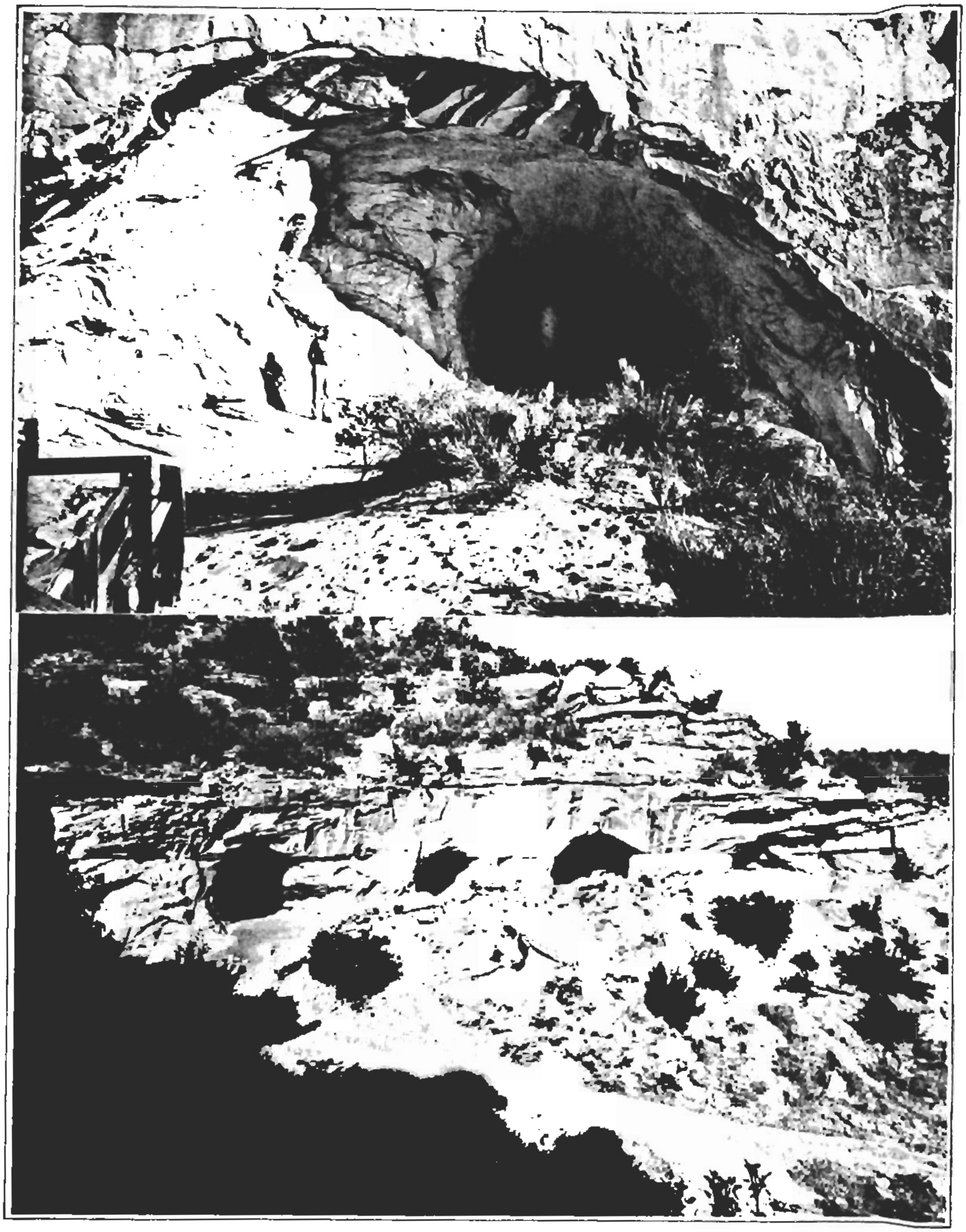


Photo 75. Sand mines near the confluence of Kanab Creek and Three Lakes Canyon. The upper is an abandoned glass sand mine, the lower is a mine with colored sand used to fill decorative bottles.

Disk 1: KANETBLZ

A3 7/8 A4 56 A3 56

Table 20. Utah Department of Transportation Inventory of Material Sites in Kane County

Pit or Site #	Location	Owner	Use of Material	Type of Deposit	Material: Present estimated quantity (cubic yds)	Material: Thickness of material	Material: Depth of overburden	Date sampled	Type of sample	
13001	NWNE-9-38S-8W	National Forest	Base Gravel, Surface Gravel	Cinder Cone	200,000+	50	0-3	1961	Cut Bank	
13002	SENE-30-39S-6W	A. Pugh	"	Talus	800,000+	30+	0-5	1967	"	
13003	SWSW-4-41S-7W	L. Heaton	"	River Terrace	600,000	50	2-5	1965	"	
13004	SENE-18-41S-7W	R. Esplin	"	"	190,000	6	0-1	1960	Test Hole	
13005	SENW-19-41S-7W	E. Sorensen	Rip Rap	Bedrock	100,000	10+	0	1961		
13006	NWSW-9-41S-8W	K. Fairchild	Base Gravel, Surface Gravel	River Terrace	Mined Out			1967	Test Hole	
13007	SESW-8-41S-8W	B.L.M.	Borrow	Talus	Mined Out					
13008	SENE-25-41S-8W	"	Borrow & Rip Rap	Stream Channel	30,000	5	0	1959	Cut Bank	[illegible]
13009	NWSW-30-41S-7W	"	Base Gravel, Surface Gravel	River Terrace	Mined Out					
13010	NWNW-31-41S-7W	"	"	"	1,000,000+	14	0-5	1964	Cut Bank	[illegible]
13011	SWNE-9-44S-6W	B. McAllister	"	Residual Cap	Mined Out			1952	Open Face	
13012	SESE-32-42N-2W	State of Arizona	"	"	Mined Out					
13013	NWNW-6-44S-4W	B.L.M.	Borrow	Stream Channel	80,000	10	0-1	1956	Open Face	
13014	SENW-13-43S-5W	"	Base Gravel, Surface Gravel	River Terrace	300,000	5	0-1	1962	Cut Bank	5
13015	NWNW-35-42S-5W	A. Judd	"	"	18,000	5	0-1	1962	Open Face	
13016	NENE-26-42S-3W	B.L.M.	"	"	1,000,000+	20	1-3	7-63	Test Hole	5
13017	SWSW-1-42S-2W	"	Rip Rap	"	16,000	10	0	1965	Open Face	
13018	E1/2NE-35-42S-2W	"	Base Gravel, Surface Gravel	"	Not Meas.			1956		
13019	SWSW-27-42S-1W	"	"	River Terrace	200,000+	10	0	1966	Open Face	8
13020	SWNE-33-42S-1W		"	"	200,000+			1957	"	
13021	NENE-4-43S-1W		"	Stream Channel	Not Meas.			1956	"	
13022	SENW-3-43S-1W	B.L.M.	"	River Terrace	600,000+	30	0-1	1964	"	
13023	NWSW-12-42S-2E	"	"	"	Not Meas.			1964	Cut Bank	
13024	SWNE-11-43S-2E	"	"	"	1,000,000+	12	3-5	1965	Test Hole	1
13025	NWSW-12-43S-2E	"	"	Stream Channel	24,000	10	0-1	1965	"	0-
13026	SWNW-29-43S-3E	"	"	River Terrace	250,000	10	15	1964	Cut Bank	5
13027	SENE-32-43S-3E	Private and B.L.M.	Borrow	"				1956		

UDOT Material Inventory of Kane County, 1968.

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Table 19. Utah Department of Transportation Inventory of Material Sites in Kane County

	Depth of Sample	Sieve analysis: Before Crushing 3"	Before Crushing 1"	1"	1/2"	Percent passing after crushing to 1" max. size No. 4	No. 10	No. 40	No. 200	Liquid Limit	Plasticity Index	Swell	Immersion compression average psi: Lime wo/	Lime w/	Abrasion 500 rev.	Sodium sulphate loss +4	Sodium sulphate loss -4
k			15	100	82	59	42	9	2						49		
		100	100	100	80	45	30	10	5						16	0	8
	15	7	37	100	66	39	31	17	5	15	NP	.003	160	360	33	11	13
le	9	10	33	100	74	45	37	26	9	17	NP	.007			38		
															50		
le	5	0	17	100	72	51	43	28	7		NP	.002	-	235	20	6	15
k	No Crushing			100		100	99	96	31	16	NP				40		
k	8	2	23	100	70	40	30	16	4	14	NP	.001	246	432	26	10	8
ce		7	33	100		51	40	33	11	16	NP	.021			25		
ce		0	0	100		97	92	45	10	13	NP						
k	5	0	28	100	70	42	34	28	9	18	NP	.011			30		
ce		0	13	100	79	53	45	35	10	15	NP	.01			27		
ole	9	3	25	100	69	47	40	22	6	14	NP	.002	74	167	34	8	6
ace															24		
		36	53	100		40	27	14	6	18	NP	.01			37		
ace	8	11	35	100	66	36	27	16	5	16	NP	.007			25	1	6
		17	30	100		36	25	18	6	17	NP	.03			22		
		11	69	100		31	21	15	5	16	NP	.028			34		
		9	31	100	71	39	29	15	4	16	NP	.01			20		
k		3	33	100	61	30	23	15	3	16	NP	.001	321	462	18	4	5
ole	10-20	0	20	100	70	62	47	34	11	19	NP	.024	173	233	14	.5	3
	0-10	0	46	100	67	48	42	27	6	18	NP	.02			14	.6	8
k	5	3	21	100	70	38	30	18	4	16	NP	0.0	317	512	20	5	8
				99		77	54	41	3	16	NP						

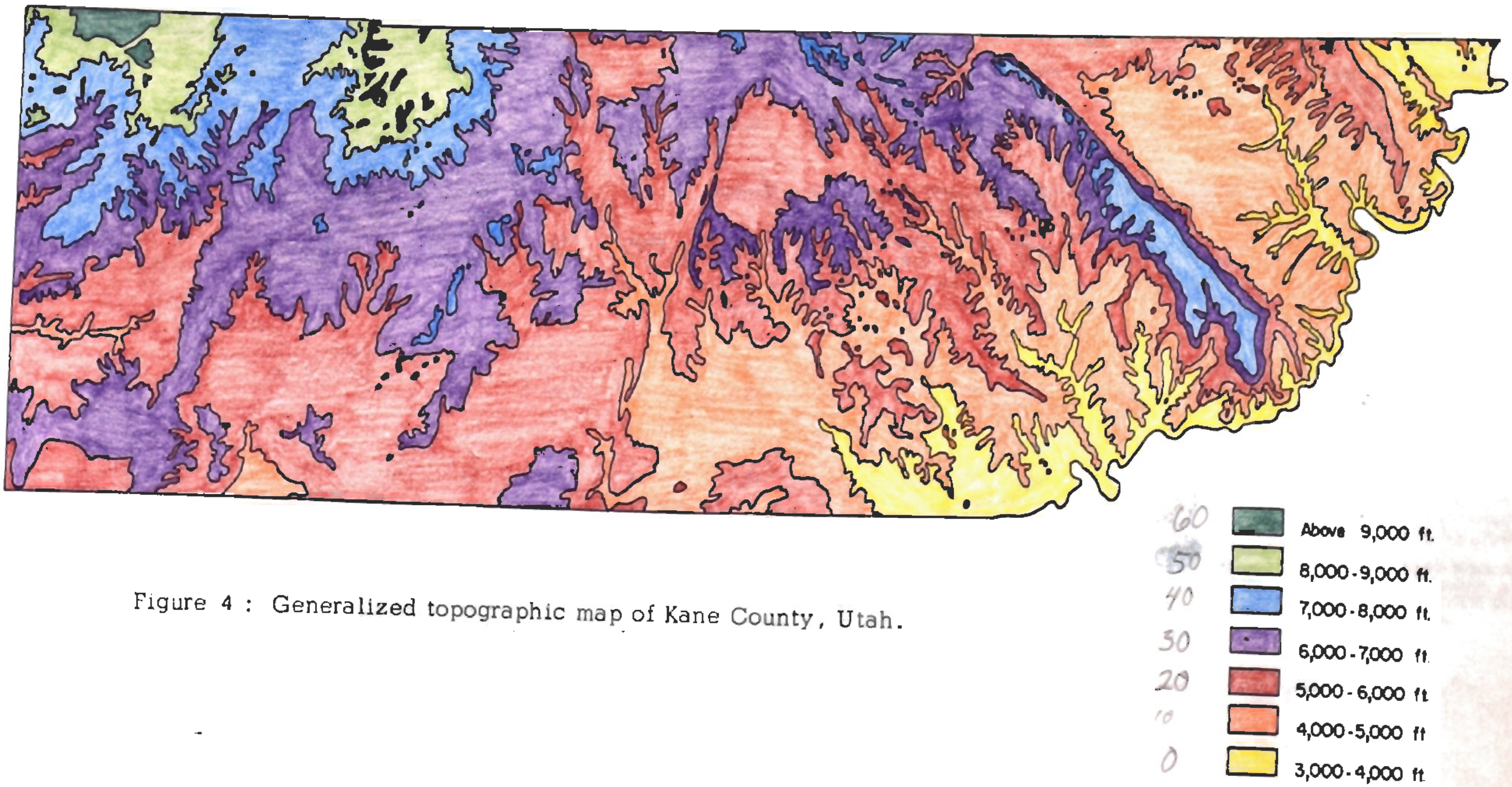


Figure 4 : Generalized topographic map of Kane County, Utah.

Table 21. Glass sand test data for Navajo Sandstone and derived sand dunes

Sample no.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	CaO %	Sodium as Na%	Potassium as K%	Titanium as Ti%	Manganese as Mn%	Location and remarks
1	97.99	0.22	0.20	0.16	0.03	0.037	0.133	0.001	0.001	Upper adit or old glass sand mine in the SESENW sec. 32, T.42S., R.6W.
2	98.30	0.25	0.16	0.02	0.05	0.028	0.182	0.001	0.002	Lower adit of old glass sand mine in the SESENW sec. 32, T.42S., R.6W.
3	99.50	0.50	0.13	0.02	0.05	0.036	0.050	0.001	0.007	Dune sand in The Sand Hills, sec. 10, T.42S., R.7W.
4	99.20	0.30	0.11	0.01	0.06	0.039	0.024	0.001	0.005	Sand from the Coral Pink sand dunes, NENWNW sec. 17, T.42S., R.7W.

Table 22. U.S. Bureau of Mines glass sand test data for Navajo Sandstone (__, not detected; detection limit for P_2O_5:100 ppm)

Sample no.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	K_2O %	CaO %	MgO ppm	Na_2O ppm	P_2O_5 ppm	TiO_2 ppm	Location and remarks
1	96.0	1.7	0.30	0.76	0.17	300	310	--	610	Quartz sandstone outcrop; massive, fine grained, minor limonite stains; NESE sec. 6, T.39S., R.1W.
2	96.5	1.5	0.21	0.84	0.13	790	390	290	250	Quartz sandstone outcrop; massive, fine grained, minor limonite stains; NWSW sec. 27, T.38S., R.3W.
3	93.7	2.7	0.33	1.3	0.04	950	410	230	670	Quartz sandstone outcrop; white, fine grained, minor traces of iron and manganese; NWSE sec. 9, T.41S., R.1W.
4	96.7	2.0	0.30	0.54	0.23	640	170	250	430	Quartz sandstone outcrop; massive, fine grained, some limonite stains; SESE sec. 34, T.40S., R.3W.

In eastern Kane County limestone units are very thin and negligible. In the western part of the county limestone is present in the following units: (1) Toroweap Formation, containing sandy, thick-bedded to massive limestone beds, (2) Kaibab Formation, with thick beds of cherty limestone, (3) Timpoweap Member of the Moenkopi Formation, with thin sandy limestone beds, (4) Kolob Limestone Member of the Carmel Formation, with thick sandy limestone and shaly limestone beds, and the (5) Claron Formation, which form the Pink Cliffs. Additionally there are thin beds of limestone and dolomite in the Virgin Limestone Member of the Moenkopi Formation, Chinle Formation, Kayenta Formation, Navajo Sandstone, and the Paria River Member of the Carmel Formation. Of these units the Kolob Limestone Member and Claron Formation are more suitable for use by virtue of accessibility and extent.

The Kolob Limestone Member of the Carmel Formation was sampled at several places in the western part of the county. The samples were analyzed for quantitative oxides and, more specifically, for whole rock analysis for use as cement rock (table 23). In most of the places sampled the material consisted of blocky medium to thick bedded rock. The remainder of the samples were of thinbedded, argillaceous limestone. The table also displays quantitative data from two commercial cement rock quarries operative in north-central Utah.

Analyses for the Claron formation carbonate rock are not available for Kane County. Certainly all the carbonate (both limestone and dolomite) rocks of the county would produce suitable crushed stone. Again the Kolob and Claron units would be most favorable because of their thickness and extent.

Building Stone

The most important qualities of a good building stone are ease of quarrying, durability, color, strength, low porosity, textures, hardness, and workability. Also, the rock should be free of closely spaced cracks, joints, bedding planes, or other lines of weakness. The uniformity of all these qualities is also desirable throughout a prospective deposit.

In the western part of the county the settlers used field stone and quarry stone mostly from three rock units for home and building construction: Moenkopi Formation, Moenave Formation, and the Kolob Limestone Member of the Carmel Formation. In the old town of Paria many home foundations were made using the blocky sandstone from the Moenave Formation. The walls of many of these homes consisted of cut and broken sandstone of the Moenkopi Formation (probably the Virgin Sandstone Member). Its flaggy and very flatbedded nature was especially prized and valued to form windowsashes. In Kanab, the old city and county building (now torn down), was constructed of sandstones of the Moenave Formation. In Mt. Carmel, the old schoolhouse (still standing) was constructed of dimension stone from the Kolob Limestone Member. Another pioneer building in Orderville, an old L.D.S. bishop's storehouse, was also constructed of dimension stone from the Kolob Limestone Member (photo 76).

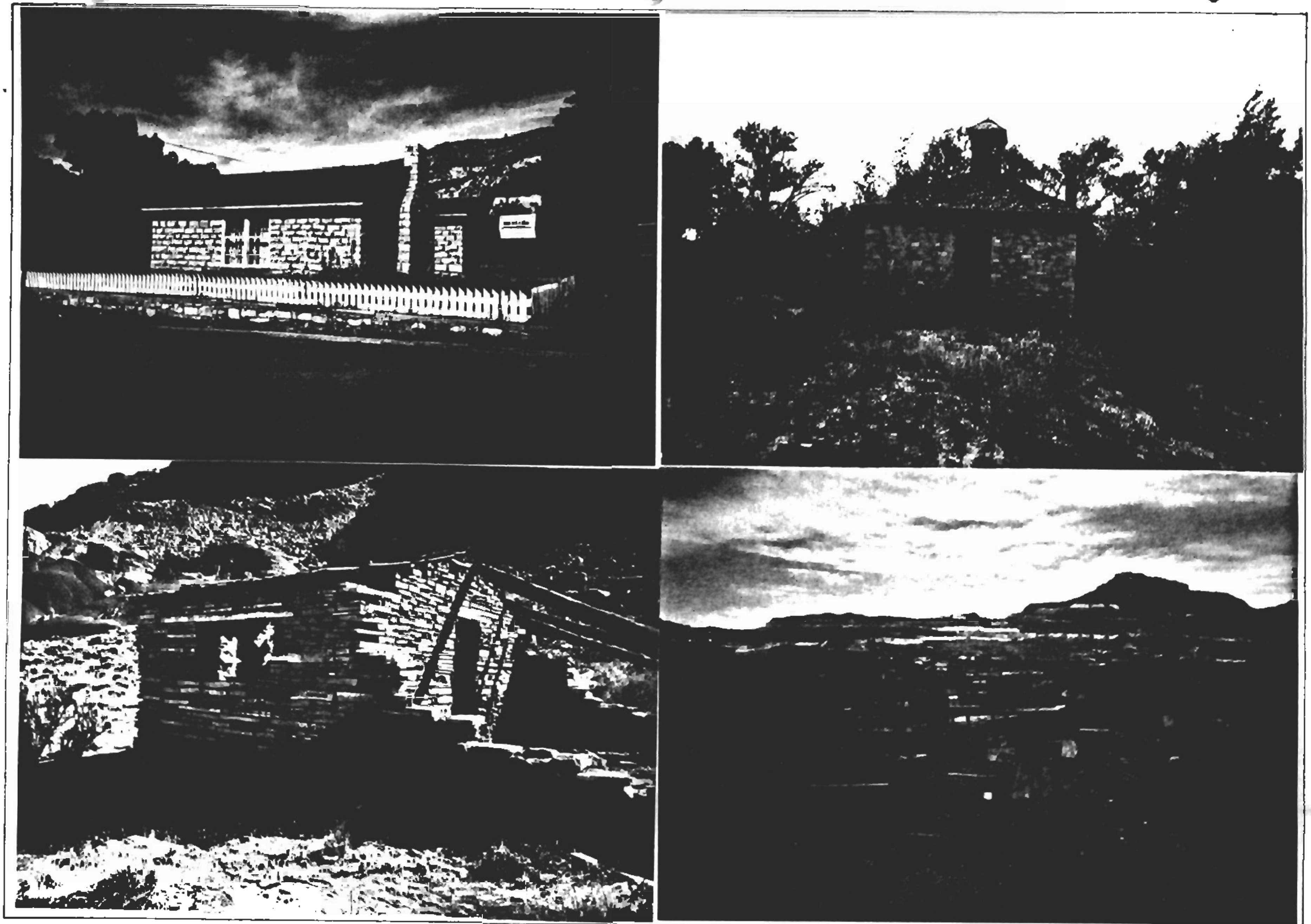


Photo 76. The use of native building stone has been minimal in Kane County. Upper left is an historical "bishop's storehouse" in Orderville and upper right is an abandoned schoolhouse in Mt. Carmel. Both buildings were constructed with the Kolob Limestone Member of the Carmel Formation. The lower two views were taken at the abandoned townsite of Paria. The flagstone of the building to the left was probably quarried from the Virgin Limestone Member of the Moenkopi Formation. The foundation blocks are of Moenave Sandstone. The ruin to the right is entirely of Moenave Sandstone.

Table 23. Quantitative Oxides of the Kolob Limestone and Analyses of Two Commercial Cement-Rock Quarries

Sample Number	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	P_2O_5	Sulfur as S	Loss on ignition
1a	61.44	1.42	10.76	1.38	0.28			0.01	0.42	
1b	65.22	0.33	9.78	0.65	0.34			0.01	0.07	
2	53.66	8.95	13.38	0.37	0.54			0.01	0.16	
3a	70.10	0.73	9.95	0.61	0.40			0.01	0.11	
3b	70.32	0.73	9.94	0.65	0.41			0.01	0.11	
4a	33.60	4.17	22.51	4.27	1.49	0.098	1.91			31.1
4b	17.87	5.55	37.50	10.59	3.20	0.143	3.57			20.8
5	52.59	0.56	3.92	0.60	0.11	0.16			-	42.93
6	37.31	1.76	22.00	5.94	1.93	0.56	1.23		-	35.70

Locations and descriptions of samples:

1a	blocky, thick bedded	NESENE Sec. 15, T 41 S, R 9 W.
1b	thin bedded, argillaceous	SENESE Sec. 15, T 41 S, R 9 W.
2	Kolob limestone	SWNWSE Sec. 24, T 40 S, R 7 W.
3a	blocky, thick bedded	NESWNE Sec. 33, T 40 S, R 4 1/2 W.
3b	thin bedded, argillaceous	NESWNE Sec. 33, T 40 S, R 4 1/2 W.
4a	blocky, thick bedded	NESE Sec. 31, T 41 S, R 7 W.
4b	thin bedded, argillaceous	NESE Sec. 31, T 41 S, R 7 W.
5	Great Blue Limestone	Grantsville Mountain
6	Twin Creek Limestone	Parleys Canyon, east of Salt Lake City.

Building stones quarried from within the county are little used today, but in many old foundations the blocky Moenave sandstone is recognized. Unfortunately it quickly granulates with age and is crushed under excessive weight. Most present day construction, if stone is called for, uses imported stone. Although not strictly building stone, Kane County petrified wood has been used for wall facings, monuments, and decorative stone. The olivine basalt blocks have been favored by some as decorative garden stones.

Gypsum

Gypsum is hydrous calcium sulfate ($CaSO_4.2H_2O$), and anhydrite is the anhydrous form ($CaSO_4$). These minerals were precipitated by the partial or complete evaporation of restricted marine brines in a dry climate. They are classified as evaporite sediments along with rock salt, primary dolomite, and potassium and magnesium salts. Most of the deeply buried material is present as anhydrite, gypsum being formed when the mineral is brought into the zone of weathering. In semiarid climates hydration progresses to 40 feet or less below the surface or behind outcrops.

Most gypsum is a compact massive finely crystalline to granular rock. It is white when nearly pure, but may be gray, bluish-gray, yellow, or pink, owing to such impurities as clay, iron oxide, or organic matter. Anhydrite is similar in appearance to gypsum, but is harder and heavier. It has little value at present because in plaster it absorbs water and swells. Three varieties of gypsum are satin spar, a fibrous form with a silky luster; selenite, a transparent cleavable form; and alabaster, massive and finely crystalline, pure white or delicately tinted and translucent. Satin spar and selenite are common in occurrence, but are not usually present in the thick beds or veins necessary for commercial production. Alabaster is found in thick beds, massive varieties are known as rock gypsum and less pure varieties are classed as gypsite (<60%). The best alabaster is used for carving and sculpturing. Nearly all commercial gypsum occurs as sedimentary beds, ranging in thickness from 3 to 100 feet or more (Bates, 1960, p. 201). Most gypsum deposits contain from 5 to 15 percent impurities (clays, halite, anhydrite, silica minerals, etc.) and some beneficiation is usually necessary.

When heated to a moderate temperature (300-350° F) gypsum loses 3/4ths of its chemically held water. On cooling, the resulting hemihydrate ($CaSO_4.1/2H_2O$) (calcined gypsum or plaster of Paris) may be mixed with water and spread, cast, or molded. It then dries into a hard mass. The calcined gypsum is manufactured into a variety of plasters, wallboard, and block for construction use, or into plasters for industrial applications. Calcined gypsum has almost totally replaced lime in plasters. Uncalcined uses of gypsum are mainly as a retarder for portland cement, as a soil conditioner, as a mineral filler, and other industrial uses.

Gypsum is abundant and widespread in Kane County; however, no deposits have been developed. Sedimentary gypsum, in beds thicker than 3 feet, is found in the upper part of the Toroweap Formation, the Shnabkaib

Table 22
22 4000

Table 21. Glass sand test data for Navajo Sandstone and derived sand dunes

Sample no.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	CaO %	Sodium as Na%	Potassium as K%	Titanium as Ti%	Manganese as Mn%	Location and remarks
1	97.99	0.22	0.20	0.16	0.03	0.037	0.133	0.001	0.001	Upper adit or old glass sand mine in the SESENW sec. 32, T.42S., R.6W.
2	98.30	0.25	0.16	0.02	0.05	0.028	0.182	0.001	0.002	Lower adit of old glass sand mine in the SESENW sec. 32, T.42S., R.6W.
3	99.50	0.50	0.13	0.02	0.05	0.036	0.050	0.001	0.007	Dune sand in The Sand Hills, sec. 10, T.42S., R.7W.
4	99.20	0.30	0.11	0.01	0.06	0.039	0.024	0.001	0.005	Sand from the Coral Pink sand dunes, NENWNW sec. 17, T.42S., R.7W.

Table 22. U.S. Bureau of Mines glass sand test data for Navajo Sandstone (__, not detected; detection limit for P_2O_5:100 ppm)

Sample no.	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	K_2O %	CaO %	MgO ppm	Na_2O ppm	P_2O_5 ppm	TiO_2 ppm	Location and remarks
1	96.0	1.7	0.30	0.76	0.17	300	310	--	610	Quartz sandstone outcrop; massive, fine grained, minor limonite stains; NESE sec. 6, T.39S., R.1W.
2	96.5	1.5	0.21	0.84	0.13	790	390	290	250	Quartz sandstone outcrop; massive, fine grained, minor limonite stains; NWSW sec. 27, T.38S., R.3W.
3	93.7	2.7	0.33	1.3	0.04	950	410	230	670	Quartz sandstone outcrop; white, fine grained, minor traces of iron and manganese; NWSE sec. 9, T.41S., R.1W.
4	96.7	2.0	0.30	0.54	0.23	640	170	250	430	Quartz sandstone outcrop; massive, fine grained, some limonite stains; SESE sec. 34, T.40S., R.3W.

Member of the Moenkopi Formation, and the Paria River and Wiggler Wash Members of the Carmel Formation (see photos 28 and 81). The Paria River Member of the Carmel Formation is largely one massive white rock gypsum bed that has a fairly consistent thickness from Slide Canyon to the western county line. In places the member can be strip-mined. It has the best potential for commercial development. A characteristic gypsum section of the Paria River Member was measured in Meadow Creek (see measured section of Paria River Member, p. 12a). Our best judgement, from examining many samples, is that the white gypsum beds contain 5 to 10 percent impurities, and these are mostly at, or near contacts with other lithologies. The gypsum beds of the Shnabkaib Member and Toroweap Formation appear to be less pure and may approach gypsite in quality; often sand grains and silt can be identified throughout. The beds of these units are not as continuous or as well exposed for surface mining as those in the Paria River Member. The Wiggler Wash Member of the Carmel Formation has good, but mostly thinner gypsum beds exposed and like those in the Toroweap and Shnabkaib are not very extensive.

Clay

No clay deposits, claystones, or shales, as far as we know, have been investigated and tested for quality in the county. However, we do know that there are fairly thick and extensive clay units that can be used for general purposes. Van Sant (1964, p. 141) described a bentonite clay bed, 3 feet thick, in a pit opened in the Dakota Formation near Cannonville, Garfield County. Clay from the pit was dried, crushed, and sold in bulk or bag for drilling mud, canal sealing, and for bonding molding sand. Tests showed that the bentonite has a 90 percent water of plasticity and its dry linear shrinkage was 19 percent. Firing tests showed that a sample cracked and warped at all temperatures from 1800 to 2400° F. Therefore the bentonite has little value in ceramics. The Dakota Formation bentonitic bed, as exposed near Cannonville, can be traced from Cannonville southwesterly to Table Mountain (Sec. 21, T 40 S, R 4 1/2 W) in Kane County. The Dakota Formation may have other such beds in its exposures throughout the county.

Many earthy mudstone and claystones of various colors are present in the Chinle Formation. These beds are 9 to 81 feet thick and some develop the bentonitic "pop corn" texture on weathered surfaces. Some Tropic Shale beds and certain horizons in the Straight Cliffs Formation are also clayey and would be suitable for lining canals and reservoirs. Studies would certainly turn up particular horizons suitable for the manufacture of bricks and other structural clay products. Some of the clays in the Straight Cliffs Formation in the Burning Hills area of the Kaiparowits Plateau have been fired by the natural burning of the coal beds in the area. The clay has been converted to many colors of brick.

Generally speaking, the resources of common clay and shales are enormous, but for development, as with many industrial and construction materials, there must be a consistent demand and a large market along with cheap, or short transport.

Gem Materials

The term "gem materials." under which these materials are usually classified, is a misnomer for such items found in Kane County. It is difficult, however, to come up with a better name that encompasses them all. Some are ornamental stones, some could be fashioned into jewelry, some are used as raw materials to create ornamental conversation pieces, others are prized for their unique shape or form, and still others are mementos of the geologic past. In Kane County the best known items include septarian nodules or concretions, petrified wood, picture rock (wonderstone), colored sand, chalcedonic polishing material, ironstone concretions, carving gypsum, fossils, jet coal, and clinker (figure 47). The most sought after, and the leading money makers, are the first four items. They can be found in fine rock shops all over the world. The cumulative value for such produced items is estimated at a minimum of $500,000. The estimate is probably too low and probably exceeds $1,000,000. The sales of these items have not been as faithfully recorded as have the records for the precious metals.

Septarian nodules. These nodules are usually found along a favorable horizon near the base of the Tropic Shale. In most places they are regarded as a lucky find, but two areas of concentration are located in the county. The first is found a few miles up Muddy Creek, northwest of Mt. Carmel and Orderville, and the second is found along the Cockscomb opposite Shurtz Gorge. Since the nodules are world class items most of the area northwest of Mt. Carmel and Orderville has been claimed by commercial operators. Suitable places, where a shallow cover of Tropic Shale exists over the Dakota Formation are stripped, the nodules collected and transported to town, where they can be safely stockpiled. The nodules are less common along the Cockscomb, hence they are not commercially pursued there, but provide a better and legal place for the collector who wishes to find his own.

The nodules range from a few inches to 18 inches in diameter and are roughly rounded balls or spheres of drab gray limestone (photo 77). When these are cut in half or broken a star of bright yellow calcite fills or partially fills the interior, the latter forming sort of a geode. Apparently the concretions were partially hollowed out by groundwater at one time in geologic history, later to be refilled by the much more beautiful calcitic filling. Those partially filled are often lined with drusy crystals. A few contain fossil cores.

It is, of course, impossible to tell how beautiful a nodule will be upon cutting, they are not of uniform quality. The cheapest are broken pieces, with uninteresting fillings. Broken pieces generally sell from $1 to $40, the higher priced ones being larger and more beautiful. Unbroken nodules are sold by the pound, the smaller ones having a lower unit price. Some are cut with the diamond saw and polished into bookends or conversation pieces, still others are polished into spheres and "eggs." The added work usually doubles or even triples the price. Especially beautiful polished pieces can cost well over a hundred dollars.

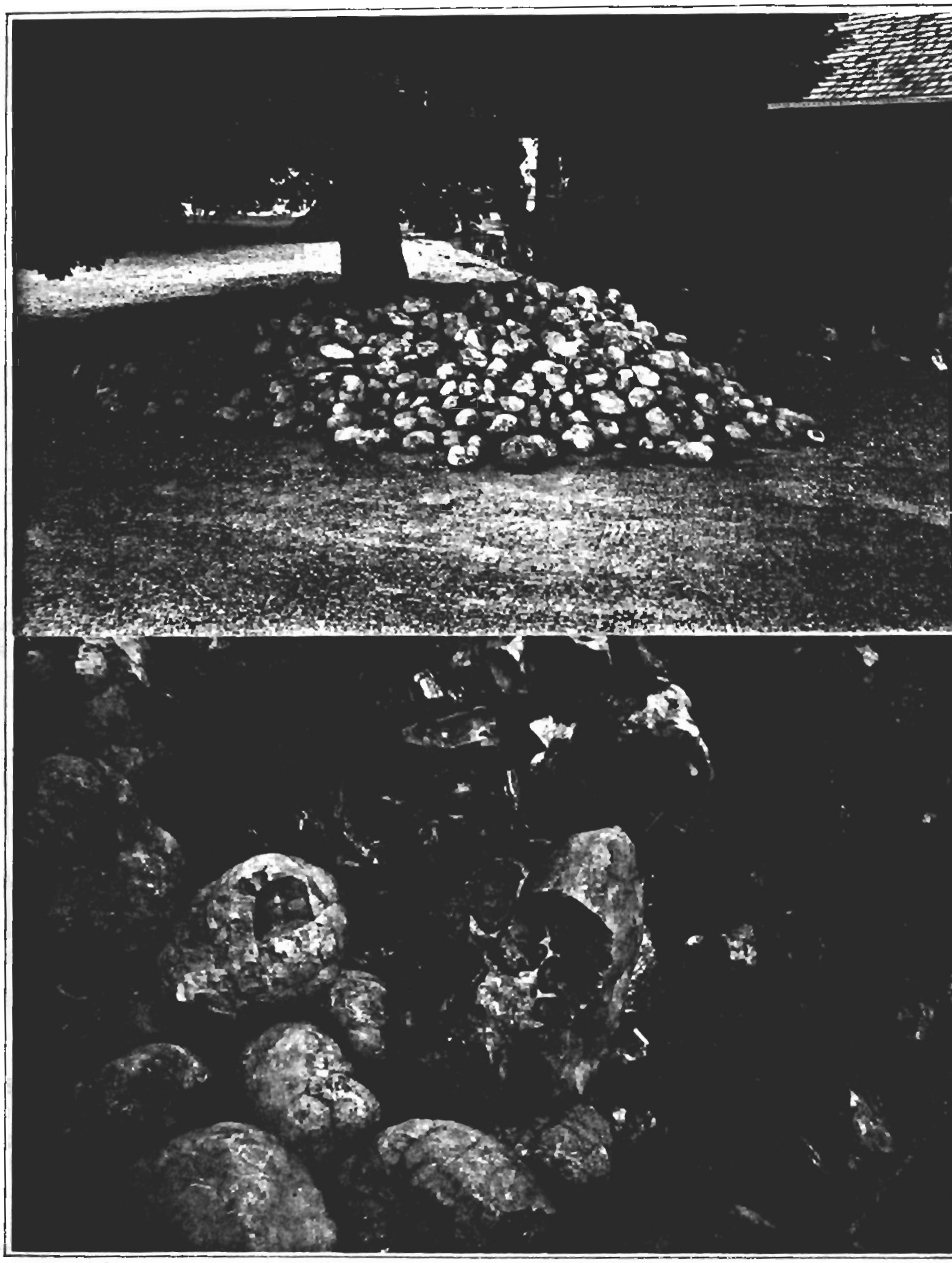


Photo 77. Septarian concretions are found at the base of the Tropic Shale near Orderville in Kane County and sold commercially all over the world. The drab gray spherical concretions or nodules are filled with bright yellow calcite.

<u>Petrified wood</u>. Petrified wood is a common item in the formations exposed in Kane County. It has been identified in all members of the Chinle Formation, in the Kayenta, Dakota, in all members of the Straight Cliffs, Wahweap, Kaiparowits Formations, and in the cobbles at the base of the Claron Formation. Most of the petrified wood is not of "gem" quality and is not worth polishing. Nevertheless, some specimens are interesting in appearance, have drusy interiors, or have other special characteristics that might make them attractive to a collector. Some of the petrified wood found in Kane County is very beautiful and is commercially collected and sold (photo 78). The best materials have been found in the Petrified Forest Member of the Chinle Formation and in the Morrison Formation.

Even though the petrified wood is found in so many of the Kane County formations and their members, the distribution is not uniform or even. They are generally preserved in channel sandstones, especially in the point bar deposits. The most beautiful petrified wood from the county has been commercially mined from the Petrified Forest Member of the Chinle Formation in Ts 40 and 41 S, R 2 W, near Paria. The logs are usually found in the lower half of the member and are surface mined. Benches with shallow overburdens are found over favorable channels and are stripped. The material is gound as logs ranging to 4 feet in diameter and in segments to 12 feet in length. Most are found in much shorter segments, averaging two feet and the average diameters range from 6 inches to 2 feet. The bark is well preserved, and the tree rings are well defined. The color is outstanding, with reds, yellows, browns, and blacks predominating. The chalcedonic material which makes up the logs polishes extremely well. The material is usually cut into bookends (quarters or halves of logs) or into complete log diameters. Attractive bookends sell from $25 to $100 a set and the best polished log diameters can be purchased from $50 to well over $1000 each. Unpolished material is sold by the pound and the price is dependent on quality.

Beautiful pieces of mahogany colored petrified wood are occasionally found in the upper part of the Morrison Formation along Fiftymile Bench and the Grand Bench. The interior structure of the wood is mostly lost and complete diameter tree trunks are extremely rare. Nevertheless, the material polishes beautifully and imperfections are less common. Polished bookends of this type are preferred by some over the more colorful Chinle wood and the prices are comparable.

For the casual collector who wants a few specimens of petrified wood, primarily to show the petrified woody features, it is recommended to walk over benches of channel sandstones in the upper part of the Wahweap Formation or Drip Tank Member of the Straight Cliffs Formation. A walk along the Shinarump Member of the Chinle Formation should also prove profitable. Much petrified wood, not suitable for polishing, has been discovered in the Monitor Butte Member(?) of the Chinle Formation in and around Sec. 2, T 43 S, R 4 W. Chips and fragments of petrified wood litter the area. Even some commercial activity has occurred nearby. The supply appears to be inexhaustible at this location. Evenso men have been known to move mountains and the amateur collector should familiarize

Photo 78. Complete section of a petrified log from the Chinle Formation. This highly polished section is colorful, excellently exhibits the tree rings and sells for more than $1,000. Petrified wood from the Chinle Formation near Paria is a world class salable item.

himself with the amount of wood collectable by law so that many can enjoy the collecting experience.

Picture rock. Picture rock in Kane County is a crossbedded sandstone that is differentially mineralized by varying iron oxide coloration along crossbedding laminae or mineralization fronts. The quarrying sites are generally near faults that acted as conduits for the mineralizing solutions or are near springs. It is observable in several formations, but probably best developed in the Navajo Sandstone, Lamb Point Tongue of the Navajo Sandstone, and Shinarump Member of the Chinle Formation near Kanab. Blocks of sandstone are quarried, sliced into thin slabs, sanded lightly, and mounted on picture frames. Some larger interesting slabs are offered in matching pairs and some of the sandstone is even ground into spheres. Ordinary crossbedding patterns do not usually provide interesting pictures and the quarries are limited to areas where contorted crossbedding is prevalent or where the mineralization fronts are irregular (figure 48). The viewer's imagination in interpreting the scenes is necessary to fully appreciate the product and every specimen is unique. To our eyes they depict billowy clouds, seascapes, mountains, miniature unconformities, and faults (photo 79).

The more color, color contrast, and the more interesting the pattern, the higher the price. Even very small framed pictures are expensive ($30-$50). Less colorful slabs and spheres, unmounted, can usually be purchased for under $20. Two especially colorful matching and mounted slabs, about 2x4 feet in size, can be priced as high as $1000. Locally, the material is known as Kanab picture stone.

One of the better deposits is located in Sec. 3, T 44 S, R 5 E, in a small reentrant along the Shinarump Cliffs near Johnson Wash. No contact with the underlying Moenkopi Formation is observable. The lowest observable sandstone beds in the Shinarump is a pebbly medium grained tan sandstone in thin lenticular beds, including some fine grained sandstone. The sequence is more than 10 feet thick and is alternatingly soft and hard. Overlying is a tan sandstone, medium grained and crossbedded, in lenticular thick to massive beds. This is the "ore" horizon and the individual lenses make several benches. The total thickness of the "ore" horizon reaches a maximum of about 17 feet. It thins to as little as 7 or 8 feet laterally. Some lenses are more decoratively colored than others. the patterning coloration is red, lavender, and black. Above this horizon is a 2 to 2 1/2 foot horizon of shale and shaly sandstone that is gray and silty and slope forming. This is overlain by thick channel pebble and cobble conglomerate and sandstone that is cliff forming and at least 20 feet thick. The pebble and conglomerate marks the top of the Shinarump Member.

Colored sand. Colored sand was and is being used by the American Indian in producing sand paintings. Local entrepeneurs use colored sand to fill colorless glass bottles, alternating the colors to produce interesting designs. All are offered to tourists as mementos of their visit to "Color Country." The color of the sand is due to small and varying amounts and oxidation states of iron oxide minerals that coat the

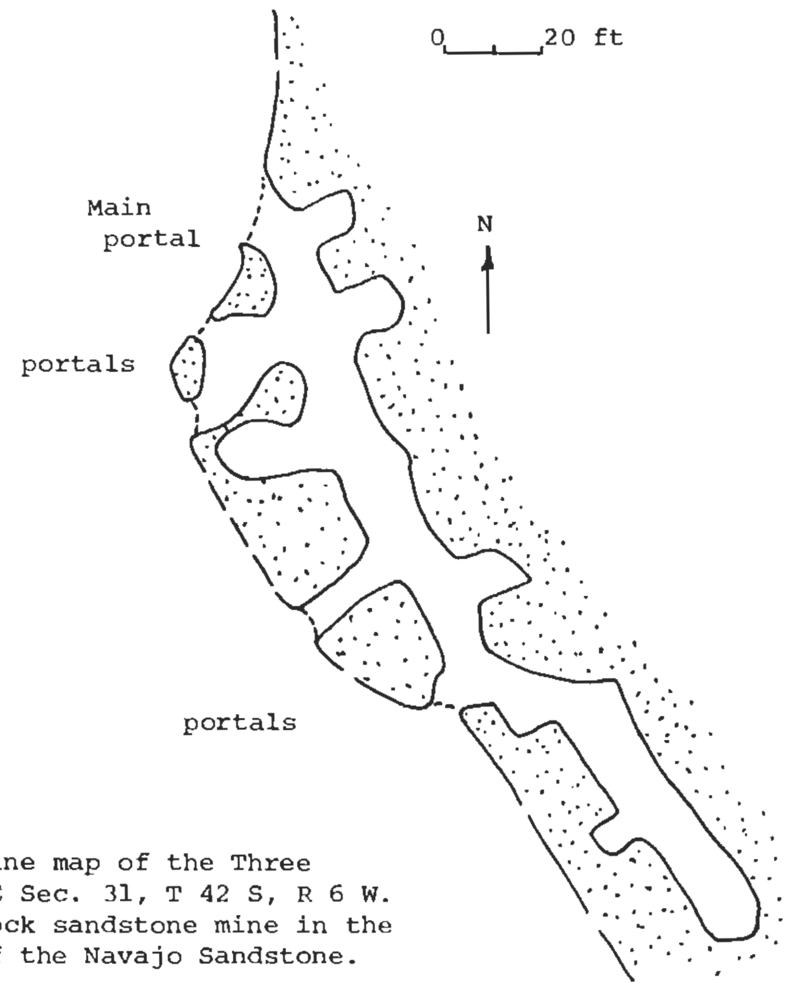


Figure 48. Mine outline map of the Three Lakes Canyon mine NE Sec. 31, T 42 S, R 6 W. This is a picture rock sandstone mine in the Lamb Point Tongue of the Navajo Sandstone.

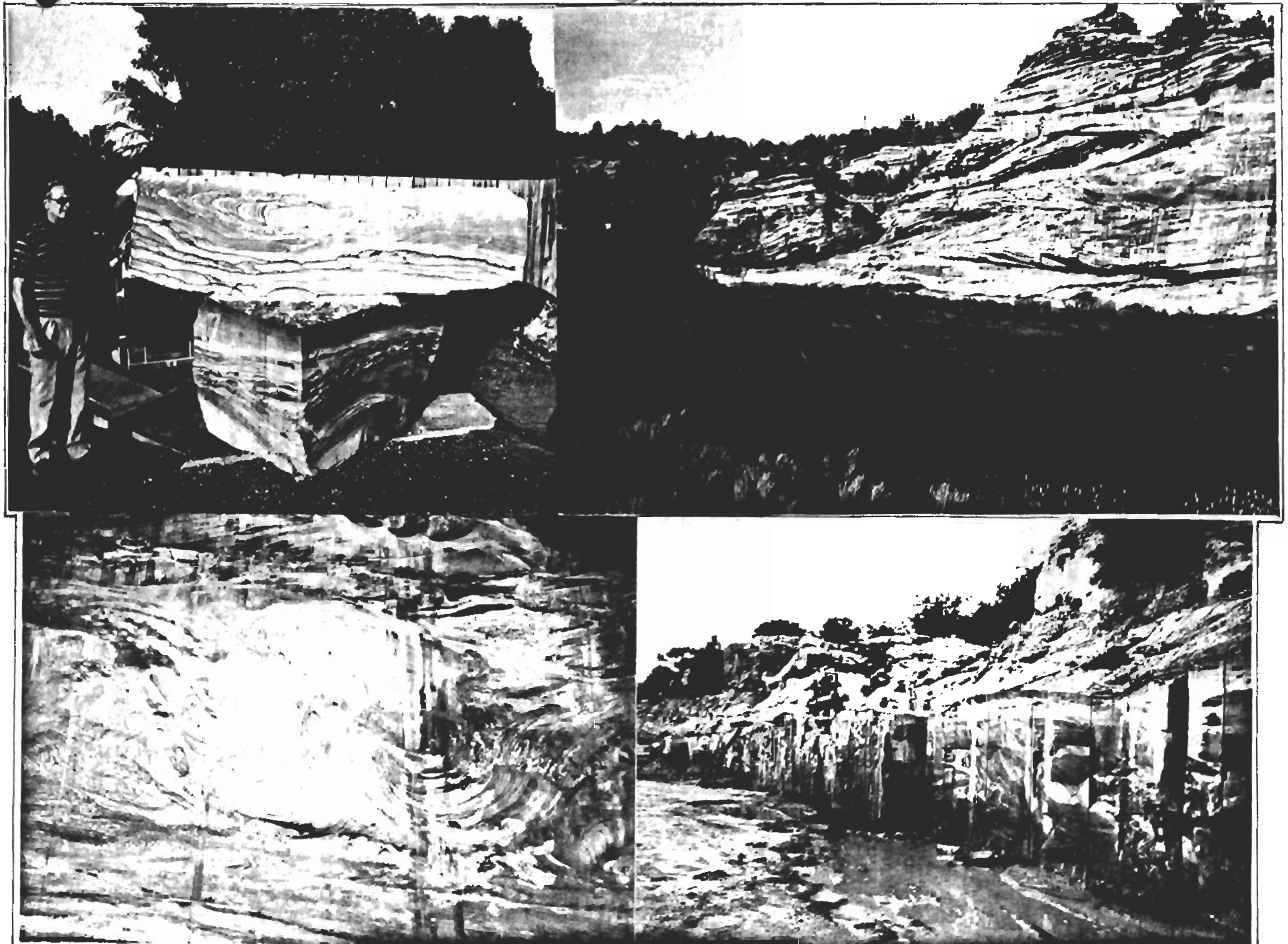


Photo 79. "Kanab" picture stone. Upper left view shows slabs of Shinarump Member exhibited in front of a Kanab rock shop. Upper right shows contorted crossbeds in the Navajo Sandstone as does the lower left view. Lower right is a view of a quarry in the Shinarump Member at the mouth of Johnson Canyon.

otherwise colorless siliceous sand grains. Colored sand can be obtained from almost every sandstone formation in the county, but certain colors are rare and hard to find. It would be unusual to find many of the colors in one locality, but such a mine exists in Kane County. It is located in the NWSESE Sec. 31, T 42 S, R 6 W in the Lamb Point Tongue of the Navajo Sandstone adjacent to a fault. The colors of sand within the mine are controlled by porosity and crossbedding. Mineralizing groundwater carried into the area through the fault system was able to permeate the sandstone in varying degrees, the color mostly dependent upon the amount of iron brought in contact with the grains. In a set of analyses it was found that the other constituents varied little (table 24).

Table 24. Analyses of colored sand from Kane County.

Color of sand	Alumina Al_2O_3	Iron Fe_2O_3	Magnesia MgO	Calcium oxide CaO
Off-white	0.25	0.16	0.02	0.05
Salmon pink	0.31	0.34	0.19	0.04
Green	0.29	0.36	0.07	0.04
Orange	0.26	0.73	0.04	0.05
Purple	0.25	0.89	0.24	0.03
Dark purple	0.40	1.53	0.24	0.04
Black	0.35	5.46	0.20	0.03

The mine is not deep and has several portals and interconnecting underground passageways (figure 49 and photo 75). Bands of colors (following crossbedding) are exposed on the walls and faces of the mine. Containers are filled along each band with enough care to avoid contamination from the other color bands. The volume of sand mined from this mine so far is approximately 40,000 cubic feet or 2000 tons. An indeterminate amount remains, but the resources are many times the amount mined. Bottles of sand sell from $1 to $50 depending on size and the beauty of the design. The shape of the bottle also influences the price. It is not known how efficient the mining is--how much of the sand can actually be used to fill colored sand bottles. If all the sand extracted from this one mine was used to fill quart jars over a million would have been filled. At $5 a bottle the value of the sand, the bottles, and the work necessary to fill the bottles would be valued at $5 million. The value of the mined sand alone should stand at $1 million. This mathematical exercise is, of course, invalid because not all of the extracted sand could have been efficiently used, or was used commercially. But it illustrates that the less glamorous non-metallic items, such as ordinary sand, can be quite valuable resources.

Chalcedony. Chalcedony is a cryptocrystalline quartz that forms during diagenesis or through groundwater action by the leaching of highly siliceous rocks. They are often found where volcanic material has been part of the depositional material. Small amounts of iron and other elements provide the coloring matter. Chalcedony is hard, easy to polish, and when interestingly colored can be fashioned into jewelry, bookends,

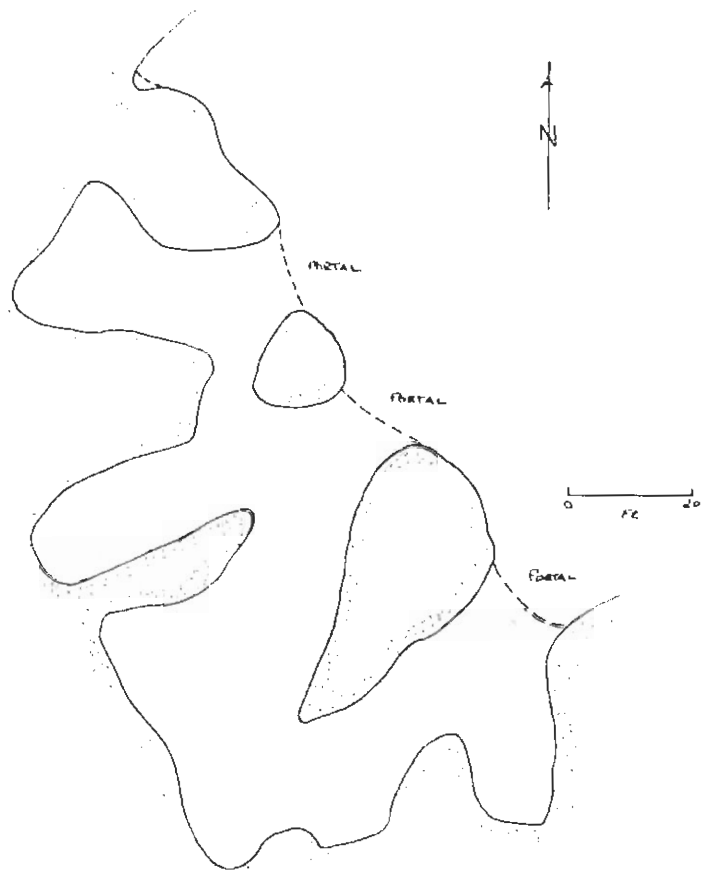


Figure 49. Mine outline map of "colored sand" or "bottle sand" mine, SE Sec 31, T 42 S, R 6 W. Ground water from a nearby fault undoubtedly mineralized these sandstones with iron oxides.

conversation pieces, and other decorative pieces. They are usually found as broken nodules, in thin beds, and as irregular concretions. Jasper, agate, and chert are varieties of chalcedony. The aforementioned petrified wood is mostly composed of the chalcedony mineral. It is tough, often without inherent fractures, breaks conchoidally like glass, and can be polished to a high luster. Value is added by working the material into cabachons, ring-stones, earrings, bookends, and spheres.

Jasper is commonly red and yellow, but occasionally it is green or grayish blue. It is the most common chalcedony found in Kane County. Agate is a variegated chalcedony, usually gray and white banded, irregularly clouded, or varied by visible impurities. Occasionally tints of brown and blue are seen. Agate is not a common chalcedony in Kane County. Chert is impure chalcedony, usually dull gray or brown in color and found in the form of nodules, irregular flattened bodies, or as thin beds in limestone strata. Chert is common in Kane County, especially in the Kaibab Limestone of Buckskin Mountain. However, the large spherical nodules of the Kaibab are nearly white and so impure as not to take a polish well.

Larger pieces of jasper are generally found in the Petrified Forest Member of the Chinle Formation and in the Morrison Formation. These units contain volcanic ashes in their makeup that have been altered through time to produce the chalcedony. In addition the cherts in the occasional limestones of these units is often jasperized. One of the better collecting localities is in the Chinle Formation near the abandoned townsite of Paria. Thin beds of jasperized material can be found along select horizons anywhere in the Petrified Forest Member. These weather out and are strewn about as rubble. Colors include yellows, reds, browns, and gray. Jasper chalcedony can occasionally be found in most non-Cretaceous formations in Kane County, but, excepting the Chinle and Morrison, are usually found as smaller, less interesting pieces. The Kane County chalcedony has only occasionally been exploited commercially.

Ironstone concretions. Concretions are rounded to irregularly shaped hardenings of rock material. In Kane County they are found in many of the formations. Most are uninteresting and not worthy of collecting. Some, by virtue of their mineral filling, interior coloration, or peculiar shapes, put them high on the list for rockhounds and tourists. Concretions are formed in nature by several means. Most involve an improvement of the rock cement either by silicification, calcification, or limonitization. Sometimes a cavity is formed in the rock when ground water dissolves a fossil or nodule of limestone from the originally deposited sediment. Later the cavity is filled or partly filled with a mineral precipitate by chemically charged ground water. Concretions with hollow cores are called geodes and the septarian nodules of Kane County, that are filled with honey-colored calcite, are of this type. Most of the aforementioned cherts and jaspers are concretions. Sometimes the cement surrounding sand grains is selectively replaced by harder bonding materials. Ironstone concretions usually form in sandstones, the cementing material being iron oxides.

Most of the sandstone units of Kane County locally contain ironstone concretions. They occur in irregular to spherical shapes, or as contorted sheets. They occur at specific horizons in the formations, where the porosity and permeability are good, indicating they are related to past groundwater activity. The degree of hardening is highly variable and the color ranges commensurately from light brown to dark brown to black.

The best ironstone concretions are probably found in the Navajo Sandstone, in the middle, more friable part. The hardening is pronounced, most pieces are dark brown and black, and the fragments are irregularly shaped (photo 80). They can be used as ash trays, pieces of art, or merely the object of a day's rock collecting. One of the better collecting localities is in an area known as the Swag, in Sec. 19, T 40 S, R 2 W.

Carving gypsum. Blocks of alabaster gypsum capable of being carved are present in the Wiggler Wash Member of the Carmel Formation. Some of the white alabaster gypsum from the Paria Member may also be suitable, but most is too grainy and friable for carving or polishing. At the Dalboe quarry the Wiggler Wash gypsum is found in beds up to 4 feet in thickness (mostly averaging 2 feet) which can be broken out in blocks in dimensions of 2x4x3 feet. There are several minable beds 5 to 10 feet apart separated by soft brown silty sandstone crisscrossed with gypsum veinlets. The alabaster is colored white, pink, brown, light greenish-gray along thin and crenulated bedding laminae. The quarry is located near Grosvenor Arch in Sec. 1, T 39 S, R 1 W. Other outcrops of Wiggler Wash gypsum are located along Wiggler Wash in the W 1/2 of T 38 S, R 1 W.

One of the uses to which the Dalboe gypsum has been put, is in the erection of a nearby religious shrine. Blocks of the gypsum have been erected into monuments and have been arranged in a Stonehenge fashion pattern. Blocks standing out in the weather have split along some of the laminae indicating an inherent weakness in the carving material (photo 81).

Fossils. Rare and especially well preserved fossils are protected by law and such finds should be reported to a suitable repository. Several such occurrences have been discovered in Kane county and additional finds are expected to occur. Dinosaur bones (Wahweap Formation), fossil fish (Moenave Formation), cephalopods (Tropic Shale), and palm fronds (Dakota Formation) are among such items found to date. Nevertheless, there are other areas in which the species are found so abundantly that they can be collected, either to be sold commercially (by claim or lease), or in limited quantities by amateurs. Crinoid stems and brachiopods are common in the Kaibab Formation, occasional asteriscus crinoids and shellfish can be found in the Kolob Limestone Member of the Carmel Formation, wood and leaf imprints are common in the Dakota, Straight Cliffs, and Wahweap Formations, and the Cretaceous sandstones contain coquinas of shellfish. Occasional sharks' teeth can be found in the marine Cretaceous sandstones. A good place to collect fossil oysters is at the to of the Dakota Formation, especially in T 42 S, R 1 W.

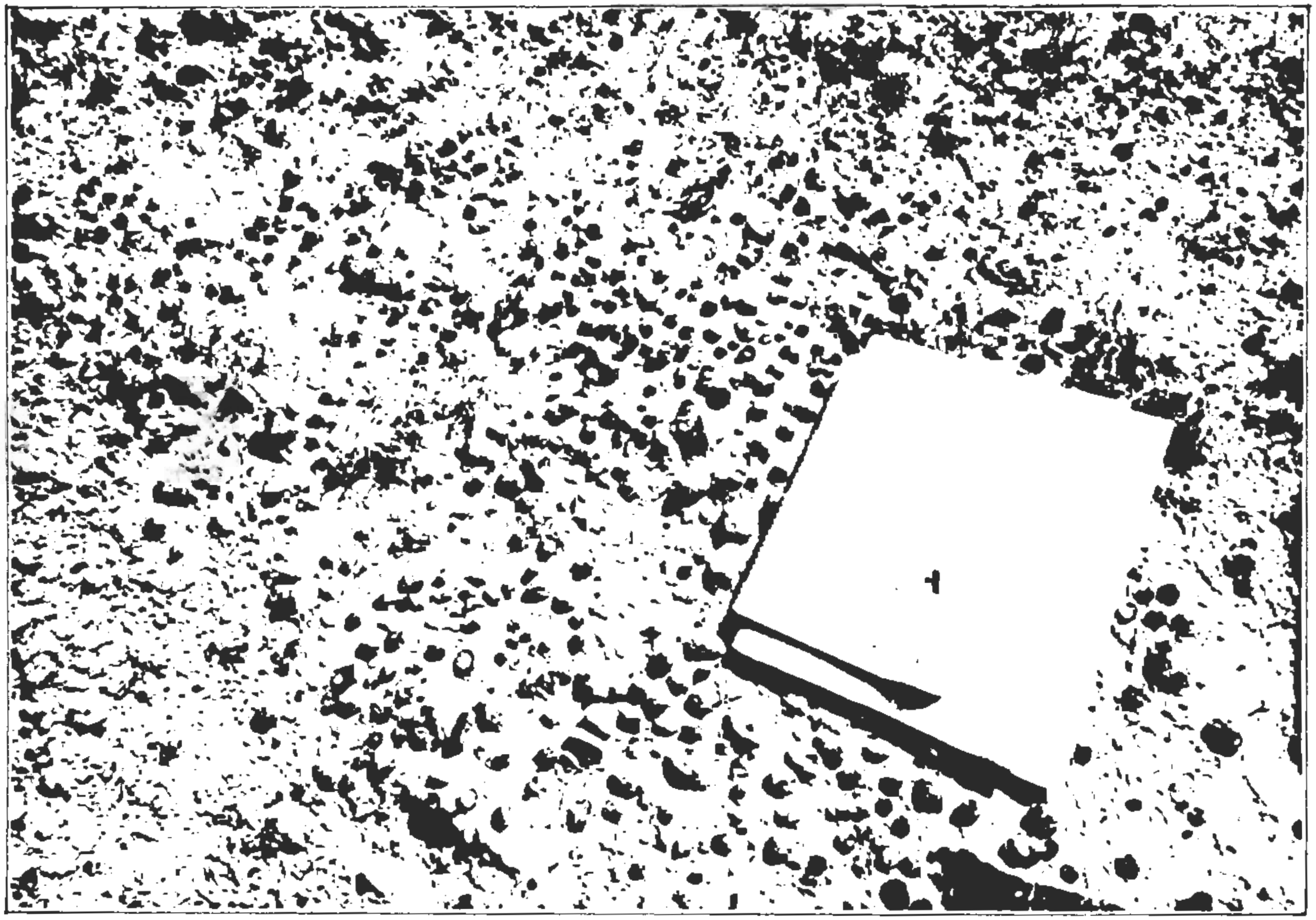


Photo 80. Iron concretions occur as small spheres, irregular shapes and forms, and as sheets. They are common in the middle of the Navajo Sandstone and are often sold as tourist items. The concretions contain up to 15 percent iron.

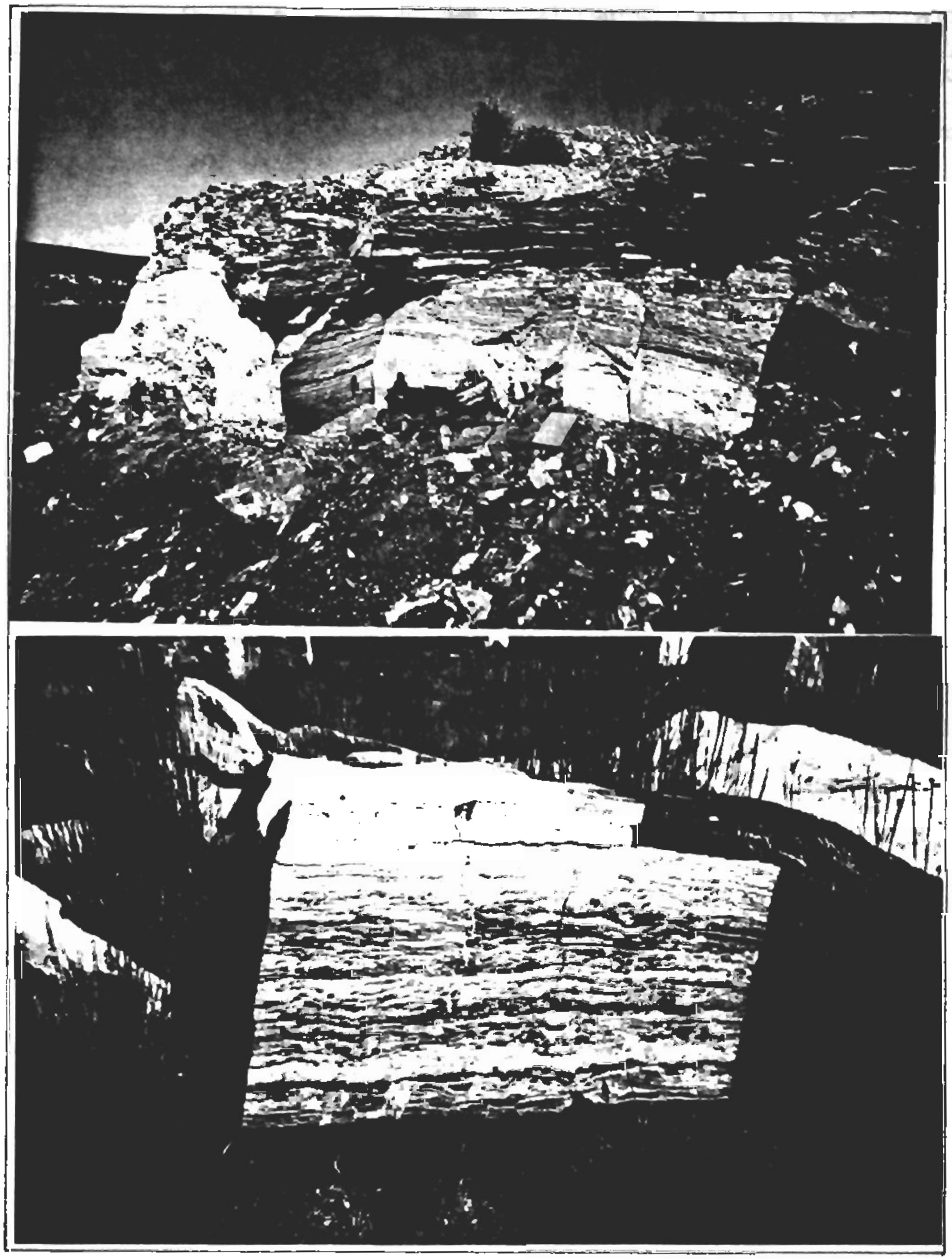


Photo 81. Gypsum in the Wiggler Wash Member of the Carmel Formation near Grosvenor Arch. Color variations occur as laminae in the rock. The gypsum could be used as carving material but has an inherent weakness in having a tendency to split along the laminae.

<u>Jet coal</u>. Small amounts of jet coal canbe found in the Straight Cliffs Formation cropping out in the Right Hand Fork of Collet Canyon along the Garfield County line. The jet coal is found as coalified branches and pieces of branches encased in clay beds. The jet is not found in the regular coal beds of the area. Jet coal is a shiny coal that breaks conchoidally with a smooth surface. It can be polished into black jewelry. Jet jewelry was popular at one time for use at funerals and other festive occasions. The jet branches are usually flattened in the clay beds parallel to the bedding.

<u>Clinker and other collectables</u>. Many of the spontaneous fires that have burned in the Kane County coal fields burned so hot that adjacent rock was baked and partially melted. Some of the baked rock formed brick of many colors, including bright yellows, greens, purples, reds, and blacks. These are occasionally collected for conversation pieces and garden stones. Well formed volcanic bombs are occasionally found in the northwestern part of Kane County near cinder cones. They are collectors' items.

GEOLOGIC HAZARDS:

Geologic hazards in Kane County include (1) mass movements, (2) swelling and shrinking rocks and soils, (3) flooding, (4) earthquakes and liquefaction, (5) sand dune migration, (6) hydrocompaction, (7) high ground water, and (8) peat bogs.

Geologic hazards are integrated into the geologic makeup of Kane County. The terrain that characterizes this distinctive region of Utah results from ongoing geologic processes operating over many millions of years. The gradual, but sometimes abrupt, processes of weathering, mass wasting, erosion, deposition, and tectonics with associated fault movements (earthquakes) have shaped the landscape. Some hazards, such as landslides and flooding, result from the climate and geology of southern Utah. Other hazards are controlled by dynamic forces operating within the earth, the hydrosphere, the atmosphere, and the sun.

The geologic hazards in Kane County are portrayed on plates 8 to 10 and defined in the map explanation. Mass movements, swelling and shrinking rocks and soils, flooding, earthquakes, faults, liquefaction, sand dunes, and hydrocompaction are discussed in the following pages. Areas of high ground water and peat bogs are described in the engineering geology reports of Long Valley and Alton that follow.

Most engineering works of man are on the surface or at a small depth beneath. Where structures are placed and how they are designed, built, and effectively maintained, must depend largely on the characteristics and relationships of the surrounding rocks, soils, and water. General measures that can minimize or avoid hazard risk are also discussed.

Mass movements

Weathering and mass movements contribute greatly to the gradation of the earth's surface. The combined weathering processes result in the weakening, splitting, and decomposition of the bedrock. The masses of rock and soil moved downslope by the force of gravity range in size from tiny bits of rock rolling down a steep slope to a large landslide, thousands of feet across, crashing down a mountainside.

In this report mass movement refers to the downslope movement of rock and earth. It includes rockfalls, colluvium, creep, talus, detrital masses, and landslides of all types. The distinction of the various types of landslides is chiefly based on the size and shape of the moving mass, the type of material, the water content, and the geometry and rate of movement. Debris slides, rock slides, debris flows, slumps, rotational slumps, and landslide zones that are combinations of materials and types of movement, have been identified in Kane County (photos 82 and 83).

Hundreds of individual mass movements plus two extensive mass movement zones are shown on the geologic hazards maps. In most cases it was possible to apply the term "active" or "less active" to each of the mass movements. However, this should not be construed to indicate the

Photo 82. Ground cracks in the lower part of the Judd Hollow Tongue along the Cockscomb. Great sheets occasionally slip down steep bedding planes without completely breaking up. See photo 83.

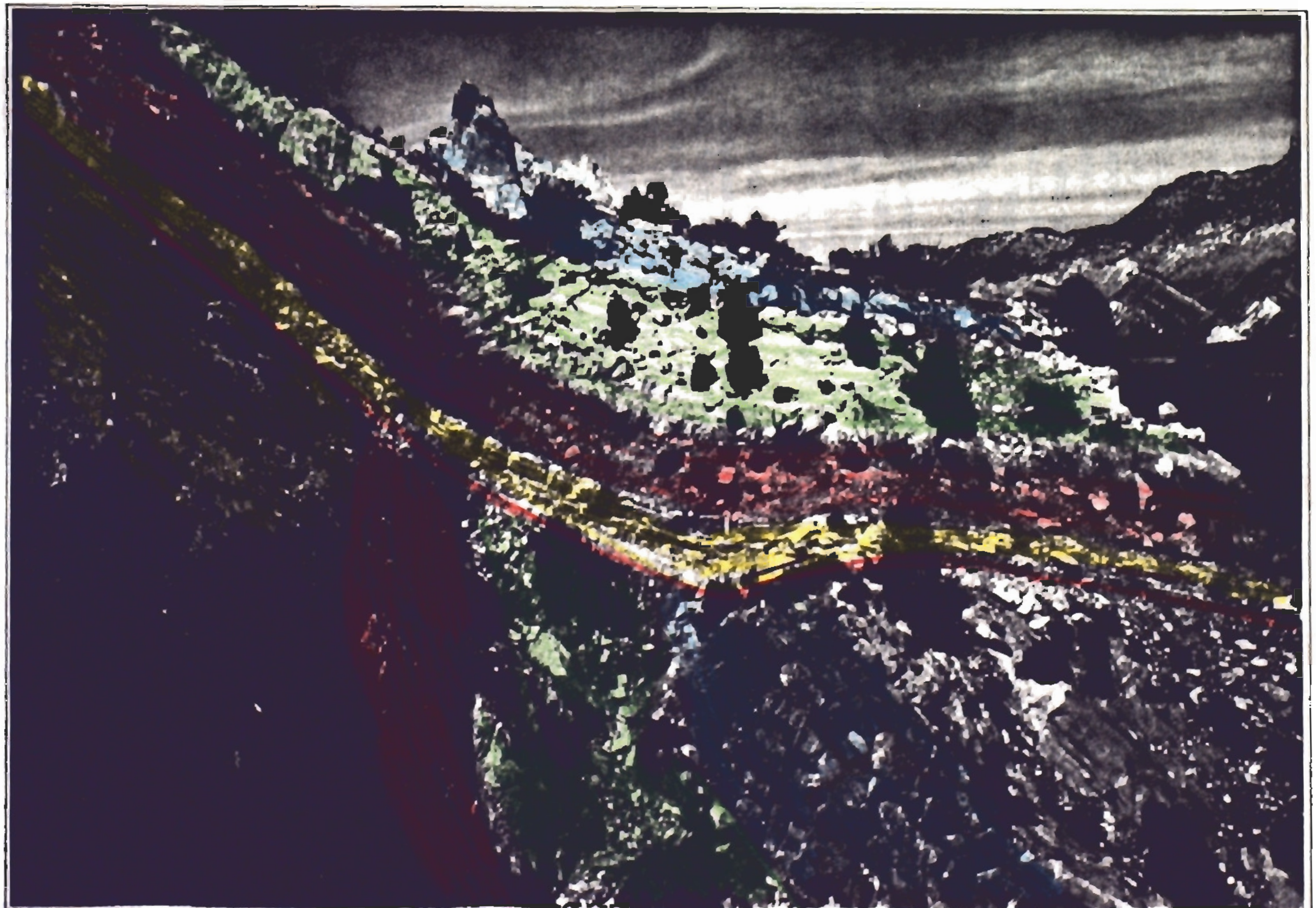


Photo 83. A plate of Judd Hollow Tongue and Thousand Pockets Tongue has slid down a steep dip slope and ridden over itself at the bottom.

relative stability of the involved slopes. Inactive appearing landslides can become active if the conditions favoring activity return. The vast majority of mass movements are found associated with five formations: Moenave Formation, Dakota Formation, Tropic Shale, Straight Cliffs Formation, and the Wahweap Formation. Two of these, the Moenave and Straight Cliffs Formations, produce debris because of the soft undercutting formations beneath them. The landslide producing capability of the Dakota Formation and the Tropic Shale is chiefly related to their clay content. The Dakota Formation in the east is thin and mostly sandstone and produces little debris. In the west it is thicker and contains much clay-bearing shale and mudstone and produces many mass movements. The Tropic Shale in the east has produced many mass movements, but becomes sandier to the west and produces little debris except where destabilized by the movements of the underlying Dakota.

We believe that mass movements were more prevalent and active during the wetter and colder parts of the Pleistocene epoch. Freeze and thaw cycles were more numerous and Shroder (1971, p. 8) states that temperatures averaged 10° to 15° F. lower and the annual precipitation averages 10 inches higher than at present.

The availability of water in regard to mass movements cannot be overly emphasized. The introduction of water into a rock or soil mass, or adjacent to a slope, will likely produce the following conditions that promote mass movements: (1) water adds to the unit weight of the material, (2) water will cause an increase of pore-water pressure with a resulting decrease in shear resistance, (3) water will likely dissolve a soluble cement which reduces cohesion and shear strength, and (4) water may freeze and thaw repeatedly, fracturing and weathering material to reduce shear strength. As more water is added these conditions become progressively worse.

The are far two many mass wasting deposits in Kane County to describe in this bulletin. Therefore only the most prominent areas, zones, and individual landslides are discussed.

Kaiparowits Plateau landslide zone. This zone extends to the southeast for 38 miles from the Garfield County line in a broad belt along the base of the Straight Cliffs. At the southeast end of the Kaiparowits Plateau the zone wraps around Navajo Point and continues northwesterly 18 miles to Mudholes Canyon then 28 zigzag miles (following the cliffs) southwesterly to the vicinity of Warm Creek. In width, the zone ranges to 2.4 miles and averages 1.3 miles. The Tropic Shale, about 700 feet thick, is overlain by tan, massive cliff-forming sandstones of the Straight Cliffs Formation where they form the impressive Straight Cliffs. The much weaker shales of the Tropic weather easily, disintegrate, and slough downslope. As the jointed sandstone above loses support, it breaks and falls in small to very large blocks.

The lower part of the Tropic Shale and the underlying Dakota Formation form a wide bench that is covered with a thick pile of colluvium that consists of gray silt, clay, and weathered shale intermixed with the tan sandstone boulders of the Straight Cliffs Formation. The broken, porous material allows the percolation of rainwater and snowmelt. Consequently, in many places, the lower part of the mass maintains a high water content. The Dakota Bench is underlain by the steep slope and cliffs of the Morrison Formation, which is 300 to 500 feet thick. When the thick colluvium on the bench becomes unstable (too muddy), it starts to move. In Pleistocene time it spilled over the edge of the Morrison slopes and cliffs. A few of the mass wasting deposits are still believed to be active. The resulting mass movements are of several types: rock slides, rockfalls, debris slides, wet debris flows, and lobate debris flows. In places, successive flows have banked debris in large compressed ridges near the base of the steep slopes. These movements have ranged from very slow to fast and the deposits range from a few feet to several hundred feet in thickness. Most of the active movements today are slow. Many areas are presently on the verge of instability and moderate to heavy precipitation could induce new mass movements and trigger movements of old slides. Many of the landslides have been considerably eroded, and hoodoos (damosels), capped by sandstone boulders are fairly common. These type of mass wasting has probably been the principal means by which the Straight Cliffs of the eastern and southern Kaiparowits Plateau have retreated from the Escalante and Colorado Rivers.

Fuller, Williams, and Colton (1981) mapped the landslide zone and distinguished areas of recent landsliding and areas of older landsliding based on geomorphology. Recent landslides (the last few thousand years) have fresh, sharp forms and are not extensively weathered. Older landslides (more than a few thousand years old) have lost much of their original form due to weathering and erosion. On our map we show their areas of "recent" landsliding as "active" because the conditions that favor movement (steep slopes, moisture content, thick debris, etc.) are still prevalent as compared to those in adjacent areas. They also discuss radiocarbon dates on wood and charcoal that were deeply buried beneath alluvium derived from a large debris flow. The two dates are 1680 ± 70 years ago and 1370 ± 110 years ago. The material eroded from the landslides and was transported as far as 5 miles from the zone. Williams (1984) in a more detailed spin-off paper, describes the landslide zone and the debris flow origin of the alluvial deposits and terraces. He cites several authors (p. 457) that have incorrectly mapped these deposits as pediment alluvium.

A few of the larger individual mass movements have been named on topographic maps, such as the Fortymile Slide in the NW Sec. 14, T 40 S, R 7 E, the Sooner Slide in E 1/2 Sec. 2, T 41 S, R 8 E, and the Soda Slide in the SW Sec. 2, T 41 S, R 8 E. These, and several other large slides (without much engineering or economic output), provide all of the practical and suitable road grades up to Fiftymile Bench. In 1973, during road studies for the region, personnel of the Utah Department of Transportation (U.D.O.T.) obtained a sample (73-7-FS-31) of Tropic Shale in the Sooner Slide area (table 25). This type of landslide material, especially when wet, is not good to build a road on, and slope stability would be a major problem.

Table ~~25~~ 24. Engineering characteristics of Tropic Shale in the Sooner Slide area as tested by U.D.O.T.

Characteristic or test	Percentage or result
Coarse sand	2
Fine sand	6
Silt and clay	92
Hydrometer analysis	31% clay
Soluble salts	7.8
Swell	1.1
Dry density	114.5 lbs/cu.ft.
A.A.S.H.O. classification	A-6(10)
Liquid limit	35
Plasticity index	14

Interior Kaiparowits Plateau mass movements. Mass movements in the interior of the plateau tend to occur in groups or linear alignments along the lower and middle parts of the Wahweap Formation. These parts of the Wahweap consist largely of gray mudstone, shale, and siltstone that weather and disintegrate easily. These are chiefly rockslides, debris slides, and debris flows. Fuller, Williams, and Colton, (1981) did not include these with their studies. The largest group of mass movements is located in the S 1/2 T 38 S and N 1/2 of T 39 S, R 3 E on the steep rugged slopes of Escalante Canyon and an unnamed tributary (tributaries of Last Chance Creek). This is the area on the plateau that receives the most precipitation (about 13 inches). Other groups of slides are around Wesses Cove and Ship Mountain Point, both of which are in the S 1/2 T 40 S, R 3 E.

Most of these mass movements are fairly well adjusted to their present slopes and will remain so until disturbed by usually heavy precipitation, erosional undercuts, earthquakes, or human activities. Rockfall is a hazard in all the canyons of the plateau.

Lake Powell shoreline mass movements. Grundvig (for U. S. Bur. Reclamation, 1980) describes and illustrates eight hazardous mass movement sites along the Lake Powell shoreline in Kane County. Five are actual or potential rockfall sites from cliffs of the Navajo Sandstone. Three sites are slump failures of the toes of sandy talus cones or piles. All of the sites are shown as "active" on plate 10. Grundvig's report indicates that in August, 1975 a boater was killed by a rockfall in Padre Bay. The Bureau of Reclamation performs landslide surveillance each year on at least part of Lake Powell to update information regularly.

The steep cliffs along the shoreline should alert everyone about the dangers of rockfall. The talus accumulates at the base at precarious angles. Great masses of rock have been known to part from the cliffs and come crashing into the water and small rocks falling from above pick up much speed in their descent. The Glen Canyon Group formations are normally strongly jointed and is the dominant means by which they deteriorate and crumble. Thin shaly partings can aggravate the danger.

The talus piles are favorite places to moor houseboats and speedboats, but when the parts above water are saturated the strength thereof may be diminished to the point where shearing would allow the whole mass to quickly slide into the lake. Sand blowing over the edges of the cliffs often accumulate to more than 100 feet above lake level. The sand deposits lie at the steepest angle of repose possible. If the lake removes the toe of such a deposit (during a storm) it can slide into the lake in a matter of seconds. Sometimes large cracks have developed in water saturated sand deposits, which can be starting points for the sliding. The danger from all of these landslides is not only from the rock that might crash on boats, or loss of support if a person or persons are walking on them, but the resultant huge waves that develop at the point of impact. Grundvig (1980) sites the case of a huge rockfall that occurred June, 1974 near Iceberg Canyon. Apparently a large slab was released along a joint and fell into the lake. The wave lifted a boat anchored across the main channel, depositing it 40 feet from the existing shoreline. Such dangers are also present in the deep canyons favored by hikers, the most dangerous places being directly adjacent to vertical cliffs and under overhangs. Perhaps the most dangerous time is in the winter, early spring, and after a torrential rainfall, when everything may become saturated.

The Chinle Formation is exposed opposite the Rincon along the shores of Lake Powell. It has acted much the same way as the Tropic Shale at the foot of the Straight Cliffs. The cliffs of the Glen Canyon Group overlie the Chinle and retreat as the softer and incompetent unit removes support. Most of the surface of the Chinle is littered and covered with boulders and clasts of all sizes. The clayey units of the Chinle have also allowed for rotational slumping within, especially in the lower part of the unit.

<u>Gray Cliffs of the Podunk Terrace</u>. The narrow Podunk Terrace is bounded along its southern margin by the Gray Cliffs, on the west by the Sevier fault zone, and on the east by the Paunsaugunt fault. Most of the mass movements (plate 8) originate in the Tropic Shale, but a few are derived from the underlying Dakota Formation. The Tropic Shale is 650 to 700 feet thick in most places and consists mostly of blue gray claystone and mudstone in the lower part and brown-gray claystone and mudstone in the upper part (Goode (1973a, 1973b). Many of the mass movements, chiefly debris slides, blockslides, and slumps, originate from the upper part of the Tropic and many of the masses contain sandstone boulders and debris from the overlying Straight Cliffs Formation. Several clusters of these masses are present along Tenney Creek, Mineral Creek, and Slide Canyon, but the largest landslides are northeast and east of Alton. Shroder (1971, p. 39-44) describes these two landslides as follows:

> "The <u>North Roundy landslide</u> is 1.0 mile northeast of Alton and is a blockslide and debris flow. It has a width of 8000 feet, a length of 3500 feet, a thickness of 100 feet, and a volume of 100

million cubic yards. The landslide material is shaly mudstone and bentonite beds of the Tropic Shale; also Straight Cliffs Formation. The causes of the landslides were unstable bentonitic mudstones of the Tropic Shale coupled with shattering of the rock, possible inflow of water, and earthquake tremors along the Sevier fault."

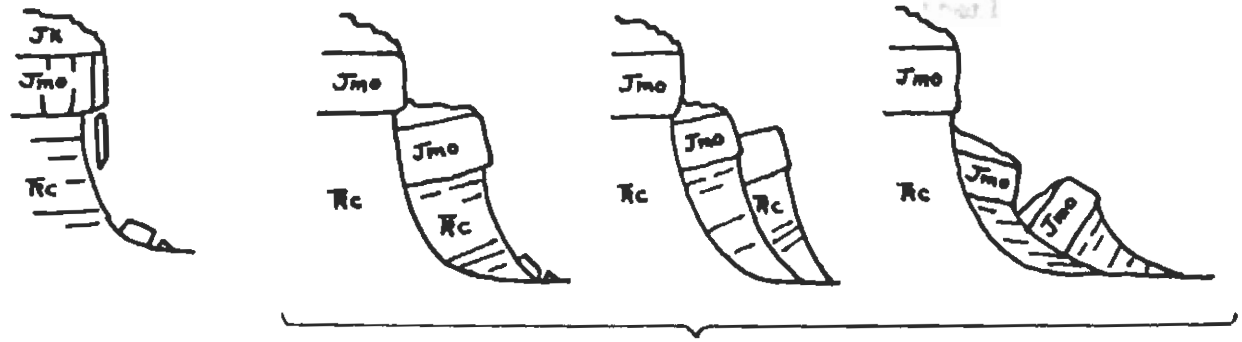
"The South Roundy landslide is 1.6 miles east of Alton and is a blockslide and debris flow. It has a width of 10,000 feet (north to south), a length of 3000 feet, a thickness of 100 feet, and a volume of 100 million cubic yards. The landslide material is debris from the Tropic Shale, the Straight Cliffs Formation, and the Wahweap Formation. The cause was failure of the Tropic Shale."

Beneath the gray slopes of the Tropic Shale is the Dakota Formation which also produces a few and generally smaller mass movements in this area. The Dakota is about 200 feet thick and is composed of interbedded sandstone, mudstone, and coal with claystone and bentonite abundant in the lower one-third. The slumps and debris slides emanate from the lower part, especially when it becomes saturated with water.

Mass movements at the base of the Vermilion Cliffs. The slopes at the base of the Vermilion Cliffs are composed of the colorful, relatively weak Petrified Forest Member of the Chinle Formation. The unit consists of argillaceous and bentonitic mudstones, sandstones, and siltstones that are easily weathered, eroded, and form moderate to steep slopes. The overlying cliff forming Moenave Formation is mainly fine grained blocky sandstone with vertical or nearly vertical joints. The Moenave and combined Chinle-Moenave have two general types of cliff retreat (figure 50). Type A involves the undermining of the Moenave, resulting in simple rockfall of sandstone debris and boulders. Type B is illustrated as progressive Toreva block failures.

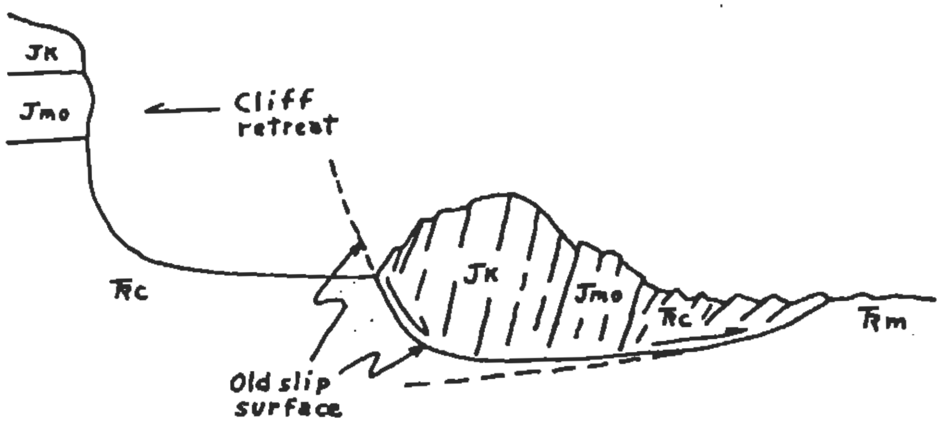
An extreme case of the latter is apparent in a NE to SW diagrammatic cross section through the Manganese King mine area in Sec. 2, T 42 S, R 3 W (figure 50, type C). A water well was drilled in this locality in 1952. From depths of 15 to 65 feet the well encountered sandy clay (Chinle?). At 65 feet a seep of water was encountered which probably is the old slip surface. At the leading edge of the slide it lies over the Moenkopi Formation which lies at a steeper dip angle than the general bedrock of the area. Whether the sliding affected the Moenkopi is unclear, but the Moenkopi is quite sensitive to loading pressures. The strike length of the slide is evident for at least a mile.

At the base of the Vermilion Cliffs aprons of colluvium developed (probably during the Pleistocene epoch) in the Paria Region which are currently being eroded. The upper surfaces of these rubble piles contain all sizes of clasts from the Moenave and Kayenta Formations, including very huge angular boulders. Chinle materials are incorporated in the basal portions of these aprons which appear to have nearly flat bottoms. The deposits partly look like pediments but may have slid downslope during their active period. Old Toreva-type blocks can often be identified in Chinle outcrops where no rubble from the overlying formations is present.



Type A

Type B



Type C

Figure 50. Diagrammatic sketches that portray landslides occurring at the base of the Vermilion Cliffs. Type A shows a typical rockfall situation. The next three sketches (Type B) shows sequential rotational block landsliding. The last sketch (Type C) shows an older landslide near the Manganese King mine from which the present cliff has retreated (see text).

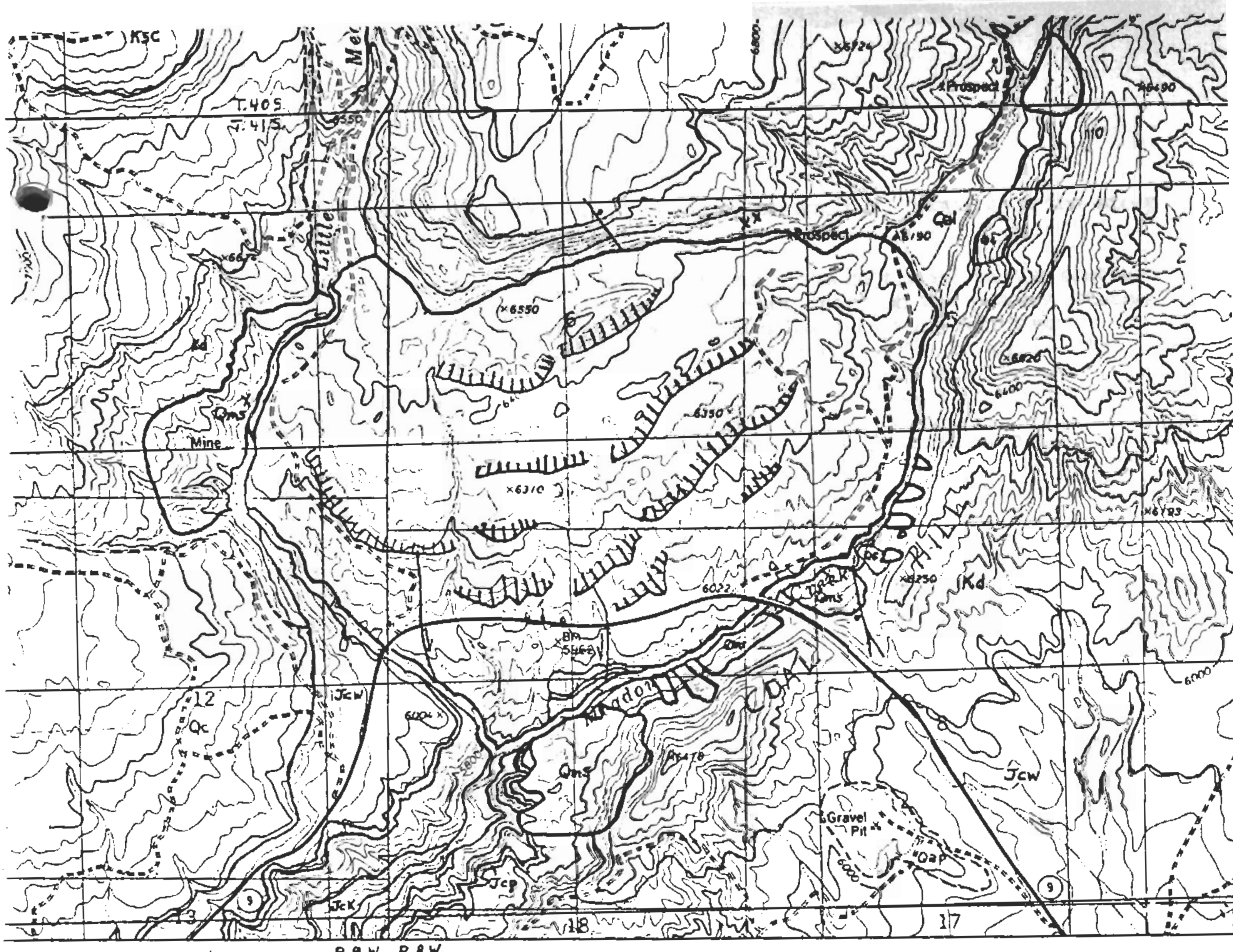
Gray Cliffs-Kolob Terrace mass movement zone. This zone is found in the northwestern part of Kane County. It develops near Meadow Creek near State Highway 9 and extends west to Clave Canyon, then northerly along the west side of Clear Creek Mountain in a broad zigzag pattern to Cogswell Point. The zone is about 24 miles in length and ranges from 0 to 1.9 miles in width. Numerous mass movements are on the slopes of Meadow Creek, Little Meadow Creek, Orderville Gulch, and the North Fork of the Virgin River. "Active" landslides of the region were mapped by Kilbourne (1984).

The Dakota Formation is the chief producer of mass movements in this part of the county and therefore it is shown only west of the Sevier fault zone on the geologic hazards map (plate 8). In most places the overlying Tropic Shale is involved in the slope failures due to movements in the underlying Dakota. One of these mass movement areas, the Coal Hill landslide complex, has been an expensive and perennial problem for the Utah Department of Transportation (U.D.O.T.)

The Coal Hill mass movement area covers about 2.5 square miles and is located in parts of Secs. 5, 6, 7, and 8, T 41 S, R 9 W. The area is about 6.6 miles west of Mt. Carmel Junction on State Highway 9 (figure 51). Elevations on the landslide complex range from 5760 feet at the toe (along Meadow Creek) to 6600 feet on the north side at the head of the slide area. The area has an average annual precipitation of 14.5 inches. The maximum precipitation occurs in the months of December to March in the form of snow that on melting seeps into the ground.

The Coal Hill landslide complex is just west of an arcuate northeast to southwest ridge called Coal Hill that is comprised of the Jurassic Winsor Member of the Carmel Formation and the overlying Cretaceous Dakota Formation. To the north the Dakota is then overlain by the Tropic Shale. All of these involved units have a regional northeast dip of 1 to 2 degrees. The area is termed a landlide complex because different hummocky masses are within it, or adjacent to it, having their own geometries and differential downslope movements. Some of the individual masses are blockslides, earthflows, slumps, and composite rotational slump-blocks along concave (upwards) sliding surfaces. Some of these masses are presently active whereas others haven't moved in years.

The largest mass movement area is between Little Meadow Creek (west side) and Meadow Creek (east side). Slopes from the head of the mass to the toe range from 6.5° to 8.7°. The terrain is very hilly, hummocky, and highly dissected by gullies. Many straight, and a few arcuate ridges are on the mass and could be either (1) pressure ridges, (2) scarps of successive, or stepped, rotational slumps, or (3) blockslides (translational) of material that originated higher on the slope. The steep southward slope of these features is shown on figure 51. We believe most are linear blocks of intact Tropic Shale that have been rafted downslope on the moving mass. The mass wasting scarps along the north side of the complex range from 240 to 350 feet in height and are higher on



Geology modified from Cashion (1967) and Stouffer (1964).

Fig 51 GEOLOGIC MAP OF THE COAL HILL AREA

EXPLANATION

QUATERNARY

- Qal — Alluvium
- Qc — Colluvium
- Qms — Mass-movement slides and slumps
- Qap — Pediment alluvium

CRETACEOUS

- Ksc — Straight Cliffs Formation
- Kt — Tropic Shale
- Kd — Dakota Formation

Unconformity

JURASSIC — Carmel Formation

- Jcw — Winsor Member
- Jcp — Paria River Member
- Jcc — Crystal Creek Member
- JcK — Kolob Limestone Member

0 1000 2000 3000 feet

Scale

X Spring

Escarpment

Shear fault; movement indicated by arrow

Normal fault; bar and ball on downthrown side the west side of the complex. Two seeps, or springs, issue from the steep scarps on the east side.

Two longitudinal north-south shear faults were traced in the southern part of the mass. These faults are 2500 feet apart on the present State Highway 9. The most active part of the complex is moving southward between the two faults. The westernmost fault splays as it approaches Little Meadow Creek. On the jumbled toe of the landslide there are numerous zigzag cracks and scarps. Most of the debris is light to dark gray, highly weathered, soft, silty shale. On scarps and slip surfaces this material is gray silt and clay with a "popcorn" texture indicative of the presence of bentonite. Little Meadow Creek is clogged with debris in one place, but the stream has eroded a tunnel beneath it. Meadow Creek is coursing over and through slide material in two places. Along the northwest bank of Meadow Creek, in the center of Sec. 7, there appear to be unaffected outcrops of the upper three members of the Carmel Formation. On the old highway (abandoned in 1964), which is approximately 210 feet south of the present roadway, has its twisted and deformed pavement offset 16 feet by the eastern shear fault. The western shear fault offsets the old pavement 20 feet. These measurements were made on July 23, 1985.

Along the steep southeast slope of Meadow Creek there are 10 mass movements that were produced by failure of the Dakota Formation. Nine of these were slumps and earthflows. The other, a rotational slump block in the N 1/2 Sec. 8, and just north of the present highway, is the original "Coal Hill" slide. This slide area is presently a large amphitheater facing the northwest. The crown height is about 90 feet and the crown length is about 1200 feet around the semi-circle. The difference in elevation from crown to toe is 160 feet and the width of the slide at the foot-line is about 700 feet. The slump material consists of gray shale, gray and black carbonaceous shale, and gray mudstone that long ago disintegrated into silt and clay. Water seeps from the slump and it is ponded on a slide bench about 20 feet above the creek level.

Along the steep west slope of Little Meadow Creek in Sec. 1, there are several slumps from the Dakota Formation. Water issues from near the base of one of these. At the south end slump debris overlies an intact interval of sub-Dakota Conglomerate. Stouffer (1964) reported on the landslides in the Coal Hill area and did his geologic work in conjunction with an extensive drilling project and seismic survey of the Utah Department of Transportation (U.D.O.T.) in 1962 and 1963. At the time U.D.O.T. was considering the realignment of a part of State Highway 9 (at that time State Highway 15) that traversed the particularly troublesome "Coal Hill" slide. This badly slumping area had been a perennial maintenance problem since the construction of the highway in 1928. As a result of the investigation it was determined that a 65 to 75 foot interval of blue gray bentonitic shales, near the base of the Dakota Formation, was the prime zone of failure (Stouffer, 1964, p. 19). The zone of failure is just above the 15 to 30 foot basal sub-Dakota Conglomerate of the Dakota and just below the "lower" coal zone. The incompetent bentonitic shales in the zone of failure were nearly always water saturated, especially during the winter and spring, and testing of 21 core samples determined that the average plasticity index was 76.0 (p. 68). The shales are highly plastic and indicate a high sensitivity to water. A north trending fault cuts through the rotational slump area. The fault plane is vertical, has several branching fractures, is upthrown to the east, and movement along it has broken and brecciated adjacent strata. This fault zone allows the downward and lateral percolation of much surface water.

The 13 seismic refraction profiles and the 38 drill holes revealed that the slide mass ranges to 79 feet in thickness. In 1964 the U.D.O.T. changed the highway alignment which now crosses Meadow Creek about 2500 feet below the old crossing. The line change was very expensive and entailed about two miles of new highway. The present highway is still on the landslide complex of Meadow Creek (photo 84). Stouffer (on his geologic map) termed this area a "creep zone" and mapped it as colluvium between Meadow Creek and Little Meadow Creek, a distance of one mile. The U.D.O.T. drill hole number 12, located 200 feet west of Meadow Creek and just north of the present highway, showed 38 feet of colluvium overlying the Winsor Member of the Carmel Formation. The U.D.O.T. seismic line number 14, 150 feet west of Meadow Creek and trending northeast parallel to the creek, showed 42 feet of colluvium overlying the Winsor.

Since 1964, the mass movement area between Meadow Creek and Little Meadow Creek has been a high-cost of maintenance road, especially the section between the two shear faults which is actively moving southward. In May, 1983, the road between the shear faults moved southward several feet. The shearing movement offset, twisted, and deformed highway pavement, subgrade, and culverts. Temporary and minimum repairs were made at the time, such as smoothing and patching the pavement. In the spring of 1985, the highway between the shear faults, and a little beyond, was completely regraded and resurfaced at a cost of about $150,000. On September 10, 1985 there was one inch of centerline offset in fissured pavement on the west shear fault and 0.5 inch centerline offset on the east shear fault. This indicates that movement along the west side of the mass is more rapid. By summer of 1986 the offsets were greater than a foot (photo xx) and new patching was necessary on the new pavement.

<u>Orderville Gulch area mass movements</u>. Fifteen "active" mass movements were mapped in Orderville Gulch. The Dakota Formation and the Tropic Shale form very steep slopes and the largest "active" slides originate in the Dakota. Above the "active" slides on the south slope of the canyon is an extensive and thick mantle of colluvium. The downslope movement of this debris is slow, but some parts more relatively faster than others. Developers and potential lot buyers should be aware of the actual and potential unstable slopes in Orderville Gulch. Many roads in the canyon lead to private lots, but several of them are on steep sloughing slopes of the Dakota or Tropic. Slope disturbances by humans could aggravate potential landsliding.

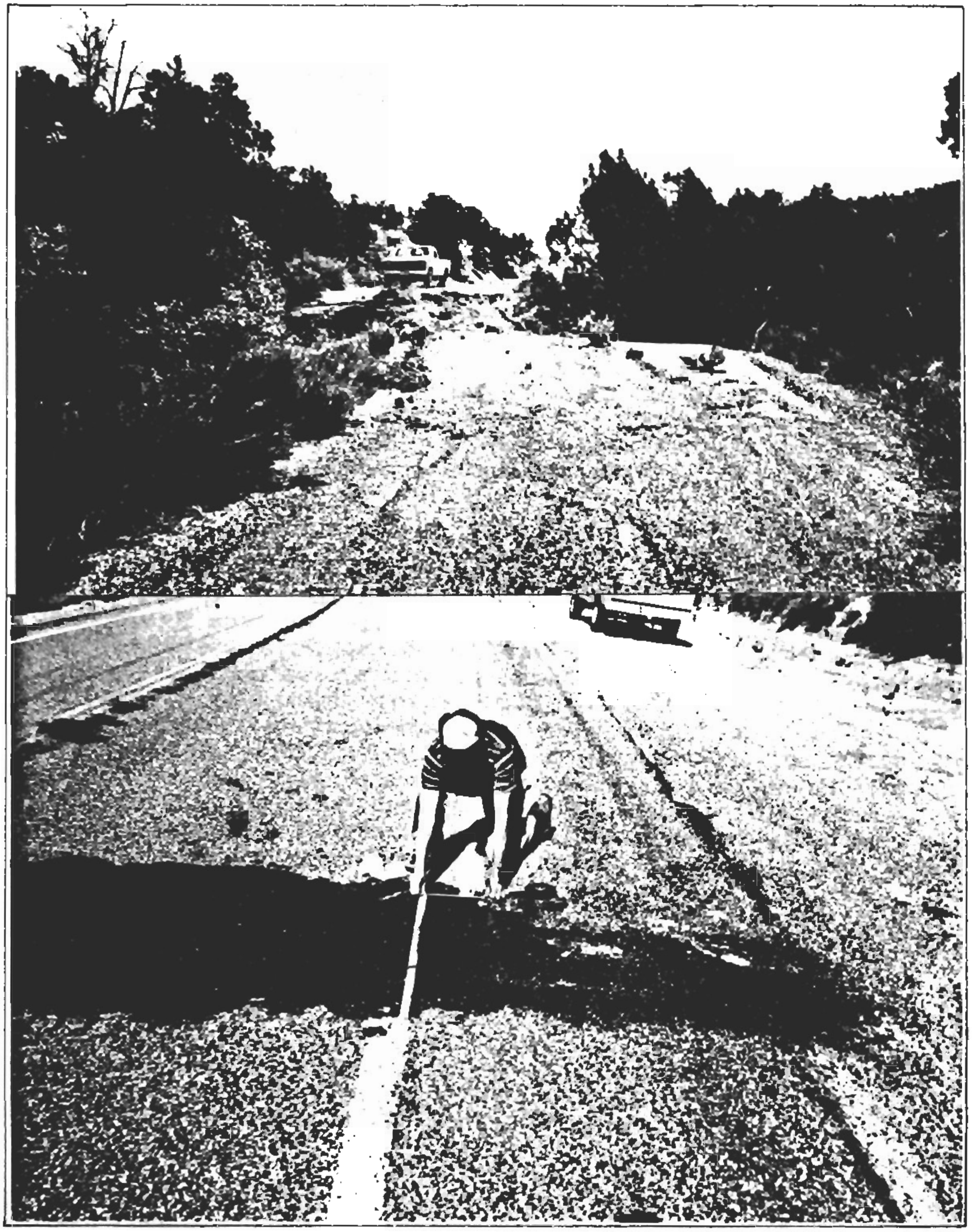


Photo 84. Road deformation along the Coal Hill slide. Upper photo shows abandoned roadway with 16 feet or more of displacement along a shear fault. Lower photo shows displacement on the new highway experienced in one year.

North Fork of the Virgin River. Additional colluvium covered areas are found along the high slopes bordering the North Fork of the Virgin River. Most of the debris is from the Dakota Formation and Tropic Shale. In general, the colluvium moves downslope very slowly. During some fairly dry years it may not move at all. In any event, these slopes are potentially unstable and movement could be aggravated by development.

Claron Formation mass movements. There are a few cut slope problems in the Claron Formation adjacent to State Highway 14 between Long Valley Junction and Strawberry Creek. Two miles west of Long Valley Junction, in the NW Sec. 21, T 38 S, R 6 W, a road cut is slumping on the south side of the road. The slump is about 90 feet long and 25 feet high. The material is silt, sand, and gravel that has weathered from the Claron Formation. In the NW Sec 23, T 38 S, R 7 W, there are several mass movements along the northwest side of the highway. Two of the sloughing areas are each about 150 feet long and 40-45 feet high. Another slump is about 75 feet long and 35 feet high (July 6, 1985). The debris is silt, sand, and marly gravel weathered from the Claron Formation.

Swelling and Shrinking Rocks and Soils (poor foundation materials)

Silt and clay are sediments that consist of the very finest grained products of erosion. Silt size particles are 0.08 to 0.002 mm in diameter and clay sized particles are 0.002 mm or less in diameter. Silt and clay minerals reflect the rocks of the source region from which they were derived. Silt particle minerals are usually quartz, feldspar, mica, garnet, magnetite, hornblende, etc. Clay particles, of colloidal sizes, consist of kaolinite, montmorillonite, bentonite, illite, halloysite, and other so-called "clay minerals." The clay minerals are chiefly hydrous aluminum silicates that have their basic chemical units arranged in a layered structure. Clays have the ability to absorb water both by interparticle and intracrystalline forces. Thus, clays tend to swell or expand when they are exposed to water. Some clays, such as montmorillonite and bentonite, have a large swell potential. Also, clays can lose water and shrink or consolidate. Either of these two phenomena can cause structural damage to edifices and other construction.

In addition to clay-bearing rocks, gypsum-and sulfate-bearing rocks can cause swelling in rocks and soils. Also, if the sulfates are dissolved then the rock or soil can differentially lose its ability to support the weight of anything built upon it. Three formations in Kane County contain considerable amounts of gypsum, the Toroweap, Moenkopi, and Carmel Formations.

Several Kane County formations, and soils that have been derived from them, have a relatively high expansive clay content. These include the Tropic Shale, the lower middle part of the Dakota, and the Chinle Formation. Other units, especially in the Cretaceous System, contain thinner horizons, but could locally cause problems. In addition, these units may exhibit other undesirable foundation characteristics.

The size gradation of a soil and four physical tests provide a means to classify it. There are several soil classification systems, but we prefer the Unified Soil Classification System (USCS), table 26. Tests are made to determine the shrinkage limit, the plastic limit, the liquid limit, and the plasticity index of a soil (see glossary for definition of these terms). These four soil-moisture conditions are often called the "Atterburg limits" or simply the index properties of a soil. A sieve analysis determines the size gradation of the soil particles. The size distribution of soil particles, in the USCS, is given in table 26.

The USCS is based on identification of soils according to their textural and plastic qualities and their grouping with respect to their performances as engineering construction materials. The soils are divided into three divisions: (1) coarse grained soils, (2) fine grained soils, and (3) highly organic soils. The coarse grained soils are those that contain 50 percent or less material smaller than the No. 200 sieve, and fine grained soils are those that contain more than 50 percent material smaller than the No. 200 sieve. Highly organic soils can generally be identified by visual examination.

The coarse grained soils are divided into gravels (G) and sands (S) which can be divided into secondary groups - GW, GP, GM, and GC; SW, SP, SM, and SC respectively (W=well graded, P=poorly graded, M=silty, C=clayey). Fine grained soils are subdivided into silts (M) and clay (C), depending on their liquid limit and plasticity index. The silts and clay groups are each divided into secondary groups based on whether the soils have a relatively low (L) or high (H) liquid limit. Representative soil types found in each of the resulting groups are given in table 26, under "Typical names."

The multiplicity of factors that govern the swelling of a particular rock or soil unit makes it imperative that tests be made on representative samples of the actual soil and rock involved during construction, in all cases where swelling damage may be expected. Local construction practices and experience should be considered in evaluating these factors. Das (1984, p. 466) has developed a potential swell classification based on the standard tests (table 27).

Table 27. Expansive soil classification system modified from Das (1984).

Liquid limit	Plasticity index	Potential swell percent*	Potential swell classification
50	25	0.5	Low
50-60	25-35	0.5-1.5	Moderate
60	35	1.5	High

*Potential swell = vertical swell under a pressure equal to overburden pressure.

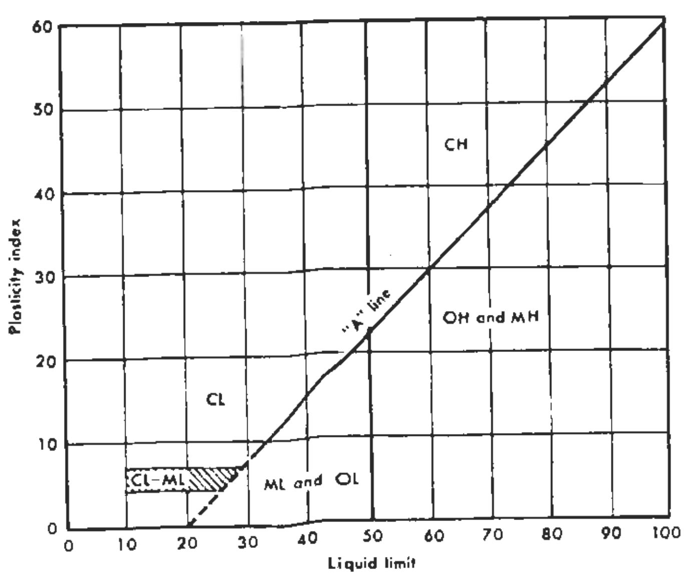
Table 26

~~Table 26.~~

UNIFIED SOIL CLASSIFICATION SYSTEM

Major divisions			Group symbols		Typical names	Laboratory classification criteria	
Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW		Well-graded gravels, gravel-sand mixtures, little or no fines	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP		Poorly graded gravels, gravel-sand mixtures, little or no fines	Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM*	d	Silty gravels, gravel-sand-silt mixtures	Atterburg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are borderline cases requiring use of dual symbols
				u			
			GC		Clayey gravels, gravel-sand-clay mixtures	Atterburg limits above "A" line with P.I. greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW		Well-graded sands, gravelly sands, little or no fines	$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP		Poorly graded sands, gravelly sands, little or no fines	Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM*	d	Silty sands, sand-silt mixtures	Atterburg limits below "A" line or P.I. less than 4	Limits plotting in hatched zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols.
				u			
			SC		Clayey sands, sand-clay mixtures	Atterburg limits above "A" line with P.I. greater than 7	
Fine-grained soils (More than half of material is smaller than No. 200 sieve)	Silts and clays (Liquid limit less than 50)		ML		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	(see Plasticity Chart)	
			CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays		
			OL		Organic silts and organic silty clays of low plasticity		
	Silts and clays (Liquid limit greater than 50)		MH		Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts		
			CH		Inorganic clays of high plasticity, fat clays		
			OH		Organic clays of medium to high plasticity, organic silts		
	Highly organic soils		Pt		Peat and other highly organic soils		

Laboratory classification criteria, coarse-grained soils: Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:
Less than 5 per cent ... GW, GP, SW, SP
More than 12 per cent ... GM, GC, SM, SC
5 to 12 per cent ... Borderline cases requiring dual symbols**



Plasticity Chart

*Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is based on Atterburg limits suffix d used when L.L. is 28 or less and the P.I. is 6 or less; the suffix u used when L.L. is greater than 28.

**Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example: GW-GC, well-graded gravel-sand mixture with clay binder.

If a soil is classified as having a low swell potential, standard construction practices may be followed. However, if the soil has moderate or high swell potential, precautions need to be taken. This may entail one, or a combination of the following (Das, 1984, p. 466): (1) Evcavating and replacing the expansive soil under, or adjacent to the foundation, (2) changing the nature of the expansive soil by such measures as compaction control, prewetting, installation of moisture barriers, and chemical stabilization, and (3) strengthening the structures to withstand heave, constructing edifices that are flexible enough to withstand the differential soil heave without failure, or constructing isolated deep foundations below the depth of the active zone.

The structural strength of a particular soil or rock is dependent on five basic physical characteristics; internal friction, cohesion, capillarity, elasticity, and compressibility, which combine to indicate the shear strength and resistance to consolidation and movement that may be expected in the life of a specific soil or rock. These factors are influenced most by the gradation of a soil and its moisture content, which in turn, determine the possible influence the various soil properties will have on the structural strength or support value of the soil or rock.

Various laboratory tests have been devised to evaluate rock and soil bearing capacities. They include shear tests, consolidation tests, and bearing value tests of various types. Four our limited testing program on the Chinle Formation and Tropic Shale, we selected the soil classification tests, combined swell-consolidation tests, and water soluble sulfate analyses. Hydrated calcium sulfate (gypsum) and sodium sulfate, or "white alkali" may have moderate swell potential if they comprise more than 15 to 20 percent of a soil or rock. Although these sulfate minerals have caused swelling damage to structures, they are more normally considered a hazard because of their corrosive effects on certain types of concrete and on buried metal pipes and cables. A commercial geotechnical laboratory in Salt Lake City did the testing as well as providing interpretations. Our sample of Chinle Formation and our two samples of the Tropic Shale were weathered, decomposed, and disturbed and perfect for most types of contemplated construction. It would have been considerably more expensive to obtain unweathered drill cores for testing.

<u>Chinle Formation tests</u>. The sample of Chinle Formation for testing was obtained in highway roadcut southeast of Kanab in SWSE Sec. 27, T. 43 S, R 6 W. The field description is highly weathered gray, grayish- red, and purple claystone and siltstone. The sampled interval was four feet. This sample (C-1) was tested and had a silt and clay content of 74.5 percent of which 16 percent was clay (figure 52). The liquid limit was 64 percent and the plasticity index was 31 percent. These results indicate that the Chinle has a moderate swell potential. The percentage of sulfate in the sample was 0.089 which indicates a negligible potential for reaction with concrete and buried metal conduits.

Part of sample C-1 was remolded to a stiff consistency at a moderate moisture content and tested for swell-consolidation (figure 53). At a pressure of 1000 pounds per square foot (1.0 Ksf) the consolidation of the sample was about 2.4 percent and consolidation predominated over swell. At this pressure the sample was wetted and a sudden volume loss, slaking, and collapse was observed. Testing was continued to 4.0 Ksf and the consolidation was 10.1 percent.

The test data indicate that the Chinle Formation has moderate swell potential based on the index properties. When slightly to highly weathered the Chinle exhibits significant slaking potential. The slaking, or physical deterioration, is expressed as a relatively sudden volume loss or partial collapse when wetted and is expected predominate over the swell potential when it is subjected to lightly to moderately loaded, relatively unconfined conditions. These conditions should be anticipated to prevail in many areas of (future) residential construction on this formation. The composition of the Chinle Formation, and derived soils, appears to be fairly uniform throughout Kane County. Our test data is empirically applicable to any of the formation and derived soils. However, it should be expected that physical and chemical properties will vary somewhat, both laterally and vertically.

In northeastern Arizona the Chinle Formation crops out extensively and has caused numerous construction problems, especially road building and maintenance. Because of the swelling clay content, methods of stabilizing the Chinle have been under consideration by the Arizona Department of Transportation since the early 1960s. O'Bannon and Mancini (1975, p. 42) collected 18 slightly weathered to hard, unweathered samples of the Chinle. The samples had an average density of 106 pounds per cubic foot and a specific gravity of 2.75. Liquid limits ranged from 28 to 44 percent and averaged 39 percent. Plasticity indexes ranged from 14 to 25 percent and averaged 22 percent. The average silt and clay content was 70 percent. Swell percentages ranged from 2.5 to 17.8 and averaged 8.8 percent. Their electro-chemical treatment of samples moderately reduced both expansive pressure and percentage of swell, but apparently had no affect on the Atterburg limits (p. 107).

<u>Dakota Formation tests</u>. The only test data we have on the Dakota is that which was done by the Utah Department of Transportation (U.D.O.T.) and reported by Stouffer (1964, p. 68). Twenty-one shale cores were tested from the unit and had an average plasticity index of 76 percent. The average moisture content of these shales was 20 percent.

<u>Tropic Shale tests</u>. Two samples of Tropic Shale (T-1 and T-2) were obtained for testing. Sample T-1 was obtained from an old roadcut in the NWSE Sec. 5, T 41 S, R 7 W and is described as a gray weathered shale. Sample T-2 was obtain from a roadcut in SESW Sec 5, T 41 S, R 7 W and is described as a dark gray relatively unweathered shale. Both sample intervals were of two feet of material.

Sample T-1 had a silt and clay content of 75.8 percent of which 25 percent was clay (figure 54). The liquid limit was 54 percent and the plasticity index was 33 percent which indicate that the Tropic Shale has a moderate swell potential. The percentage of soluble sulfate in the sample was 0.584, which would severely react with concrete or buried pipes. The

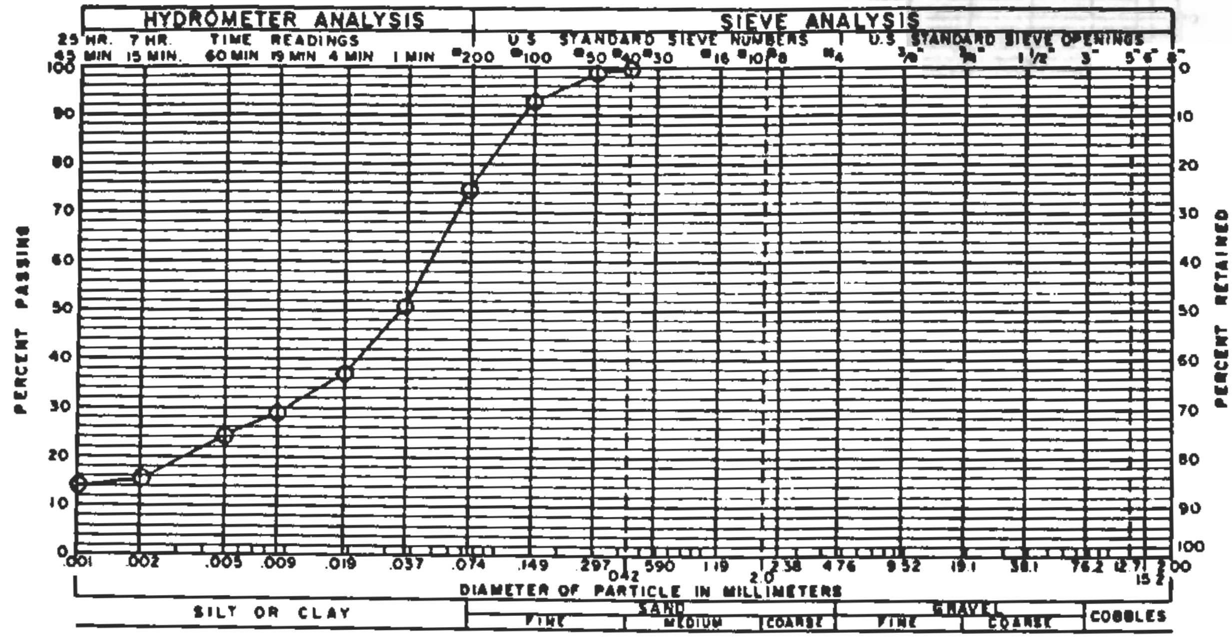


Figure 52. Gradation and index properties of the weathered Chinle Formation.

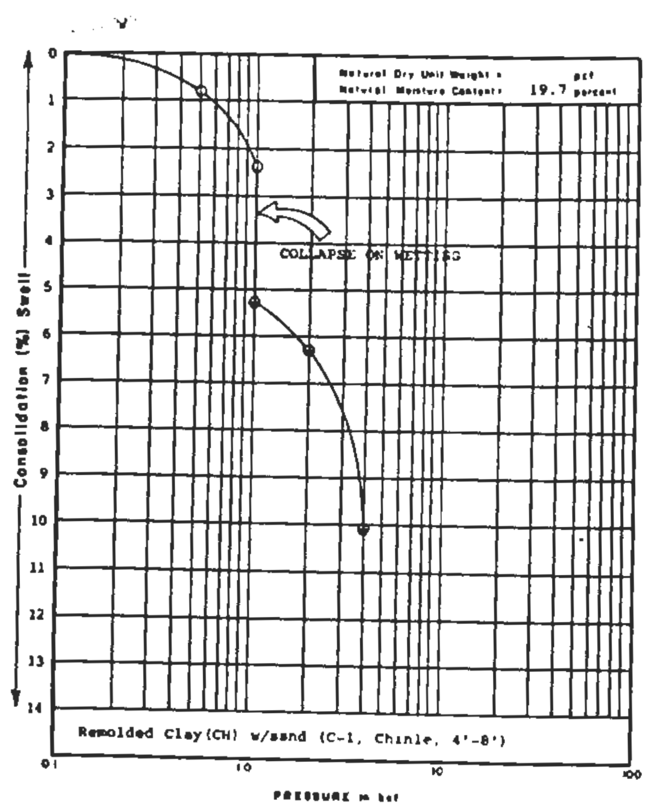
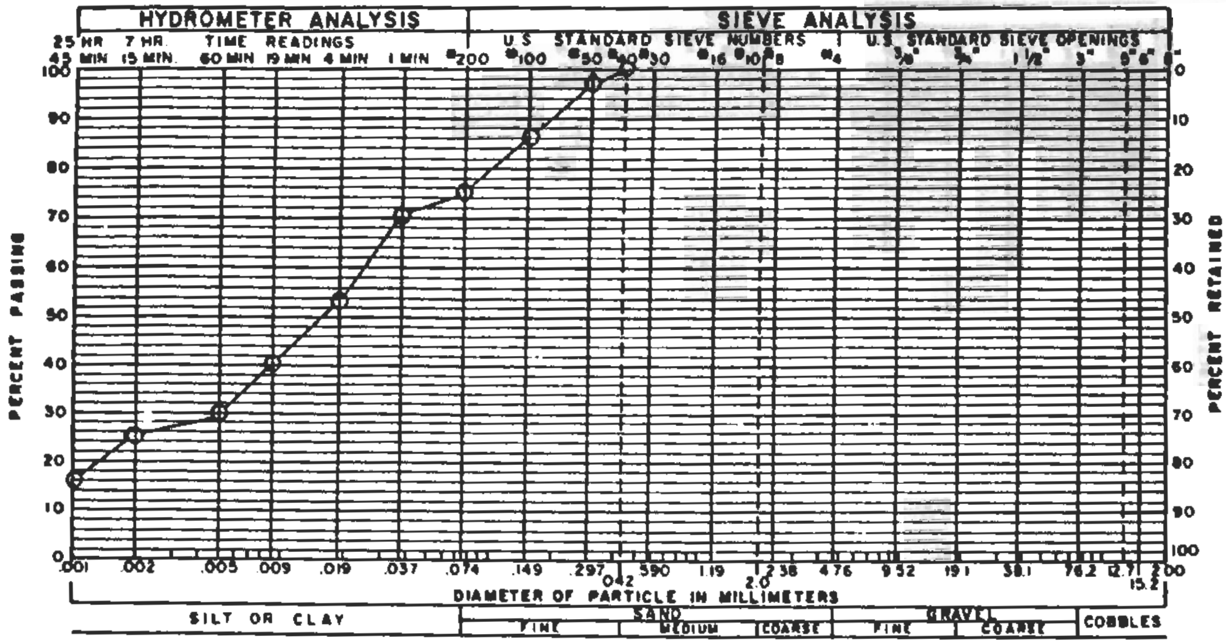


Figure 53. Swell-Consolidation Test of the weathered Chinle Formation.



GRAVEL 0 % SAND 24.2 % SILT AND CLAY 75.8 %

LIQUID LIMIT 54 % PLASTICITY INDEX 33 %

SAMPLE OF Clay(CH) w/sand FROM T-1, 0' - 2'

Figure 54 Gradation and index properties of weathered Tropic Shale.

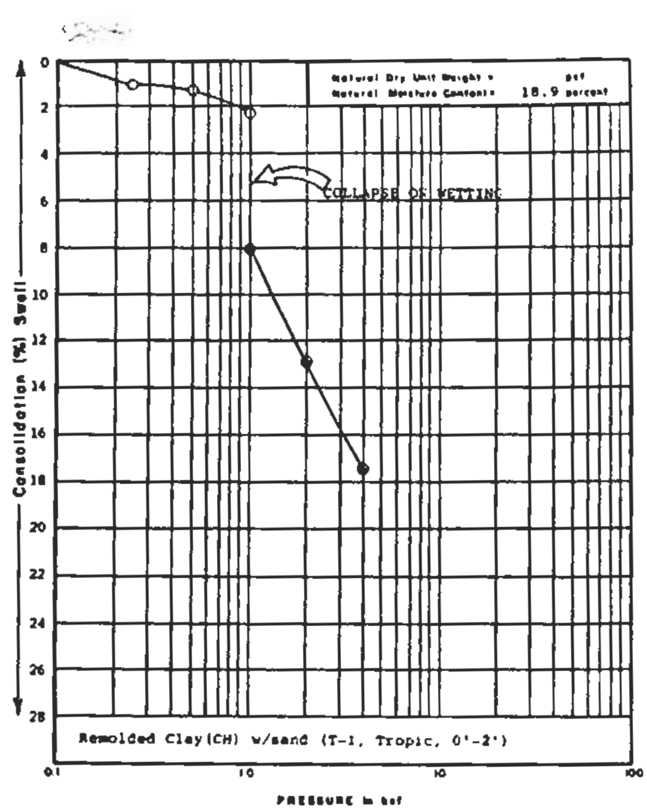
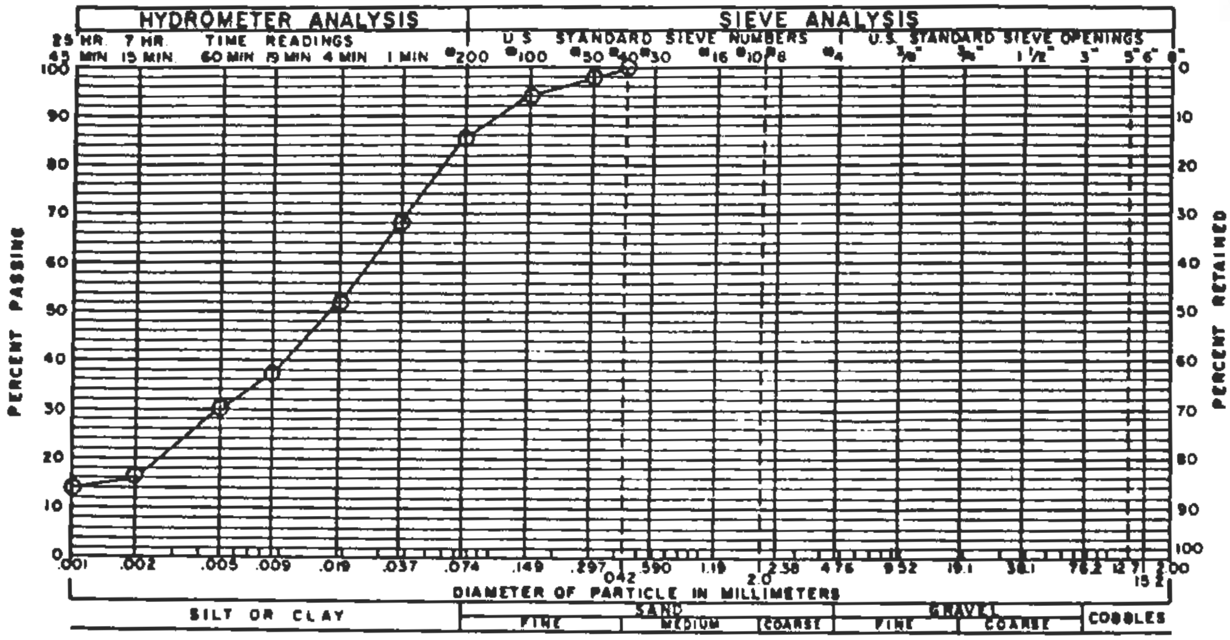


Figure 55. Swell-Consolidation Test of weathered Tropic Shale.



GRAVEL 0 % SAND 15.1% SILT AND CLAY 84.9 %

LIQUID LIMIT 51 % PLASTICITY INDEX 35 %

SAMPLE OF Clay (CH) w/sand (Claystone) FROM T-2, 0' - 2'

Figure 56. Gradation and index properties of relatively unweathered Tropic Shale.

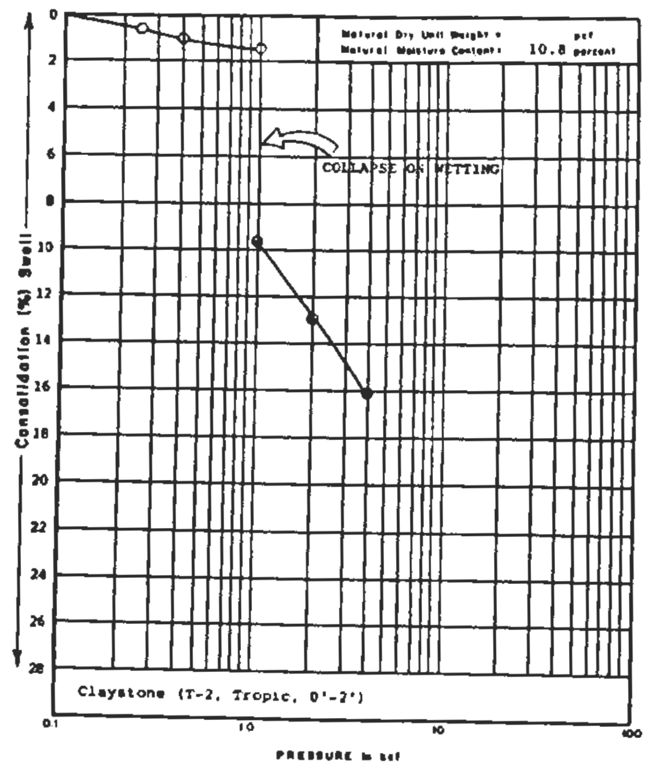


Figure 57. Swell-Consolidation Test of relatively unweathered Tropic Shale.

consolidation testing on T-1 was made on a disturbed sample remolded to a stiff consistency at a moderate moisture content. At a pressure of 0.5 Ksf the consolidation was 1.2 percent and at 1 Ksf the consolidation was 2.3 percent (figure 55). At the latter pressure water was added and the sample slaked and collapsed to consolidation of 8 percent. Testing was continued and at a pressure of 4 Ksf the consolidation was 17.4 percent. The physical deterioration, wetting behavior, and structural performance comments on sample C-1 apply to sample T-1.

Sample T-2 had a silt and clay content of 84.9 percent of which 16 percent was clay (figure 56). The liquid limit was 51 percent and the plasticity index was 35 percent which indicate that the shale has a moderate swell potential. The percentage of soluble sulfate was 0.289, which would potentially react with concrete or buried pipes.

The consolidating testing on sample T-2 was made on a shale fragment that was trimmed to conform to the test apparatus. At a pressure of 0.4 Ksf the consolidation was 1 percent (figure 57). At a pressure of 1 Ksf the consolidation was 1.4 percent. At this pressure the sample was wetted and slaking and collapse occurred and the consolidation went to 9.6 percent. Testing continued and at 4 Ksf the consolidation was about 16 percent. The consolidation of sample T-2 was slightly less than that of sample T-1. The test results of both samples indicate that weathered and near surface Tropic Shale will consolidate significantly, slake, or partially collapse under light to moderate loads in relatively unconfined conditions.

As previously noted, if abundant enough, gypsum and other sulfates can cause swelling in rocks or soils and solution can lower the bearing capacity. The Toroweap Formation locally contains thick gypsum beds in its upper member, but its area of exposure is quite small. The unit underlies hard limestone beds under most of the county. The Moenkopi Formation crops out in the Shinarump Flats physiographic subdivision. The Middle Member chiefly has thin layers and crisscrossing veins of gypsum, usually 1 inch or less in thickness. Also some sandstone and siltstone beds are partly cemented with gypsum. The Shnabkaib Member, however, contains much gypsum. In the SW Sec. 13, T 41 S, R 2 W, this member has 6 white, light green, and reddish-brown gypsum beds that were 0.2 to 6.8 feet thick. Several thick sandstone and siltstone units contain thin layers of gypsum as veinlets as well. Any type of construction on these two members of the Moenkopi Formation face the potential of significant swell and the potential loss of bearing strength. Also, of course, the sulfate might react with concrete and buried pipes.

In western Kane County the Paria Member of the Carmel Formation contains thick gypsum beds as white, massive alabaster or rock gypsum. One measured gypsum bed is 26.9 feet thick and others range from 2.8 to 9 feet in thickness. In central Kane County the Wiggler Wash Member has significant gypsum and smaller amounts have been discovered in the Kolob Limestone Member. The Wiggler Wash gypsum has beds to four feet in thickness and many beds are crisscrossed by thin veins of secondary satin spar gypsum. The same construction hazards apply to these members of the Carmel Formation.

Flooding

All of the perennial and intermittent streams of Kane County are subject to erratic and unpredictable overbank flooding (photo 85). It is more likely to occur in the Colorado River Basin than in the Great Basin streams. Historically, cloudburst floods have been more recurrent and severe than floods associated with spring snowmelt. Table 28 shows the historic record of major floods that are associated with summer, locally intense thunderstorms. These heavy, short-lived storms produce local flash floods that erode banks above floodplains and erode the canyon walls in which they flow. They "clean out" their channels, carrying all sizes of debris in their wake. It is the most effective method of erosion operative in the county. Each year has its flooding, although the same areas may not be affected. Over the years those that occur in the undeveloped areas go unreported. It is not uncommon to find that a canyon road has been washed out along 6 miles or more. In some cases it is almost impossible to find even remnants of the former road.

The compilations by Woolley (1850-1938) and Butler and Marsell (1939-1969) are chiefly from newspaper articles. The greatest flood damage has occurred adjacent to the East Fork of the Virgin River, Kanab Creek, Johnson Wash, and the Paria River, because of the past and present concentration of population and agriculture along these streams. A series of extraordinary cloudburst floods during the 5 year period 1882-1886 caused erosion of the Kanab Creek channel to a depth of 50 feet and a width of 200 feet. During this period dams were repeatedly washed away. In 1874 the present townsite of Paria was settled by 15 families. For 9 years the community prospered, garden and crop yields were good and cattle increased in number. However, floods of the Paria River in 1883 were followed by the unusually severe winter of 1883-84 and by more floods in the summer of 1884 that washed away farmhouses and croplands. In the spring of 1884 Paria had its maximum population of 107, but by September only 48 people remained (Gregory and Moore, 1931, p. 30). It was evident that the Paria River occasionally claims its floodplain. To local residents, Johnson Wash is notorious for flash floods and the mouth of the canyon, long ago, was aptly termed "Hells Bellows." U. S. Highway 89 is within this area and the bridge over Johnson Wash suffers spasmodic damage. On August 1, 1983, erosion of the bridge abutments by flash flooding resulted in repairs costing $45,000.

The supervisor of the Kane County Road Department has numerous flooding and erosion problems in the county (Davis, 1984). Among the most persistent and expensive areas are the following. (1) Flooding, erosion, and landslides along the North Fork county road cause damage amounting to an average of $15,000 annually. This is the unpaved road that connects State Highway 9 to State Highway 14 (Navajo Lake). These problems occur in the spring and are due to the melt of the winter snowpack on the Markagunt Plateau and Kolob Terrace. (2) Summer flash flooding, erosion, and sand deposition from Pugh Canyon, one mile southeast of Kanab, results

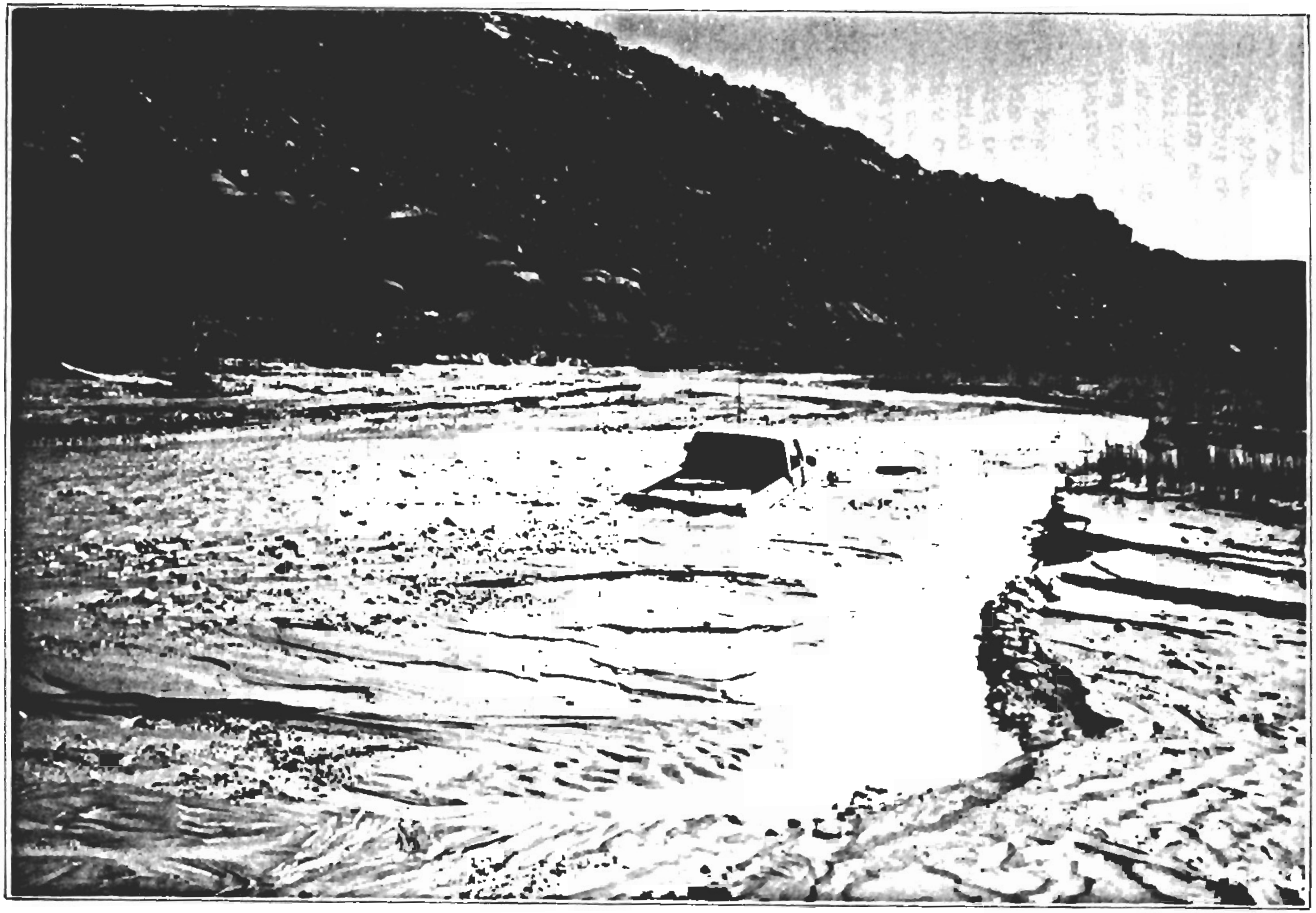


Photo 85. This hapless motorist attempted to cross the Paria River during flood. Flooding of the creeks and washes is a regular hazard in Kane County and precautions should be taken. Severe flooding fills the entire width of the wash and cuts away paralleling roadways and fields.

in repairs costing about $7,000 annually. (3) Summer flash flooding and erosion cause damage to county road crossings of Thompson Creek, Skutumpah Creek, Adams Creek, and others in the area. New culverts, rebuilding, and regrading the road costs around $6,000 per year. (4) Summer flash flooding and erosion of the Sheep Creek and Willis Creek county road crossings, and others in the area (T 38 S, R 5 W) result in annual damages of about $30,000. Other regular damage to roads in Kane County occurs along the Cottonwood Creek road (East Kaibab monocline), roads on the Kaiparowits Plateau, and the Hole in the Rock road.

Maps showing the flood-prone areas of Kane County have been published by the U. S. Dept of Housing and Urban Development (HUD). The 45 flood hazard boundary maps are dated 1978, except for the Kanab flood map which is dated 1985. These maps portray the extent of the 100-year flood (flood with a one percent chance of occurring annually) on major streams, and were used to show the flood-prone areas on plates 8 to 10. On our observations we have added additional areas. It should be pointed out that even if the drainage is not depicted on the HUD maps or ours, a flash flood can occur in, or issue from any (photo 86).

Table 28. Historical floods in Kane County, 1870-1983.

Date	Locality[1]	Stream[2]	Remarks
1 Aug 1881	Orderville	East Fork of Virgin River	Cloudburst-heavy rain of an hour's duration. Town was flooded and "hundreds of loads of rock, timber, and rubbish" were deposited in streets and fields. Damage estimated at $2800 to $3000.
30 Aug 1882	Kanab	Kanab Creek	Streets flooded, cellars filled, hay and grain damaged. Third flood in season; the first two were not large. Creek bed deepened 10 to 15 feet, and irrigation ditch was filled with sand.
29 Jul 1883	Kanab	Kanab Creek	"Heaviest flood known in this part of the country." Masses of earth as large as a common house floated down the stream with willows still standing. Extensive damage to crops, and all farming land in canyon was destroyed. Some cattle killed. Canyon near old city dam cut 50 feet down and 16 rods wide. Flood lasted 7 to 8 hours. Fresh cutting in channel opened up several new springs.
12 Mar 1884	Kanab	Kanab Creek	Five successive days of rain bring floods down creek, doing damage to extent of $500. Rainfall unprecedented.
10 Sep 1885	Kanab	Kanab Creek	Flood damages irrigation ditches. Estimates of two former floods give fresh cutting at canyon mouth as 64 to 69 feet total depth. (Probably exaggerated, see next item).

Photo 86. Narrow steep-walled canyons are favorite places for hikers, but should be avoided when summer thunderstorms threaten the watershed above.

12 Apr 1886	Kanab	Kanab Creek	Heavy runoff (probably a winter spring freshet) washed out dam and added 10 feet to depth of channel. Total depth reported as 50 feet.
18, 28, 31 Aug and 1 Sep 1886	Kanab	Kanab Creek	Four successive floods. First filled cellar of Tithing Office and caused settlement of building. Secon flood deposited sand and gravel on several acres. Third of series caused some damage to three properties. Largest flood of series occurred in conjunction with intense rain and hail storm. Hailstones as large as 1 1/2 inches were noted. Correspondent says, "The dams in the creek...went out some time ago, but we are so used to that I had almost forgot to mention it."
5 Jul 1896	Kanab	Kanab Creek	Cloudburst damages flumes and threatens dam.
1 Sep 1909	Orderville	East Fork of Virgin River	About $3000 damage ensued from recent storms. The river cut away much cropland and destroyed bridges at its height on Aug 31...canyon roads washed out in many places.
7 Aug 1941	Alton	Main, Rush, & Little Roundy Canyons	Heavy rainfall resulted in heaviest flood in over 30 years. Floods from canyons east of town did considerable damage to meadows and to grain and hay fields. At least $1000 damage to meadows and to grain and hay fields. At least $1000 damage to irrigation ditches that were washed out or filled with sand. The water 10 feet deep in the big wash, which took out all crossings and carried Sink Valley bridge half a mile downstream.
8 Aug 1941	Kanab		In Kanab 1.05 inches of rainfall in 1 hour Friday afternoon did little damage.
13 Aug 1942	Mt. Carmel		Storm raged in Mt. Carmel. Hail shattered corn and roads flooded with water.
11 Aug 1950	Kanab	Buckskin Creek	A flash flood stranded 64 members of a film shooting company in the mountains 40 miles to the east of Kanab. A torrent 7 feet deep filled Buckskin Creek after heavy rain and hailstorm.
8 Oct 1954	Orderville Glendale & Springdale	East Fork of Virgin River	More than $500,000 damage in three towns and surrounding farmland. "Worst flood in

90 years" in Orderville where 1.2 inches of rain were recorded during the short storm. Water poured from all small canyons into the Virgin River which reportedly crested at 4 feet in Orderville. Two bridges across the river in Orderville were weakened and the town's culinary water system was washed out in four places. Floodwater swirling down the town's main street moved cars and clogged street with debris including boulder weighing "at least a ton." Most basements in town flooded; winter feed crop ruined. In Glendale many basements flooded and mud and silt 6 to 12 inches deep reported to cover every lawn.

4 Aug 1955 Kanab Kanab Creek Today nearly 150 members of a motion picture company were working on scenes of a Lone Ranger picture near Kanab when a flood in Kanab Creek rose so fast they had to scramble up the banks to dry ground. Most of the company was marooned for nearly 3 hours.

10 Aug 1955 Kanab Barracks Canyon A flash flood down Barracks Canyon, 18 miles northwest of Kanab marooned 150 members of a motion picture company for 3 hours The storm lasted about 1 hour. Many pieces of equipment used to film a western movie were swept away by the flood.

20 Aug 1957 Kanab Kanab Creek, Johnson Wash, Paria River. Flash floods in eastern Kane County Johnson Wash; stranded more than 225 persons. Two culverts washed out 20 miles east of Kanab trapping 100 workers from Glen Canyon dam project. Heavy flooding of Kanab Creek stranded 125 employees of National Broadcasting Company 5 miles south of Kanab. Johnson Wash, Buckskin Gulch, and Paria River all ran at record levels.

22 Aug 1957 Kanab Heavy rain washed out culverts and roads in Kanab area.

21 Sep 1957 Kanab Buckskin Gulch & Paria River Heavy rain washed out numerous roads in southern Utah and flooded homes. Buckskin Gulch and Paria River were flooded.

4 Jul 1961 Kanab Hog Canyon General rain over most of Utah July 4. High intentsities in isolated areas caused floods on several streams. On one stream, Hog Canyon, 2 miles north of Kanab, the peak discharge of 6580 cfs from 18.5 square miles has a recurrence interval of greater than 50 years. Only 0.85 inches of precipitation recorded at Kanab.

24 Aug 1961 Mt. Carmel Muddy Creek ...but only 0.38 inch of rain at Orderville, less than 3 miles from Mt. Carmel, where Muddy Creek peaked at 8190 cfs, which is about 3 times that of a 50 year flood.

17 Sep 1961	Glen Canyon City	Wahweap Creek	Nine year old girl swept away by floodwaters in Wahweap Creek.
28 Jun 1962	Orderville	East Fork of Virgin River	Orderville hit by two flash floods. One flood hit from the north as another came from the south. Damage to the town estimated at several thousand dollars. A wall of water crossed U. S. Highway 89 in local business district. Stores, swimming pools, and basements were filled. Mud deposited on lawn and gardens.
18 Aug 1963	Mt. Carmel	Mineral Gulch	A large flood occurred in Mineral Gulch, 3 1/4 miles west of Mt. Carmel. The peak discharge was 3210 cfs from a 7.6 square mile drainage area. No precipitation was recorded at Orderville.
31 Aug 1963	Kanab	Paria River	A peak discharge of flood in Paria River near Kanab from 645 square miles was 15,400 cfs which is 1.4 times the expected 50 year period.
12 Aug 1964	Kanab	Hog Canyon	Flash flood in Hog Canyon, a tributary of Kanab Creek, about 2 miles north of Kanab. Peak discharge of 10,850 cfs from drainage area of 18.5 square miles represents a discharge of 4.7 times that of a 50 year flood.
2 Sep 1966	Glen Canyon City	Tributary to Wahweap Creek	Thunderstorm caused a peak flow of 479 cfs from small drainage area of 1.61 square miles in tributary to Wahweap Creek. 1.1 miles northwest of where U.S. Highway 89 crosses the Utah-Arizona boundary.
Spring 1983	Mt. Carmel Junction	East Fork of Virgin River	High flows of the river have greatly eroded U. S. Highway 89 embankment 0.5 miles north of Mt. Carmel Junction. A $40,000 wire gabion structure was constructed to protect the highway embankment in 1984.
Summer 1983	Kanab	Hog Canyon	Two or three cloudburst floods during the summer have severely eroded the abutments of the Hog Canyon bridge on U. S. Highway 89. A new bridge, costing $300,000 was built in 1985.
1 Aug 1983	Kanab	Johnson Wash	A flash flood eroded the bridge abutments and damaged the county road embankments 3.5 miles north of U. S. Highway 89 on the Johnson Canyon road. Damage repairs were estimated at $50,000.

Sources: Woolley (1946), Butler and Marsell (1972), Davis (1984).
[1]Community affected or nearest town.
[2]If no stream is indicated the flooding was on streets, yards, fields, or elsewhere.

Faults, earthquakes and liquefaction

Faults are fractures in the crust of the earth along which movement has taken place (photo 87). The movement along faults may be translational or rotational. An earthquake is produced by a sudden fault movement. Billions of tons of rocks may be displaced in a moment, releasing enormous energy. In the process of breaking and moving, vibrations termed "seismic waves" are generated that travel through the earth and along its surface. Earthquakes are generated below the earth's surface and this point is the focus or hypocenter. The spot on the surface vertically above the hypocenter is the epicenter.

An earthquake can be expressed in terms of both intensity and magnitude. Intensity is a measure of the observed effects of an earthquake on people, buildings, and natural features. Intensity values are denoted by Roman numerals in the Modified Mercalli Intensity Scale which ranks seismic effects into 12 levels of increasing severity. The scale ranges through imperceptible shaking, people awakening, movement of furniture, damage to chimneys to, finally, catastrophic destruction. Magnitude is an instrumental measure of the amount of seismic energy generated at the hypocenter of the earthquake. It is based on the amplitude and period of the recorded vibrations and the distance of the seismograph from the epicenter. On the Richter scale, magnitude is given in whole numbers and decimal fractions. Because of the logarithmic basis of the scale, each whole number increase in magnitude represents a tenfold increase in measured amplitude. As an estimate of energy, each whole number in the magnitude scale corresponds to the release of about 31 times more energy that the amount associated with the preceding whole number value. Although the Richter Scale has no upper limit, the largest known earthquakes have magnitudes in the 8.8 to 8.9 range.

Earthquakes tend to reoccur along faults which reflect zones of weakness in the earth's crust. The fact that a fault, or fault zone, has recently experienced an earthquake offers no assurance that enough stress has been relieved to prevent another. Western Kane County is within the Intermountain Seismic Belt (ISB), a zone of extraordinary earthquake activity extending from Arizona northward through Utah, eastern Idaho, western Wyoming, and terminating in northwestern Montana. Seismicity is characterized by shallow focal depths with most less than 10 miles (15 km) (Smith and Sbar, 1974, p. 1205). The ISB is more than 800 miles long, up to 65 miles wide, and has one of the highest levels of earthquake risk in the contiguous United States. In western Kane County the ISB includes the Paunsaugunt fault, the Johnson Canyon fault zone, the Kanab Creek fault zone, and the Sevier fault zone (plate 8). Smith (1978, p. 132) states that a distinct feature of the Colorado Plateaus is the zone of seismicity

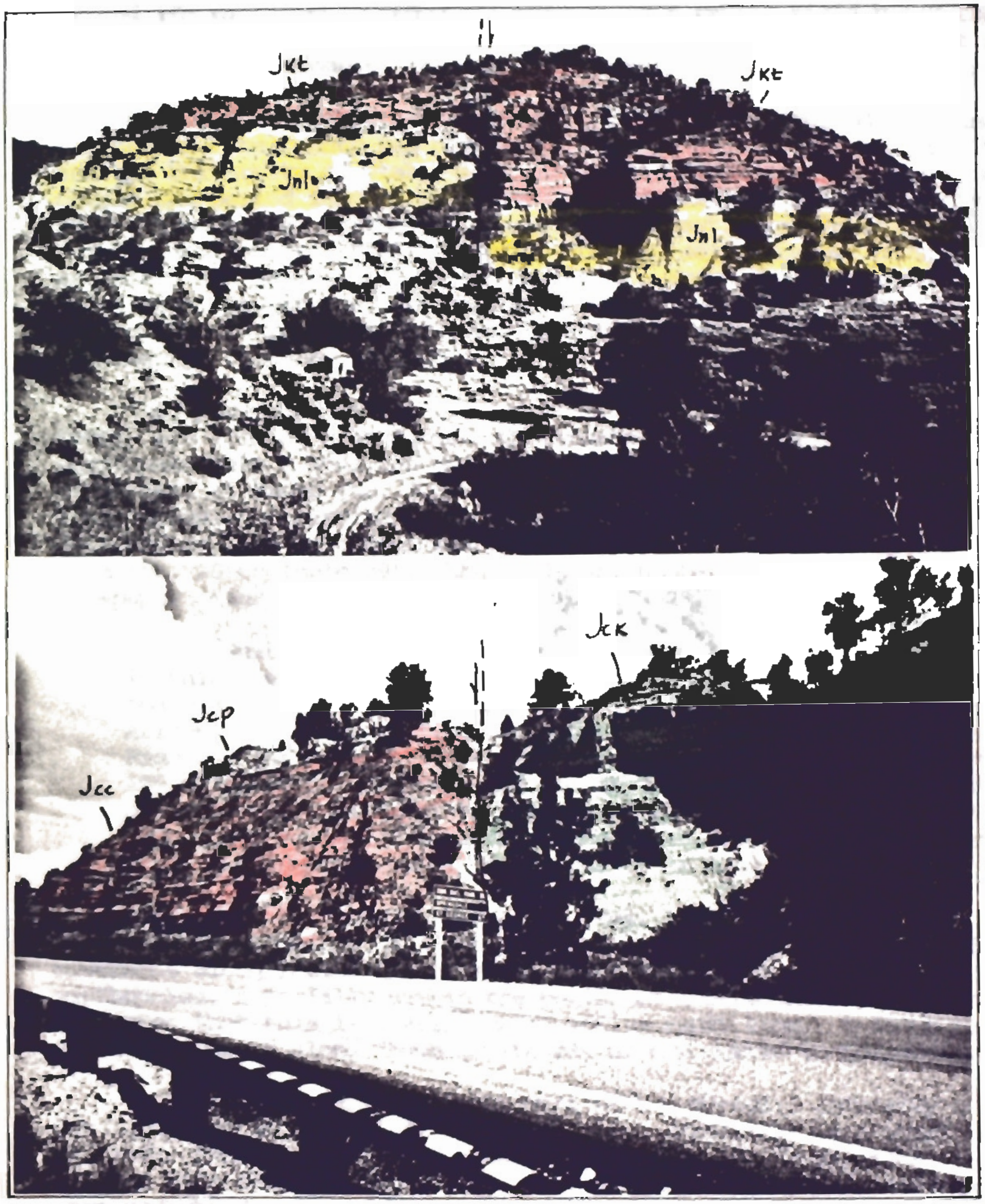


Photo 87. Faults in Kane County. Movement along faults is thought the cause of earthquakes, of which several have historically been felt in the county. Above is a view of a fault west of Three Lakes Canyon on the active Kanab Creek fault zone. Below is a view of the "Golf Course" fault, just west of Mt. Carmel Junction, a splay fault on the Sevier fault zone.

around its margin which suggests that it is a rather rigid block that does not permit internal strain release in the form of earthquakes, but may allow vertical movements or rotations (strain release) at its edges.

A record of historical earthquakes of Richter magnitude 2.0 and greater in Kane County has been compiled from Arabasz and others (1979) and the University of Utah Seismology Catolog (1986). The tabulation covers the period 1850 to February 1986 and lists 33 seismic events (table 29). Through 1949 earthquake epicenters and estimated intensities were largely derived from "felt" reports, distant seismographs, newspaper articles, and several scientific journals. From 1950 to the present, the epicenters, magnitudes, and depths of focus (when determined) of the earthquakes, were almost entirely intrumental and determined by seismograph stations in Utah.

The epicenters of the two greatest magnitude earthquakes in Kane County are located near Kanab. On December 5, 1887, a strongly felt earthquake with a modified Mercalli Intensity of VII (magnitude = 5.7) was pinpointed at Kanab (No. 2 on table 29). On July 21, 1959, an instrumentally monitored earthquake with a Richter magnitude of 5.5 was detected and its epicenter was located just south of Kanab on the state line (No. 20 on table 29). The following quote was taken from a Kanab newspaper after this earthquake, dated July 23, 1959:

> "What was described as the strongest earth tremor ever felt in this area occurred Tuesday morning at approximately 10:45 a.m. and was felt in a wide area covering southern Utah and northern Arizona. It appears from reports that the tremor centered near Fredonia (Arizona). It was felt as far south as Flagstaff, Arizona, 195 miles south of Kanab, and was strong enough in Kanab to break plaster from buildings, knocked over several floor lamps and dishes from the shelves... Persons in the Kanab, Fredonia area reported the quake lasting from about 10 seconds to as long as 2 minutes."

Four other earthquake epicenters (Nos. 1, 18, 19, and 23) are plotted in the Kanab vicinity. All 6 earthquakes are thought to be related to movements along faults in the Kanab Creek fault zone. This number of earthquakes, especially within the period of instrumental monitoring, indicates that this is a seismically active fault zone. A large part of the displacement along these faults may have occurred in Quaternary time.

On January 1, 1924, an earthquake with a Mercalli Intensity of III was localized at Orderville in Long Valley. From that date until November 23, 1927, there were 14 additional shocks, all with intensities of II or III, at this same epicenter (Nos. 3-17 on table 29). These earthquakes were undoubtedly caused by slippage along a fault in the Sevier fault zone. Epicenters 26 and 30, both west of the Sevier fault zone and both with focal depths of 4 1/2 miles, could be related to movement on a Sevier fault plane if it had a listric dip, at depth, to the west. Quaternary basalt flows are displaced by faulting in the Sevier fault zone around Black Mountain in Secs. 32 and 33, T 39 S, R 6 W. Best, McKee, and Damon

Table ~~29~~ 27. Earthquakes of Richter Magnitude 2.0 or greater in Kane County, 1850 to February 1986.

Epicenter Number	Date	Time+	Magnitude	Maximum Intensity	Depth (Km.)	Epicenter Location Latitude (N)	Epicenter Location Longitude (W)
1	Sept. 5, 1885	0335	3.0*	III		37°02.84'	112°31.34'
2	Dec. 5, 1887	1530	5.7*	VII		37°02.84'	112°31.34'
3	Jan. 1, 1924	2315	2.3*	III		37°19.04'	112°35.47'
4	May 15, 1926	1951	3.0*	III		37°19.04'	112°35.47'
5	June 1, 1926	0520	2.3*	II		37°19.04'	112°35.47'
6	June 5, 1926	1100	3.0*	III		37°19.04'	112°35.47'
7	June 22, 1926	0340	2.3*	II		37°19.04'	112°35.47'
8	June 28, 1926	0600	2.3*	II		37°19.04'	112°35.47'
9	July 12, 1926	0520	3.0*	III		37°19.04'	112°35.47'
10	July 15, 1926	-	2.3*	II		37°19.04'	112°35.47'
11	Oct. 1, 1926	1515	3.0*	III		37°19.04'	112°35.47'
12	Oct. 4, 1926	2030	3.0*	III		37°19.04'	112°35.47'
13	Oct. 23, 1926	0000	3.0*	III		37°19.04'	112°35.47'
14	Nov. 12, 1926	0340	3.0*	III		37°19.04'	112°35.47'
15	Nov. 16, 1926	1415	3.0*	III		37°19.04'	112°35.47'
16	Nov. 23, 1927	0245	2.3*	II		37°19.04'	112°35.47'
17	Nov. 23, 1927	0930	3.0*	III		37°19.04'	112°35.47'
18	Dec. 25, 1934	1000	3.7*	IV		37°02.04'	112°31.34'
19	Mar. 5, 1951	2300	3.7*	IV		37°00.00'	112°32.40'

Sources: Arabasz and others, 1979; University of Utah Seismology Catalogue, 1986.

*Magnitude not instrumentally measured, but estimated from maximum Modified Mercalli intensity assuming Gutenberg-Richter relation; MAG = 1 + 2/3 INT (Gutenberg and Richter, 1956).
+The date and origin time are Greenwich Mean Time (GMT). "Local time" is 7 hours earlier than GMT.

(1980, p. 1038, sample 28) report that the basalt in upper Long Valley has a K-Ar radiometric date of $0.56 \pm 0.06 \times 10^6$ years B.P.

Earthquake epicenter No. 22 is possibly related to the Johnson Canyon fault zone. The movement below epicenter No. 33 was probably a crustal adjustment due to the loading of Lake Powell. Seven or eight epicenters in the county are enigmatically placed in relation to surficially mapped faults.

Under certain conditions earthquake ground shaking can result in soil liquefaction which can result in settlement or tilting of buildings, flow failures of slopes, and large deformations of the ground surface. Liquefaction primarily affects water saturated cohesionless soils (sandy soils). Ground shaking induces rearrangement and denser packing of the soil particles and sand grains; gravity loading produces excess fluid pressure that causes pore water to make a channel and carry soil particles to the surface. Field studies have identified recent geologic deposits and sandy soils to be most susceptible to liquefaction (Committee on Earthquake Engineering, 1985, p. 2). Riverbank, floodplain, and alluvial fan deposits, most notably those deposited within the last 1000 years, are most prone to such failures. A high water table (most likely 10 feet or less) is a crucial and essential condition.

Kane County has an abundance of unconsolidated recent surface and subsurface sandy deposits that have variable silt contents. However, it is only those areas adjacent to rivers, streams, springs, and lakes that have the necessary high water table for liquefaction. During a sufficiently strong earthquake, areas of potential liquefaction (especially during spring months) include: (1) adjacent to the East Fork of the Virgin River in Long Valley, (2) adjacent Kanab Creek, (3) adjacent to Johnson Wash and the area south of its mouth, and (4) adjacent the Paria River. The exact delineation of these areas cannot be shown on the geologic hazards maps.

Hydrocompaction

In warm dry climates certain originally wet alluvial deposits may, after drying, form loose, porous, low-density soils that are susceptible to collapse when they are wetted and/or subjected to loading. This process of collapse or subsidence is termed hydrocompaction. It is a result of reduction in intergranular strength due to wetting and includes compaction under natural overburden load as well as compaction that occurs only with the addition of a surcharge load (human construction). Hydrocompactible soils are usually found in regions where seasonal rainfall seldom penetrates more than 2 or 3 feet of the soil, and they invariably occur above the water table (Lofgren, 1969, p. 273).

Dry, sandy to silty alluvial deposits, including alluvial fans, floodplains, and mixed alluvial and eolian deposits, are prevalent in the county. No undeniable case of hydrocompaction has been reported, but there are indications. Gill (1981), in a report on sites investigated for a new Kanab high school, found a definite subsidence feature and other depressions in the mouth of Toms Canyon (Flood Canyon), on the northeast side of Kanab. Due to a lack of soil test data and structural performance, areas of potential hydrocompaction are delineated on the geologic hazards maps. Damage from hydrocompaction can be minimized by thoroughly wetting and precompacting soils (on the ground surface or on floors of excavations) before construction begins.

Sand dune encroachment

There are two large areas of thick, wind-blown sand in the county. The first of these areas, the Sand Hills, lies astride U. S. Highway 89 in the east part of T 42 S, R 7 W and the west part of T 42 S, R 6 W. The second area is in the east part of T 43 S, R 8 W and Secs. 7, 8, and 18 of T 43 S, R 7 W. Part of this area is a state park (Coral Pink Sand Dunes State Reserve). The sand in both areas is derived form the Navajo Sandstone. During unusually strong winds, these sand sheets and dunes can migrate over roads or produce poor visibility during a storm. Sand dunes on the highway could cause a sudden reduction in velocity that might cause a driver(s) to loose control of his vehicle. Road departments become involved in sand removal.

Kane County has six major perennial streams that flow southwesterly, south, and southeasterly across the county: (1) North Fork of the Virgin River, (2) East Fork of the Virgin River, (3)Kanab Creek, (4) Johnson Wash, (5) Paria River, and (6) Escalante River. These streams originate in the Markagunt Plateau, the Paunsaugunt Plateau, and in other plateaus north of Kane County. There are stretches of streams that are perennial and several smaller perennial streams such as Orderville Gulch, Meadow Creek, and Muddy Creek.

ENGINEERING GEOLOGY OF URBANIZING AREAS:

People are being attracted to Kane County by the scenic vistas, the mild winter climate, the grandeur of Lake Powell, the outdoor recreation, and the alpine and forest setting on the Markagunt Plateau. The growth in population and construction is presently occurring in four main areas: Kanab, Johnson Canyon, Long Valley, and on the Markagunt Plateau. Three other areas have growth potential: Alton (coal development), Big Water and its satellite communities (nearness to Lake Powell), and Bullfrog Basin (to a limited extent).

As urbanization proceeds, land must be carefully examined to avoid problems that might develop because of geologic hazards. Developments, sooner or later, will encroach onto steep slopes, flood pathways, and poor foundation materials. Community and county building constraints should be adhered to. Soils, foundation conditions, slope stability, groundwater conditions, and surface water features are described, where appropriate, for the above mentioned areas. A table listing the general terrain and construction characteristics of soils and rocks in the county is included at the end of the individual area reports. No U. S. Soil Conservation Service soil surveys have been made, therefore engineering test data on soils is woefully lacking. In the urbanizing areas we obtained eight samples for testing and classification by a commercial soil test lab in Salt Lake City.

Markagunt Plateau

The top of the plateau is a forest and grassland area on flat to rolling, smoothly rounded topography. The greatest relief is found at about 1300 feet in the vicinity of Navajo Lake. The Claron Formation, practically horizontal, forms the smooths slopes and rounded hills and ridges. Four basaltic cinder cones are present. Blocky and jagged basalt flows cover the floor of Duck Creek Valley from Navajo Lake eastward to Aspen-Mirror Lake. All drainages, except the valley occupied by Navajo and Duck Lakes, flow to the northeast. The major northeast flowing streams are Duck Creek, Strawberry Creek, and Swains Creek. State Highway 14 is the main road.

Because of the heavy winter snowfall people usually only live on the plateau during the summer when the temperatures are pleasantly warm. Summer homes and cabins are presently clustered in four main areas: (1) Duck Creek north of U-14 in the SW Sec. 5 and SE Sec. 6, T 38 S, R 7 W., on August 27, 1985 there were 47 cabins and several others under construction; (2) Willis Creek south of U-14 in the S 1/2 Sec. 8 and the N 1/2 Sec. 17, T 38 S, R 7 W., many cabins plus a restaurant are present; (3) Strawberry Creek, south of U-14 in Secs. 16 and 21, T 38 S, R 7 W.; on August 27, 1985 there were 36 summer homes plus an airplane runway; and (4) Swains Creek 1.6 miles south of U-14 in Secs. 27 and 34, T 38 S, R 7 W., on August 27, 1985 there were more than 42 summer homes and several more were under construction. There is also a store and a landing strip.

In all the stream valleys the alluvium is largely derived from the Claron Formation. It is mostly a light brown to dark brown sandy silt and, in places, there are thin pebbly beds and thin black or brown silt clay layers. A sample (N-1) of alluvium was obtained from the west bank of Strawberry Creek, 0.5 miles southwest of U-14 in the NENE Sec. 21, T 38 S, R 7 W. The sample represents soil from the ground surface to a depth of 3 feet and was described as a brown sandy silt. The soil has a Unified Soil Classification (USCS) of ML, with a silt and clay content of 65.5 percent, a liquid limit of 32.2 percent, and a plasticity index of 9.7 percent (figure 58). When wet, this soil would have a very low stability and load-bearing capacity. There are no summer homes, as yet, built on the Strawberry Creek floodplain and it is recommended that none will. Until proven otherwise, it might be prudent to consider sample N-1 as a soil typical of alluvium in the other stream valleys as well.

A local summer resident stated that Strawberry Creek floods over its banks in late May about every other year and is another reason not to build adjacent to it. Duck Creek, Strawberry Creek, and Swains Creek are perennial streams and the water table on their floodplains is within a few feet of the ground surface. In the Duck Creek sinks, SESW Sec. 5, and the NW Sec. 8, T. 38 S., R. 7 W., the water table is very close to the ground surface and no one should contemplate building in that area.

In the Duck Creek, Strawberry Creek, and Swains Creek areas the summer homes are built on gentle slopes, moderate slopes, and steep slopes covered by residual and colluvial material derived from the Claron Formation. Here and there a cabin, or part of one, is built directly on the Claron. Fresh, unweathered beds in this unit should form competent foundation rock. However, on most of the moderate to steep slopes the colluvium is 1 to 12 feet thick, and the loose, unconsolidated debris cannot maintain as steep a slope as the underlying bedrock surface. A sample (N-2) of Claron derived colluvium was obtained on a steep slope north of Duck Creek Village in the NENE Sec. 7, T 38 S, R 7 W. A channel sample of 4 feet was taken and described as reddish-brown silty sand and gravel. The gravel was light gray, hard limestone. The soil had a USCS of GM, with a silt and clay content of 22.4 percent, a liquid limit of 18.3 percent, and was non-plastic (figure 59). The soil is permeable and granular. Under most conditions a soil with these characteristics is stable and has a good load-bearing capacity. However, the worst case scenario has not happened as yet. If the colluvium on the steep slopes (greater than 27^{o}) ever gets loaded enough, or wet enough, or has part of the toe removed, it will translate downslope.

Alton

The town of Alton is on the Podunk Terrace in the NW Sec. 12, T 39 S, R 6 W (figure 60). The town is in a tributary valley of Kanab Creek which flows one mile to the southeast. There is a high craggy ridge of the Claron Formation west of Alton and low, rolling hills of the Tropic Shale northeast and south of town. The relief in the area is about 600 feet. The Sevier fault zone is immediately west of Alton and it trends to the northeast. On the west side of the zone the downdropped Claron Formation

Photo 92. View of Mollies Nipple, a landmark remnant of the White Cliffs (Navajo Sandstone) in south-central Kane County.

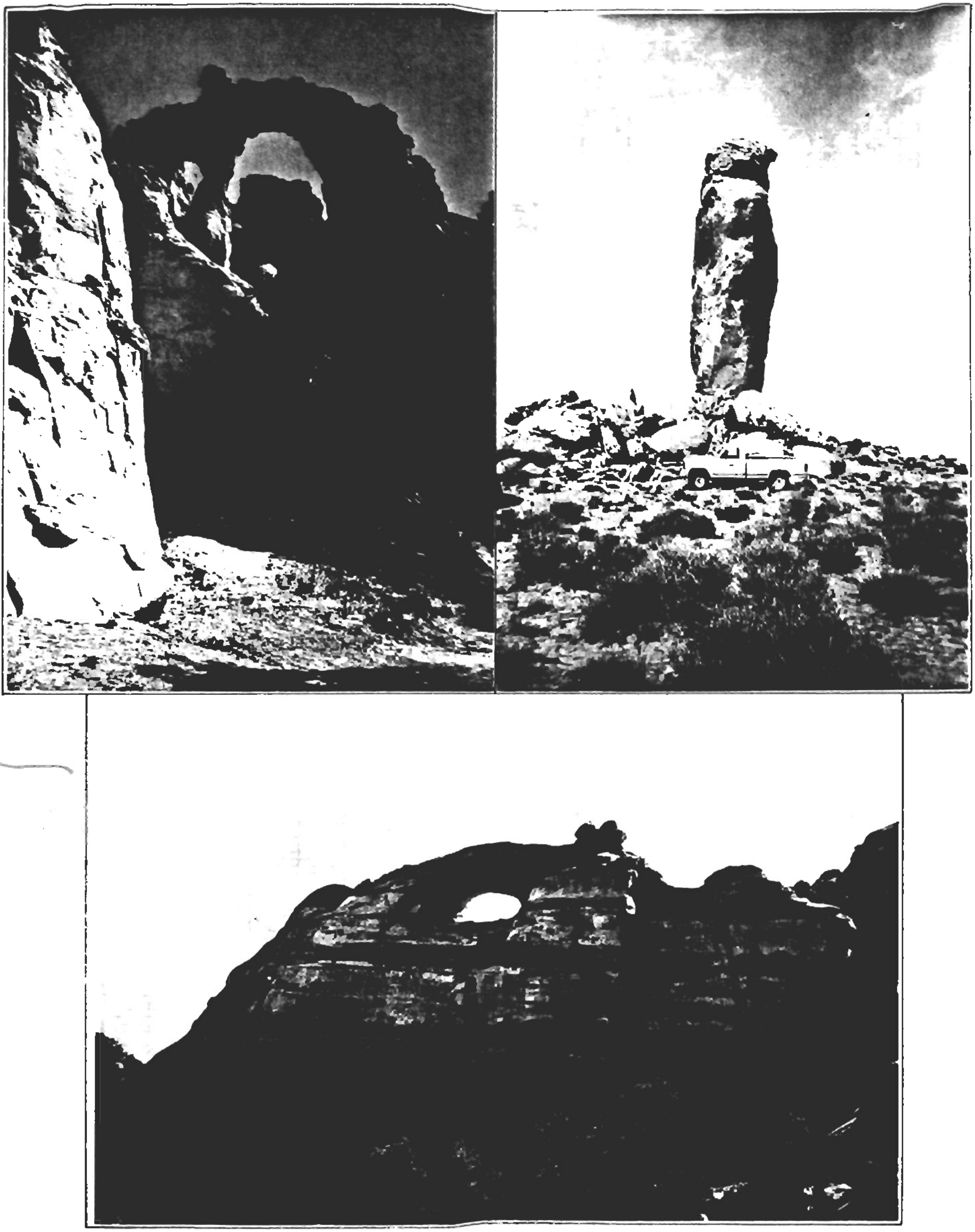
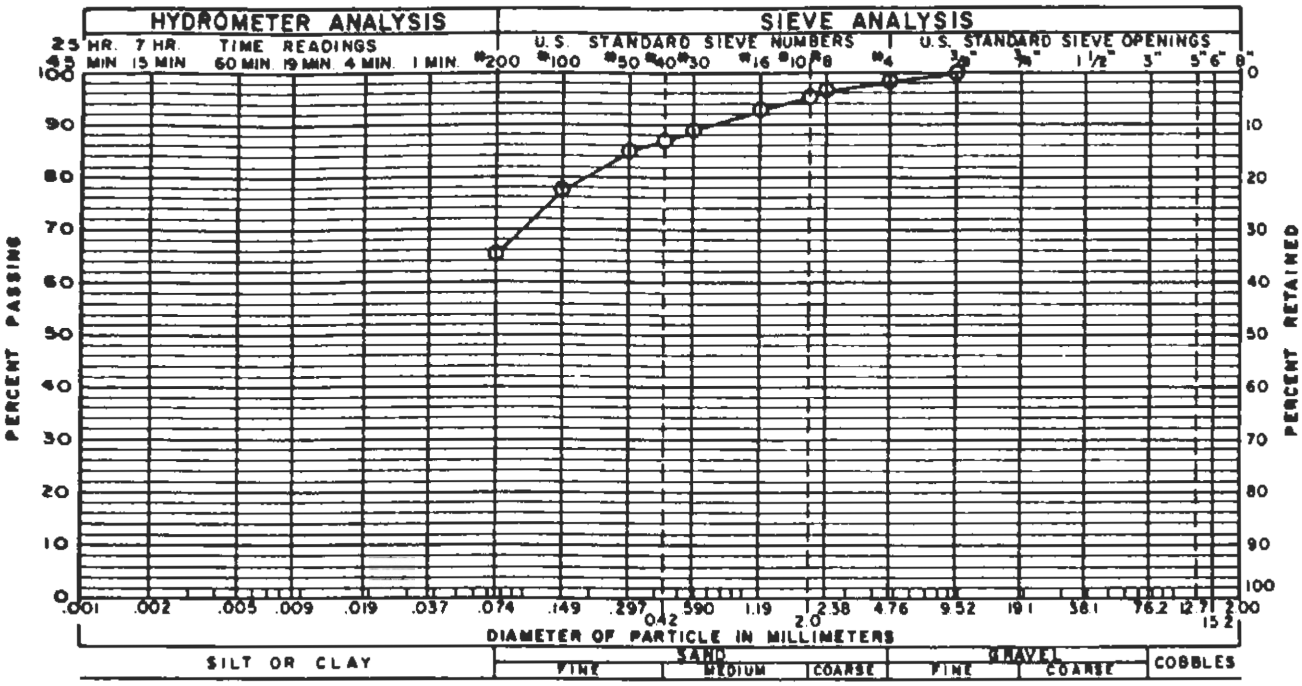


Photo 90. Geologic tourist attractions of Kane County. Upper left is view of Grosvenor Arch cut in Henrieville Sandstone and sub-Dakota Conglomerate. Upper right is Lone Rock, a monolith of "slickrim" Entrada. The lower view is of Starlight Arch, in the lower Navajo Sandstone.

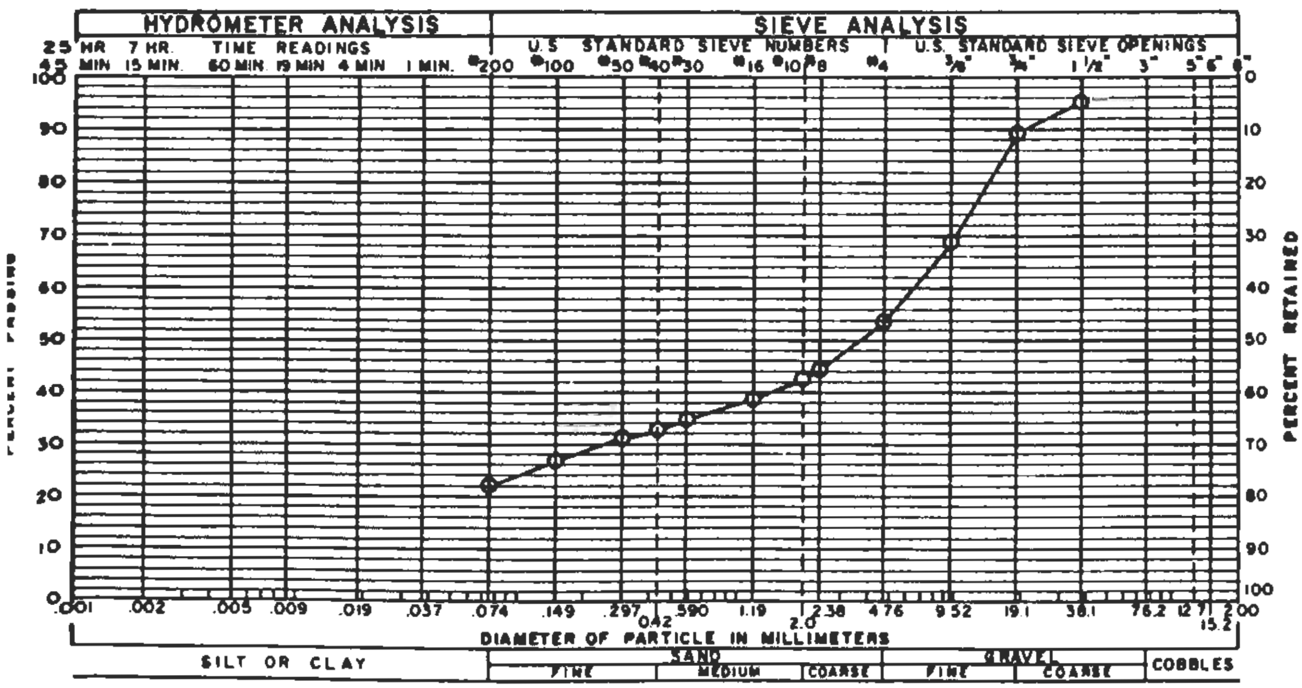


GRAVEL 4.2 % SAND 30.3 % SILT AND CLAY 65.5 %

LIQUID LIMIT 32.2 % PLASTICITY INDEX 9.7 %

SAMPLE OF Sandy Silt (ML) ~~(A-4)*~~ FROM TP N-1 @ 0-3.0'

Figure 58. Test data on Strawberry Creek alluvium.



GRAVEL 57.3 % SAND 20.3 % SILT AND CLAY 22.4 %

LIQUID LIMIT 18.3 % PLASTICITY INDEX NP %

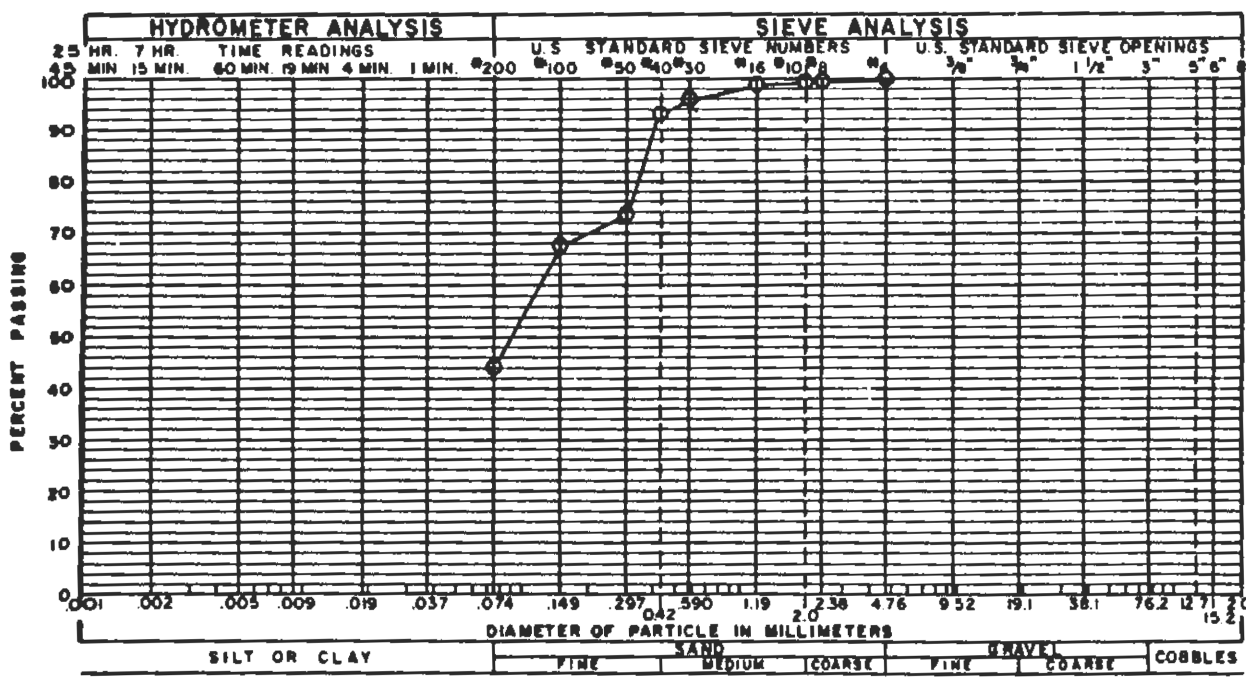
SAMPLE OF Silty Gravel w/Sand (GM) ~~(A-1-6)*~~ FROM TP N2 @ 0-4.0'

GRADATION TEST RESULTS

~~*Indicates AASHTO Classification~~

Figure 59. Test data on colluvium from the Claron Formation

~~JOB NO. 1757~~ ~~FIGURE 4~~



GRAVEL 0.3 % SAND 55.4 % SILT AND CLAY 44.3 %

LIQUID LIMIT 34.8 % PLASTICITY INDEX 11.2 %

SAMPLE OF Silty Sand (SM) ~~(A-6)~~* FROM TP K1 @ 1-4.5'

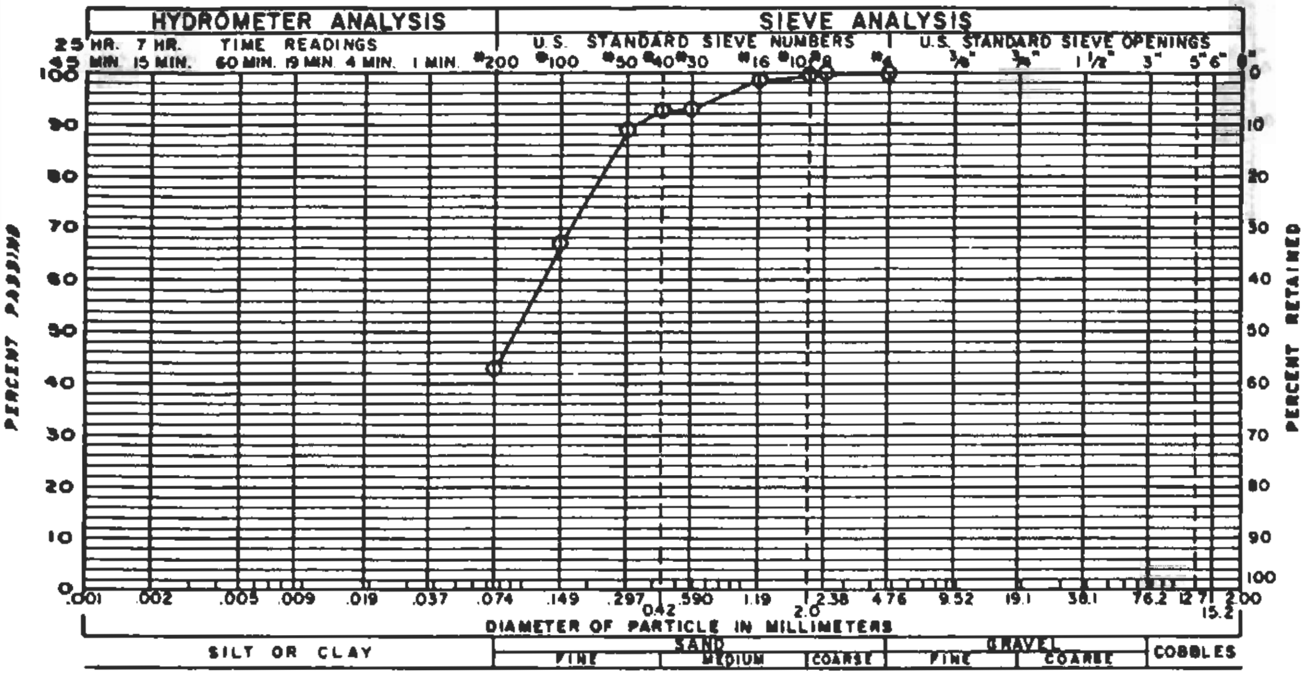
GRADATION TEST RESULTS

~~*Indicates AASHTO Classification~~

~~JOB NO. 1757~~ ~~FIGURE 2~~

Fig. 65. Test data on alluvium derived from Petrified Forest Mbr of Chinle Formation at mouth of Toms Canyon.

Delta

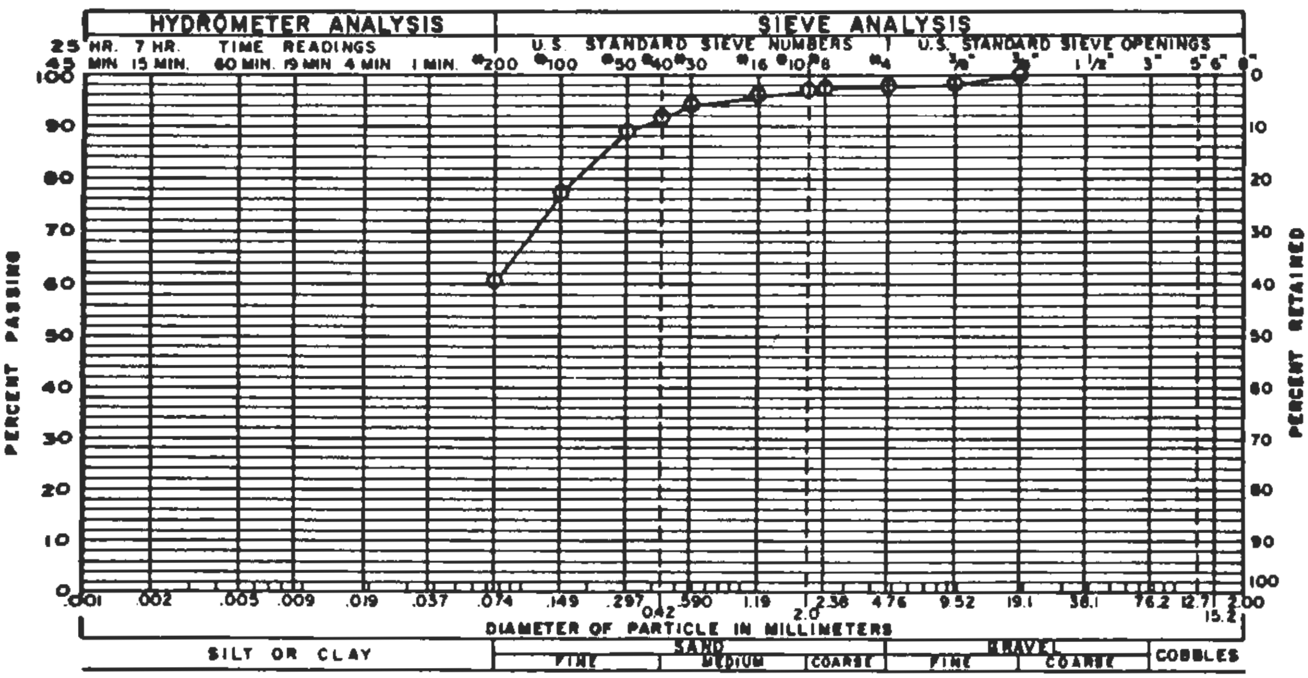


GRAVEL 0.4 % **SAND** 56.6 % **SILT AND CLAY** 43.0 %

LIQUID LIMIT % **PLASTICITY INDEX** NP %

SAMPLE OF Silty Sand (SM) ~~(A-4)*~~ FROM TP K2 @ 1-5.0'

Fig. 66. Test Data on Kanab Creek Alluvium



GRAVEL 2.9 % **SAND** 36.7 % **SILT AND CLAY** 60.4 %

LIQUID LIMIT 20.4 % **PLASTICITY INDEX** 2.1 %

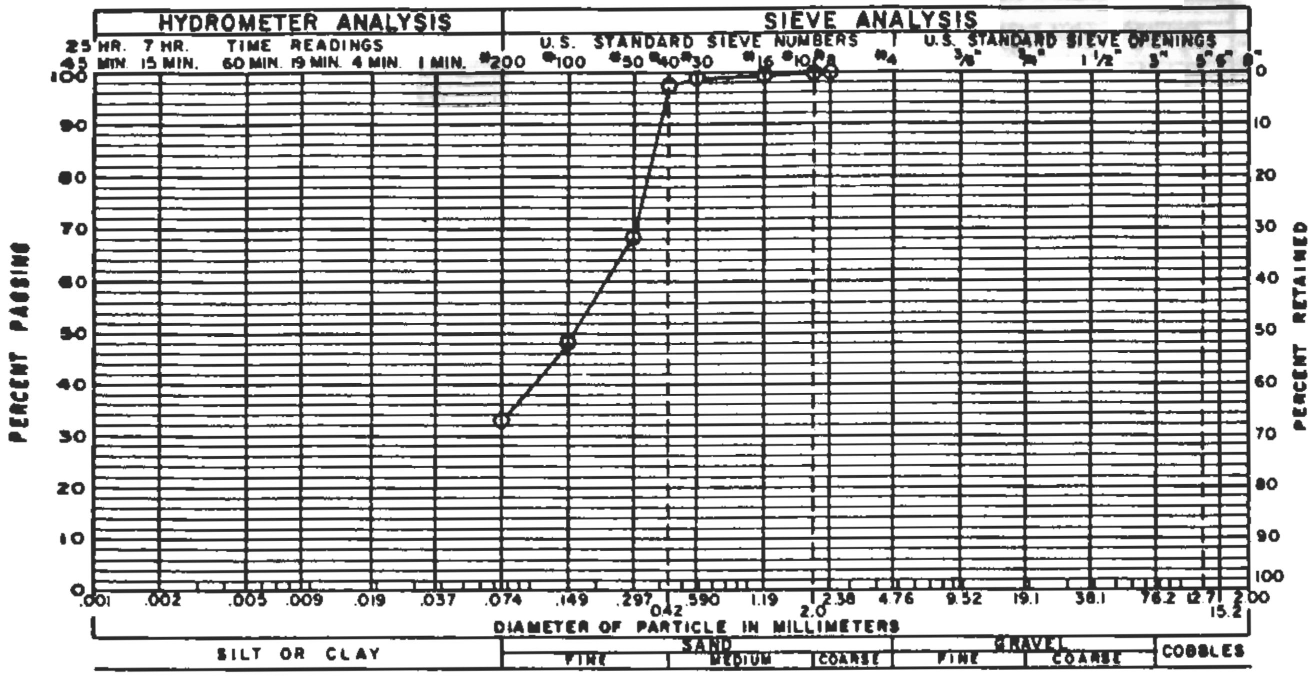
SAMPLE OF Sandy Silt (ML) (A-4)* FROM TP K3 @ 0-2.0'

GRADATION TEST RESULTS

*~~Indicates AASHTO~~ Classification

~~JOB NO. 1757~~ *Fig. 67. Test Data on Kanab Alluvium Derived From Kanab Creek or Washed Down from Vermilion Cliffs.* ~~FIGURE 3~~

Delta

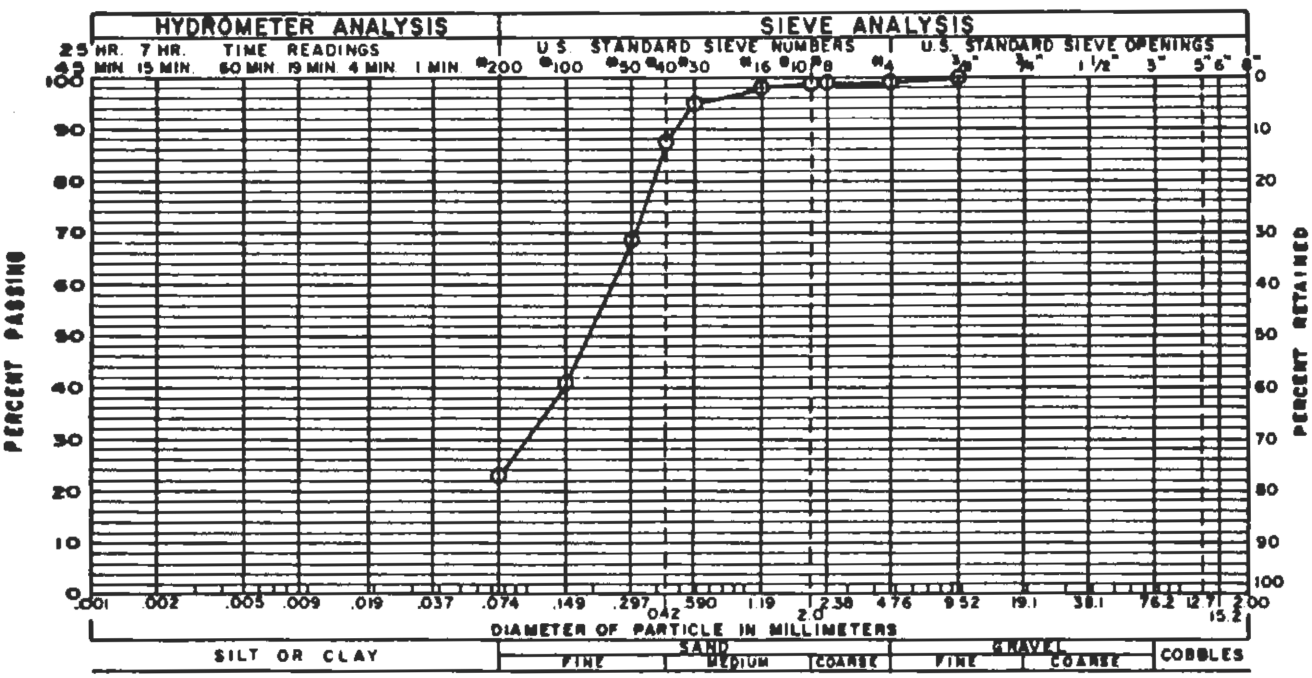


GRAVEL 0.1 % SAND 66.6 % SILT AND CLAY 33.3 %

LIQUID LIMIT % PLASTICITY INDEX NP %

SAMPLE OF Silty Sand (SM) ~~(A-2-4)~~ * FROM TP J1 @ 0-4.5'

Fig. 68.- TEST DATA ON Johnson Creek alluvium.



GRAVEL 1.1 % SAND 75.9 % SILT AND CLAY 23.0 %

LIQUID LIMIT % PLASTICITY INDEX NP %

SAMPLE OF Silty Sand (SM) ~~(A-3)~~ * FROM TP J2 @ 0-4.0'

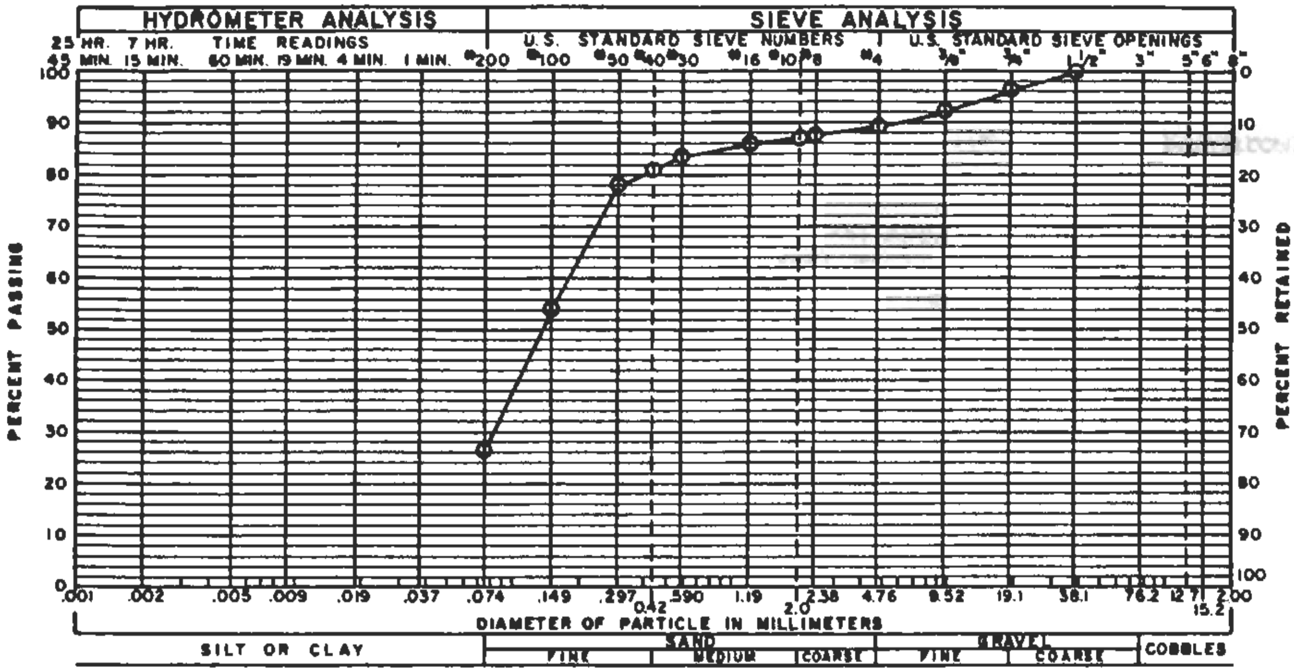
Fig. 69. TEST DATA ON Johnson Creek alluvium.

GRADATION TEST RESULTS

~~*Indicates AASHTO Classification~~

~~JOB NO.~~ 1757

~~FIGURE 1~~



GRAVEL 12.8 % SAND 60.8 % SILT AND CLAY 26.4 %

LIQUID LIMIT 19.8 % PLASTICITY INDEX NP %

SAMPLE OF Silty Sand (SM) ~~(A-2-4)~~ * FROM TP J3 @ 0-4.5'

Fig. 70. Test data on Johnson Creek alluvium

abuts against the Tropic Shale, the Wahweap Formation, and the Kaiparowits Formation in succession to the northeast.

The Tropic Shale forms low smooth slopes around the perimeter of the valley and shallowly underlies it. Several knolls and ridges in the valley also consist of Tropic Shale. The alluvium in the valley is exposed in the banks of Kanab Creek which displays 20 feet of alluvial gray clayey silt and gray sandy silt beds that weather yellow. The alluvial thickness is indicated in a Nevada Power Company water well drilled in 1961 in the SENSWNW Sec. 18, T 39 S, R 5 W, about 1.4 miles southeast of Alton. Clay and silt were logged to a depth of 52 feet where bedrock was encountered (Cordova (1981, p. 71). Most of the alluvial clay and silt in the valley was derived from the Tropic Shale.

On August 21, 1961, the groundwater level in the Nevada Power Company well was at a depth of 86 feet. However, this may have been an artesian level. Price (1982), in his groundwater map of the Alton-Kolob coal fields, shows that the expected depth to groundwater in the Alton amphitheater is 500 to 1000 feet. Shallow, and seasonally high, groundwater is shown on figure 60 in four areas.

Four large mass movements are present in the general vicinity of Alton (Shroder, 1971, p. 39-45). All four are Pleistocene or Holocene failures of the Tropic Shale. The south edge of the North Roundy landslide is one mile northeast of Alton. Large hummocky masses, about 100 feet thick, are present on the west and east slopes of North Roundy Canyon. The Dry Hollow mass movement is on the west slope of Dry Hollow in SW Sec. 32, T 38 S, R 5 W. In places it is 500 feet thick. The South Roundy mass movement is 1.6 miles east of Alton and the lower edge of the debris flow is close to the 7400 foot contour on the mountainside. The hummocky mass is about 100 feet thick and covers almost the entire western half of Sec. 8, T 39 S, R 5 W. Shroder (1971, p. 44) found a Ponderosa pine log in the debris and obtained a radiocarbon date of 750 $\pm$ 200 years B.P. The Dry Canyon mass movement is 2.5 miles southeast of Alton in the E 1/2 Sec. 17, T 39 S, R 5 W. It also has a thickness of 100 feet.

Construction of any kind should be avoided on these mass movement areas. If construction is absolutely necessary then slope stability studies need to be done. Proposed cuts on these slopes should be viewed dimly. Caution should be kept in mind when construction is contemplated in the Alton area. The Tropic Shale and the valley alluvium derived from it contain expansive clays and soluble salts. Foundations, roads, and buried utilities should be treated accordingly. Utility lines of all types should be buried below the frost-free depth of four feet. No critical buildings should be constructed on the fault lines shown on figure 60. The Sevier fault zone is considered to be seismically active.

Long Valley

Long Valley is about 23 miles in length and has an average width of about 1200 feet. The widest parts, 2500 to 3500 feet, are occupied by the towns of Glendale, Orderville, and Mt. Carmel. The major tributaries are

Stout Canyon, Lydias Canyon, Red Hollow, and Muddy Creek. Growth and construction activities, thus far, have been rather gradual. Long Valley was assisted in its formation by the intense faulting along the Sevier fault zone. Faulting has affected strata ranging in age from Jurassic to Pleistocene. A basalt flow, dated 560,000 years B.P. (Best, McKee, and Damon, 1980, p. 1038), has been displaced by faulting near Black Mountain, adjacent to upper Long Valley.

A large variety of Quaternary deposits are present throughout the valley: alluvial fans, old river terraces (of at least two ages), spring tufa, marsh and peat deposits, mass movements, and pediment sands and gravels. However, the most widespread deposit is alluvium of the East Fork of the Virgin River (figures 61 to 63). Exposures of the alluvium can be observed along the banks of the river, which range from 2 to 40 feet in height (just northwest of Glendale). In many places these exposures are vertical. There is no "typical" exposure of the floodplain and channel deposits which consist of heterogeneous, lenticular, and variably thick horizons of sandy silt, fine sand, silty sand, and sand and gravel. The two following measured sections will serve to illustrate the nature of the alluvium.

Measurement of alluvium just north of Orderville in NENE Sec. 4, T 41 S, R 7 W.

1.	Grayish-tan, calcareous fine sandy silt	4.1 feet
2.	Grayish-tan, calcareous, silty fine sand	2.5
3.	Tan silty sand and gravel (clasts of quartzite, chert, limestone, and sandstone.	0.7
4.	Grayish-tan silty fine sand.	0.6
5.	Tan silty sand and gravel with cobbles of limestone and sandstone.	1.3
6.	Grayish-tan, calcareous, silty fine sand	1.9
7.	Tan silty sand and gravel with cobbles of limestone and sandstone.	0.6
8.	Brown, calcareous, silty sand	0.4
9.	Tan silty sand and gravel with cobbles of limestone and sandstone.	1.1
	Total	13.2 feet

Measurement of alluvium just northeast of Mt. Carmel in NESW Sec. 19, R 7 W.

1.	Reddish-brown silty fine sand	1.7 feet
2.	Light gray silty fine sand	0.3
3.	Reddish-brown silty fine sand with pebbles along base	0.7
4.	Light gray silt	0.4
5.	Gray sand and grit	0.2
6.	Reddish-brown silty fine sand	0.3
7.	Gray silty sand and gravel with boulders (mostly limestone)	7.6
	Total	11.2 feet

The alluvial thickness is indicated by two drillers' logs (Cordova, 1981, p. 72): (1) a water well just north of Mt. Carmel Junction in the SWSESW Sec. 19, T 41 S, R 7 W. drilled into bedrock (Carmel Formation) at a depth of 46 feet. A well just northeast of Orderville in the NENENE Sec. 4, T 41 S, R 7 W was bottomed at a depth of 75 feet and was still in alluvium. Groundwater was encountered at a depth of 24 feet.

Alluvial fans have not been deposited at the mouths of the main tributary canyons of Long Valley. The main creeks are graded to the level of the Virgin River and erosion has kept pace with the deposition. Numerous small and medium sized canyons have pronounced alluvial fans at their mouths. The fan materials are normally very lenticular beds and lenses of silty sand and gravel with boulders. Generally, the same material extends a considerable distance up the canyons. For the most part these are flash-flood deposits and, over the years, deposition has exceeded erosion. Slope-wash is also an important component in these canyons.

Along the sides of Long Valley are remnants of at least two ancient river terraces. The lowest and youngest deposits (Qt_1), consist of unconsolidated and bedded sanded and gravel. The highest and oldest terrace (Qt_2), is composed of well-indurated conglomerate that is plastered onto the formations that form the valley sides. These conglomerates are usually orange-brown in color. In one place a lava flow has channeled into the deposit.

Pediment sands and gravel are present on a bedrock surface that slopes westward from the base of the Elkhart Cliffs. On the pediments south of Orderville and east and southeast of Mt. Carmel, the material consists of 1 to 8 feet of red to brown silty sand. On a large pediment east of Mt. Carmel Junction the material consists of 1 to 15 feet of sand and gravel.

In 1961 segments of the present U. S. Highway 89 were constructed through upper Long Valley. The U.D.O.T. soils investigation revealed some marsh and peat areas in the S 1/2 Sec. 30, T 39 S, R 6 W, about 3.0 miles southwest of Alton Junction. Part of the area is presently occupied by a commercial campground. Two test holes just west of a large pond revealed the following (table 30). Most of the area has a high groundwater table. Several samples of the peat, and silt and peat, were obtained and tested. These materials would not perform as a foundation for any kind of structure, they have a very poor load-bearing capacity, an infinite time settlement curve, and would have a non-uniform settlement. On the USCS system they would be classified as Pt.

Four mass movements of the Tropic Shale were mapped along the east side of Glendale. The three largest, in places, may be 60 to 70 feet thick. It is possible that the slumps were initially triggered by a movement in the adjacent Sevier fault zone.

Table 30. Two Utah Department of Transportation test holes in S 1/2, T 39 S, R 6 W.

U.D.O.T. test hole # 7		U.D.O.T. test hole #8 (132 feet N of hole #7)	
silt and clay	5.6 feet	silt and clay	10.0 feet
peat	17.9	peat	6.8
lava boulders	6.1	silt and peat	3.2
		sandy silt	5.0

In general, all the areas mapped as alluvium (Qa) should be adequate and safe for all types of construction in Long Valley. In tributary canyons flash floods occur regularly and roads or homes should not be build adjacent the stream channels or near the mouths of the canyons. For the most part, the main construction problems that might be encountered in Long Valley would be (1) the Tropic Shale poor load bearing capacity, expansive clays and soluble salts, as well as potential slope failures; (2) peat bog areas described above and areas of high ground water in upper Long Valley; (3) building on moderate to steep slopes that are covered by potentially unstable colluvium; and (4) presently unevaluated hazards of soil liquefaction and hydrocompaction.

Kanab

Kanab, the county seat, is located just south of the Vermilion Cliffs and adjacent to Kanab Creek (figure 64). Kanab Creek Estates, a rapidly growing suburb, lies south and southwest of Kanab. The Kanab area is built on alluvium deposited by Kanab Creek and pediment alluvium derived from the Vermilion Cliffs. Three soil samples were obtained and tested, (K-1) a sample from 1.0 to 4.5 feet in depth of an alluvial reddish-brown silty sand and obtained from a canal bank at the mouth of Toms Canyon in the NENENE Sec. 28, T 43 S, R 6 W; (K-2) a sample from 1.0 to 5.0 feet in depth of an alluvial reddish-brown and light gray stratified silty sand obtained from the west bank of Kanab Creek in the NENWSW Sec. 33, T 43 S, R 6 W; and (K-3) a sample from 0 to 2.0 feet in depth of an alluvial reddish-brown sandy silt taken from a ditch bank in the SESENE Sec. 5, T 44 S, R 6 W.

The alluvium of sample (K-1) was largely derived from the nearby Petrified Forest Member of the Chinle Formation. The sample was 55.4 percent sand and 44.3 percent silt and clay (figure 65). It had a liquid limit of 34.8 percent, a plasticity index of 11.2 percent, and a USCS classification of SM. This soil would have a good load bearing capacity when compacted to maximum practical density, but it would lose this bearing capacity if water is absorbed. The soil is compressible and would rebound very little if load is removed. It would be very expansive if compacted as a subgrade at a moisture condition below optimum.

Sample (K-2) is alluvium deposited by Kanab Creek. It contains 56.6 percent sand and 43.0 percent silt and clay (figure 66). The soil was non-plastic and has a USCS classification of SM. For engineering purposes this soil is better than (K-1). It will maintain good stability through a wide range of densities and would only have a small change in volume if water were added.

Sample (K-3) is alluvium either washed from the Vermilion Cliffs or deposited by Kanab Creek. The sample is 36.7 percent sand and 60.4 percent silt and clay (figure 67). It has a liquid limit of 20.4 percent, a plasticity index of 2.1 percent and a USCS classification of ML. The sample contains considerably more silt and clay than sample (K-2). The soil of (K-3) will be relatively unstable at all moisture contents and have very low stability and bearing capacity.

The three soils described possibly represent the difference range of all the alluvium shown as Qa on figure 64. In general the soils range from silty sands to sandy silts. The pediment alluvium from the Vermilion Cliffs probably grades into, and interfingers with the alluvium of Kanab Creek. One-half mile southeast of Kanab, and beyond, there are northeast trending ridges of the Chinle Formation. Soils adjacent to these ridges should have characteristics similar to those of (K-1).

The best exposures of the alluvium are in the banks of Kanab Creek. Sixty-five feet of thin to medium bedded alluvium is exposed in the NWNW Sec. 28, T 43 S, R 6 W. In 1974 a water well was drilled to a depth of 225 feet in the SENWSE Sec. 27, T 43 S, R 6 W (Cordova, 1981, p. 63 and 72). The driller's log showed valley fill to a depth of 95 feet where the Chinle Formation was encountered. On October 14, 1976 the water level was at a depth of 42.87 feet. The alluvium-Chinle contact under the area is probably a surface of significant erosional relief.

For general construction in the Kanab area a few simple precautions appear necessary. Adequate compaction of all soils should be made before construction. This includes the floors of excavations as well as subgrades of streets and building foundations. It is well advised to provide a substantial base course, preferably a well graded gravel on all subgrades. The compaction should negate the effects of hydrocompaction and the gravel base course should accommodate the effects of expansive soils.

Almost every year, in July or August, there are one, or several, locally intense cloudbursts that result in flash flooding and erosion from one or several canyons. Toms Canyon and Pugh Canyon, northeast and east of Kanab, are notorious for these summer events. Construction should not take place in the floodpath of any canyon.

Johnson Canyon

Johnson Canyon is 10 miles east of Kanab and is a major NNW trending canyon through the Vermilion Cliffs. The canyon is a fault zone and faulting and subsequent erosion of broken strata are believed to have formed the canyon. Within and in the mouth of the canyon, as well as to the south, the alluvium was deposited by Johnson Wash and by slope wash from the Vermilion Cliffs. The two components probably merge and interfinger with each other. Three samples of alluvium were obtained and tested, (J-1) a sample from 0 to 4.5 feet in depth of a brownish-gray to reddish-brown silty sand obtained from a trench excavation in the NWSE Sec. 36, T 43 S, R 5 W, (J-2) a sample from 0-4 feet in depth of a brownish-gray silty sand obtained from a vertical bank of Johnson Wash in the NESW Sec. 12, T 43 S, R 5 W, and (J-3) a sample from 0. to 4.5 feet in depth of a brownish-red silty fine sand obtained from the west bank of Johnson Wash in the SENE Sec. 24, T 43 S, R 5 W. The banks of Johnson Wash are 40 to 50 feet high in places.

All three alluvial samples are non-plastic and have a USCS classification of SM. Sample (J-1) has a sand content of 66.6 percent and a silt and clay content of 33.3 percent (figure 68). Sample (J-2) contains 75.9 percent sand and 23.0 percent silt and clay (figure 69). Sample (J-3) has 60.8 percent sand and 26.4 percent silt and clay (figure 70).

With respect to construction there is nothing detrimental about these soils. However, as in the Kanab area, adequate compaction should be carried out to obtain maximum densities before construction begins. This should mitigate any future hydrocompaction effects. Johnson Canyon, its tributary canyons, and adjacent Willis and Flood Canyons are all subject to summer flash flooding. No construction is recommended in, or near, the stream or wash channels.

Big Water (Glen Canyon City)

This community is built on a blanket of eolian and alluvial sand. The sand is mostly clear white, tan, and pink, rounded and subrounded grains, perhaps largely derived from the Entrada and Carmel Formations. East of town and along the high west bank of Wahweap Creek is an old river terrace of sand and gravel. The deposit ranges from 10 to 12 feet in thickness, and in places, to as much as 20 feet. The gravel mostly consists of quartzite, volcanics, chert, and sandstone. The gravel terrace quite likely extends westward underneath the sand blanket and may underlie most of Big Water.

West of Big Water, on East Clark Bench, are two sparsely inhabited settlements--Church Wells and an unnamed place. Southeast of Big Water and adjacent Wahweap Creek and Wahweap Bay of Lake Powell, are several small settlements and business establishments. All of these places are built on the same sand blanket as that of Big Water.

In places the sand may lack a soil binder and may be unstable under wheel loads except when they are damp. The sands would be affected only slightly my moisture conditions, have no volume change, and make suitable subgrades for roads and foundations when confined and compacted.

Bullfrog

Most of the roads and buildings of this recreational community are built on two embayments of eolian and alluvial sand derived from the

Entrada Sandstone. Surrounding the embayments and separating them, the Entrada Sandstone forms ridges, hills, cliffs, and crops out along the Lake Powell shoreline. The Entrada Sandstone is a competent unit and poses no construction problems. The comments on the eolian and alluvial sand at Big Water apply to the sand at Bullfrog. Gravel terraces cap some of the Entrada ridges around Bullfrog.

WATER RESOURCES:

Water is a vital resource in any area, and if a true dollar value could be placed on it, would exceed that of any other. It is especially vital in semi-arid climatic areas such as Kane County, and can be a limiting factor in its development. The source of the water is from the precipitation that falls either as snow or rain. Water resources are usually divided into surface water and ground water. Geology helps understand the ground water supply, but the two are interrelated so that one cannot be understood without the other.

The best water collecting areas for both surface and groundwater supplies are the high altitude areas. Precipitation is generally at its highest and evapotranspiration is lowest. Areas with more than an 18 inch potential evapotranspiration index contribute little if any water to the ground. The precipitation that falls as snow and lingers on the ground the longest is most likely to contribute to ground water supplies and not be lost as runoff or evaporation. Surface water supplies either originate in the county or are through-going. Many of the headwaters of the upper Virgin River, upper Sevier River, Kanab Creek, Johnson Creek, and Kaibab Gulch (tributaries included) originate in the Markagunt and Paunsaugunt Plateaus. The headwaters of the Paria River are in the High Plateaus of Garfield County. The Kaiparowits Plateau is not as high as the Markagunt or Paunsaugunt and the principal drainages are all intermittent (Wahweap Creek, Warm Creek, Last Chance Creek, Left Hand Collet Wash, etc.) and flow only for a short time in the spring. Occasionally they drain the torrential rains of summer and carry high flows for short periods of time. The Escalante River and Colorado River (now Lake Powell) are through-going streams.

A stream course may donate water to the ground or receive water from the ground. Generally there is more receiving at higher altitudes and more giving at lower altitudes. Ground water seepage into streams generally keeps the perennial streams flowing in the warm period of the year and when drought conditions prevail. The average annual runoff of some important Kane County streams is 55,000 acre feet per year from the the Escalante River at its mouth, 30,000 acre feet per year from the Paria River at Lees Ferry, 50,000 acre feet per year on Kanab Creek at Kanab, and 219,000 acre feet per year at Hurricane in the Virgin River.

Storage of water occurs in reservoirs. There are only two surface water reservoirs of consequence in and adjacent to Kane County. Navajo Lake has a capacity of 10,700 acre feet and Lake Powell has a capacity of 23 million acre feet. Water in the ground is also in storage in ground water reservoirs. Leakage or overflow is noted as springs. Water is held in both hard rock units and in unconsolidated deposits. The size of some groundwater reservoirs is enormous. Cordova (1981, p. 1 and 37) reports that the Navajo Sandstone ground water reservoir in and around western Kane County holds an estimated 200 million acre feet.

The suitability of rocks as ground water reservoirs is dependent upon their physical makeup. The two most important values are porosity and permeability. Formations of the Colorado Plateaus have been tested by Jobin (1956) for regional transmissivity, which is the capacity of a rock formation as a whole to transmit fluids. Generally rocks are subdivided on the basis of their transmissivity into (1) relatively impermeable rocks, such as limestones, shales, mudstones, and evaporites, (2) uniformly permeable rocks, such as eolian sandstones, and (3) rocks of differing or alternating permeabilities, such as the fluvial sandstones, siltstones, and conglomerates. Jobin assigned many of the formations a value based on the natural logarithm of the product of the arithmetic mean thickness in feet and the arithmetic mean permeability in darcys. Table 31 is modified to fit Kane County and illustrates the potential value of Kane County units as sources of ground water.

Table 31. Estimated regional transmissivity of geologic formations in Kane County, Utah, based on Jobin (1956)

Formation	Transmissive type	Value*	Comments
Unconsolidated	Differs moderately	1-7	Numerous springs
Volcanics	Differs moderately	0-7	Some large springs
Claron Fm.	Differs slightly-I	1-5	Few large springs
Kaiparowits Fm.	Differs highly	1	
Upper Wahweap	Differs moderately	3.5	
Lower Wahweap	Uniform[1]	0-1	
Drip Tank Member	Differs slightly-P	2.5	Small springs
John Henry Member	Differs highly	1	
Smoky Hollow and Tibbet Canyon Members, and western Straight Cliffs Fm.			
	Differs moderately	2.5	Small springs
Tropic Shale	Uniform-I	0	
Dakota Formation	Differs highly	3.3	Small springs
Morrison Fm.	Differs highly	3.8	Small springs
Summerville Fm.	Uniform-I	0	
White Point, Romana Mesa, and Henrieville			
	Differs slightly	1-3	
Entrada Sandstone	Uniform-P	3.2	
Carmel Formation	Differs slightly-I	0-3	
Page Sandstone	Uniform-P	3-4	Small springs
Temple Cap Ss	Differs moderately	2-3	
Navajo Sandstone	Uniform-P	6.1	Excellent aquifer
Tenney Canyon	Uniform-I	1	
Lamb Point Tongue	Uniform-P	6.5	Excellent aquifer
Kayenta Formation	Differs	2.1	A few small springs
Wingate Sandstone	Uniform-P	3.6	Small springs
Moenave Formation	Differs slightly-I	2.5	
Petrified Forest	Uniform-I	0	
Shinarump Member	Differs moderately	1-4	Small springs to west
Moenkopi Formation	Differs slightly-I	0-1	
Paleozoic rocks	Uniform (both P & I)	0-5	

*estimated value of transmissivity-larger numbers indicate best aquifers. P=mostly permeable; I=mostly impermeable, heavy fracturing or solution of these rocks may provide for excellent ground water bearing capabilities.

Table 31 indicates favorability in a general way because local conditions may alter the water carrying characteristics considerably. The more uniformly permeable sandstone aquifers, normally with the most pore space may locally be tightly cemented, whereas normally tight limestone or shale may be highly fractured or dissolved along joints. The ground water is naturally tapped at springs or can be produced in wells. Springs can occur in a variety of places, most small springs in the county occur at the base of a permeable sandstone where it rests on an impermeable barrier, such as a clay layer. Even a very thin partings can be an effective barrier to further downward migration of water. Spring horizons or seep planes can usually be identified by the abundant growth or vegetation along a particular horizon. The yields of springs is dependent upon local conditions, but can often be enhanced by suitable development.

The depth to which wells must be drilled is again dependent upon local conditions, but broad generalizations have been made (Price, 1977). The same is true of expected yields. Generally wells in the Navajo Sandstone (best aquifer) may yield 50 to 500 gallons per minute (sustained yields), wells dug into other Jurassic and Cretaceous sandstones may yield 5 to 50 gallons per minute, and the tighter (less permeable) units 1-5 gallons per minute. In addition the unconsolidated deposits along the more important surface waterways may locally provide a good supply of water. Wells in the sandstones adjacent to Lake Powell might be capable of producing 500 to 1000 gallons per minute and illustrates the close relationship between surface and ground waters (photo 88).

As groundwater percolates through the rocks it can take chemical matter into solution and it can deposit chemical matter in the rocks. If the aquifers, through which the water migrates, contains easily soluble materials, the the water will increase in dissolved solids. The type of dissolved chemicals can affect the desirability and use to which the water can be put. One measurement of water quality is the total dissolved solids (TDS) content, measured in parts per million or milligrams per liter. Generally, the higher the TDS the less desirable the water (table 32).

Table ~~32~~ 30. Water quality classification (Price, 1977; others).

Class	mg/l	
Fresh	0-1000	
Slightly saline	1000-3000	} brackish water
Moderately saline	3000-10,000	} brackish water
Very saline	10,000-35,000	
Briny	35,000 +	

Dissolved solids generally consist of silica, iron, manganese, calcium, magnesium, sodium, potassium, bircarbonate, carbonate, sulfate, fluoride, and others. The acidity and alkalinity of the water are also

Photo 88. Water well pump near Hole in the Rock. Water is of prime importance to agricultural endeavors in Kane County. The abundant sandstone formations of the county are often tapped for their groundwater content. Many of the communities use groundwater as their source of culinary water.

important. It is beyond the purpose of this report to define the effect of each, but calcium and magnesium make the water hard, iron and sulfates contribute to odors and discoloration, bicarbonate and sulfate can cause adverse physiological conditions, and still others or combinations of others would have adverse affects on irrigated plants or on stock. Generally water for human consumption (culinary water) should have less than 500 ppm TDS, but humans can usually tolerate up to 1000 ppm; cattle and horses can usually tolerate higher levels, usually up to 3000 ppm.

The expected water quality is related to the type of rock that makes up the ground water reservoir. The best porous and permeable sandstone aquifers provide water of the best quality because they usually contain few chemicals. Rocks with much shale, gypsum, and organic debris generally provide waters with a greater TDS content, especially sulfates and bicarbonates. Limestones provide hard water, but otherwise can be of good quality (photo 89). Also water obtained near the recharge (higher) areas generally contain lower amounts of dissolved solids.

Kane County is fortunate with respect to its ground water quality. Water from the best aquifer (Navajo Sandstone) usually contains water containing 100-500 mg/l TDS. Ground water from units of Tertiary and Cretaceous age, excluding the Tropic Shale and Dakota Formation, contains 100 to 1000 mg/l in the west and 500 to 3000 mg/l TDS in the Kaiparowits Plateau. Ground water from the Carmel, Tropic, Chinle, and Moenkopi Formations would be expected to contain the least desirable water.

All of the important towns in Kane County, including Fredonia, Arizona, obtain their municipal supplies from wells extracting ground water from the Navajo Sandstone or Lamb Point Tongue of the Navajo Sandstone. Details about the expected yield and quality of water wells and springs and surface waters in Kane County were beyond the purposes of this report, but the interested reader may find much additional information in an abundant literature on the subject: Connor and Mitchell (1958), Cordova (1981), Feltis (1966), Goode (1964, 1966, 1969), Hendricks (1964), Iorns and others (1964, 1965), Jobin (1956), Price (1977a, 1977b, 1979, 1980, 1981, 1982, 1983), and Wilson and Thomas (1964).

Photo 89. Cascade Spring and Falls. Water from Navajo Lake drains through underground channelways dissolved along joints in the Claron Formation.

Scenic Wonders and Generalized Geologic History of Kane County

Kane County, in south-central Utah is a part of "Color Country" because of the colorful geologic formations of the area. The exposed beauty of these formations plus the intricate erosional forms that display them have been attractive to tourists and local inhabitants as well as to geologists. Much land has been set aside for tourism and recreation (see Land Ownership, p. 9, table 3, and figure 9). Additionally much land is being investigated for suitability as wilderness or roadless areas. Kane County has national parks, state parks, a national recreation area, National Forest and Bureau of Land Management sites, and a primitive area within its borders.

The southern and highest part of Bryce Canyon National Park is in Kane County. It owes its beauty to the spectacular Pink Cliffs of the Claron Formation, which have been sculpted into towers, minarets, castles, natural bridges and arches, and other interesting forms. Man's woes, works, and zeal fades into insignificance in the massive, chaotic and lonely immensities of the nature-sculpted magnificence. The onslaught of such vastness, such violent color and configuration stuns one momentarily. It is awesome indeed, and it takes a while to regain perspective. After a time it seems to become a spiritual experience, which was the value attached to it by prehistoric man and handed down to present day Indians. The park is the result of the eternal cycle of Earth's uplift and erosion. This region began rising about 13 million years ago, until parts of it were more than 2 miles above sea level, but the contoured rocks we see now were deposited by lakes that once covered the area. From hour to hour, from sunrise to sunset the scene changes. What may be a fairly accurate description of the color at 2 p.m. is no longer viable at 4 p.m.

Kodachrome Basin State Reserve is a fairly secluded section of unusual rock formations (mostly Carmel and Entrada Formations). Vivid sandstone spires reflect numerous hues, changing constantly with the angle of the sun. These sandstone spires are pipes that have been recemented to a degree of induration that surpasses that of the country rock. At least 60 of these collapse or breccia pipes have been counted in the vicinity. Kodachrome Basin was named by the National Geographic Society for its splendid color.

The Coral Pink Sand Dunes State Reserve is known for its geological diversity and gets its name from the fine shifting pink sand unique to the area (from the middle of the Navajo Sandstone). The sand dunes have been used often in Hollywood movies. They are exposed with a backdrop of the Vermilion Cliffs exhibited along the Sevier fault. Like in other areas of color country the sand colors change to the eye according to the time of day. The area is especially beautiful at sunset. It is a haven for dune buggy enthusiasts.

Glen Canyon National National Recreation area exposes the 1800 mile shoreline of Lake Powell, of which part is along Kane County. The Kane County portion exposes not only part of Glen Canyon itself but the

Escalante River Canyon. Because of the canyons the lake is described as the most incredible and fantastically beautiful body of water in the United States and quite possibly the world. There is such an excess of color and diversity of structure that one is held enthralled from one moment to the next. The exposed rocks are of the Glen Canyon Group: Navajo Sandstone, Kayenta Formation, and Wingate Sandstone. There are endless side canyons along the lake where the formations rise vertically out of the water (in some places to more than 500 feet), where arches have formed, and where the beauty that is above the water is perfectly reflected in the lake below.

"Nothing can exceed the wonderful beauty of Zion... ...In the nobility and beauty of structure there is no comparison... ...There is an eloquence to their forms which stirs the imagination with a singular power, and kindles in the mind a glowing response," (Dutton, 1882). Zion National Park is mostly in Washington County, but a small portion extends over the line into Kane County. The basis of the park are the massive cliffs of the crossbedded Navajo Sandstone. The impressive White Cliffs come to a climax in Zion National Park. The most famous landmark in the Kane County portion is Checkerboard Mesa. When viewing the Navajo Sandstone one is immediately impressed by the high angle crossbeds. These can be viewed outside of the park as well and an excellent place is in Three Lakes Canyon along U. S. Highway 89 north of Kanab. In addition to the crossbeds are the narrow canyons, monuments, and arches which have been carved in it (photos 90 and 92). Some of the narrow canyons follow joints which are relatively quite straight. Its bare rock outcrops extend across the county and many of these areas are being studied as primitive areas. The Paria Canyon Primitive area has already been set aside.

Two areas being studied for primitive area consideration are the canyons of the Paria River north of the ghost town of Paria and Hackberry Canyon (photo 91). The capping formation is the Navajo Sandstone, but the canyons themselves are cut into the Kayenta, Moenave and Chinle Formations as well. Hikers can be delighted by spectacular and colorful views around each bend in the canyon. The area around the ghost town of Paria is especially beautiful. The banded colorful outcrop of the Chinle Formation is often called "the land of the sleeping rainbow." Below the Chinle are the chocolate brown outcrops of the Moenkopi Formation which are handsomely sculpted into interesting badlands.

Perhaps the most famous arch in Kane County is Grosvenor Arch named after the founder of the National Geographic Society, Gilbert C. Grosvenor. It is cut in Henrieville Sandstone and in the sub-Dakota Conglomerate. It is xxx ft high and is xx ft wide. There are many arches cut in many formations across the county and these are marked with triangles on plates 4, 5 and 6. Because the formations are so beautifully exposed in Kane County, the geologist should find special pleasure in traversing its roads. One should not omit seeing the cinder cones and fresh lava fields on the Markagunt Plateau, looking southward from the top of the Pink Cliffs, driving the Cottonwood Canyon road along the Cockscomb, seeing the giant debris flows along the Straight Cliffs, looking into Kaibab Gulch from the top of Buckskin Mountain, and driving

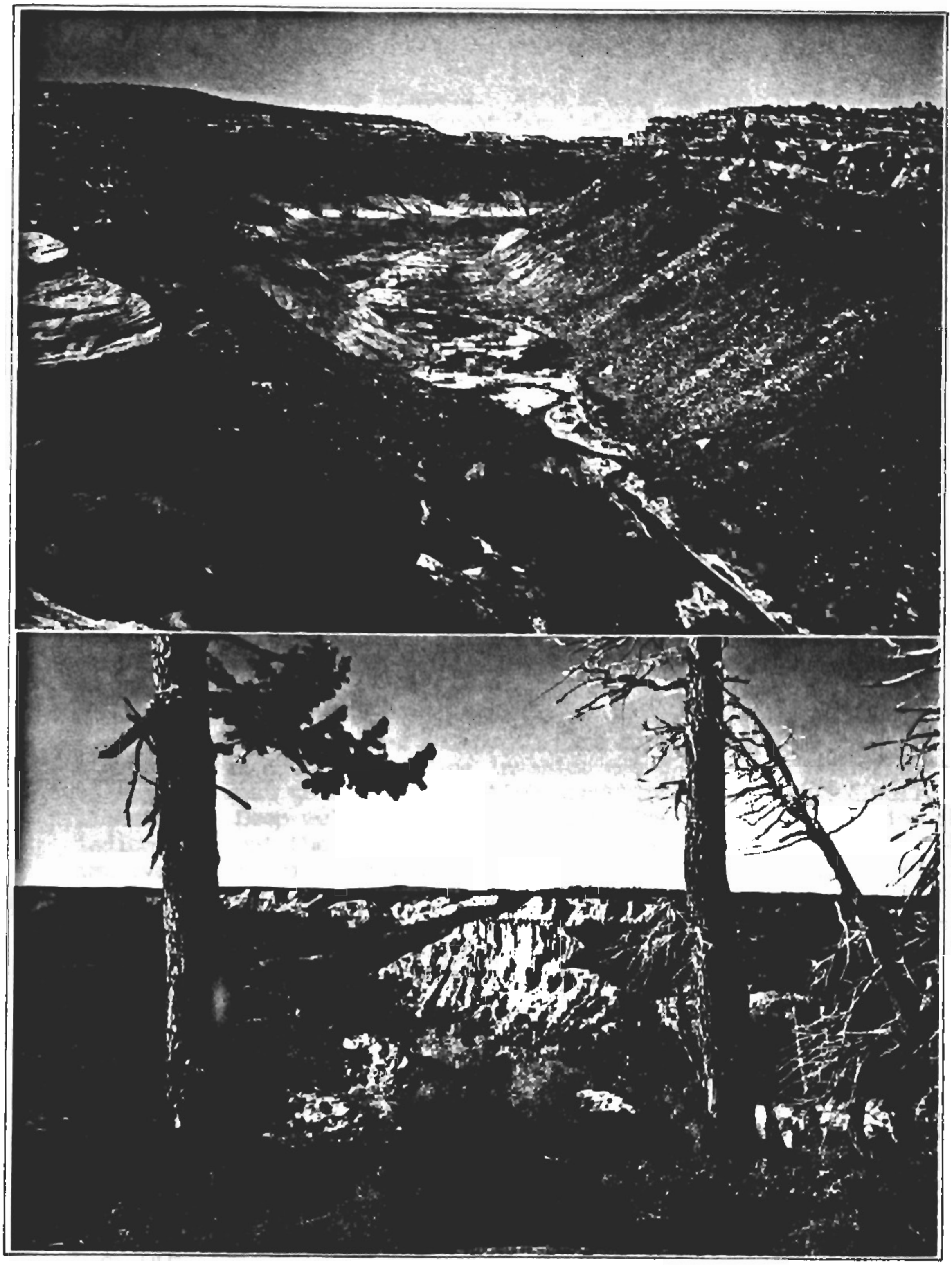


Photo 91. Gorgeous colors adorn the rocks of Kane County. Upper view is of Hackberry Canyon and the lower view is of the Pink Cliffs at the south margin of the Markagunt Plateau.

across the Kaiparowits Plateau. Kane County is one of the best places to see well exposed geologic formations, structures, and landforms in the world.

The geologic wonders of Kane County become more enjoyable with a general knowledge of its geologic history. Figure 71 diagrammatically shows the Grand Staircase and when and under what circumstances some of the formations were deposited. Kane County has had a very varied geologic history, several times covered by seas and oceans, sometimes experiencing tidal flat or floodplain environments, and relatively recently one of uplift, erosion, and volcanism.

Little is known about the geologic history of Kane County prior to Permian time inasmuch rocks deposited earlier are not exposed at the surface. Some information is available from deep drillholes and from evidence in surrounding areas, notably the Grand Canyon. At the Grand Canyon the Colorado River has cut into Precambrian rocks at least 1.6 billion years old that participated in mountain building episodes (Matzatzal Orogeny)(Hintze, 1973, p. 11). These rocks are highly metamorphosed (Vishnu Schist) and were intruded by granites. Thick sequences of younger Precambrian rocks were deposited (at least 15,000 ft), including sandstones, quartzites, shales, limestones, lava flows, and conglomerate that were tilted and eroded before rocks of Cambrian age were deposited.

During much of Lower Paleozoic time Kane County received sediments on a continental shelf. A marine invasion moved over the shelf in Cambrian time, from west to east, depositing sandstone, shale, and finally limestone. Deep wells pass directly from Devonian into Cambrian rocks indicating that the shelf received no sediments during the missing time intervals (Ordovician and Silurian) or that any deposited were removed prior to Upper Devonian time. The Upper Devonian sediments deposited were relatively thin and deposited under shallow marine conditions with nearby fluctuating shorelines. Parts of the Devonian suffered some erosion before the Mississippian rocks were deposited.

Limestone deposition under marine below wave base conditions prevailed. This limestone (Redwall) was elevated and subjected to subaerial solution and erosion and developed a karst topography on its upper surfaces. Sinkholes were filled by the initial Pennsylvanian deposition (Molas). Deepening marine basins developed in Utah during Pennsylvanian time which were separated by "divides" or platforms over which deposition was very thin or missing. One of these divides crosses central Kane County north-south and is known as the Piute Platform. The mostly marine rocks of the Pennsylvanian thicken east and west of the platform.

The earliest Permian rocks were also affected by the Piute Platform. However, subsidence occurred and the thickness of Permian rocks nearly amount to the thickness of all the other Paleozoic rocks combined. Some of the units were deposited under marine and restricted marine conditions and contain some land derived sediments. Others were deposited in

THE GRAN

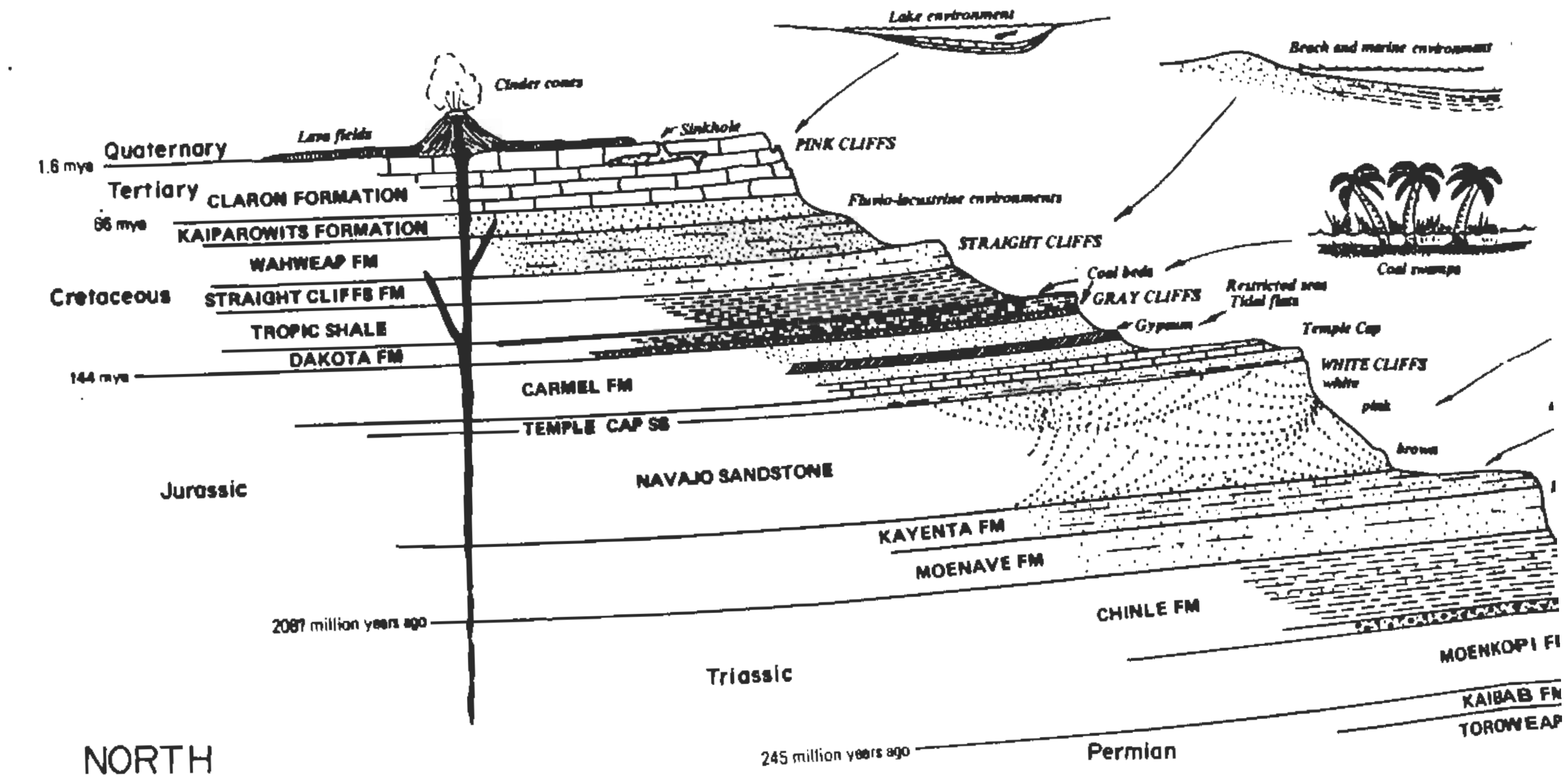
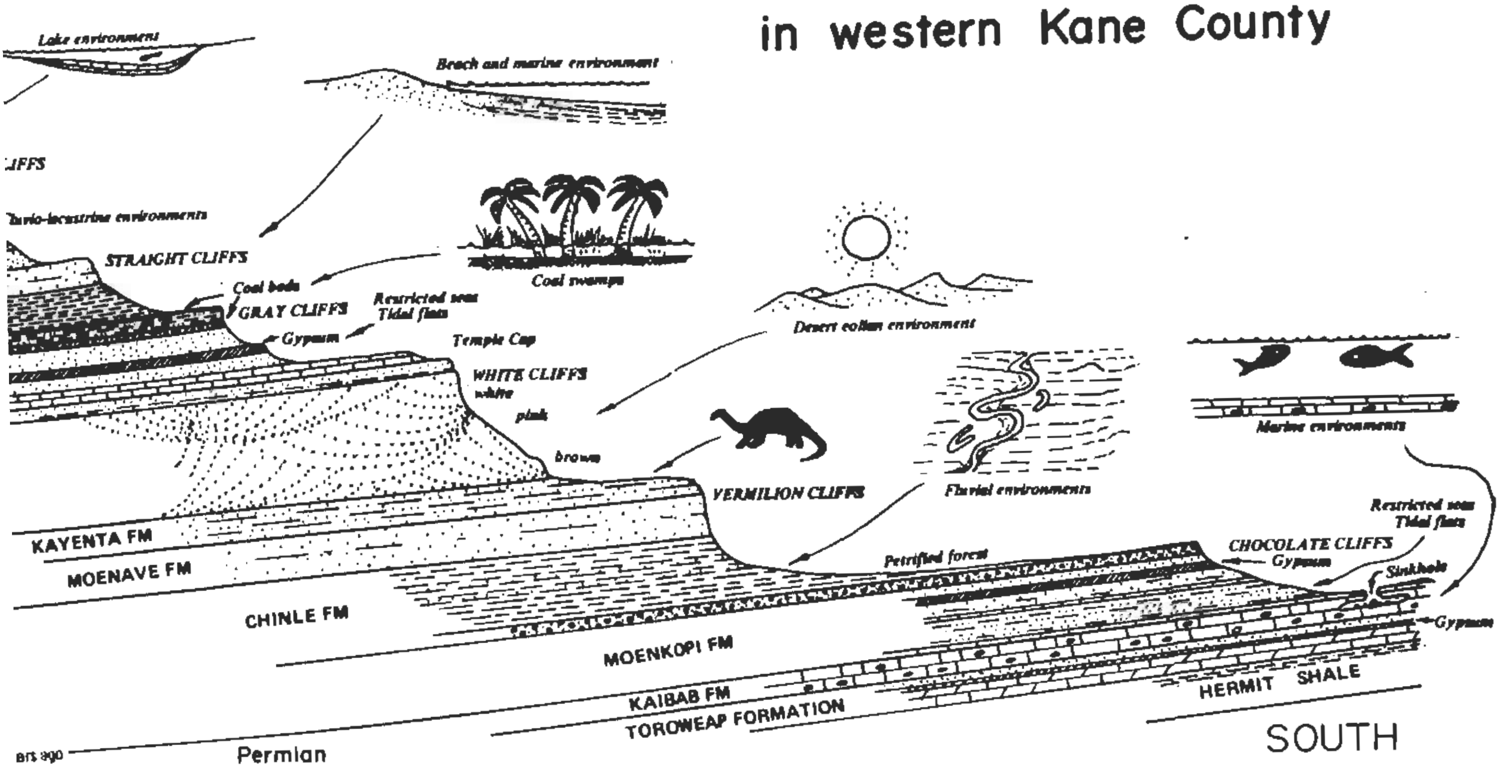


Figure 71. Diagrammatic cross section of the Grand Staircase in western Ka
geologic formations, the age and environments of deposition, and famou
"risers" of the staircase. The section pictures the most colorfully e

THE GRAND STAIRCASE
in western Kane County



section of the Grand Staircase in western Kane County. Reference is made to ge and environments of deposition, and famous lines of cliffs which build the The section pictures the most colorfully exposed geologic section in the world.

littoral and mud flat situations and as basin edge beach deposits. The marine sedimentation is recorded as a series of alternating transgressions and regressions, mostly transgressing west to east.

An unconformity marks the transition from the Paleozoic to the Mesozoic. The Triassic period is represented by rocks of the Early and Late parts, the middle missing and represented by an unconformity. In Early Triassic time marine conditions prevailed to the west and mostly mud flat conditions prevailed in Kane County. Several relatively brief marine transgressions spread into Kane County and deposited the Timpoweap, Virgin, and Shnabkaib Members between the red silts and sandstones of the remainder of the Moenkopi Formation. The initial Moenkopi sediments in Kane County are somewhat younger than those deposited to the north, west, and even to the east. The earliest Moenkopi rocks in Kane County are thought to contain the Meekoceras fauna. The basal Timpoweap Member is variable in thickness and contains numerous breccias containing material from the Permian Kaibab beneath suggesting deposition began with a series of turbidity currents.

The Chinle Formation was deposited in river floodplains. The initial sediments were coarser grained and deep channels were cut into the Moenkopi below. Thereafter shallow rivers meandered across the nearly flat area that was dotted irregularly with shallow lakes. Forests were present along the stream courses and many of the logs were petrified in the stream channels. Volcanos, active in southern Arizona (Hintze, 1973, p. 58), spread volcanic ash onto the floodplain from time to time that soon altered to bentonite. The volcanic ash provided a ready source of silica for the petrifaction process and to create the thin layers of chalcedony prevalent in the unit. At one place in Kane County (near Paria) a coal bed was formed.

There is some doubt as to the age of the Glen Canyon Group of formations which were deposited next. They are considered to be of latest Triassic or earliest Jurassic age and consist mostly of sandstones with subordinate siltstones, intraformational conglomerates, siltstones, and limestones. In this report they are treated as if they were completely Jurassic in age. After the Chinle was deposited the region was subjected to a period of non-deposition and some erosion may have followed (Wilson, 1958, p.165). When deposition was renewed the western part of the county was an area of shallow stream channels, mud flats, with lakes and ponds scattered over the flood plain. Fresh water fish inhabited the lakes. To the east a nearly equal amount of fine grained sand was deposited, probably in a desert eolian environment. The source of the sediment is thought to have been eastward. In Kayenta time fluvial conditions dominated, but in the east eolian sediments interfinger with the fluvial. To the west the sediments become finer and finer, reverting mostly to siltstone. Eventually the desert eolian environments became prevalent over the whole area and the Navajo Sandstone was deposited. The lower part of the Navajo interfingers with the upper part of the Kayenta. Some investigators believe the Navajo may be a product of marginal marine deposition.

If the desert eolian environments are the correct interpretation the area was a Sahara like desert with high sand dunes and rare shallow lakes in low areas. Evenso the formation was a good aquifer at depth and probably supported a deep water table. The normal sweeping high angle crossbeds, characteristic of the Navajo, are occasionally highly contorted, especially in the lower part, and may indicate liquefaction activity induced by earthquakes before the rock was thoroughly cemented.

The top of the Navajo was eroded nearly flat before the remainder of Jurassic units were deposited producing the J-1 unconformity. Thereafter a Middle Jurassic seaway opened from the north and extended to southern Utah. At first the sea lay to the west or north of Kane County. Western Kane County was lowered in elevation and briefly received mudflat and eolian sediments (Temple Cap Formation). Then the western half of the county was covered by a shallow sea in which limestone and clayey limestone were deposited (Kolob Member of the Carmel Formation). This deposition extended as far east as Big Water. In eastern Kane County the environments were similar to those that produced the Temple Cap Formation and the Page Sandstone was deposited. The western seaway regressed and the Crystal Creek Member was deposited in a mudflat environment. Eventually the desert eolian or beach eolian environments briefly returned and the Thousand Pockets Tongue of the Page Sandstone was deposited almost as far west as Johnson Canyon. Another brief transgression followed and extended across the county; the sea was restricted and gypsum (Paria River Member) was deposited in the western half of the county. Before returning to strictly mudflat deposition a thin white chippy limestone layer covered the northern two-thirds of the county. The south was landward and tongues of beach eolian sands and even gritstone intertongue with the mudflat sediments. The remainder of the Carmel Formation deposition was primarily in mudflat environments on which restricted embayments developed to the north depositing additional gypsum beds.

By Entrada time the sea had regressed and its depositional environments are described as tidal flat, sebka, and beach. For a while, after the deposition of the Entrada was completed, the area was subjected to subaerial erosion, the upper surface of the Entrada was bevelled to a peneplain (J-3 unconformity). Another sea invaded Utah from the north and deposited the Curtis Formation in northern and central Utah. The sea did not reach southern Utah or Kane County. The marine Curtis deposits interfinger with the marginal marine Summerville Formation which undergoes facies changes to the south and west (Romana Mesa Sandstone and Henrieville Sandstone) to beach and lowland deposits. The true Summerville Formation is present in easternmost Kane County near Bullfrog Bay.

Thereafter, the Morrison Formation was unconformably (J-5) deposited over the Summerville, Romana Mesa, and Henrieville sediments. The Morrison is represented principally by braided stream channel deposition and subordinate flood plain overbank deposition from sources to the south and west (Sevier Orogenic Belt?). The presence of petrified wood in the county and dinosaur bones elsewhere indicates the terrestrial nature of the deposition.

After the end of Morrison deposition, Kane County was tilted and eroded and the next deposition probably did not occur until latest Lower Cretaceous time or earliest Upper Cretaceous time. Western Kane County was uplifted and the K-0 unconformity successively cuts out formations from east to west. In eastern Kane County the Cretaceous deposits rest on the Morrison Formation. Along the Washington County line the Cretaceous deposits rest on the bevelled edges of the Winsor Member of the Carmel Formation. Although the Cretaceous units are occasionally found as channels in the Jurassic units, the unconformity represents a peneplain.

The initial Cretaceous sedimentation was fluvial with sources to the west or south. The deposition may not have resulted in a blanket deposit and deposited discontinuously over Kane County. The coarse clastic deposits often contain petrified wood, carbonized wood fragments, clay galls, and fragmented rock from below. Not long thereafter the epicontinental Cretaceous sea invaded Utah from the east, eventually covering all of Kane County. In advance of marine deposition, fluvial, lagoonal and nearshore sands (Dakota Formation) were laid down. Coal forests developed at intervals, especially to the west. The source of sediments was westward in the Sevier Orogenic belt.

The inundation by the sea is recorded in the Tropic Shale which contains many types of marine fossils. At least one sandstone tongue (Sugarledge Sandstone) extends into the Tropic from the west. Eventually the Cretaceous sea regressed making way to offshore, beach, and lagoonal depositional regimes (Tibbet Canyon and Smoky Hollow Members of the Straight Cliffs Formation). To the north, in central Utah, another transgression of the sea followed, but in Kane County the next interval of time is marked by an unconformity (Peterson, 1969b, p. J10-J14). When deposition resumed (John Henry Member), the Kaiparowits Plateau area was a marginal lowland with heavily vegetated lagoons and sandy beaches. The sea lay eastward and received offshore sands. To the west the lagoonal deposits interfinger with fluvial deposits. Some northwest trending folding took place simultaneously with the deposition and synclinal areas received a thicker prism of sediments. Peat collected in the lagoons to form thick coal beds.

The sea regressed from Utah and fluvial sedimentation spread eastward (Wahweap Formation). The subtle folding continued and the synclinal basins continued to receive a greater share of the sediment. In latest Cretaceous time (and extending into Early Tertiary time) broad basins and uplifts developed on the Colorado Plateau area (Laramide Orogeny?). High mountains are thought to have existed in western Utah and the area between them and the present Circle Cliffs Upwarp subsided slowly to continue to receive sediment.

In early Paleocene time most of Kane County received a flood of gravels that now lie unconformably on the Cretaceous sediments. Then a large lake covered the same area producing the pink and white limestones of the Claron Formation. It certainly covered all of Kane County from the Kaiparowits Plateau westward. How far south the lake might have extended is also unknown. In later Eocene time lacustrine environments alternated with fluvial environments. This is the point in time where the ancient stratigraphic record ends in Kane County (excluding Quaternary deposits). To the north deposition continued well into Oligocene time where great quantities of volcanic materials were deposited.

From the work of McKee and McKee (1972) and Lucchitta (1972) we find that Basin and Range faulting and tectonic activity began to affect the Colorado Plateau about 18 million years ago (latest early Miocene). According to Lucchitta's work deposits as young as 18-20 million years ago show that the drainages flowed northward across the present Lake Mead area in Arizona into the Colorado Plateau area. The Muddy Creek Formation was deposited next and laid down in the Lake Mead area in interior basins formed by Basin and Range faulting. The deposition is thought to have ended a little over 10 million years ago (late Miocene). The McKee's indicate that Tertiary gravels along the southern margin of the Colorado Plateau originated to the south at a time when southern Arizona was higher than the Grand Canyon. Basalt cobbles from the gravels have ages of 10-12 million years. They indicate that the Verde River drainage, which flows south in Arizona, was well developed 5 million years ago so that the major part of the Grand Canyon uplift occurred 5-10 million years ago which coincided with the major canyon erosion. Lucchitta further indicates that younger deposits indicate that the Colorado River was well established 3.3 million years ago (Pliocene) and was flowing within 350 ft of its present grade.

It is assumed that these tectonic activities extended well into Utah. The Grand Canyon uplift and the High Plateaus uplift in Utah were probably simultaneous events and general uplift, (although not as high), probably occurred across the entire Colorado Plateau. The general northward dip is thought to have been established in Kane Couty along with the displacements along the Sevier and Paunsaugunt faults. It is also thought that the Kaibab upwarp and East Kaibab monocline were established at that time. Folds marginal to the faults (Harris Mountain and Deer Range anticlines) may represent some initial deformation prior to the major Basin and Range fault movements. It is not known whether the deformation (other than general uplift) extended east of the East Kaibab monocline. Differential erosion has dominated the scene from 10 million years ago cutting the spectacular canyons and forming the impressive cliffs of the region.

During Pleistocene time the area was affected by increased precipitation and generally lower temperatures. The more incompetent beds became saturated and mass movements were commonplace. The development of colluvium was extensive, even to the point of completely mantling the higher cliffs. Gravel benches and surfaces (pediments) developed at the foot of escarpments and flat sandy areas covered the low areas. As erosion continued along the more important drainages gravel terraces were stranded at levels above the new stream gradients. Cliff retreat was prevalent especially along the Straight Cliffs and Vermilion Cliffs. Great blocks along the points sheared along old joint planes and dropped down. Along the drainages there is evidence that the terrace gravels were displaced. In the northwestern part of the county volcanism made its appearance, blocky basalt poured down the plateaus and cinder cones were built up. The volcanic activity may have continued into Holocene time considering the fresh appearances of the deposits.

In Holocene time the evidence points to a dryer regime of climate. The great debris flows that surround the Kaiparowits Plateau are mostly inactive and are undergoing erosion. A few, especially around the Markagunt Plateau, are still active, fed by moisture from higher rainfall on the High Plateaus. The Pink Cliffs are shedding their colluvial mantles. Most of the principal drainages flow in alluvium filled valleys, the sediments of which were deposited in Holocene time. Presently the streams are cutting gorges and gullies during periodic flash flooding in this thick alluvium and there is evidence to indicate that much of this has occurred in the last few hundred years.

Measurement of the Hermit Formation in Buckskin Gulch, Sec. 9-43S-4E, Kane County, Utah, by E. A. Noble (1928, p. 46).

Coconino Sandstone: Arenaceous limestone or calcareous sandstone.

Hermit Formation:

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. 3ft

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 conretionary 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 1ft

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 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. 7ft

4. Very massive bed, like No. 3; upper portion contains buff streaks and blotches. 22ft

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. 7ft

6. Massive red concretionary sandstone, like No. 3. 3ft

7. Red soft sandy shale, like No. 5. 8ft

8. Massive red concretionary sandstone, like No. 3. 4ft

Talus: Extends downward to the bed of Kaibab Gulch (Buckskin Gulch) and conceals all underlying rocks.

Total exposed thickness: 55ft

Measurement of the Coconino Sandstone(?) at Buckskin Gulch (formerly Kaibab Gulch), Sec. 9, T. 43 S., R. ~~4 E.~~ 2 W., Kane County, Utah, by E. A. Noble (1928, p. 46).

Toroweap Formation: Buff limestone in massive beds from 6 inches to 4 ft thick; forms a strong cliff. 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. Lower 1 ft is massive bed of chert; forms an alcove.

Coconino(?) Sandstone:

1. Massive bed of hard fine-grained buff sandstone; forms strong cliff. The rock is vesicular, and weathered surfaces are cavernous. Basal 3 ft 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. 9ft

2. Buff shaly sandstone, soft, poorly exposed; forms alcove. 2ft

3. Gray crystalline limestone in massive beds ranging from 4 inches to 2 ft thick. Rock hard and more or less vesicular; forms strong cliff. 8ft

4. Buff gnarly sandstone; soft; forms alcove; weatheres 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. 8ft

5. Alternating beds of buff sandy shale in paper-thin laminae and buff chert. One chert bed is 6 inches thick. 2ft

6. Buff hard fine-grained arenaceous limestone or calcareous sandstone; seamed with calcite; exhibits faint cross-bedded structure on weathered surfaces. 2ft

7. Lumpy and gnarly fine-grained sandstone; soft; forms alcove. 1/2ft

8. Buff hard fine-grained arenaceous limestone or calcareous sandstone; seamed with calcite; forms a cliff. 2ft

9. 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. 2ft

10. Buff hard fine-grained arenaceous limestone or calcareous sandstone; forms cliff. 2ft

11. Irregularly bedded buff soft fine-grained sandstone; structure contorted and gnarly. 5ft

12. Sandy buff crystalline limestone; hard; weathers into nodular lumps; very fossiliferous, but all fossils seen were too poorly preserved to be determinable. 1/2ft

13. Buff calcareous shale. 1/2ft

14. Sandy buff limestone, somewhat cherty; fossiliferous but fossils very poorly preserved. 1/2ft

15. Soft lumpy sandstone, very irregularly bedded; largely a conglomerate or breccia of sandstone lumps embedded in a matrix of churned up sand. 3ft

16. Buff sandy calcareous shale. 1ft

17. Yellowish-buff hard fine-grained evenly bedded sandstone. 2ft

18. Buff soft fine-grained sandstone; bedding gnarly and contorted. 5ft

19. Buff fine-grained hard arenaceous limestone or calcareous sandstone; laminae very thin, horizontal; makes a small cliff. 1ft

20. One-inch parting of calcareous shale in paper-thin laminae.

21. Arenaceous limestone or calcareous sandstone, like No. 19. 2ft

22. Two-inch parting of calcareous shale, like No. 20.

23. Arenaceous limestone or calcareous sandstone, like No. 19. 1ft

24. Same kind of rock as No. 23, but even more thinly laminated. 1ft

25. Arenaceous limestone or calcareous sandstone, like No. 19. 2ft

26. Calcareous shale, like No. 20 1/2ft

27. Arenaceous limestone or calcareous sandstone, like No. 19. 1ft

Total thickness: 63 3/4ft

Hermit Shale: (Description on page 16)

Toroweap Formation.

Measurement of the Toroweap Formation (less 64 ft previously ascribed to the Coconino Sandstone [p. 18]), Sec. 9, T. 43 S., R. 2 W., by L. F. Noble, 1928, p. 44-45.

Kaibab Limestone: 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 ft in thickness.

Toroweap Formation (upper slope-forming unit):

1. Soft sandstone; bedding contorted. Contacts with overlying and underlying beds are uneven, wavy. 1ft

2. Gray crystalline limestone, texture sugary. 1ft

3. Irregulary bedded hard sandy limestone; under surface very eneven; this and the two overlying beds make small cliffs. 3ft

4. Soft buff contorted sandstone; contains lenses of red shale averaging less than an inch thick; makes a slope and alcove; outcrops partly concealed. 15ft

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. 7ft

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. 8ft

7. Gray sandy limestone, in part travertine; makes a small cliff. 3ft

8. Beds of breccia and travertine interstratified with irregularly bedded yellowish-buff sandstone; make a cliff. The upper 2 ft 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. 8ft

9. Beds of breccia and soft sandstone like No. 8; make a slope; much of the breccia resembles fanglomerate. 17ft

10. Brownish-buff fine-grained calcareous sandstone in beds up to 1 foot thick; almost a limestone. 6ft

11. Reddish sandstone; forms slope; outcrops partly concealed. 3ft

12. Buff hard fine-grained sandstone, composed of tiny transparent quartz grains, which sparkle in the sunlight; forms a small cliff. 2ft

13. Reddish soft fine-grained sandstone. 8ft

14. Buff to brown porous calcareous brecciated sandstone seamed with calcite; largely travertine; forms a small cliff. 2ft

15. Red soft sandstone; bedding gnarly and contorted; outcrops largely concealed. 15ft

16. Buff to brown calcareous sandstone seamed with calcite; forms a small cliff; bedding irregular, gnarly. 2ft

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. 2ft

18. Red soft fine-grained sandstone; outcrops largely concealed. 12ft

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. 5ft

20. Largely concealed; the few outcrops seen consist of brownish-buff soft sand. 12ft

21. Gnarly buff calcareous sandstone. 3ft

22. Concealed; probably soft sandstone. 12ft

23. Breccia in travertine, like No. 19. 3ft

Total upper slope-former 150ft

(Lower cliff-forming limestone):

24. Platy gray limestone in beds averaging one-fourth inch thick. 4ft

25. Dense siliceous buff limestone in beds ranging from 1 to 3 ft thick. Bands of chert nodules abundant. 10ft

26. Dense siliceous limestone, like No. 25; forms two massive beds each 9 ft thick; contains many cavities lined with quartz crystals; contains also nodules of chert, but the chert is not conspicuously abundant. 18ft

27. Massive arenaceous limestone exhibiting gnarly contorted bedding on weathered surfaces. 7ft

28. Buff arenaceous limestone or calcareous sandstone forming a single massive bed; bedding planes level and even. 12ft

29. Soft calcareous sandstone; bedding irregular, gnarly, forms alcove. 10ft

30. Arenaceous limestone; most beds exhibit faint cross-bedding on weathered surfaces, but some exhibit gnarly bedding; makes a steep ledgy slope. 16ft

31. Buff limestone in massive beds from 6 inches to 4 ft 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. 22ft

32. Massive bed of chert; forms an alcove. 1ft

Lower cliff-forming unit	100ft
"Coconino Sandstone"	64
Total Toroweap Formation:	314ft

Measurement of the Kaibab Formation, NW Sec. 5, T. 44 S., R. 2 W., Kane County, Utah, Pine Hollow Canyon Section.

Timpoweap Member of Moenkopi Formation (only a thin veneer remains at this location.

Permian Rocks--Kaibab Formation:
Alpha? Member:

1. Limestone, tan, medium-bedded, blocky, cliff-forming, upper part of unit has numerous dark brown weathering tubes, many in vertical orientation, filled with sandy chert. 3.6ft

2. Covered slope. 2.8

3. Interbedded chert and sandstone unit (banded); chert is bone-colored and in beds 1-3 inches thick; sandstone is brown, fine-grained, also in beds 1-3 inches thick. 1.9

4. Limestone, tan, cherty, thin- to medium-bedded, forms ledgy slope. 8.1

Total Alpha? Member 16.4ft

Beta Member:

5. Limestone, tan-gray, massive, cliff-forming, fossiliferous. 24.3ft

6. Limestone, tan, massive, cliff-forming, contains large productid brachiopods and pectens. 14.3

7. Limestone, gray, cliff-forming, weathers hackly, contains spherical (white and brown chert nodules to 6 inches in diameter). 4.7

8. Limestone, gray, cliff-forming, thinbedded to massive, weathers hackly, fossiliferous (brachiopods, crinoid stems, bryozoa). 9.3

9. Sandstone, medium tan, fine-grained, calcareous, contains nodular chert and fossils (corals, brachiopods, and crinoid stems). 5.4

10. Interbedded limestone and sandstone; limestone, grayish tan; sandstone, tan and fine-grained with thin gray chert horizons; upper part of unit has poorly preserved crinoid stems. 5.8

11. Limestone, tan-gray, sandy, gnarly bedded, cherty, thinbedded. 2.7

12. Sandstone, tan, coarse-grained, calcareous, forms top of cliff made by underlying unit. 1.9

13. Sandstone, yellow-tan, fine- to medium-grained, slightly calcareous, massive, cliff-former. 13.9

14. Limestone, tan, sandy, thickbedded to massive, a few thin sandstone partings near the top of the unit, thin horizons of white chert nodules. Some chert nodules are hollow and lined with quartz of calcite crystals. 28.7

15. Sandstone, tan, fine-grained, calcareous, occasional layers of nodular gray chert. 6.6

16. Limestone, gray, crystalline, thick-bedded, fractures lined with calcite crystals, a few thin partings of tan, fine-grained sandstone, forms ledgy slope. 26.4

Total Beta Member	144.0
Total Kaibab Formation	160.4

Measurement of the Timpoweap Member of the Moenkopi Formation, east side of Buckskin Mountain, NE Sec. 26, T. 42 S., R. 2 W., Kane County, Utah

Lower Red Member of the Moenkopi Formation:

Timpoweap Member of the Moenkopi Formation:

11. Sandstone, tan, very fine-grained, calcareous, chippy weathering 1.0ft

10. Limestone, tan, weathers yellowish, sandy, very hard, contains small blebs of chert in lower part, single bed, contains poorly preserved fossils on upper surface (gastropods and pelecypods) 5.0ft

9. Limestone, tan, sandy, forms notch in cliff 1.0

8. Dolomite, tan, sandy, contains small amounts of chert, thickbedded to massive 9.0

7. Dolomite, tan and gray, blocky, contains small chert blebs and pebbles, very hard 1.5

6. Sandstone, tan, fine-grained, weathers chippy 2.0

5. Siltstone, chocolate brown, forms indentation in cliff, grades into unit 6. 1.5

4. Sandstone, tan, slightly calcareous, thin to medium-bedded, contains chert pebbles, interbedded with thin bedded tan siltstone. 2.5

3. Siltstone, tan, sandy, laminated, forms indentations in steep slope 0.9

2. Sandstone, tan, fine- to medium-grained, slightly calcareous, thin- to thickbedded 5.0

1. Siltstone, tan, sandy, interbedded with subordinate tan, fine-grained sandstone, both laminated to medium-bedded, sandstones calcareous, siltstones non-calcareous, several horizons of white chert up to 4 inches thick 5.5

Total Timpoweap Member 34.9ft

Kaibab Formation: Limestone, medium gray, medium to thickbedded, hard and blocky, contains sandy chert tubes, weathers hackly.

Measurement of the Lower Red Member of the Moenkopi Formation, near Road Canyon at north end of Buckskin Mountain, W 1/2, Sec. 23, T. 41 S., R. 2 W., Kane County, Utah

Virgin Limestone Member of Moenkopi Formation:

Lower Red Member of Moenkopi Formation:

11. Siltstone, brown, with thin beds of brown fine-grained sandstone, slope-former and platy weathering 17.4 ft

10. Sandstone, brown, silty, fine-grained, thin-bedded, platy weathering, ledge-forming 2.9

9. Siltstone, like unit 11 11.5

8. Sandstone, light-brown, calcareous, platy weathering, ripple-marked, forms slight ledges. 47.5

7. Siltstone, with occasional thin, tan, fine-grained sandstone beds, reddish-brown, earthy weathering, slope-former. 23.6

6. Sandstone, tan, fine-grained, calcareous, thin-bedded, forms blocky ledge or ledges. 2.6

5. Siltstone, reddish-brown, with occasional thinbedded fine-grained tan sandstone interbeds, bedding indistinct to shaly, forms earthy slope. 49.7

4. Sandstone and interbedded siltstone, brown, thin-bedded, platy-weathering, slope-former. 34.0

3. Covered slope, sand. 2.1

2. Sandstone, light-brown, fine-grained, thin-bedded, platy-weathering forms ledge. 2.1

1. Siltstone, brown with some thin interbeds of silty shale, brown fine-grained sandstone, also occasional horizons of tan-gray, micaceous, calcareous fine-grained sandstone; lower 15 ft is bleached to yellow-tan, the color irregularly crossing bedding planes, slope-former. 26.9

Total Lower Red Member 220.3 ft

Measurement of the Virgin Limestone Member of the Moenkopi Formation near Road Canyon, SE Sec. 23, T. 41 S., R. 2 W., Kane County, Utah.

Middle Red Member of Moenkopi Formation:

Virgin Limestone Member:

5.	Sandstone, tan, fine-grained, calcareous, forms ledge.	3.5 ft
4.	Siltstone, light greenish gray, clayey, calcareous, bedding indistinct.	2.0
3.	Siltstone and interbedded mudstone, chocolate brown, calcareous, thinbedded, contains thin gypsum seamlets, shaly towards top.	12.0
2.	Sandstone, light brown, silty, thin-bedded, platy weathering.	2.2
1.	Sandstone, light-brown to tan, fine-grained, calcareous, medium-bedded, cliff-former.	10.0
	Total Virgin Limestone:	29.7 ft

Measurement of the Middle Red Member of the Moenkopi Formation, west of Paria, W 1/2, Sec. 23, T. 41 S., R. 2 W., Kane County, Utah:

Shnabkaib Member of Moenkopi Formation:

Middle Red Member of Moenkopi Formation:

20.	Sandstone, light brown, fine-grained, silty, forms ledge, weathers platy.	10.0 ft
19.	Mudstone, chocolate brown, silty, slope former.	6.0
18.	Sandstone, brown to grayish green, silty, ripple-marked, micaceous, with thin interbedded mudstone, slope-former.	15.5
17.	Sandstone, like unit 1, ripple-marked.	4.0
16.	Siltstone, dark-brown, gypsum seamlets, bedding indistinct, occasional light-green sandy horizons, slope-former.	32.7
15.	Sandstone, light-brown to tan, gypsum veinlets, thin bedded to shaly, thin interbeds of brown shale, forms ledges.	10.7
14.	Siltstone and interbedded mudstone, dark brown to chocolate brown, thin bedded, criss-crossing gypsum veinlets.	7.7
13.	Siltstone, dark-brown, interbedded with occasional horizons of light green slightly micaceous sandstone, forms vertical cliff or steep slope, criss-crossed with gypsum veinlets (paper thin to 1/2 inch thick). Laterally this unit forms an earthy orange tan slope with horizontal light-gray bands.	67.2
12.	Covered slope, earthy, probably underlain with unit 13.	98.6
11.	Covered, stream alluvium.	10.0
10.	Siltstone, like unit 13.	22.3
9.	Sandstone, light gray green, fine-grained, silty, thin bedded to shaly, ledge-former, partly cemented with gypsum.	3.5
8.	Siltstone, dark brown, bedding indistinct, paper-thin gypsum seamlets, slope former.	16.2
7.	Covered slope, earthy, probably like unit 8.	8.8
6.	Covered slope, but exposed laterally like unit 8.	10.5
5.	Covered slope.	30.6
4.	Siltstone, brown to dark brown, slightly micaceous, occasional thin sandstones, tan, fine grained.	5.1
3.	Sandstone, dark brown, silty, fine grained, shaly to thin bedded, ripple-marked, forms ledges, weathers chippy.	2.7
2.	Siltstone, like unit 13.	7.7
1.	Sandstone, tan, platy, ripple-marked.	0.5
	Total Middle Red Member:	370.3 ft

Virgin Limestone Member of the Moenkopi Formation.

Measurement of the Shnabkaib Member of the Moenkopi Formation west of Paria, SW Sec. 13, T. 41 S., R. 2 W., Kane County, Utah.

Upper Red Member of Moenkopi Formation:

Shnabkaib Member of Moenkopi Formation:

16.	Sandstone, tan, very fine-grained, criss-crossed with gypsum veinlets, cliff-forming.	24.7 ft
15.	Sandstone, brown, very fine-grained, shaly, gypsiferous.	14.3
14.	Covered slope, earthy.	24.5
13.	Gypsum bed.	0.2
12.	Covered slope, earthy.	3.6
11.	Gypsum bed (selenite).	0.5
10.	Covered slope, earthy.	20.3
9.	Gypsum, with interlayered greenish-gray siltstone.	4.5
8.	Siltstone, like unit 4.	21.5
7.	Gypsum, silty, light green.	1.4
6.	Gypsum, sandy, light green, thin layers.	6.8
5.	Sandstone, greenish-gray, fine grained, ripple-marked.	5.5
4.	Siltstone, reddish-brown, alternating with greenish-gray, shaly, siltstone, occasional thin beds of greenish-gray very fine grained sandstone.	61.5
3.	Gypsum, sandy, reddish-brown, forms low resistant ledge.	1.5
2.	Sandstone, reddish brown, very fine-grained, micaceous, occasional thin layers of gypsum, forms steep slope.	11.8
1.	Siltstone, chocolate brown, with interebedded greenish-gray shaly thinbedded, mottled and ripple-marked siltstone and sandstone.	18.1
	Total Shnabkaib Member:	220.7 ft

Middle Red Member of Moenkopi Formation:

Measurement of the Upper Red Member of the Moenkopi Formation, near Pioneer Gap, SWSE Sec. 32, T. 43 S., R. 4 W., Kane County, Utah:

Shinarump Member of Chinle Formation: Sandstone, light tan-gray, medium grained, crossbedded, medium to thick lenticular bedding, calcareous, contains tan siltstone partings, at base are clay galls, petrified wood, quartzite cobbles, and oscillation ripple marks, sharp contact with underlying Moenkopi Formation.

Upper Red Member of Moenkopi Formation:

11.	Siltstone, light tan gray.	1.0 ft
10.	Siltstone, reddish brown, slope former.	10.4
9.	Sandstone, light brown, very fine-grained, calcareous, shaly to thin bedded, ripple marks, platy weathering.	17.2
8.	Sandstone, lavender, very fine to fine grained, calcareous, massive, forms vertical cliff.	12.5
7.	Sandstone, reddish-brown, fine-grained, micaceous, platy.	8.9
6.	Sandstone, brown, very fine grained, silty, calcareous, massive, forms vertical cliff.	17.3
5.	Sandstone, light brown, calcareous, weathers platy, shaly to medium bedded, forms a blocky ledge.	9.3
4.	Covered slope, sand and boulders from above.	38.2
3.	Siltstone, reddish-brown, earthy weathering, interbedded with thin, green, fine grained sandstone (siltstone to sandstone ratio is 10:1), slope-forming.	24.5
2.	Siltstone and sandstone, like unit 3, but siltstone to sandstone ratio is 3:1.	20.5
1.	Covered slope, contact with underlying Shnabkaib Member is poorly exposed and typical gypsum outcrops merge into upper red slope.	3.9
	Total Upper Red Member:	163.7 ft

Shnabkaib Member of Moenkopi Formation: Sandstone, light brown, white and greenish, fine-grained, porous, friable, with criss-crossing gypsum veinlets, forms earthy ridges with characteristic upper thin gypsiferous sandstones.

Measurement of the Chinle Formation at Petrified Hollow, Sec. 2, T. 43 S., R. 4 W., Kane County, Utah:

Moenave Formation (lower unit): Sandstone and mudstone, moderate reddish orange, in medium to thick beds; sandstone is well cemented, fine-grained, and forms ledges; mudstone is less resistant and forms slopes and indentations. Contact with unit below appears conformable.

Petrified Forest Member of Chinle Formation:

26.	Sandstone, white, very fine-grained, friable.	1.0 ft
25.	Siltstone, reddish-brown, shaly, slightly micaceous.	14.5
24.	Sandstone, white, fine-grained, friable, upper 6 inches well cemented, forms a ledge.	4.8
23.	Siltstone, reddish brown, forms earthy slope.	7.4
22.	Pebblestone, white, composed of fine-grained sandstone clasts, no bedding.	2.0
21.	Sandstone, white, very fine-grained, forms a low ledge.	1.3
20.	Gritstone, white, pebbly (mostly fine-grained sandstone pebbles).	1.7
19.	Mudstone, mostly gray, but interlayered with some red and reddish-brown beds, all bentonitic and most form earthy slopes.	399.3
18.	Mudstone, red, bentonitic.	3.8
17.	Siltstone, mottled purple, yellow, and red, clayey.	5.0
16.	Sandstone, light-gray, coarse-grained to gritty and pebbly, cross-bedded, friable and massive.	20.4
15.	Sandstone, dark-brown to lavender, silty, fine- to medium grained, crossbedded, friable and poorly cemented, deposited on a surface of some relief.	5.2
14.	Sandstone, like unit 16 above.	32.0
13.	Mudstone, interlayered gray, lavender, and red beds, bentonitic, with thin interbedded sandstones, slope-former.	81.4
12.	Sandstone, pale lavender, very fine-grained to fine-grained, weathers to reddish-brown earthy slope.	15.8 ft
11.	Covered slope.	32.0
10.	Sandstone, light gray, medium-grained, friable.	0.2
9.	Mudstone, gray, bentonitic.	0.1
8.	Sandstone, greenish gray, very fine-grained (base of Petrified Forest Member if Monitor Butte is recognized below).	0.3
7.	Covered slope.	16.2
6.	Claystone, greenish gray, silty, weathers to light gray, contains petrified wood.	9.2
5.	Sandstone, reddish-brown, silty, very fine-grained, contains dark-brown nodular-weathering limestone, lenticular, weathers to earthy slope.	1.7
4.	Covered, but probably underlain with unit 3.	20.8
3.	Sandstone, light gray, fine- to medium-grained, friable, logs and branches of petrified wood are abundant, several thin beds of sandy clay at base contains jet wood (base of Monitor Butte Mbr, if recognized).	13.0

Shinarump Member of Chinle Formation:

2.	Sandstone, gray, fine-grained, slop former.	3.0
1.	Interbedded sandstone and conglomerate, gray; sandstone is medium-grained, friable, lenticular, and forms ledges; conglomerate contains clasts up to 2.5 inches in diameter (chert, quartzite, and sandstone), matrix is calcareous grit, contains petrified wood.	6.0

Total Petrified Forest Member:	691.1 ft
Total Shinarump Member:	9.0 ft
(Total Petr. Forest Mbr):	630.2 ft
(Total Monitor Butte Mbr):	58.9 ft
(Total Shinarump Mbr):	9.0 ft
Total Chinle Formation:	698.1 ft

Moenkopi Formation, Upper Red Member:

Measurement of the Moenave Formation in Kitchen Corral Canyon in SESW Sec. 22, T. 41 S., R. 3 W., and NWNE Sec. 34, T. 41 S., R. 3 W., Kane County, Utah.

Kayenta Formation (lower unit): Conglomerate (intraformational), lavender-brown, clasts to pebble-size, ledge former.

Moenave Formation, Springdale Sandstone Member:

14.	Sandstone, pinkish-tan, very fine-grained, friable; prominent 2 ft parting of shaly light-brown sandstone 10 ft above the base; unit is cliff and ledge-forming.	41.3 ft
13.	Sandstone, pinkish-tan to lavender, very fine-grained, ledge- and slope-forming (shaly to thin-bedded in slopes and thickbedded in ledges.	24.9
12.	Sandstone, tan, very fine-grained, silty, massive, cliff-former.	15.9
11.	Sandstone, light brown, fine-grained, shaly to thin-bedded, forms earthy slope.	12.6
10.	Sandstone, pinkish-brown, fine-grained, low angle crossbedded, occasional siltstone partings, thick-bedded to massive, cliff-former.	22.3
9.	Sandstone, reddish-brown, fine-grained, silty.	3.4

Note: Measurement shifts here from SESW Sec. 22 to NWNE Sec. 34, T. 41 S., R. 3 W.

8.	Sandstone, reddish-brown, fine-grained, low angle cross-bedding, occasional thin siltstones and clay pellet conglomerate, thick-bedded to massive, cliff-former.	41.5
	Total Springdale Sandstone	161.9 ft

Dinosaur Canyon Member:

7.	Sandstone, reddish-brown, fine-grained, silty, occasional cream to gray interbeds, slightly calcareous, medium-bedded, forms low ledges.	100.5
6.	Sandstone, reddish-brown, fine-grained, occasional cream to gray interbeds, slope-former.	23.8
5.	Sandstone, reddish-brown, fine-grained, massive, cliff-former.	17.5
4.	Siltstone and subordinate claystone, reddish-brown, shaly, with thin interbeds of fine-grained reddish-brown sandstone with cream-colored splotches, slope-former.	60.3
3.	Claystone, reddish-brown, shaly, slope-former.	13.5
2.	Sandstone, reddish-brown, very fine-grained, silty, thick-bedded to massive, cliff-former.	40.2
1.	Sandstone, reddish-brown, fine-grained, poorly sorted, thin-bedded, with interbeds of reddish-brown siltstone and claystone; unit has gray bands and is a slope-former.	17.0
	Total Dinosaur Canyon Mbr.	272.8 ft
	Total Moenave Formation	434.7 ft

Chinle Formation: Mudstone, purple, with a mottled zone of silty and clayey coarse-grained sandstone, slope-former.

Measurement of the Kayenta Formation near the confluence of Coyote Creek and the Escalante River, NE Sec. 13, T. 39 S., R. 8 E., Kane County, Utah

Navajo Sandstone (description of basal part): Sandstone, tan and lavender alternating, fine- to medium-grained, somewhat crossbedded, massive, grades upward to typical tan or salmon-colored Navajo Sandstone, may represent reworked Kayenta Formation, contact is a sharp bedding plane parting.

9.	Sandstone, lavender or purple, medium grained, micaceous, medium- to thick-bedded, semi-resistant.	12.5 ft
8.	Sandstone, lavender gray, medium-grained, carbonate cementation, forms resistant ledge, varies in thickness from 2 inches to 2 ft.	2.0
7.	Sandstone, pink-tan, slightly micaceous, medium-grained, low-angle crossbedding, partly friable, partly well-cemented (carbonate) lenses, resistant and ledge-forming, thickbedded to massive.	14.5
6.	Sandstone, like unit 7, but without well-cemented lenses, more friable, forms step-like slope.	21.0

5. Sandstone, pink, fine-grained, silty and crossbedded, occasional thin interbeds of well-cemented (carbonate) sandstone, channeled, cliff-former. 37.4

4. Sandstone, mottled greenish gray and reddish-brown, silty to very fine-grained, forms cliff undercut. 1.7

3. Sandstone, pink, fine-grained, friable and poorly exposed in slope. 24.9

2. Sandstone, lavender to pink, fine- to medium-grained, some intervals finely laminated, low-angle crossbedding, appears thickbedded to massive, contains thin well-indurated dolomitic sandstone lenses, resistant, forms cliff. 43.0

1. Sandstone, like unit 2, but partially covered by scree. 37.4

Total Kayenta Formation: 194.4 ft

Wingate Sandstone (upper part): Sandstone, orange, very fine-grained, slightly micaceous in the upper 20 to 30 ft, massive, smooth weathering, cliff-former, contact sharp.

Measurement of the Lamb Point Tongue of the Navajo Sandstone in Cottonwood Canyon, SW Sec. 15, T. 43 S., R. 7 W., Kane County, Utah:

Tenney Canyon Tongue of the Kayenta Formation (lowest unit): Sandstone, reddish-brown, fine-grained, shaly to thin-bedded, slope-former.

Lamb Point Tongue:

5. Sandstone, tan, medium-grained, eolian crossbedded with occasional contorted crossbeds, cliff-former. 48.8 ft

4. Sandstone, like unit 5, but slope and ledge-forming. 64.0

3. Covered slope (tan sand from ledges and cliff above). 80.4

2. Covered slope (fine-grained orange-brown sand) 65.7

1. Sandstone, orange, medium-grained, friable, crossbedded with angles up to 36°, crossbed sets up to 25 ft in thickness, massive, cliff-former. 74.1

Total Lamb Point Tongue 333.0 ft

Kayenta Formation: Reddish-brown blocky siltstone.

Measurement of the Tenney Canyon Tongue of the Kayenta Formation in Three Lakes Canyon, SWSE Sec., 30, T. 42 S., R. 6 W., Kane County, Utah.

Main Body of Navajo Sandstone (not described):

Tenney Canyon Tongue:

7. Sandstone, orange-red, fine-grained, low angle crossbedding, thinbedded, platy, the upper few inches have been reworked. 11.8 ft

6. Sandstone, orange-red, fine-grained, low angle crossbedding, massive, cliff-former. 10.4

5. Sandstone, reddish-brown, fine-grained, thick-bedded, with thin red silt interbeds, weathers to smooth ledges. 68.4

4. Sandstone, reddish-brown, fine-grained, thin silty interbeds, weathers earthy. 21.5

3. Sandstone, tan, fine-grained, limy, hard. 0.5

2. Sandstone, reddish-brown, fine-grained, silty. 4.7

1. Limestone, light-gray, hard, blocky. 1.0

Total Tenney Canyon Tongue: 118.3 ft

Lamb Point Tongue: Sandstone, fine- to medium grained, eolian crossbeds, some contorted, massive and cliff-forming.

Measurement of the Temple Cap Sandstone on Harris Mountain (Elephant Butte quadrangle) in S 1/2, Sec. 31, T. 42 S., R. 8 W., Kane County, Utah.

Kolob or Limestone Member of Carmel Formation (lowermost unit): Sandstone, light tan, medium-grained, calcareous and well-indurated, forms ledge or steep slope; probably reworked Temple Cap Sandstone. Lies over J-2 unconformity.

Temple Cap Sandstone:

8.	Sandstone, light gray to tan, fine- to medium-grained quartzose grains, calcareous, single massive crossbedded set, forms cliff.	30.0 ft
7.	Sandstone, tan, fine- to medium-grained, very friable, forms steep slope, massive, poorly exposed, high-angle crossbedding.	15.0
6.	Sandstone, light tan, mostly medium-grained, very loosely cemented, high-angle crossbedded, mixed resistance to erosion forming ledgy to rough slopes, becoming more resistant toward the top.	36.0
5.	Siltstone, light red and platy alternating with tan very fine-grained silty sandstone, forms slope, poorly exposed.	20.0
4.	Sandstone, light gray and light tan, subangular to subround grains, calcareous, forms ledge, probably medium to thickbedded, low-angle crossbedding.	13.0
3.	Alternating reddish-brown siltstone and very fine-grained silty sandstone, slope-forming and poorly exposed.	13.0
2.	Sandstone, light gray to pinkish gray, mostly fine, subrounded quartz grains, calcareous, weathers into thin (1 inch) plates to medium beds (2.5 ft thick) with reddish brown silty partings. The thicker beds appear lenticular, are well cemented hard ledge-formers.	15.0
1.	Siltstone, reddish-brown, sandy, or very fine-grained silty sandstone, massive, slope-former.	15.0
	Total Temple Cap Sandstone	157.0 ft

Measurement of the Page Sandstone in Coyote Gulch, NENE Sec. 16, T. 39 S., R. 7 E., Kane County, Utah.

Carmel Formation: Sandstone, very light tan, weathering light gray, fine- to medium-grained (fU-mL), very friable, evenly bedded, calcareous, forms reworked zone of Page Sandstone about 0.9 ft thick and is overlain by reddish-brown earthy weathering, slope-forming siltstone.

Page Sandstone:

3.	Sandstone, very light tan to gray, fine- to medium-grained (fU-mL), friable but resistant, massive eolian crossbedding, very calcareous.	18.5
2.	Siltstone, dark reddish brown, shaly, weathers to earthy slope.	4.0
1.	Sandstone, tan to light brown, medium grained (mL), subrounded and frosted grains, thin beds, reworked Navajo Sandstone.	2.1
	Total Page Sandstone	24.6 ft

Navajo Sandstone: Sandstone, tan to light brown, medium grained (mL-mU), quartzose, frosted, subangular to rounded, eolian crossbeds with sets to 8 ft in thickness, massive, cliff-forming, upper contact is unconformity.

Measurement of the Thousand Pockets Tongue near West Cove along a road cut on U. S. Highway 89, NWSW Sec. 19, T. 42 S., R. 1 W., Kane County, Utah:

Carmel Formation (main body):

Thousand Pockets Tongue of Page Sandstone:

12.	Sandstone, tan, medium-grained, friable.	12.8
11.	Sandstone, gray, fine- to medium-grained, angular quartz grains, high-angle crossbedding, massive.	43.1
10.	Sandstone, like unit 11, but containing red bands and streaks.	74.7
9.	Sandstone, reddish-brown, fine-grained, irregular bedding, thin siltstone partings, earthy weathering (tongue of Carmel Fm)	11.0
8.	Sandstone, light-gray, medium-grained, high angle crossbeds, criss-crossed with fractures.	49.3

7. Sandstone, light-gray, medium-grained, high-angle crossbeds, massive, cliff-forming. 11.3

6. Siltstone, reddish-brown, earthy weathering, slope-former (start of Judd Hollow Tongue [Crystal Creek Member]). 11.3

5. Limestone, mottled gray and lavender, sandy, platy weathering, forms ledge (top of Kolob Limestone). 3.0

4. Siltstone, like unit 6. 10.6

3. Claystone, medium-gray, upper part greenish-gray, earthy weathering. 7.5

2. Sandstone, tan, weathers tan and lavender, calcareous, platy, grades upward into limestone that is stained blotchy green and gray, thinbedded, ledgy. 14.4

1. Sandstone, reddish-brown, medium-grained, earthy weathering. 9.0

Total upper Thousand Pockets	130.6 ft
Total Carmel Tongue	11.0 ft
Total lower Thousand Pockets	60.6 ft
Thousand Pockets Tongue of Page Sandstone:	202.6 ft
Total Judd Hollow Tongue	55.8 ft

Navajo Sandstone (main body):

Measurement of the Carmel Formation at Meadow Creek (The Barracks quadrangle) in S1/2 S1/2, Sec. 7, T. 41 S., R. 8 W. (Winsor Member), NESW Sec. 18, T. 41 S., R. 8 W. (Paria River and Crystal Creek Members), and NWSW Sec. 18, T. 41 S., R. 8 W. (Kolob Limestone Member).

Dakota Sandstone: Claystone, grayish brown, sandy, bentonitic, weathers to a popcorn surface.

Carmel Formation--Winsor Member:

37. Sandstone, yellow and white, medium grained, some grit, slope-former, earthy weathering. 165.8

36. Covered slope 15.1

35. Sandstone, light brown, silty, fine-grained, interbedded with light-gray, fine-grained sandstone, weathers to earthy slope. 15.8

34. Siltstone, chocolate brown. 3.4

33. Sandstone, like unit 35 with several thin brown shaly siltstone partings. 8.9

Total Winsor Member 236.2 ft

Paria River Member:

32. Limestone, light-gray, fossiliferous with molds and casts of pelecypods. 0.6

31. Siltstone, light gray, shaly. 2.5

30. Sandstone, like unit 35 in Winsor Member 10.5

29. Gypsum, alabaster, white, cliff-former. 9.0

28. Siltstone, green; upper part interbedded with gypsum layers; slope-former. 4.7

27. Gypsum, alabaster, white, massive, clifff-former. 26.9

26. Shale, gray (grayish-green at base), sandy, criss-crossed with gypsum veinlets. 2.5

25. Gypsum, alabaster, white, blocky. 2.8

Total Paria River Member 59.5 ft

Crystal Creek Member:

24. Siltstone, gray, sandy, with thin shaly brown bands. 2.5

23. Sandstone, banded light-brown and light gray, fine- to medium-grained, very friable. 6.0

22. Covered slope (abundant gypsum debris). 27.1

21.	Sandstone, like unit 23.	93.4
20.	Siltstone, brown, chippy weathering.	2.0
19.	Sandstone, brown, coarse-grained.	1.6
18.	Sandstone, like unit 23.	14.5
17.	Sandstone, light-brown, silty, medium-grained, poorly sorted, occasional 2-3 inch parting of light green siltstone, slope-former.	16.1
16.	Gypsum, white, sandy.	2.5
15.	Sandstone, light-gray, friable, weathers earthy.	6.0
14.	Siltstone, brown, sandy.	2.0
13.	Shale, brown, sandy, slope-former.	3.0
	Total Crystal Creek Member	176.7 ft

Kolob Limestone Member:

12.	Shale, gray, interbedded with blocky light-gray crystalline limestone in beds 4 to 6 inches thick, slope-former.	12.4
11.	Limestone, gray, blocky, thin to medium bedded, fossillferous, stylolitic, forms a thick ledge.	5.2
10.	Limestone, gray, sandy, shaly, platy, ripple marks, slope-former	10.7
9.	Limestone, gray, thin to medium bedded, ledge former.	9.1
8.	Limestone, shaly, like unit 10.	117.0
7.	Limestone, gray, blocky, top and bottom are platy.	4.1
6.	Limestone, gray and tan, thinbedded, small bodies of calcite, occasional paper-thin, gray limy siltstones, weathers chippy, slope-former.	40.1
5.	Limestone, tan, blocky, forms low ledge.	2.1
4.	Covered slope (gray shaly limestone?)	9.5
3.	Limestone, tan, sandy, platy, blocky, oscillation ripple marks, a few thin beds of calcite nodules, forms cliffy ledge.	26.0
2.	Siltstone, purple, slope-former.	5.8
1.	Siltstone, bright reddish-brown, shaly with 2 bands of light-gray sandy siltstone.	6.9
	Total Kolob Limestone Member	248.9 ft
	Total Carmel Formation:	694.1 ft

Temple Cap Sandstone: Sandstone, tan, medium-grained, friable, eolian crossbedding, upper 2 ft are horizontal beds and might be reworked, unit is massive and forms a cliff.

Measurement of the Entrada Sandstone along the west and north sides of Kodachrome Flat, Sec. 3, T 38 S, R 2 W, Kane County, Utah measured by Mark E. Jensen.

Henrieville Sandstone: Sandstone, with interbedded shale, pale grayish-orange fresh, yellowish-gray weathered, very fine grained, moderately sorted, noncalcareous, well indurated, contains large scale low angle crossbedding, forms ledges and cliffs, well exposed.

Entrada Sandstone:

10. Sandstone, yellowish-gray fresh and weathered, very fine grained, moderately sorted, calcareous, moderately cemented, thick bedded, flaggy splitting, forms a slope, moderately exposed — 5.6 ft

9. Sandstone, very light gray to pale yellow fresh (pods and stringers), yellowish-gray to grayish-yellow weathered, very fine grained, well sorted, noncalcareous, moderately indurated, very thick bedded, forms a slope, moderately exposed, lower contact appears sharp, crossbedded. — 7.9

8. Sandstone, yellowish-gray (5Y 8/1) fresh, yellowish-gray (5Y 7/2) weathered, very fine grained, moderately sorted with 5% well rounded medium grained quartz and 3 percent dark chert grains, calcareous cement, well cemented, very thin to medium bedded, flaggy splitting, forms slopes and cliff, well exposed, contains crossbedding in beds to about 1 ft thick, also contains iron-rich concretions and thin beds, lower contact has shale below and sandstone above. Contains interbedded shale, pale grayish-green fresh, grayish-yellow green weathered, noncalcareous, laminated bedding, shaly splitting, in beds to 0.2 ft thick. — 62.5

7. Sandstone, banded very pale orange and pale reddish orange fresh and weathered, toward top unit becomes yellowish-gray (5Y 8/1), with bands of moderate reddish-brown fresh, and moderated reddish-orange weathered, very fine to fine grained, subrounded, moderately sorted, with 2-5% dark chert grains, calcareous cement, moderately cemented, thin to medium bedded, muddy to flaggy weathering, forms banded slopes, moderate to well exposed, sharp lower contact. Contains small low angle crossbedding. Iron staining in bed near middle of unit. With interbedded mudstone, dark reddish-brown to pale yellowish-brown fresh, moderate reddish-brown (10R 4/4) to yellowish-gray weathered, calcareous cement, moderately cemented, laminated to very thin bedded, shaly to flaggy splitting, forms a slope, well exposed, in beds to 1.6 ft thick. — 194.8

Total Escalante and Cannonville Members: 270.8 ft

6. Siltstone, sandy, dark reddish-brown fresh, grayish red (5R 4/2) weathered, very poorly sorted, slightly calcareous, poorly cemented, contains abundant iron staining, laminated to very thin bedded, shaly to soily weathering, forms a small ledge and slopes, well exposed, has light colored band along top, sharp lower contact. — 1.4 ft

5. Sandstone, pale reddish orange fresh and weathered, very fine grained, very poorly sorted with grains up to medium, contains grains of dark chert and feldspar, calcareous cement, moderately cemented, thin to thick bedded, blocky splitting, forms ledges and slopes, well exposed, contains low angle crossbedding, laminations, and intraclastic texture. — 121.2

4. Shale, dark reddish-brown fresh and weathered, light colored sandstone bands above and below, forms a small recess in sandstone ledges, well exposed. — 1.9

3. Sandstone, like unit 5. — 15.5

2. Siltstone, similar to unit 6, except this unit has light colored bands both above and below. — 1.4

1. Sandstone, pale reddish-brown fresh, moderate reddish-orange weathered, very fine grained, poorly sorted, calcareous, well cemented, massive bedding, forms a rounded cliff, well exposed, contains large scale high angle crossbedding in some parts, lower contact covered. Along base of cliff is siltstone, sandy, moderate reddish-brown to yellowish gray fresh and weathered, silt to very fine

grained, poorly sorted, contains black chert and quartz to fine grained size, and biotite, calcareous, well cemented, thin bedded, flaggy splitting, forms recess and slopes at base of cliff, very poorly exposed 148.9+

Total Gunsight Butte Member: 290.3+ ft

Total Entrada Sandstone: 561.1+ ft

Carmel Formation, Winsor or Wiggler Wash Member: Covered, forms gentle slopes and ledges, sandstone or siltstone.

Measurement of the Summerville Formation near the mouth of Halls Creek on Lake Powell, Sec. 4, T 38 S, R 10 E.

Morrison Formation: Sandstone, medium grained and gritty, crossbedded, prominent ledge former.

18. Alternating sandstone and siltstone, red brown and lavender, thin even beds, includes a 2-6 inch gypsum layer. 4.8 ft

17. Sandstone slope interrupted by occasional bed of blocky sandstone, fine to medium grained, with gypsum layer 2 inches thick. 6.4

16. Sandstone, brown hues, fine to medium grained, finely laminated. 1.1

15. Sandstone, off white on fresh surfaces, weathers tan, fine to medium grained, single bed finely laminated, forms resistant ledge. 2.5

14. Sandstone, red brown to off white coloration, evenly bedded, fine grained thin to medium beds with alternating resistance to erosion, red brown unit more resistant than off white units. 28.5

13. Alternating fine grained sandstone, off white tan brown in medium beds each 4 to 10 ft apart, separated by thin bedded siltstone and sandstone, mostly red brown, some dark purplish and off white banding, nonresistant. Medium bedded sandstone forms resistant slight ledges, like a staircase. 21.8

12. Siltstone and sandstone, mostly red brown, some dark purplish and off white banding, thin to medium bedded, non resistant, forming red brown slope. 14.0

11. Sandstone, gritty, off white, very friable, crisscrossed with gypsum veinlets, but stands as a ledge, single bed. 2.2

10. Sandstone, red brown, fine grained, 3 ft beds, rounded weathering, alternating with 2 to 6 inch beds, blocky weathering. 11.2

9. Siltstone alternating with sandstone, thin bedded, slope former, even beds, multi-colored. 5.6

8. Sandstone, banded red brown and white, fine grained, very thin bedded, but together forms thick ledge, weathers into the thin laminations. 1.2

7. Siltstone like unit 9. 5.5

6. Sandstone, off white, red brown, mottled, forms resistant ledge. 1.6

5. Siltstone and sandstone, purple, red brown, orange, and white, colors interbedded, thin even beds, slope former. 10.6

4. Sandstone, off white, thin to medium bedded, ledge former. 1.6

3. Siltstone, banded purple, white, orange, and red brown, slope former. 4.7

2. Sandstone, light greenish white, fine grained. 1.6

1. Sandstone, off white and red brown mottled, mostly fine grained and earthy weathering, contorted medium bedding. 12.5

Total Summerville Formation: 38.1

Entrada Sandstone:

Measurement of the White Point Member of the Summerville? Formation near White Point, NWSWSW Sec. 11, T 38 S, R 5 E, Kane County, Utah

Morrison Formation: Conglomeratic sandstone, light brown to white, crossbedded, pebbly streaks along crossbedding. Overlies unit below unconformably. Unit immediately overlying the White Point is siltstone, medium reddish-brown (10R 4/6) alternating with grayish yellow green (5GY 7/2). Weathers crumbly, bedding indistinct to absent, calcareous and slope-forming. Laterally this unit contains substantial lenses, up to 2 ft thick, of pebble conglomerate, channeled into the underlying sandstone.

White Point Member:

11.	Sandstone, yellowish gray (5Y 7/2), weathers to same color, fine to medium grained, poorly sorted, frosted grains, angular to subangular, calcareous. Resistant unit and weathers irregularly due to solution of grooves along the surface. Massive.	9.0 ft
10.	Siltstone, medium reddish brown (10R 4/6) alternating with grayish yellow green (5GY 7/2), bedding indistinct to absent, calcareous and slope forming.	4.5
9.	Sandstone, like unit 11, but without grooves.	1.0
8.	Siltstone, grayish yellow green (5GY 7/2), fine grained, slightly calcareous, shaly, breaks into flakes.	6.0
7.	Siltstone, dark reddish brown (10R 3/4), weathers slightly darker, fine grained, containing occasional sand grains. Slightly calcareous, bedding indistinct or missing, slope former.	1.5
6.	Sandstone, like unit 9, weathers into blocks.	2.0
5.	Siltstone, like unit 7, but color seems to fade upward.	9.0
4.	Sandstone, yellowish gray (5Y 7/2), fine grained, poorly sorted, containing fin grained and medium grained particles, calcareous. Slightly more resistant than beds above and below, bedded 6 to 14 inches, forms a weak ledge.	4.0
3.	Siltstone, moderate reddish brown (10R 4/6) alternating with yellowish gray (5Y 7/2) and containing some thin fine grained sandstones. All units are calcareous, but the redder the siltstone the weaker the reaction to acid. Sand grains are slightly frosted, subangular to subrounded. Forms an earthy slope; it is difficult to determine where weathered surfaces end and fresh surfaces start. Bedding in the siltstone is imperceptible.	44.0
2.	Gritstone, pinkish gray (5YR 8/1), poorly sorted, subangular to subrounded grains, friable and calcareous. Unit is massive but weathers into 2 inch ledges. Lowest 1/2 ft is a pebble conglomerate; generally finer toward the top (graded bedding).	2.5
1.	Reworked sandstone, grayish yellow green (5GY 7/2), including some pebbles and grit, calcareous, massive, friable and easily weathered, lowest 1/4 inch a fine sandstone with darker green color. Poorly sorted.	0.5
	Total White Point Member:	84.0 ft

Entrada Sandstone: Sandstone, massive, crossbedded, grayish-white weathering, not measured.

Measurement of Sandstone at Romana Mesa at Crosby Canyon, SW Sec. 9, T 43 S, R 4 E.

Morrison Formation: Sandstone, light tan, medium grained to gritty, conglomeratic, fluvial crossbedding. The base is an unconformity with a relief of 15 to 20 feet.

Sandstone at Romana Mesa:

7.	Sandstone, light tan, very fine to fine grained, crossbed streaks are medium grained, medium bedded to massive, low angle crossbeds, friable but forms cliffs and ledges, occasional thin lenticular layers of reddish-brown siltstone, sandstone is irregularly silty (silty sandstone is softer and less resistant), calcareous, occasional lenticular interbeds of medium to coarse light greenish-gray calcareous sandstone.	39.6 ft

6. Sandstone, light tan, very fine to coarse grained, loosely cemented, massive, high angle eolian crossbeds (forms single crossbed set), calcareous, relief on top. Near the top the unit has worm tubes and green mineralization fronts. 24.6

5. Sandstone, like unit 7. 48.8

4. Siltstone, reddish-brown, sandy, calcareous, shaly in places, thinbedded, less resistant than units below and above. 1.3

3. Sandstone, gray-tan, very fine grained to fine grained, silty, increasingly siltier towards the top of the unit, calcareous. 14.3

2. Siltstone, like unit 4. 4.0

1. Sandstone, light grayish-tan, very fine grained, silty, calcareous, grades upward by mottling into the reddish-brown unit, reworked Entrada Sandstone. 1.5

Entrada Sandstone: Sandstone, light tan, very fine to fine grained, angular to subangular grains, calcareous, loosely cemented, friable but forms cliffs, massive, crossbedded, contact with overlying Sandstone at Romana Mesa is sharp.

Measurement of Henrieville Sandstone along the west and north sides of Kodachrome Flat, Sec. 3, T 38 S, R 2 W, Kane County, Utah as measured by Mark E. Jensen.

Dakota Formation: Sandstone, with interbedded shale, pale grayish-orange fresh, yellowish-gray weathered, very fine grained, moderately sorted, noncalcareous, well indurated contains large scale low angle crossbedding, forms ledges and cliffs, well exposed. A conglomerate is present in some places between the Dakota and Henrieville; pebble conglomerate, clasts are rounded chert, mudstone, and sandstone, also there are sandstones in the conglomerate. The conglomerate is lenticular and up to 3 ft thick.

Henrieville Sandstone:

1. Sandstone, white fresh with pale yellow to dark yellowish-orange iron staining along bedding planes and crossbedding, grayish-yellow to pale grayish orange weathered, very fine grained, well sorted, approx. 1 to 2% white feldspar, approx. 1 to 2% dark chert, slightly calcareous, moderately cemented, porous, very thickbedded, blocky, forms cliffs and slopes, well exposed, lower contact is wavy and sharp. Contains abundant crossbedding, cross bed sets become thicker upward in unit, some crossbedding contains coarse grains. 91.7 ft

Entrada Sandstone: Sandstone, yellowish-gray fresh and weathered, very fine grained, moderately sorted, calcareous cement, moderately cemented, thickbedded, flaggy splitting, forms a slope, moderately exposed.

Measurement of the Morrison Formation near "Triangle Point", E 1/2, Sec. 4, T 39 S, R 6 E, Kane County, Utah.

Dakota Formation: Sandstone, light brown, fine to medium grained, calcareous, thin to medium bedded, contains iron concretions, ledge-forming, contact with conglomerate below is sharp and well defined.

sub-Dakota Conglomerate: Conglomerate, light gray, pebbles of sandstone, chert, quartzite, and hard siltstone, poorly sorted with cobbles to 4 inches in diameter and averaging 1 inch. 5.4 ft

Morrison Formation:

19. Sandstone, green, fine grained, earthy weathering, slope forming. 9.0 ft

18. Sandstone, yellow, very fine grained and silty, earthy weathering. 7.2

17. Mudstone, green and maroon, earthy weathering. 3.2

16. Sandstone, yellow, fine grained, friable, forms earthy slope and soft ledges. 26.5

15. Mudstone and siltstone, maroon, earthy weathering, slope forming. 3.3

14. Conglomeratic sandstone, yellow and white, crossbedded, ledge forming, pebbles to 1/2 inch in diameter. 19.6

13. Sandstone, white to yellow, fine grained, friable with limonitic streaks, forms slopes and low soft ledges. 6.4

12. Conglomeratic sandstone, tan to yellow gray, crossbedded, cliffy. 14.5

11. Sandstone, white, blocky, calcareous, hard, interbedded with subordinate maroon mudstone and gray conglomerate. 11.6

10. Conglomeratic sandstone, white to tan, massive cliff former, with clasts to 1.2 inch diameter. 57.4

9. Conglomeratic sandstone, brown, medium bedded, blocky, with interbeds of friable yellow fine to medium grained sandstone and thin red mudstone partings. 14.6

8. Conglomeratic sandstone, white, pebbles to 2 inches in diameter, thick bedded to massive, upper part has checkerboard patterns, calcareous, crossbedded, forms rough benches, bare rock surfaces. 70.0

7. Conglomeratic sandstone, brown, pebble to 3 inches in diameter, subrounded to subangular, calcareous, crossbedded, forms strong cliff. 21.2

6. Interbedded mudstone and sandstone, earthy weathering, poorly exposed slope former; mudstone, maroon and green; sandstone, light greenish-gray and white, friable. 37.1

5. Conglomeratic sandstone, pebbles to 4 inches in diameter, resistant cliff former. 19.3

4. Covered bench, probably underlain by dark reddish brown siltstone, green mudstone, white sandstone, all thinbedded to massive and earthy weathering. 28.9

3. Conglomeratic sandstone, poorly exposed. 5.3

2. Covered bench, probably underlain by conglomeratic sandstone, green and maroon mudstones, and very friably silty sandstones. 42.9

1. Conglomeratic sandstone, gray to tan; sandstone is fine to coarse grained, crossbedded, thickbedded to massive; pebbles and granules are streaked along the crossbeds with diameters up to 1/2 inch. Pebbles are of sandstone, quartzite, chert, feldspar; pebble colors are tan, orange, red, green, gray, and black. Fluvial lenticular unite. 16.7

Total Morrison Formation: 414.7 ft

Summerville? or Sandstone at Romana Mesa: Uppermost bed is sandstone, white, medium grained, mostly subangular grains, weathers earthy, is calcareous and is 4 ft thick. This is underlain by reddish-brown siltstone.

Measurement of the sub-Dakota Conglomerate in Lone Rock Canyon, NWSE Sec. 24, T 43 S, R 3 E, Kane County, Utah.

Dakota Formation: Sandstone, brown, fine to medium grained, weathers hackly, contains small angular white flakes and pebbles, thin to medium bedded. Overlies the sub-Dakota Conglomerate unconformably.

Sub-Dakota Conglomerate:

2.	Sandstone, light tan, medium to coarse grained, gritty and pebbly, massive.	9.8 ft
1.	Conglomerate, lavender. Overlies unit below unconformably.	1.5
	Total sub-Dakota Conglomerate:	11.3 ft

Morrison Formation: Conglomeratic sandstone, tan, medium grained to pebbly, occasional pebbles to 2 inches in diameter, subangular to angular grains, fluvial trough crossbedding, lenticular thick beds (total Morrison at this location is 71.5 ft).

Measurement of Dakota Formation near the southwest corner of Table Mountain, 2.8 miles north of Skutumpah, NW Sec. 21, T 40 S, R 4 1/2 W, Kane County, Utah measured by Mark E. Jensen.

Tropic contact not visible; measured to top of burned sandstone (coal bloom), overlain by yellowish sandy soil.

13.	Sandstone, moderate reddish-orange fresh, pale reddish-orange weathered, very fine grained, poorly sorted, calcareous, well cemented, thin to medium bedded, slabby splitting, forms a ledge, moderately exposed, contains small scale crossbedding and silty partings, basal part of unit is brecciated, lower contact is irregular. Directly above coal burn area.	11.6+ ft
12.	Coal ash and mudstone, ash is white to grayish pink fresh and weathered, forms a recess below sandstone, contains interbedded lenses of mudstone, very dark red fresh and weathered, sooty feel (Smirl coal zone).	0.9
11.	Mudstone, olive gray (5Y 4/1) and dark gray fresh, moderate light gray weathered, thin bedded, shaly splitting, noncalcareous, friable, forms a slope, moderately exposed, contains carbonaceous layers or lenses. Top 0.9 ft is carbonaceous mudstone, black fresh.	17.9
10.	Sandstone, dark yellowish-orange fresh, grayish-orange pink weathered, very fine grained, poorly sorted, calcareous cement, well cemented, thick bedded, blocky splitting, forms a ledge, well exposed, contains crossbedding and iron staining.	5.0
9.	Mudstone, olive gray (5Y 4/1) and dark gray fresh, moderate light gray weathered, noncalcareous, friable, thin bedded, shaly splitting, forms a slope, moderately exposed, fragments of iron rich siltstone as float on surface.	6.7
8.	Sandstone, grayish-orange fresh and weathered, very fine grained, subangular, poorly sorted, 20% white to cloudy quartz grains, very thick bedded, blocky to massive splitting, forms a cliff, well exposed, contains crossbedding with angles to 20 degrees, and large scale crossbedding. Contains mud balls in a band about 2 inches thick near center of unit.	33.6
7.	Mudstone, medium light gray fresh, medium light gray to light gray weathered, very thin bedded, shaly splitting, forms a recess, moderately exposed, gradational contact with underlying unit.	1.1
6.	Coal, black to grayish black fresh and weathered, mostly a dull luster on surface, forms a recess, poorly exposed, lower contact sharp.	0.9
5.	Interbedded mudstone and sandstone; mudstone, olive gray (5Y 4/1) and brownish black fresh, light gray weathered, noncalcareous, friable, thin bedded, shaly splitting, forms a slope, well exposed, lower contact is sharp, contains carbonaceous and coaly beds; sandstone, grayish-orange to dark yellowish-orange fresh, grayish-orange weathered, very fine grained (vfL-vfU), moderately sorted, calcareous, moderately cemented, contains iron staining, thin bedded forms a slope, covered.	65.4

4. Sandstone, pale grayish-orange fresh, very pale orange to grayish-orange weathered, very fine to fine grained (vfL-fU), subangular to subrounded, poorly sorted, calcareous cement, well cemented, thick to very thick bedded, forms cliff and ledges, well exposed, lower contact sharp, contains crossbedding which dips to 25 degrees from overlying beds, laminations, soft-sediment deformation, and occasional granule-sized clasts. 22.5

3. Coal, black fresh and weathered, mostly dull luster, with interbedded carbonaceous mudstone more abundant near top, forms recess beneath cliffs, poorly exposed, sharp lower contact. Sandy claystone split (0.1 to 0.1 ft thick) 0.8 feet from base (Bald Knoll coal zone). 2.3

2. Mudstone, medium dark gray fresh, noncalcareous, moderately indurated, thin bedded, covered, contains fragments and specks of coal. 0.8

1. Sandstone, pale yellowish-brown fresh, medium light gray weathered, very fine to fine grained (vfL-fL), poorly sorted, noncalcareous, poorly indurated, medium bedded, shaly splitting, forms slopes, poorly exposed, lower contact sharp, contains clasts of carbonaceous mudstone. Contains interbedded mudstone, dusky yellowish-brown fresh, light gray weathered, poorly exposed, shaly splitting, forms slopes. 7.9 ft from base of this unit is a localized sandstone, possibly a channel: sandstone, dark yellowish-brown to very pale orange fresh, moderate yellowish-brown weathered, fine to medium grained, fining upward to siltstone, medium to thick bedded, forms a rounded ledge, well exposed, outcrop is less than 20 ft wide, contains well rounded conglomerate near base, granule to pebble size, fragments of coal and wood with random orientation (fluvial environment), approximately 5 ft thick (possibly sub-Dakota Conglomerate?). 32.4

Total Dakota Formation: 201.1+ ft

Carmel Formation, Winsor Member: Sandstone, pale olive fresh (wet), yellowish-gray weathered, yellow and red bands present farther down in unit, very fine grained, moderately sorted, slightly calcareous, poorly cemented, thin to medium bedded, shaly to flaggy splitting, forms slopes, well exposed.

Measurement of the Tropic Shale on east side of Muddy Creek, north of Mt. Carmel and approximately 1.3 miles north of Deer Hollow, NE Sec. 36, T 40 S, R 8 W, Kane County, Utah as measured by Mark E. Jensen.

Straight Cliffs Formation: Sandstone, dark yellowish-orange to very dark yellowish-orange fresh, pale yellowish orange weathered, very fine grained, moderately sorted, calcareous cement, well cemented, medium to very thick bedded, slabby to massive splitting, forms a cliff, good exposure, contains laminations, low angle crossbedding, and rare vertical burrows, lower 25 ft contains interbedded shale and mudstone, upper part is massive sandstone, interbedding along lower contact.

Tropic Shale:

3. Interbedded shale and sandstone; shale, medium dark gray fresh, very pale yellowish-brown weathered, calcareous, friable, laminated, shaly splitting, forms slopes, fair exposure. Changes to mudstone in upper part of unit; sandstone, pale red (10R 6/2) and dark yellowish-orange fresh, pale yellowish brown (10YR 6/4) weathered, very fine grained (vfL) to silty, moderately sorted, calcareous, well cemented, thin to medium bedded, shaly to slabby splitting, forms slopes and ledges, fair exposure, contains localized spots of iron staining around small (3/8 inch) sandy balls. 40.2 ft

2. Sandy siltstone, light gray fresh, pale yellowish orange weathered, silt to very fine grained (vfL), moderately sorted, calcareous, moderately cemented, very thin bedded, flaggy splitting, forms slopes, good exposure, with interbedded shale. 36.6

1. Interbedded mudstone, shale, sandstone, and minor claystone; mudstone, medium dark gray and pale yellowish-brown (wet) fresh, medium light gray to grayish-orange and pale grayish-orange weathered, very thin bedded, shaly splitting, calcareous cement, friable, forms grayish-orange slopes, fair exposure, lower contact is covered; shale, dark gray and moderate yellowish-brown fresh, medium light gray weathered, silty, slightly calcareous, friable, laminated, shaly splitting, forms slopes; sandstone, dark yellowish-orange, yellowish-gray, and pale grayish-orange fresh, moderate yellowish-orange and dark yellowish-orange weathered, very fine grained (vfL-vfU), moderately to poorly sorted, calcareous, moderately cemented, very thin to thick bedded, flaggy to blocky splitting, forms ledges and slopes, poor exposure, contains calcite fracture fillings and rare ripple marks, sandstone increases in abundance upward in unit. Upper 85 ft of unit is interbedded shale (70%) and sandstone (30%). Septarian nodule mines are present about 60 ft from base. The nodules consist of limestone fragments with very coarsely crystalline calcite in the interior and as fracture fillings. The nodules are 0.4 to 1.2 feet in diameter. Fractures are present in various places in the slope of this unit, indicating mass movement. 709.6

Total Tropic Shale 786.4 ft

Dakota Formation: Carbonaceous shale, black to dusky brown fresh, grayish-black weathered, laminated, shaly splitting, forms slopes, poor exposure, contains tiny stringers and specks of coal. This same unit is a coal burn zone laterally. Where burned, it is overlain by siltstone to sandstone, moderately reddish-orange to very pale yellowish-brown (10YR 7/2) fresh and weathered, silty to very fine grained (vfL), noncalcareous, well indurated, laminated to very thin bedded, shaly splitting, forms slopes and small ledges, fair exposure.

Measurement of the Straight Cliffs Formation in a side canyon branching north from Broad Hollow, and approximately 5/8 mile southwest of first trout pond in Meadow Canyon, Sec. 29, T 39 S, R 4 W, Kane County, Utah as measured by Mark E. Jensen.

Wahweap Formation: Sandstone, grayish-orange fresh, moderate yellowish-orange weathered, very fine to fine grained (vfL-fU), subangular, poorly sorted, quartz with 5% dark grains and rare muscovite, well cemented, thin bedded, flaggy splitting, forms a slope above cliffs of the Straight Cliffs Formation, well exposed, contains small scale low angle crossbedding.

Straight Cliffs Formation:

5. Sandstone, grayish-orange fresh and weathered, very fine to fine grained (vfL-fU) with occasional larger grains, subrounded, poorly sorted, quartz with iron staining, well cemented, medium to very thick bedded, slabby to blocky splitting, forms ledges and slopes, well exposed, contains crossbedding, and local areas of high iron content giving a bumpy weathered surface. Minor shale in slopes, medium olive gray (5Y 4/2) fresh, thin bedded, shaly splitting, forms slopes, poorly exposed. At 96.8 ft from base of unit is conglomerate in float (conglomerate less than 1 ft thick), grades laterally to sandstone. Upward from the conglomerate for a distance of of 25 ft, iron is locally abundant as cement and banding (staining), and unit contains occasional mud balls up to 0.75 inch in length. In upper 32.1 ft of unit sandstone colors include white fresh and very pale orange weathered, grain size is fine grained (fL-fU), subangular, and unit contains iron staining and low angle crossbedding. 153.9 ft

4. Shale and sandstone interbedded; shale, grayish-brown to grayish-black and medium dark gray fresh, grayish-brown and medium gray weathered, carbonaceous, very thin to thin bedded, shaly splitting, forms slopes, moderately exposed; sandstone, very dark yellowish-brown (10YR 3/2) fresh, brownish-gray weathered, very fine grained, silty, poorly sorted, poorly indurated, very thin to thin bedded, flaggy to shaly splitting, forms slopes and rounded ledges, moderately exposed, contains fragments of carbonaceous material up to very coarse (vcL) grained, and yellow sulfate. 9.9

3. Sandstone, light gray fresh, pale grayish-orange (10YR 8/4) weathered, very fine grained, poorly sorted, well cemented, thick bedded, forms a cliff and slope, well exposed, upper part of unit contains pelecypod shell fragments (locally as large as 3 inches in length). 6.7

2. Sandstone, grayish-orange and pale yellowish-brown fresh, grayish orange, medium light gray, and dark yellowish-orange weathered, very fine to fine grained (vfL-fL), quartz with 10% dark grains and occasional feldspar grains, poorly sorted, moderately to well cemented, very thick bedded, blocky splitting, forms rounded cliffs, ledges, and slopes, moderately to well exposed, contains low to high (to 30 degrees) angle crossbedding and laminations (the high angle cross-bedding is in sets to 4 inches thick, and forms a herringbone type pattern, indicating 2 different directions of current), also contains rare iron concretions. Slope forming intervals are also thin to medium bedded, and contain carbonaceous partings. Contains interbedded shale, medium dark gray fresh and weathered. 38.5

1. Sandstone, similar to unit 2, except contains only about 5% dark grains, feldspar grains were not noted, and only low angle crossbedding was present. The lower contact is covered. 121.9

Total Straight Cliffs Formation 330.9 ft

Tropic Shale: Shale, olive gray (5Y 4/1) and dark yellowish-brown (10R 4/4) fresh, medium light gray and grayish-orange weathered, laminated, shaly splitting, forms slopes, moderately exposed, contains silty layers.

Measurement of the Wahweap Formation taken in Secs. 32 and 33, T. 38 S, R 1 E, 0.75 miles northeast of Grosvenor Arch, Kane County, Utah as measured by Mark Jensen and Richard Stancliffe.

Kaiparowits Formation: Sandstone, yellowish-gray (5Y 7/2) fresh and and weathered, very fine to fine grained (vfL to fU), subrounded, medium sorted, equant, calcite cement, well indurated, platy to massive beds, abundant cross-stratification (up to 1 ft thick), forms earthy slopes with rounded steps, moderately exposed.

Wahweap Formation:

12. Sandstone, mottled very light gray (N8) and pale yellowish-orange (10YR 8/6), fine to medium grained (fU to mU), subrounded, very well sorted, equant, 1-2% black and 1% orange inclusions, silica cement, well indurated, thick to massive beds, cross-stratification (4 inches thick), abundant limonite vein and joint fillings, limonite staining, forms rough rounded steps and ledges, well exposed, sharp lower contact. 96.7 ft

11. Sandstone, grayish orange (10YR 7/4), pale yellowish brown (10 YR 6/2) and pale reddish-brown (10R 5/4) fresh, weathers yellowish-orange (10YR 8/6); very fine to medium grained (vfL-mL), subrounded, well sorted, equant; 1% black inclusions, calcite cement, moderately indurated; massive beds, ripple marks and cross-stratification; forms rounded cliffs to rubbly and step like ledges, well exposed; this unit generally forms an extensive dip slope, lenses of conglomerate with fragments to 1 cm are present though not abundant. 178.6

10. Sandstone, mottled pale yellowish-orange (10YR 8/6) and very light gray (N8) fresh and weathered; very fine to fine grained (vfL to fL), subrounded to rounded, well sorted, equant; some carbonaceous material, petrified wood made of ironstone, limonite cement, friable; thick bed, forms earthy recess, poorly exposed. 2.1

9. Sandstone, like unit 11 except that soft sediment deformation was observed, small (2mm diameter) gastropods found in lower part of unit and some conglomerate float containing bone fragments. 252.6

Total "upper" Wahweap Formation: 530.0

8. Sandstone interbedded with shale; sandstone, yellowish gray (5Y 8/1), weathering pale yellowish-brown (10YR 6/2), very fine to fine grained (vfL to fL), subrounded, well sorted, equant, calcareous, moderately indurated, fissile to thin beds, ripplemarks, some scour marks, cross-stratification, limonite staining, forms an earthy slope, very poorly exposed to covered; shale, medium gray (N-5) and dusky yellow green (5GY 5/2) fresh and weathered, some silt, calcareous, friable, fissile beds, forms an earthy slope, partially covered. 173.2

7. Sandstone, similar to sandstone of unit 5 except weathers yellowish-gray (5Y 8/1), fissile to thick bedded, stains pale yellowish-brown (10YR 6/2), forms rounded steps, locally well exposed. 23.0

6. Siltstone, pale olive (10Y 6/2) fresh and weathers grayish-yellow (5Y8/4), calcareous, friable, fissile, forms earthy slope, partially covered. 13.8

5. Sandstone, like unit 8, except no cross-stratification was observed. 59.6

4. Sandstone, yellowish-gray (5Y 7/2), fresh and weathered, very fine grained (vfL-vfU), subrounded, well sorted, equant, 1% black inclusions, calcite cement, well indurated, very thin to thin beds, some horizontal laminae, some stained grayish-red (5R 4/2), forms a chippy earthy slope, partially covered. 36.0

3. Interbedded sandstone shale, like unit 8, except no cross-stratification or scour marks were observed in the sandstone. 24.0

2. Sandstone, similar to sandstone of unit 8, except has an additional fresh color of pale yellowish-orange (10YR 8/6) and beds are fissile to thick. 25.7

1. Interbedded sandstone and shale, like unit 5, lower contact sharp. 48.5

Total "lower" Wahweap Formation: 403.8 ft
Total Wahweap Formation: 933.8 ft

Straight Cliffs Formation: Sandstone, bands of grayish-orange (10YR 7/4), very light gray (N8), pale yellowish-orange (10YR 8/6) and dark yellowish-orange (10YR 6/6), fresh and weathered, very fine to medium grained (vfU-mL) with some conglomerate lenses containing grains to 1cm, subrounded to rounded, well sorted, equant, iron and calcite cement, well indurated, cross-stratification present, ironstone concretions and bands, lower 35 ft form a rough cliff but predominately rough blocky steps and ledges with some smooth benches, well exposed, thick to massive beds.

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