THE GEOLOGY OF THE GRAND STAIRCASE IN SOUTHERN UTAH: A ROAD LOG AND GUIDE FOR PUBLIC SCHOOL TEACHERS

Geological Society of America 2002 Rocky Mountain Section Annual Meeting, Cedar City, Utah

Larry E. Davis, Department of Geology, College of St. Benedict / St. John's University, Collegeville, MN 56321

Robert L. Eves, Division of Geosciences, Southern Utah University, Cedar City, UT 84720

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As we started on, we left behind a long line of cliffs, many hundred feet high, composed of orange and vermilion sandstones. Have named them "Vermilion Cliffs". When we were out a few miles I looked back and saw the morning sun shining in splendor on their painted faces. The salient angles were on fire, and the retreating angles were buried in shade. I gazed and gazed until my vision dreamed, and the cliffs appeared a long bank of purple clouds piled high from the horizon high into the heaven.

John Wesley Powell, 1869

In many places, canyons have cut the terrace platform deeply, and open in magnificent gateways upon the broad desert plain in front. We look into them from afar, wonderingly and questioningly, with a fancy pleased to follow their windings until their sudden turns carry them into distant, unseen depths.

Clarence E. Dutton, Surveyor, Powell Expedition
Tertiary History of the Grand Canyon District, 1882

The "Grand Staircase" is a majestic geological feature of unparalleled beauty and mystery. Many of the secrets of Earth's history are contained within the various rock formations exposed at each step. One might imagine each step as a book; each formation as a chapter in the book; and each rock layer as a page. The books are stacked and slightly offset with the spines facing northward. Each page records in the special hieroglyphics of geology the events of the past - the timeless currents of a tropical marine sea, the shifting sands of a vast desert, the meandering flow of rivers to the sea. As one climbs over the steps, interpreting the geological record, Earth's secrets are revealed. The "books" have been set aside for all to read and enjoy in Grand Canyon, Zion, and Bryce Canyon National Parks and the Grand Staircase-Escalante National Monument (GSENM).

General Overview of the Grand Staircase

The term "Grand Staircase" was first applied to this region by Charles Keyes (1924). The series of topographic benches and cliffs, which form the "Grand Staircase", step progressively up in elevation from south to north (figure 1). The risers correspond to cliffs and the steps correspond to the broad benches, terraces, or plateaus in the staircase (figure 2). The bottom of the staircase commences at the top of the Kaibab Uplift, which correlates with, and is in the same stratigraphic position as, the highest bench of the Grand Canyon in Arizona. The first riser above the bench is the Chocolate Cliffs, which are not well developed and consist of the upper red member of the Lower Triassic Moenkopi Formation capped by the Upper Triassic Shinarump Conglomerate Member of the Chinle Formation. The next step is known as the Shinarump Flats. This bench is mostly developed on top of the resistant Shinarump Conglomerate Member and in the overlying, less resistant, Petrified Forest Member of the Chinle Formation. The Vermilion Cliffs form the next riser, which is well developed in the GSENM. The cliffs are composed of the resistant red sandstone beds of the Lower Jurassic Moenave and Kayenta Formations. The Wygaret Terrace forms the next step and includes the soft upper part of the Kayenta and the lower part of the Lower Jurassic Navajo Sandstone. The imposing White Cliffs form the next riser and consist of the upper part of the Navajo Sandstone and the Middle Jurassic Co-op Creek Limestone Member of the Carmel Formation. The bench on this riser is the Skutumpah Terrace built on the remaining soft parts of the Carmel Formation and the overlying Entrada Formation. The Gray Cliffs are a series

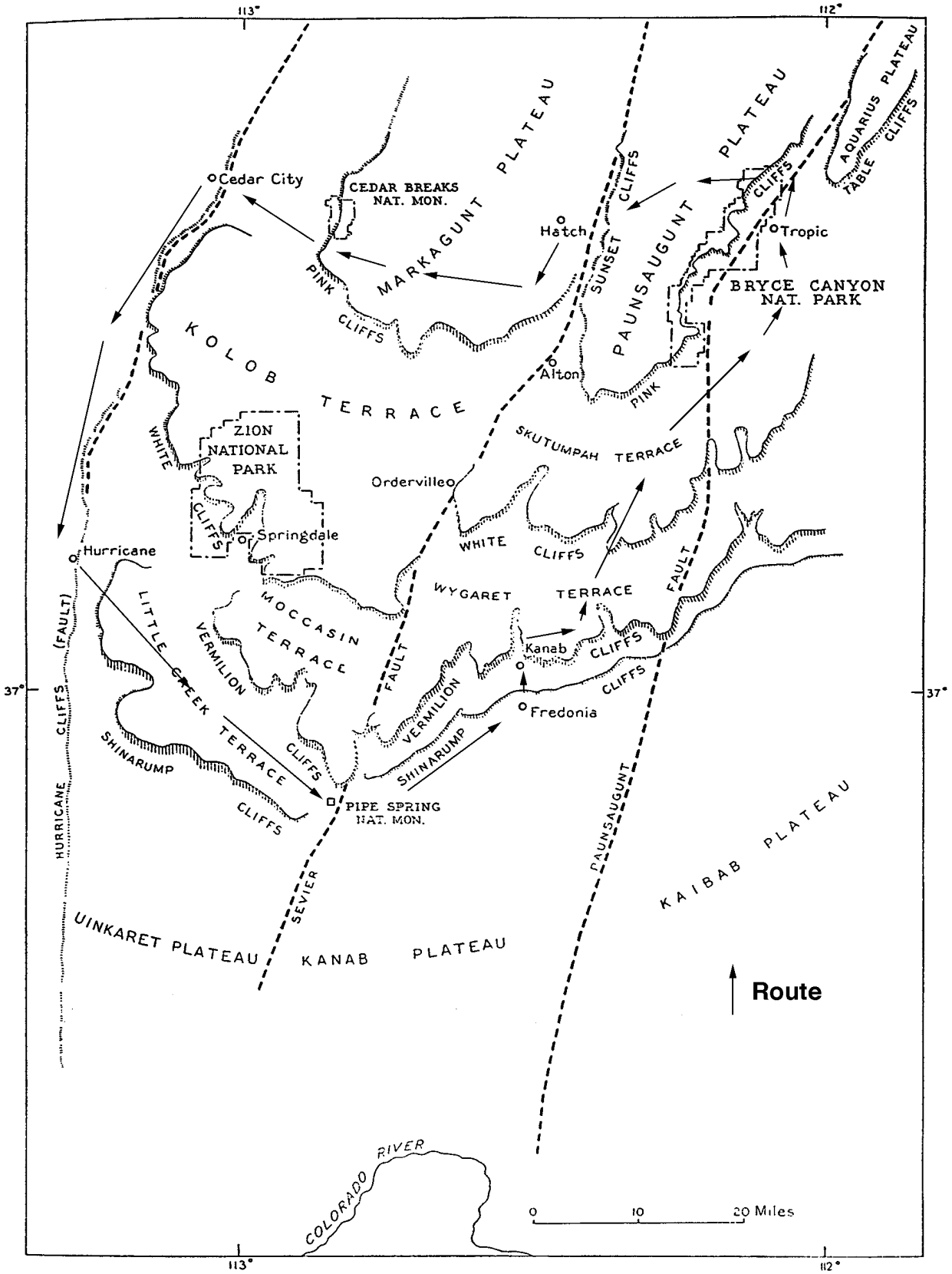

Figure 1. Sketch map showing the position of major plateaus, terraces, and cliffs in the Grand Staircase (after Gregory, 1950).

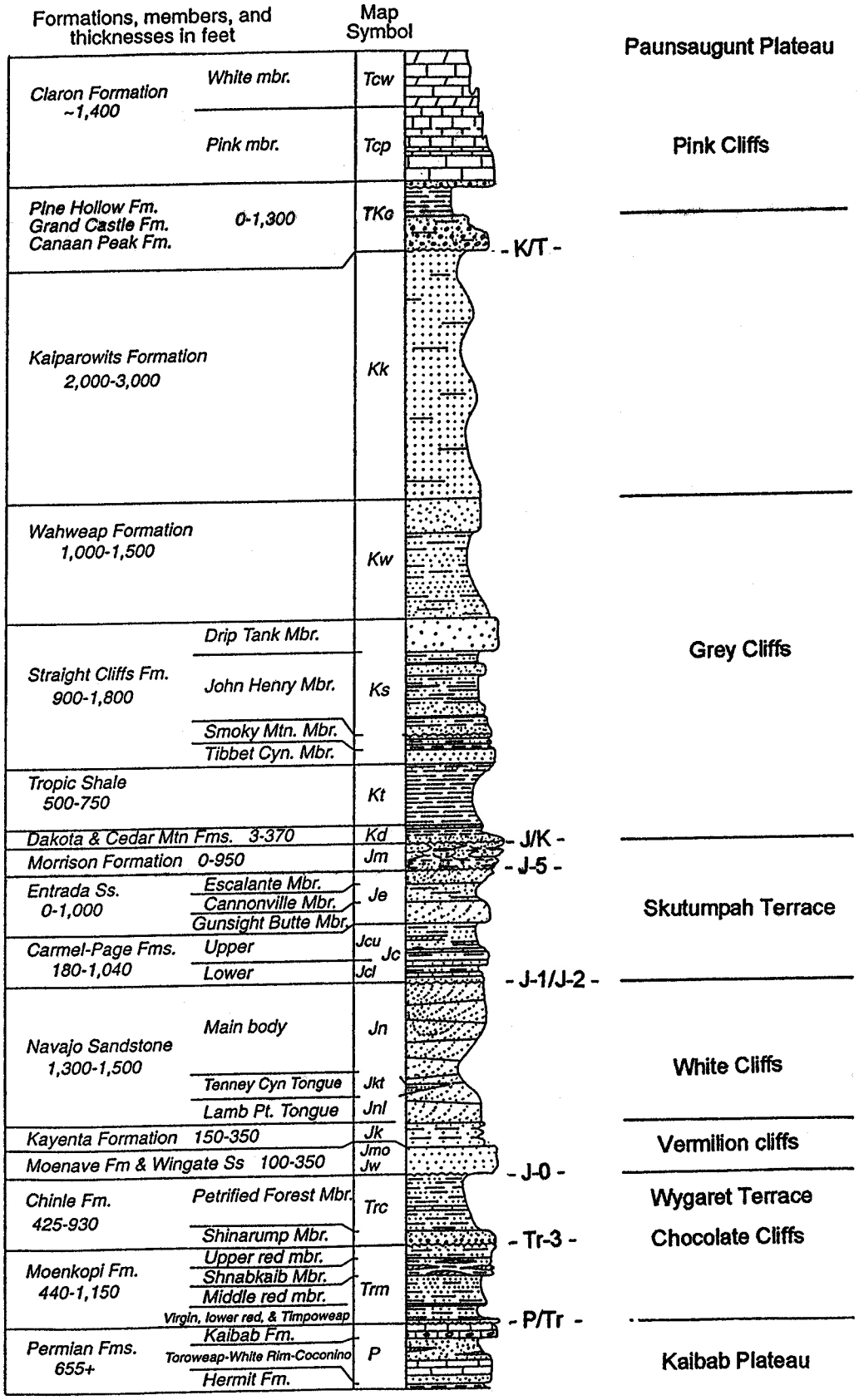

Figure 2. Grand Staircase Stratigraphy (adopted from Doelling and others, 2000, p. 201).

of low cliffs formed by hard Cretaceous sandstone and less resistant shale beds. Several benches have formed between these cliffs in the softer shale beds and sandstones of the Tropic, Straight Cliffs, Wahweap, and Kaiparowits Formations. The final riser, mostly north and west of the monument, in Dixie National Forest and Bryce Canyon National Park, is formed by the Pink Cliffs. The Pink Cliffs consist of lower Tertiary limestones and marls of the Claron Formation that are sculpted into the beautiful natural features found in Bryce Canyon. The cliffs culminate as the Paunsaugunt Plateau, which is the uppermost bench or step of the "Grand Staircase."

Geologic History

The Grand Canyon records the earliest history of the Colorado Plateau, albeit some chapters and pages are missing. Although the rocks exposed in the Grand Canyon are not part of this field trip, a brief discussion of the upper Grand Canyon sequence is provided.

The rocks of the Grand Staircase reveal nearly 275 million years of geologic history (Hintze, 1988). Permian age rocks are the base of the Grand Staircase. Deposition of these rocks occurred when the North American plate occupied an equatorial position, with the Colorado Plateau region located slightly south of the paleoequator (Levin, 1999). The environment was transitional consisting of lowland streams, flood plains, and marine tidal flats that deposited the sandstones and mudstones of the Hermit Shale and Toroweap Formation. To the east, dunes of wind blown sand in a vast desert formed the White Rim Sandstone exposed in Capitol Reef and Canyonlands National Parks. Further to the east in Colorado lay the Uncompahgre Uplift and adjacent fluvial and coastal plains (figure 3). The Kaibab Sea transgressed from the west far enough eastward to deposit the fossiliferous Kaibab Limestone on top of the Hermit Shale and Toroweap Formations. The Hermit Shale, Toroweap, and Kaibab Formations crop out in the upper Grand Canyon sequence, the Virgin River Gorge southwest of St. George, Utah, and in the Circle Cliffs in the GSENM. During this field trip we will observe the Kaibab Limestone in route to Stop 1.

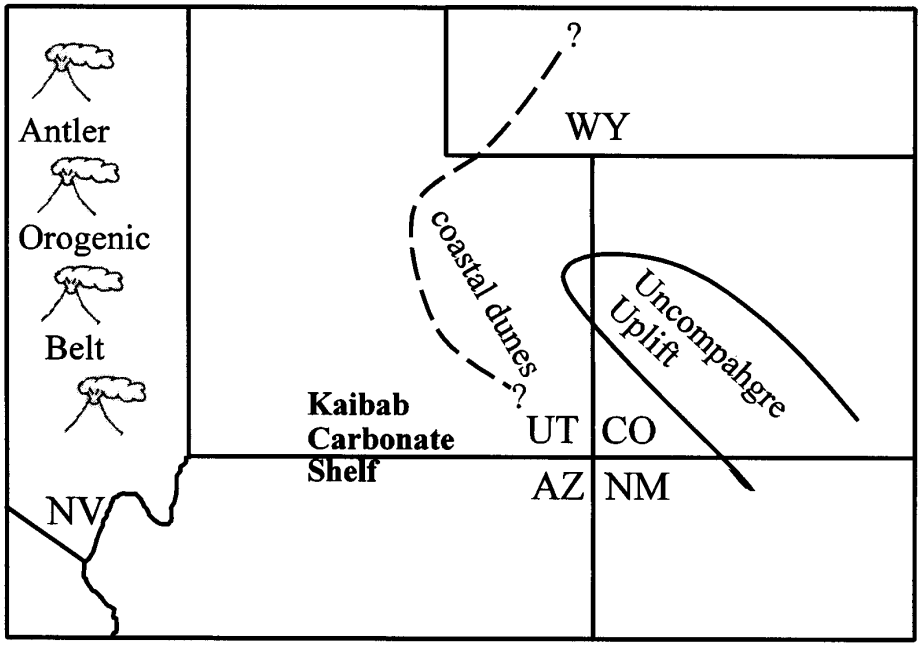

Figure 3. Permian paleogeography of the Four Corners area during deposition of the Kaibab Limestone (adopted from Condon, 1997).

The end of the Permian represents the largest extinction event recorded in the fossil record. A 10-million year unconformity, the Tr-1, separates Permian and Triassic rocks, and represents a period of subaerial exposure and erosion of the Kaibab Limestone. The early Triassic represents a continuation of the Permian paleogeography, with North America occupying an equatorial position. The Grand Staircase region formed a western interior basin with an Antler - Mogolion volcanic arc to the west-southwest and the Uncompahgre Uplift and ancestral Rocky Mountains to the east-northeast and the basin accumulated a thick sequence of marginal marine sediments (figure 4). The basal Rock Canyon Conglomerate Member, characterizing the beginning of Moenkopi deposition, is a chert pebble conglomerate. The resistant cherts came from the underlying Kaibab Limestone, while the Uncompahgre Uplift supplied finer-grained sediments. Blakely and others (1993) have

documented four major transgressive/regressive cycles in the Moenkopi. Minerals in the Moenkopi attest to the arid climate of southern Utah during early Triassic time. Poorly circulated, mineral-rich, waters of the western interior basin were evaporated, depositing beds of gypsum and gypsiferous siltstone, common components of the Moenkopi. Similar conditions exist today in the Persian Gulf region.

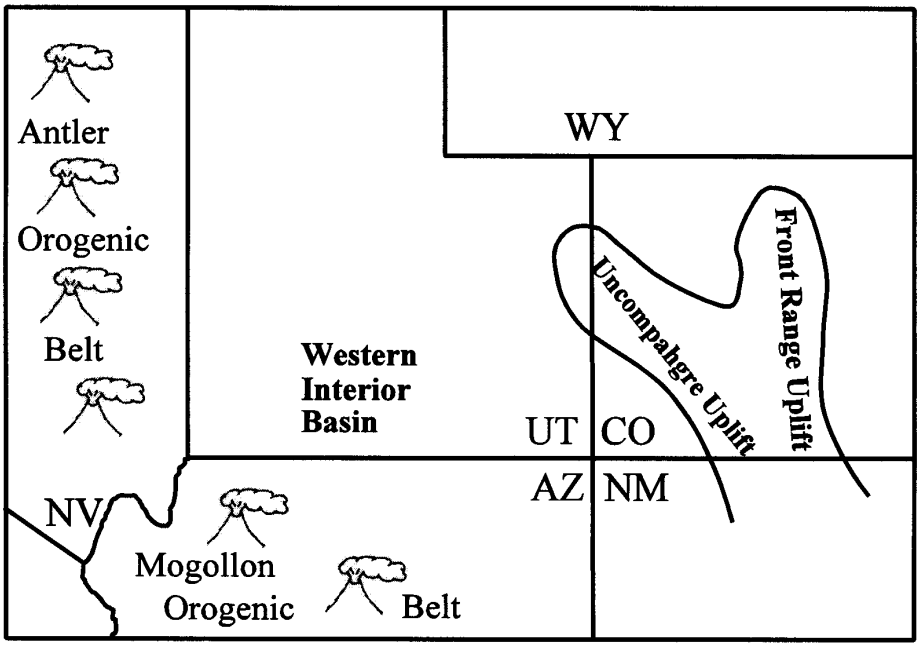

Figure 4. Triassic paleogeography of the Four Corners area during deposition of the Moenkopi and Chinle Formations (adopted from Dubiel, 1994).

Moenkopi deposition ceased by the end of the early Triassic and an interval of exposure and erosion lasting 20-million years ensued. Blakey and Gubitosa (1983) recognized deep channels cut into the Moenkopi. This unconformity is designed the Tr-3, and is overlain by the Shinarump Conglomerate, the basal member of the Chinle Formation, which marks the beginning of late Triassic deposition on the Colorado Plateau. The 500-foot-thick Chinle Formation consists of conglomerates, sandstones, siltstones, shales, and fresh-water limestones deposited in a variety of terrestrial environments, including broad fluvial flood plains, lakes, and marshes. The Chinle is easily recognized by its resistant, gray-brown basal conglomerate and the overlying finer sediments with a variegated pattern of purple, red, green, gray, and brown colors, which weather into rounded, low-lying hills and knobs. The highlands surrounding the extensive Chinle depositional basin supplied these sediments. The abundant volcanic ash associated with Chinle deposition, derived from a western volcanic arc, has altered to bentonite, which develops a popcorn-like surface texture following a rainfall. The Chinle and under lying upper red member of the Moenkopi constitute the Chocolate Cliffs of the Grand Staircase, and also provides the colorful backdrop for the Painted Desert of northern Arizona. The Chinle is perhaps most famous for its petrified wood found in the Petrified Forest Member.

Dubiel (1994) characterizes the Late Triassic climate of the North American western interior as tropical with seasonally high rainfall (monsoons). Evidence for this interpretation includes organic-rich lake and marsh deposits, as well as a fossil record of diverse vegetation. Fluctuating water tables produced alternating oxidizing (dry) and reducing (wet) conditions in the iron-rich sediments resulting in the variegated colors of these fine-grained, low-energy, deposits (Dubiel and others, 1987). Gradually the region became more arid as evidenced by eolian dune and playa lake deposits at the top of the formation. This pattern of aridity continues into the Jurassic Period.

A 5- to 10-million year period of non-deposition and erosion marks the Late Triassic and Early Jurassic transition and is termed the J-0 unconformity. The arid conditions initiated in the latest Triassic, which prevailed throughout the Jurassic, were brought about by changes in North American paleogeography due to the breakup of Pangaea. Tectonic activity to the west continued to produce periodic volcanic ash eruptions, as well as the initiation of a series of orogenic events, beginning with the Nevadan orogeny, which would continue sporadically for the next 150 million years.

During the Early Jurassic much of the Colorado Plateau experienced desert-like conditions and deposition of extensive eolian sands, exceeding 2,000 feet in thickness. Extensive tidal flat deposits form the lower Moenave Formation and consist of fine-grained sandstones and silty sandstones. These lithologies eventually give way to the stream-deposited, channeled sands and muddy overbank flood plain deposits of the upper Moenave and Kayenta Formations. The upper Moenave consists of mudstones and siltstones to fine-grained sandstones with thin, discontinuous lenses of intraformational conglomerates. The Kayenta Formation consists primarily of siltstones and fine-grained sandstones. The red-hued, resistant sandstones of the Moenave and Kayenta Formations make up the spectacular Vermilion Cliffs of the Grand Staircase. Both the Moenave and Kayenta Formations share a complex intertonguing relationship with the deposition of eolian sands to the north and east. Eventually, a gradual south-southwestern expansion of the Navajo Desert overtakes the Kayenta fluvial plain (figure 5), and by the Middle Jurassic, the Grand Staircase region is engulfed in desert-like conditions.

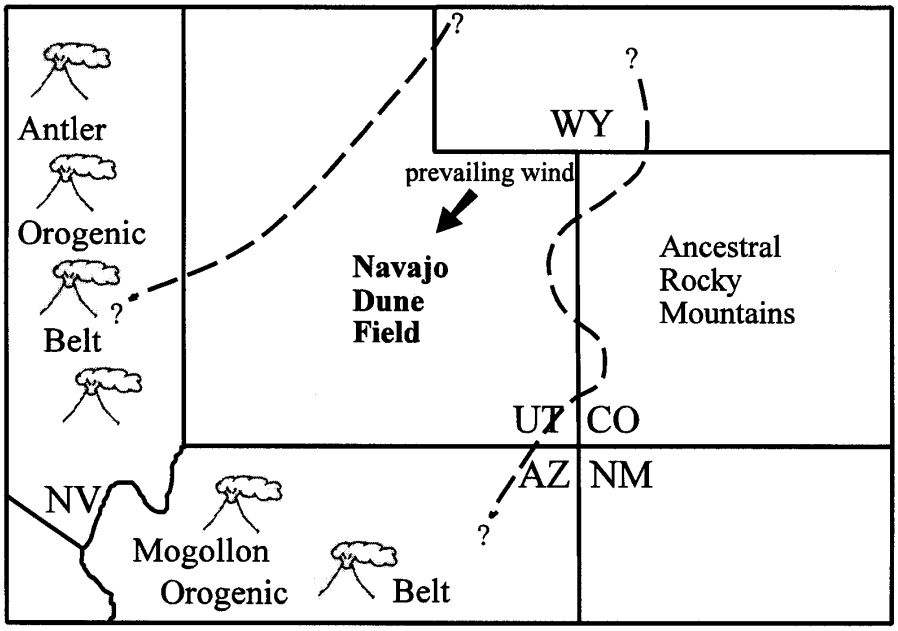

Figure 5. Early Jurassic paleogeography of the Four Corners area during deposition of the Navajo Sandstone (adopted from Peterson, 1994).

The high cliffs of spectacularly cross-bedded, white Navajo Sandstone represents the largest preserved coastal and inland eolian system in the geologic record of North America (Blakey and others, 1988; Peterson, 1988; Peterson and Turner-Peterson, 1989), and forms the distinctive White Cliffs of the Grand Staircase. The Navajo Sandstone is well known for its lithological uniformity, consisting of moderately well-cemented, well-rounded, frosted, fine- to medium-grained quartz grains. The sand was likely recycled from Paleozoic and Triassic sandstones to the north, possibly as far north as Alberta, and from local sources (Peterson, 1988). The large-scale cross-bedding of the Navajo is similar to the large, high relief dunes of the Sahara in North Africa. In Zion National Park, measurements of single cross-bed sets suggest a minimum dune relief of 60+ feet.

Toward the end of the Middle Jurassic, sea level began to rise once again and the Sundance Seaway transgressed southward from Idaho and Wyoming (figure 6), but arid terrestrial conditions continued in the region and deposition was dominated by eolian processes. The upper Navajo Sandstone underwent a period of erosion, known as the J-1 unconformity, marked by a discontinuous layer of chert pebbles. In southwestern Utah, the J-1 unconformity is capped by a west-thickening wedge of eolian-derived sandstone. The position of this sandstone atop the Navajo forms a cap on the many "temples" of Zion National Park, and hence the name Temple Cap Sandstone. Erosion of the Temple Cap Sandstone resulted in a patchy distribution and produced the J-2 unconformity. In places, the J-2 and lower J-1 unconformities merge (Brenner and Peterson, 1994**).**

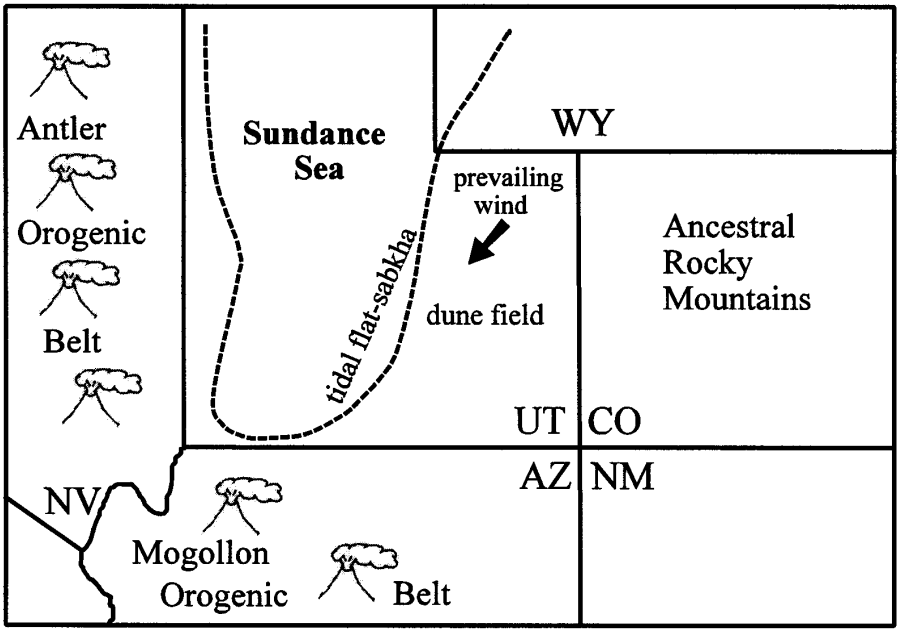

Figure 6. Middle Jurassic Paleogeography of the Four Corners area during deposition of the Carmel Formation and Page Sandstone (adopted from Peterson, 1994).

Continued rise of sea level eventually reached into the Grand Staircase region and signaled the return of marine deposition as evidenced by the Carmel Formation overlying the J-2 erosional surface. Eolian deposition continued in south central Utah with the deposition of the Page Sandstone. The Carmel Formation and Page Sandstone intertongue in the Paria River area, and reflect one of the complex interplays between marine, sabkha, fluvial, and eolian depositional systems typical of Carmel sedimentation (figure 7). The Carmel Formation even contains volcanic material, but the source area for these volcanics is disputed (Chapman, 1993, Riggs and Blakey, 1993). In the Grand Staircase region, the Carmel Formation consists of five members, including a tongue of the Page Sandstone called the Thousand Pockets Member. The Carmel Formation also contains several fossiliferous limestone and shale units. The presence of gypsum beds, such as those found in the Paria River Member, are indicative of highly evaporitic conditions in poorly circulating waters of the Sundance Seaway.

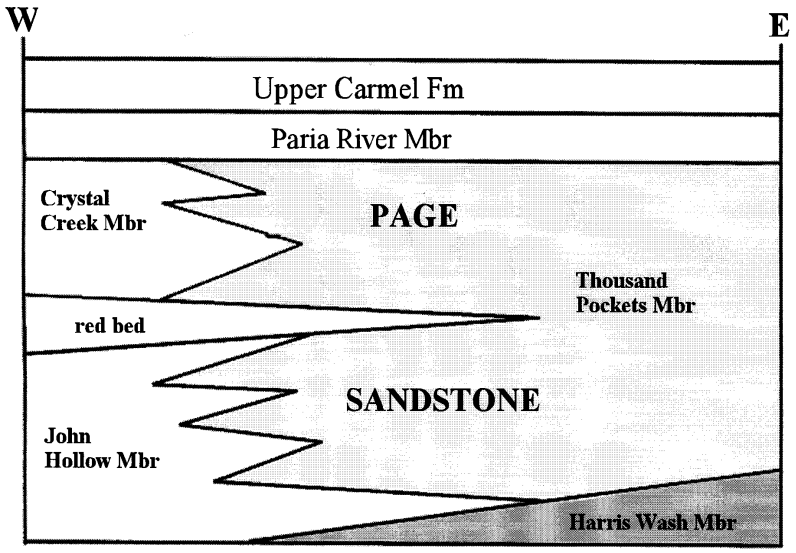

Figure 7. Intertonguing relationship of the Carmel Formation and the Page Sandstone (adopted from Blakely, 1994).

As the Sundance Sea withdrew northward near the end of the Middle Jurassic, another eolian system quickly advanced over the region and initiated deposition of the Entrada Formation (figure 8). Prior to Cenozoic erosion, the Entrada probably covered the entire Colorado Plateau region (Peterson, 1994). The Entrada is highly variable, but at most localities in the Grand Staircase region, the Entrada is a cross-bedded eolian sandstone (Peterson, 1994). In the GSENM, the Entrada Formation consists of three members (in ascending order) the Gunsight Butte Member, the Cannonville Member, and the Escalante Member. We will observe only the lower two members on this field trip.

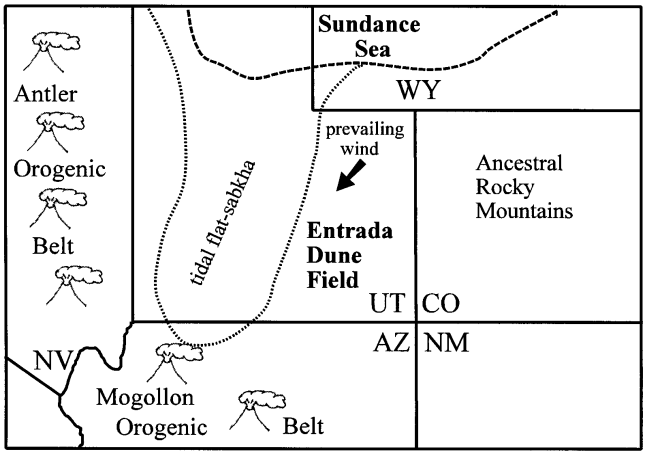

Figure 8. Late middle Jurassic paleogeography of the Four Corners area during deposition of the Entrada Sandstone (adopted from Peterson, 1994).

The Gunsight Butte Member weathers into sandstone cliffs and rounded, bare knobs. The sandstones are reddish-orange, silty to fine grained, with sparse medium to coarse, frosted, subrounded to rounded grains of pink and gray quartz (Doelling and others, 2000). The Cannonville Member generally forms steeper slopes of yellow-white sandstone with faint red bands. The Cannonville Member consists of interbedded, very fine-grained sandstones, silty sandstones, and siltstones (Doelling and others, 2000).

The Cretaceous Sevier orogeny represents a time of renewed mountain-building activity in western North America. At the same time, sea level began to rise to form the Cretaceous Western Interior Seaway, which eventually extended from the Gulf of Mexico northward into the Yukon and the Northwest Territories of Canada to connect with the Arctic Ocean (figure 9).

The Cretaceous rocks of the Colorado Plateau are dramatically different from the soft pastel and brilliant orange/red colored rocks lying below. Cretaceous rocks are more subdued shades of gray, brown, and yellow and form the Grey Cliffs of the Grand Staircase. Thick, resistant sandstones alternate with equally thick and less resistant shales to form a 3,000-4,000 foot thick sequence of cliffs and slopes.

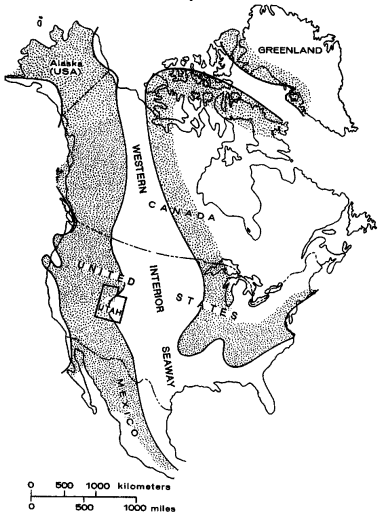

Figure 9. The Cretaceous Western Interior Seaway and emergent land areas in North America (stippled pattern) during the Late Cretaceous (from Peterson and Turner-Peterson, 1989).

The oldest stratum of the Grey Cliffs is the Dakota Sandstone. The Dakota Sandstone is composed of sandstone, conglomerate, mudstone, siltstone, and coal deposited in coastal, flood plain, and shallow marine environments. In the region of the Grand Staircase, the Dakota averages 200-300 feet thick, but thins to the east. The base of the formation is identified by a coarse pebble and cobble conglomerate that persists throughout most of the region (Cobban and others, 2000), and grades upward into finer sediments containing carbonaceous material and thin coal seams. The uppermost Dakota is marked by an oyster (*Exogyra olisiponensis* Sharpe) coquina horizon and organic-rich shale, which represents the first of four transgressive-regressive cycles during the Cretaceous.

The blue-gray Tropic Shale overlies the Dakota Formation in the Grand Staircase region and represents deposition of muds in the deeper waters of the Cretaceous Western Interior Seaway. In the GSENM, the Tropic Shale averages 700 to 900 feet thick and forms distinctive slopes prone to landslides and slumps. Bentonite beds are abundant throughout the Tropic and are correlated with well-established ammonite biozones (Cobban and others, 2000). The lower part of the Tropic contains several distinctive calcareous concretionary zones. The limestone concretions yield an extremely rich molluscan fauna, particularly ammonoids, which are useful in biostratigraphic correlations (Cobban and others, 2000). The upper Tropic becomes sandy as it grades into the overlying Straight Cliffs Formation.

The 900- to 1,800-foot-thick Straight Cliffs Formation represents the final regressive phase of the Cretaceous Western Interior Seaway and consists of four distinctive members. In ascending order, the basal Tibbet Canyon Member is a resistant, cliff-forming, shallow marine sandstone; the Smokey Hollow Member consists of ledge- and cliff-forming, lagoonal and flood plain shales and sandstones; the John Henry Member is a slope- and ledge-former of deltaic and fluvial shales, coals, and sandstones; and the upper, prominent cliff-forming, fluvial deposited, coarse-grained sandstones of the Drip Tank Member. The Tibbet Canyon and Smokey Hollow Members represent the regressive phase of the Cretaceous Western Interior Seaway (Doelling and others, 2000) and are the only members of the formation known to contain marine fossils (Cobban and others, 2000).

Two major coal seams in the John Henry Member represent significant economic deposits. These coal deposits were at the center of the initial controversy involving the GSENM. These coals have been studied (Hettinger and others, 1996) and several companies have expressed an interest in mining these them. Mining is bitterly opposed by environmental groups. Dutch-owned Andalex Resources was moving forward with plans for mining operations, but stopped when the GSENM was established by Presidential Proclamation on September 18, 1996.

Overlying the Straight Cliffs Formation are slope forming, finergrained sediments of the Wahweap Formation. More resistant, cliff-forming sandstones are present in the upper part of the Wahweap. The 1,000- to 1,500-foot-thick Wahweap is composed of interbedded, less-resistant mudstones and siltstones and resistant and non-resistant sandstones and conglomerates (Doelling and others, 2000). Wahweap sediments accumulated in fluvial, flood plain, and lacustrine environments, resulting in locally rich, fossil bearing deposits. Fossils include petrified wood, vertebrates (including dinosaurs), and gastropods.

The Kaiparowits Formation tops of the Grey Cliffs, and consists of over 2,000 feet of slope- and badlands-forming, drab gray to olive-gray shales and subarkosic sandstones. The Kaiparowits Formation cuts deeply into the eroded upper Wahweap Formation. Doelling and others (2000) describes the subarkosic sandstone as mostly very fine to fine grained, poorly sorted, and weakly cemented with calcite. The grains are mostly quartz, with orthoclase, albite, biotite, calcite, gypsum, clay, iron, and bits of coal or charcoal. Mudstones, siltstones, and sandy limestones and limey siltstones probably represent lacustrine deposits on a subsiding alluvial plain (Doelling and others, 2000). Vertebrate fossils, including dinosaurs, are common in the Kaiparowits Formation, particularly in the lower half of the formation (Eaton and others, 1999).

The close of the Cretaceous Period was punctuated by a global extinction event that obliterated 65 percent of the known species, including the 140-million year reign of the dinosaurs. Changes in depositional environments followed as the Cretaceous Western Interior Seaway receded. Sevier orogenic events had ended during the Cretaceous, and, to the west, the Sevier Highlands were gradually reduced by erosion during early Paleogene time. During the latest Cretaceous, and continuing into the early Paleogene, renewed mountain building (the Laramide orogeny) was initiated (Elston and Young, 1989). The Laramide resulted in the final stage of the formation of the North American Cordillera - the Rocky Mountains. The Laramide orogeny partitioned the Sevier foreland basin into a series of internally drained, non-marine, depositional basins bounded by basement-cored uplifts (Dickinson and others, 1986; Goldstrand, 1994). Large lakes began to occupy the inter basins, which extended from southwestern Wyoming to southwestern Utah. Uplifted areas produced by the Laramide orogeny became the main source of sediments, which filled the basins.

Stratigraphically, in the region of the Grand Staircase, the Canaan Peak, Grand Castle, and Claron Formations overly the Kaiparowits. The Canaan Peak Formation spans the K-T boundary. Both the Canaan Peak and Grand Castle Formations are conglomeratic, with the Canaan Peak being composed mainly of quartzite and felsic volcanic clasts, whereas, the Grand Castle Formation is composed mostly of quartzite and limestone clasts. The Claron Formation forms the Pink Cliffs, and uppermost step of the Grand Staircase.

The Claron Formation consists of two informal members, a lower pink limestone member and an upper white limestone member (Bowers, 1972). Ott (1999) recognized a cyclicity in deposition due to fluctuating lake levels. These two members are laterally continuous throughout the Markagunt, Paunsaugunt, Seiver, and Table Cliffs Plateaus. In the Bryce Canyon area, a discontinuous conglomerate unit found at the base of the lower pink member is less than 20 meters thick and contains well-rounded clasts of quartzite, chert, and limestone and is considered to be the Grand Castle Formation by Bowers (1972). Due to the lack of definitive age indicators, the Claron Formation is inferred by Bowers (1972) to be middle to late Eocene in age. At Bryce Canyon, a 35-meter thick conglomerate unit lies unconformably above the lower pink and upper white members of the Claron Formation and has been informally designated as the Conglomerate at Boat Mesa by Bowers (1990).

The timing and mechanism for the uplift of the Colorado Plateau and formation of the Grand Staircase is controversial. Baars and others (1988, p. 111) state that the Colorado Plateau is structurally unique in that it has been only moderately deformed compared to the more intensely deformed regions around it and appears to have behaved as a relatively stable structural unit during Laramide deformation. According to Peterson and Turner-Peterson (1989) regional uplift and volcanic activity were initiated by the Oligocene (late Paleocene). The resulting cinder cones and lava flows can be observed throughout the region, such as the volcanics from the Mount Dutton caldera, which cap the northern end of the Paunsaugunt Plateau. More recently, faulting brought on by crustal extension formed tilted fault blocks that result in the north-south-trending basins and ranges in western Utah and Nevada. The Grand Staircase is located to the east of the Basin and Range Province, and the Johnson Canyon and Paunsaugunt faults are the easternmost of the basin and range faults. The GSENM sits at the southern end of the dissected high plateau topography resulting from these faults. This movement continues to the present.

Following a period of aridity in the late Oligocene to middle Miocene, the Colorado River captured the flow of the Green River and the Green and Colorado river drainages were fully integrated by the early Pliocene (Peterson and Turner-Peterson, 1989; Elston and Young, 1989). By the end of the Pliocene, erosion of the Colorado River through the relatively soft Paleozoic strata had cut the Grand Canyon close to its present depth and most of the present character of the Colorado Plateau had been achieved (Peterson and Turner-Peterson, 1989).

Due to alpine and plateau glaciation, some landscape modification occurred during the Pleistocene. During the last phase of Pleistocene glaciation, the Clovis people (mammoth hunters) followed the Siberian mammoth herds across the Barrengia landmass (Bering land bridge) from Asia into southern Alaska and the Yukon Territory. These early hunters probably gave rise to the Folsom people (bison hunters). No direct evidence of Clovis or Folsom peoples exist on the Colorado Plateau; however, the region has yielded an assemblage of Late Pleistocene megafauna, including mammoths and mastodons, the giant ground sloth, musk and shrub oxen, camels, bison, several species of ancestral horses, and three species of bear (Nelson, 1990). Humans had arrived on the Colorado Plateau about 12,000 years B.P., during the waning stages of Pleistocene glaciation.

Holocene erosion has continued to deepen canyons, but only slightly. The nature of Holocene erosion and deposition have not changed since the Powell's explorations of the plateau country in the late 1800s. The impact of modern humans on the landscape continues to be accessed and debated.

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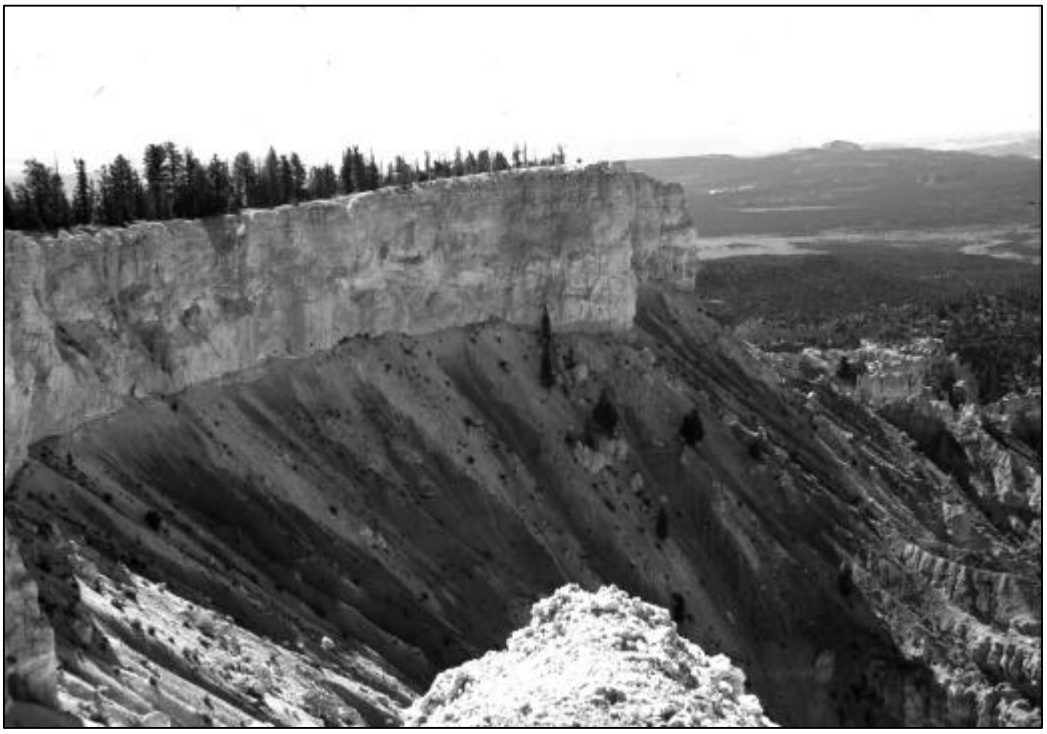


Looking south over the Skutumpah and Wygaret terraces from Yovimpa Point.

ROAD LOG

Note: Directions for viewing from the vehicle are given as clock hour, where the front of the vehicle is always 12 o'clock. A feature directly to the right of the vehicle is then 3:00; to the left at 9:00. A feature at 1:00 or 2:00 is only slightly to the right of the front of the vehicle.

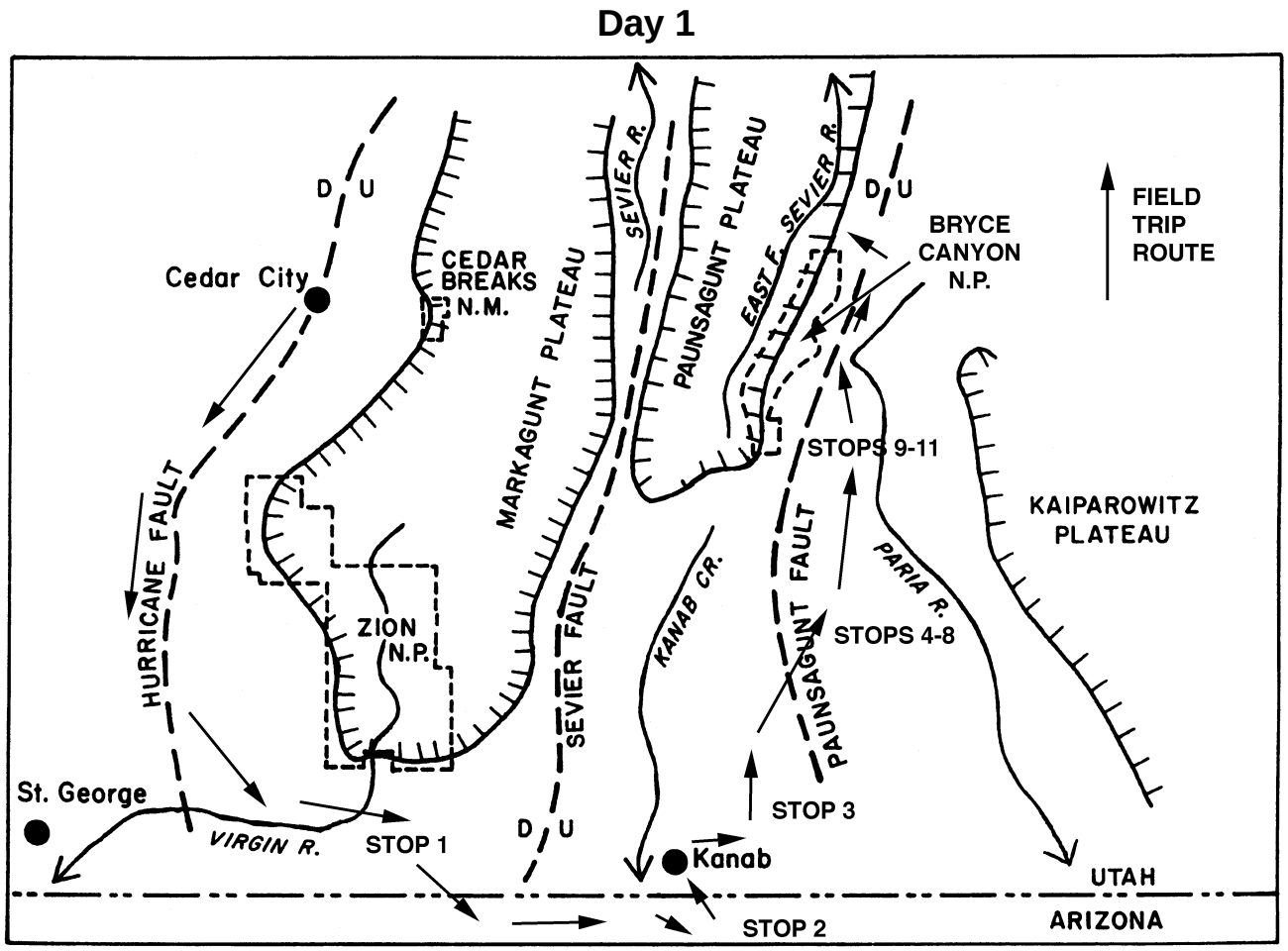


Figure 10. Sketch map of Day 1 field trip route (from Harris and others, 1997)

We will drive south via I-15, along the Hurricane Fault scarp. We will leave the interstate at the Toquerville, Utah, exit and proceed generally south-southeast through La Verkin and Hurricane, Utah; Colorado City, Pipe Spring, Fredonia and LeFevre Point, Arizona; and then drive north-northeast through Kanab, Johnson Canyon, to Tropic, Utah. This circuitous route provides excellent views of the Chocolate, Vermillion and White Cliffs of the Grand Staircase. In Johnson Canyon we will view the White, Gray and Pink Cliffs and travel on the Skutumpah Terrace. In the course of our travels, we will familiarize ourselves with the geologic history, sedimentology, and stratigraphy of the region.

MILEAGE

Interval	Cum	Description
0.0	0.0	Motor Pool Parking Lot, the western-most SUU parking lot, located at 200 South 1150 West, in Cedar City, Utah. Turn right out of SUU Motor Pool Parking Lot.
0.1	0.1	Turn left on 200 South Street, and proceed east.

0.6	0.7	Stop sign at the junction of 200 South and 300 West Streets. Turn right (south) on 300 West.
0.3	1.0	Stop sign at junction of 300 West and 400 South Streets. Continue south on 300 West.
0.2	1.2	Stop sign at junction of 300 West and 600 South. Continue south on 300 West.
0.1	1.3	Stop sign at junction of 300 West and south Main Streets. Turn right (south) on Main.
0.1	1.4	Signal, continue south on Main Street.
0.9	2.3	Signal, continue south onto southbound I-15 freeway on-ramp.
2.3	4.6	Pleistocene lava flow in road cut at 9:00 and 3:00.
10.0	14.6	Rest area, I-15.
2.9	17.5	Cliffs at 9:00 are Triassic Moenkopi Formation.
1.4	18.9	Exit 40. Kolob Canyon, Zion National Park. See Grant (1987) for a discussion of the geology of Kolob Canyons. Located at 2:00-3:00, the Pine Valley Mountains. This laccolithic to extrusive complex is approximately 23 million years old. At the base of the mountains (1:00 -2:00) are a series of basalt flows that create a prominent, tree-covered, ridge. We will drive across the toe of the ridge, west of its truncation by Ash Creek Canyon.
4.1	23.0	Hurricane fault scarp at 9:00. Most of what you see is Kaibab Limestone (base), Triassic Moenkopi Formation, with a recent basalt cap. The basalts in this area have recently been dated in order to constrain slip rates on this segment of the Hurricane fault, see Lund and others, 2001.
2.7	25.7	Located on the east side of I-15 at Exit 33, is the San Daniel Campsite used by the Escalante–Dominguez party on the night of October 14, 1776. These Dominican Fathers traveled from Santa Fe, New Mexico in search of an overland route to Monterey, California. They had many adventures, which are chronicled in *The Dominguez–Escalante Journal*, edited by Ted Warner, and translated by Fray Angelico Chavez (University of Utah Press, 1995, 153 pages). The party camped at the San Daniel Campsite after being abandoned by two native American guides they had found along Ash Creek on the north side of the Black Ridge. From here, the party continued south through Toquerville, along the Hurricane Cliffs, and across the Arizona Strip to eventually cross the Colorado River and return to Santa Fe, New Mexico.
3.3	29.0	Pine Valley laccolith outliers along I-15 viewed at 11:00, 1:00, 2:00 and 3:00.
2.7	31.7	Exit 27 of I-15 to Toquerville / Hurricane, proceed to stop sign, then turn left (south) on SR-17.
0.7	32.4	Cenozoic lavas fill paleo-valleys high on the cliff at 9:00.
0.1	32.5	Navajo Sandstone at 3:00. Slivers of this rock have here been caught in the Hurricane fault zone and are sporadically capped on by Quaternary volcanics.
1.3	33.8	Toquerville city limits.
0.1	33.9	Cross Ash Creek.

0.6	34.5	J. Conrad Naile (Naegle) Home and Dixie Mission Winery. The Naegle Big House, known as the Naegle winery, or the Naile House. Constructed in 1866-68 by John Conrad Naile (Naegle), a Mormon polygamist, rancher, farmer, and colonist. The house served several purposes - a home for several wives and family; headquarters for Naegle's widespread ranching and business enterprises; and as a winery. The Naegle family relocated to Mexico in the late 1880s.
1.2	35.7	Road on right leads to Toquerville Cemetary.
0.4	36.1	Quaternary basalts and capping Quaternary alluvium.
0.3	36.4	La Verkin city limits.
0.2	36.6	Crossing La Verkin Creek.
0.2	36.8	Smith Mesa at 9:00.
0.4	37.2	Junction of SR-17 and SR-9, SR-17 ends. Continue south on SR-9.
1.4	38.6	Crossing Virgin River. The canyon walls are comprised of Quaternary basalts and show columnar jointing. Just beneath the Virgin River bridge and upstream is the small commercial spa called Pah Tempe Hot Springs, which has welcomed visitors from around the world for over a century. There are seven hot mineral pools (100°F), a swimming pool, a campground, and a bed-and-breakfast. These heated waters flow upward along fractures associated with the Hurricane fault, the scarp of which is visible at 3:00.
0.1	38.7	Road on left leads to Pah Tempe Hot Springs.
0.1	38.8	Hurricane city limits.
0.8	39.6	Turn left on 100 East Street in Hurricane. Continue to the stop sign and turn left on SR-59. Drive up scarp of Hurricane fault through Quaternary basalts and alluvium. The Hurricane fault is commonly used to draw the western margin of the Colorado Plateau in southwest Utah. The 160-mile long fault runs from south of the Grand Canyon northward past Cedar City, Utah, where it forms the precipitous west boundary of the Markagunt Plateau. The lack of erosional degradation of the escarpment suggests some recent movement. Toquerville, Utah, sits on the west side of the Hurricane fault which has over 8,000 feet of stratigraphic separation. About 1,500 feet of this displacement has occurred since the eruption of a Quaternary basalt flow across the fault. Offsets of up to 20 feet in unconsolidated gravel at the base of the fault (Steward and others, 1997) suggest even more recent movement. A magnitude 5.8 earthquake near St. George on September 2, 1992 has been attributed to movement on the Hurricane fault (Christenson, 1995).
0.6	40.2	View at 9:00 of several cinder cones and Pine Valley Mountains.
0.3	40.5	View at 11:00 of Smith Mesa site of U.S. Air Force ejection seat testing in 1950s and 60s.
0.5	41.0	Permian Kaibab Formation on both sides of the road.
1.2	42.2	Riding on top of the Timpoweap Member of the Moenkopi Formation. View at 11:00 is a butte composed of other Moenkopi Formation members. Lower red member forms the slope that rises from valley floor, and is capped in low ridge by cliff-forming Virgin Limestone Member. Middle red slope is comprised of the middle red, Shnabkaib, and

upper red Members and is capped by the basal Shinarump Conglomerate Member of the Triassic Chinle Formation.

0.6 42.8 **STOP 1.** Turn left off of SR 59 to the petroleum seeps in the Timpoweap Member, Moenkopi Formation. Return to SR-59.

Mile 42.8 Petroleum seep in the Timpoweap Member, Moenkopki Formation.

1.8 44.6 At 12:00 is a recent cinder cone and valley-fill lava flow extending to your right.

2.3 46.9 View at 3:00 is of a cinder cone being mined for road metal.

2.5 49.4 At 12:00 is our first view of J. W. Powell's Vermillion Cliffs, exposed here along the western edge of the Moccasin Terrace (Gregory, 1950). The Vermillion Cliffs are composed of the Jurassic Moenave and Kayenta Formations.

0.5 49.9 View at 9:00 is the Temples of Zion in Zion National Park. "Temples" are composed of the Jurassic Navajo Sandstone and Temple Cap Formations.

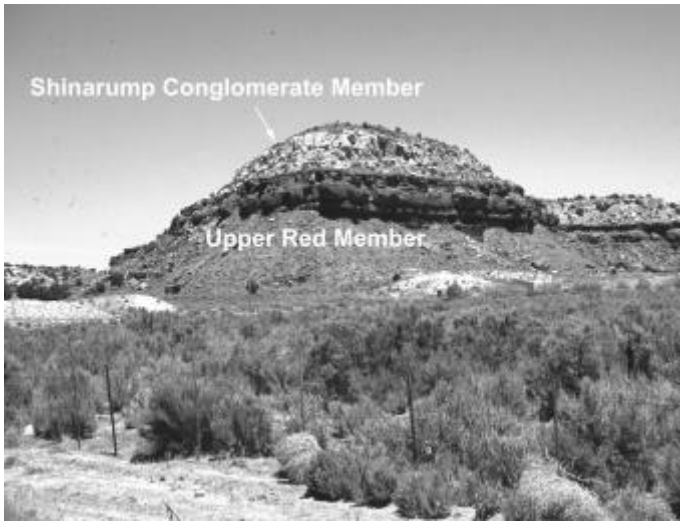
1.0 50.9 View at 3:00 of a cinder cone, called Cinder Mountain, on the east facing dip slope of Little Creek Mesa.

9.8 60.7 Entering Hilldale, Utah. In the early days of Mormon history, polygamy was openly practiced. Believing participation to be commandment, from 1852 until 1890, the LDS (Mormon) Church leaders preached and encouraged members, especially those in leadership positions, to marry additional wives. A majority of the Latter-day Saints, however, never lived the principle. Reactions from outside the church to participation in polygamy were immediate and negative. In 1862 the United States Congress passed the Morrill Act, which prohibited plural marriage in the territories, disincorporated the LDS Church, and restricted the church's ownership of property. The nation was in the midst of the Civil War, however, and the law was not enforced. The Latter-day Saints continued to practice polygamy despite these laws, since they believed that the practice was protected by the freedom of religion clause in the Bill of Rights. Wilford Woodruff, then president of the LDS Church, initially supported the continued practice of polygamy; however, as pressure increased, he began to change the church's policy. On 26 September 1890 he issued a press release, the Manifesto, which read, "I publicly declare that my advice to the Latter-day Saints is to refrain from contracting any marriages forbidden by the law of the land." The Manifesto was approved at the

church's general conference on 6 October 1890. Fundamentalist groups who believe that the church discontinued polygamy only because of government pressure continued the practice. As these groups were discovered by the LDS Church, their participants were excommunicated. Some of these polygamists have appointed their own leaders and continue to live in groups, including those in Colorado City (formerly Short Creek), Arizona, and Hilldale, Utah.

0.6	61.3	Arizona-Utah border.
0.1	61.4	Entering Colorado City, Arizona. Road changes to Arizona Highway 389 East. The region to the south is called the Arizona Strip, and lies north of the Colorado River and Grand Canyon. The Arizona Strip encompasses five million acres of the far northwestern corner of Arizona north of the Colorado River and south of the Utah border. An arid, isolated, and sparse landscape, the region nonetheless has sustained a rich human history, from the 8,000 year-old remains of paleo Indians to the creation of the million-acre Grand Canyon-Parashant National Monument in January of 2000. The Arizona Strip has been an important regional ranching area since the late 19th century.
3.6	65.0	View at 2:00 is of Mount Trumble and the new Grand Canyon-Parashant National Monument. From an environmental history perspective the region records climate change, human use, and paleoecological transformations over the past 50,000 years. It has been an important site for ecological restoration of forests, springs, and wildlife such as desert bighorn, pronghorn antelope, and California condor. The new monument essentially doubles the area of Grand Canyon National Park, protecting a vast area of northern Arizona from development.
6.3	71.3	View at 11:00 of the upper Moenave, Kayenta, Navajo transition, the southern exposure of Powell's Vermillion Cliffs.
3.2	74.5	View at 12:00 of the Kaibab Uplift (East Kaibab monocline).
0.1	74.6	Entering Kaibab Paiute Indian Reservation.
5.0	79.6	Road on left to Pipe Spring National Monument. Pipe Spring, and near by Moccasin Spring, are the only perennial water sources on the high desert plain between the North Rim of the Grand Canyon and the Vermilion Cliffs. Water flows from the subsurface along the Sevier fault. For countless centuries the native peoples of the region, the Kaibab Paiute, relied on the springs for their existence. Later, in the mid-1800s, Mormon families moved into the region and struggled to build self-reliant communities. In 1870, Mormon settlers built a fortified ranch at Pipe Spring and raised tithe cattle owned by the LDS Church. The purpose of the ranch was to provide meat and dairy products for workers on church projects in St. George, Utah. The old Mormon ranch at the spring was purchased by the National Park Service in 1923.
1.7	81.3	View at 10:00 of the Chocolate (lower) and Vermillion Cliffs.
3.2	84.5	Road on the right is the Toroweap turn off which leads to the Toroweap section of the Grand Canyon where one can view Vulcan's Throne and Anvil and Lava Falls, the highest navigable falls in North America. The features formed when late Tertiary lavas flowed into the Grand Canyon to form a temporary dam.
6.1	90.6	Road to the left leads to Six Mile Village. Leaving Kaibab Paiute Indian Reservation.
1.5	92.1	Crossing Kanab Creek and entering Fredonia, Arizona.
0.5	92.6	Junction of Arizona Highway 389 East and US 89A. Turn right and travel south on US 89A.

7.5	100.1	View at 9:00 of the Grand Staircase that includes the Chocolate, Vermillion, White, and Pink Cliffs.
8.4	108.5	Exposures of the Kaibab Limestone dipping west off the flanks of the Kaibab Uplift (East Kaibab monocline).
2.5	111.0	**STOP 2.** LeFevre Overlook, Kaibab National Forest, elevation 6,700 feet. Complete view to the north of the Grand Staircase. **LUNCH STOP.** Return to US 89A and travel north, back toward Fredonia, Arizona and Kanab, Utah.
13.9	124.9	Low cliff at 2:00 is the middle red member of the Moenkopi Formation with Chocolate Cliffs behind it.
2.1	127.0	Chocolate / Vermillion Cliffs in the middle distance.
4.3	131.3	Junction of Arizona Highway 389 and US 89A. Continue north on US 89A.
1.6	132.9	Paramont Petroleum Asphalt Terminal on the right. View at 11:00 of the Chocolate Cliffs. Upper red Moenkopi, and Shinarump Conglomerate, Chinle Formation, and in background the Vermillion Cliffs composed of Moenave and Kayenta Formations.
0.6	133.5	Chocolate Cliffs.

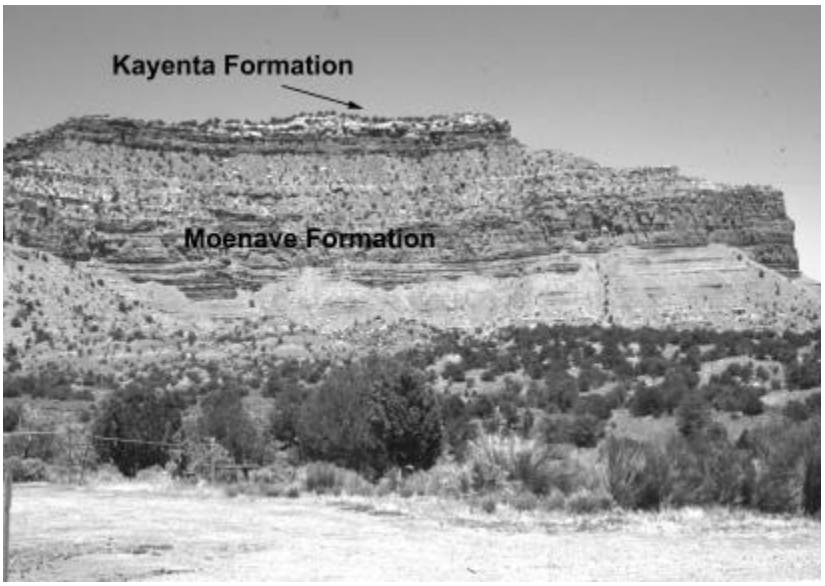


Mile 133.5 Exposure of the Chocolate Cliffs north of Fredonia, Arizona.

1.3	134.8	Utah / Arizona border.
0.1	134.9	Entering Kanab, Utah city limits (Kanab is the Paiute word for "willows"). Vermillion Cliffs visible in all directions.
0.2	135.1	Kanab Fort historical marker on left. Kanab Fort construction begun in 1864 by Jacob Hamblin as protection from Indians and as a base of exploration. Severe and frequent Indian attacks made it impractical to maintain. The fort was abandoned in 1866 and reoccupied in 1870, by Levi Stewart and others sent to do missionary work and establish peace with local Indians. In December of 1870, a fire in the fort killed Levi's wife and five sons. Restored fort used as a movie prop in "Fury at Furnace Creek" and "The Apple Dumpling Gang."

2.5 137.6 Junction of US 89A and US 89. Turn right at stop light on US 89 and drive east toward Page, Arizona.

2.0 139.6 Vermillion Cliffs.



Mile 139.6 Exposures of the Vermillion Cliffs east of Kanab, Utah.

7.2 146.8 Turn left (north) on Johnson Canyon Road.

0.3 147.1 View at 1:00 of the Vermillion Cliffs in the foreground and White Cliffs in the background.

1.3 148.4 **STOP 3**. Look at upper Moenave Formation of the Vermillion Cliffs. This area provides exposures of an interfingering zone between strata of the Jurassic Kayenta Formation and the overlying Navajo Sandstone. According to Hintze (1988), the Kayenta Formation in this area is split by the Lamb Point Tongue of the Navajo Sandstone. The strata below the Lamb Point Tongue is still the Kayenta Formation, but the strata above the Lamb Point Tongue and below the Navajo Sandstone is referred to as the Tenney Canyon Tongue of the Kayenta Formation. This interfingering suggests that this area represents the margins of the Navajo and Kayenta depositional basins.

1.8 150.2 Cross bridge.

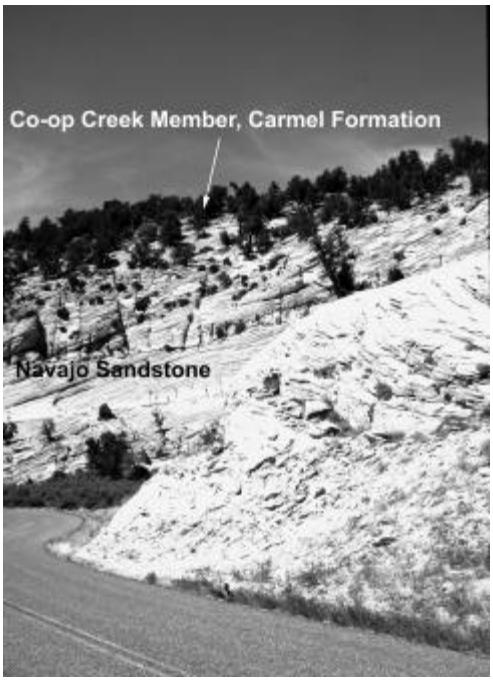
0.1 150.3 View at 3:00 is “biscuit” weathering in the lower Kayenta Formation.

1.8 152.1 Movie set on the right was used for the Gunsmoke TV series.

0.5 152.6 **STOP 4**. View at 10:00 of the Lamb's Point Tongue of the Navajo Sandstone and the overlying Kayenta. Faulting can be observed on the west side of the road in a fault zone that parallels Johnson Canyon. Named the Johnson Canyon fault zone, the faults are considered active (Doelling and Davis, 1989).

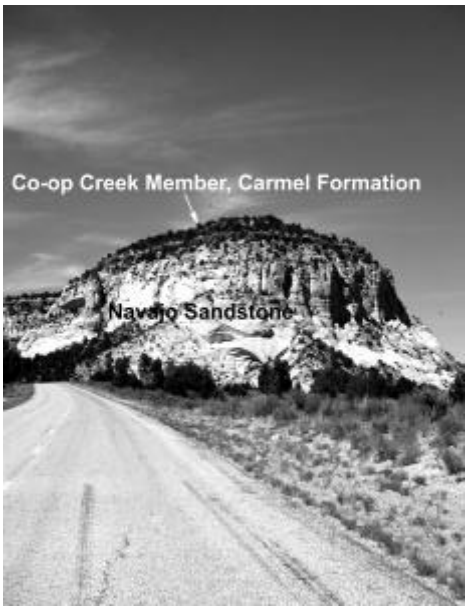
Mile 152.6 Weathering features in the Kayenta Formation, Johnson Canyon, Utah.

1.5	154.1	More displaced strata at 10:00, exposures of White Cliffs of the Navajo Sandstone at 11:00.
1.1	155.2	View at 2:00 "biscuit" weathering and soft sediment/slump features. View at 1:00, an excellent example of the Lamb Point Tongue of the Navajo Sandstone.
1.4	156.6	**STOP 5**. View of Pink Cliffs at 11:00. Road to Lock Ridge, Flood Canyon, Nephi Pasture, and Buckskin Wash on right. In this region of the Monument, the stratigraphic interval can be divided into a series of formal (upper case names) and informal (lower case names) units. Starting form the exposed base, in ascending order: Lamb Point Tongue of Navajo Sandstone, Tenney Canyon Tongue of Kayenta Formation, brown Navajo Sandstone, pink Navajo Sandstone, and white Navajo Sandstone (Doelling and others, 2000). The brown and white Navajo Sandstone units are resistant and form cliffs, while the pink Navajo Sandstone is softer and forms benches and low hills.
0.9	157.5	Cross Johnson Wash, then a cattle guard.
1.0	158.5	Entering the Grand Staircase–Escalante National Monument (GSENM), sign on right. GSENM, administered by the Bureau of Land Management (BLM), was established by Presidential Proclamation on September 18, 1996, to protect an array of geological, paleontological, historical, archaeological, and biological resources. The Monument covers about 1.9 million acres of land in south-central Utah. About 68 percent of the Monument is in Kane County, while the remaining 32 percent is in Garfield County. The Monument is surrounded on three sides primarily by national forest and national park lands, and by other BLM administered lands to the south and west. Kodachrome State Park also adjoins the monument near Cannonville.
1.5	160.0	View at 12:00 of the Navajo Sandstone–Carmel Formation (Co-op Creek Member) contact.



Mile 160.0 Navajo Sandstone - Carmel Formation contact.

2.1 162.1 Cross wash, pull off on right shoulder. **STOP 6**. The outcrop at road level is the Navajo Sandstone. Note the large scale, high-angle cross-beds and truncated dune tops. The drainage on the right is Skutumpah Canyon, and the road continues up Johnson Canyon. The Co-op Creek Member of the Carmel Formation sits on the white Navajo Sandstone. This erosional surface forms the Skutumpah Terrace. The olivine lava flow visible up Johnson Canyon, and upon which the road lies, is a disconnected flow from Bald Knoll, located approximately seven miles to the north.



Mile 162.1 Navajo Sandstone - Co-op Creek Member, Carmel Formation contact.

1.9	164.0	**STOP 7**. See the information kiosk at the junction of Johnson Canyon, Glendale Bench (left fork) and Skutumpah (right fork) Roads. The lava flow at 12:00 is part of the Bald Knoll flow. View the Gray Cliffs at 12:00. Examine the yellow to gray thin beds of the Co-op Creek Member of the Carmel Formation. Bear right on the Skutumpah Road toward Cannonville.
0.6	164.6	View at 9:00 to 11:00, Gray Cliffs composed of Dakota, Tropic Shale, and Straight Cliffs Formations. The valley is comprised of the Carmel Formation.
0.8	165.4	Take the right fork, toward Deer Springs Ranch.
1.2	166.6	Sand and gravel pit located adjacent to road in Quaternary alluvium is visible at 9:00. Also visible at 9:00, in the distance, are the Gray Cliffs. In this area, the Cretaceous Dakota Formation immediately overlies the Middle Jurassic Carmel Formation because the Middle Jurassic Entrada Formation, Upper Jurassic Morrison Formation, and the Upper Jurassic to Lower Cretaceous Cedar Mountain Formation have been removed by erosion. This gap in geological time is locally referred to as the sub-Dakota unconformity.
0.4	167.0	Junction Mill Creek Road on left. Continue on Skutumpah Road.
0.2	167.2	Paria River Member of the Carmel Formation at 10:00. This unit forms a series of light-gray knobs on the left side of the road. It contains both pink and white gypsum.
1.1	168.3	At 9:00, view a limestone bed in the upper Paria River Member of the Carmel Formation.
1.5	169.8	Junction Skutumpah Pasture and Timber Mountain roads.
4.0	173.8	Road cut in upper Carmel Formation.

Mile 173.8 Road cut in the upper Carmel Formation, Skutumpah Road.

0.4	174.2	View at 9:00 the upper Carmel (Winsor Member) to Dakota transition. At 1:00 view the Navajo Sandstone elevated here by a fault. Cross cattle guard, entering Deer Springs Ranch.
0.1	174.3	Cross Dunham Wash.
0.6	174.9	Junction. Keep left on main road, which passes through a cut in the Carmel Formation. The road to the right provides access to private property along Deer Springs Wash and to the Ranch.
0.3	175.2	Junction. Stay on main road. Gray Cliffs visible at 9:00.
0.6	175.8	Road cut in pediment gravels. The gravels here have been eroded from Upper Cretaceous sandstone formations and the basal Claron Formation, which makes up the hoodoos and spires of Bryce Canyon National Park.
0.1	175.9	Cross Meadow Creek. Pink Cliffs (Claron Formation) visible in the left distance.
0.8	176.7	Road proceeds up Dry Valley.
1.1	177.8	Road drops into Lick Wash and Podunk Creek.
0.4	178.2	**STOP 8**. Lick Wash. After crossing Lick Wash, an infrequently used road extends south (right). White to light-gray outcrops of the Navajo Sandstone are visible to the south. These are bounded by a northeast-trending fault with the downthrown block to the northwest (Doelling and others, 2000). The hill to the east of where we are parked shows yellow-gray, thin-bedded Co-op Creek limestone covered by red- and white-banded beds of the Crystal Creek Member of the Carmel Formation. The Crystal Creek Member is overlain by the buff to tan colored Thousand Pockets Tongue of the Page Sandstone. This is the western most exposure of the Thousand Pockets Tongue. Gypsum of the Paria River Member of the Carmel Formation directly overlies the Thousand Pockets Tongue, wherever the Thousand Pocket Tongue is present. The Paria River Member is overlain by the yellowish and reddish Winsor Member. Looking north from this location the Gray Cliffs, primarily composed of Dakota Formation rocks, are visible. Some pinkish coloration is present in these cliffs due to the natural burning and oxidation of thin coal beds in the Dakota. Under the gray is a harder yellow layer that is difficult to distinguish from the underlying Winsor Member beds. This hardened yellow layer is an erosional remnant of the Entrada Formation. The unconformity at the base of the Dakota cuts out the Entrada west of this location, so up until now, we have seen Dakota resting directly on the Winsor Member of the Carmel Formation. From this point eastward, the Dakota rests on the Entrada Formation. We will walk the upper portions of Lick Wash, a small slot canyon to the south. After the stop, the road log continues eastward on the main road.
1.0	179.2	On the right, outcrops of the Thousand Pockets Tongue rest on the Crystal Creek Member of the Carmel Formation. Gypsum of the Paria River Member overlies the yellow Thousand Pockets Tongue. Gray Cliffs continue on the left.
2.8	182.0	Cross Bullrush Hollow. Pink Cliffs visible at 9:00.
1.0	183.0	More gypsum of the Paria River Member exposed at 11:00.
1.2	184.2	**STOP 9**. Paria River Amphitheater Overlook at turn in road. In the middle ground to the north we see the Winsor Member of the Carmel Formation (a white to pink siltstone), which overlies the Paria River Member of the Carmel Formation, which in turn overlies the yellow Thousand Pockets Tongue of the Page Sandstone. The Thousand Pockets Tongue overlies red beds of the Crystal Creek Member of the

Carmel Formation, which overlies the Co-op Creek Member here in Indian Hollow. The Pink Cliffs exposed in the distance across the amphitheater are part of the Table Cliffs Plateau. The hill south of Table Cliff Plateau is Canaan Peak in the northern Kaiparowits Plateau. The flat benches ahead in the valley are various Carmel members capped with pediment gravels. After a brief stop we will continue driving down Indian Hollow, which starts in the Winsor Member of the Carmel Formation and stratigraphically descends to the Co-op Creek Member of the Carmel Formation.

1.0 185.2 Cross wash in the Co-op Creek Member. The road will be in this member for the next few miles.

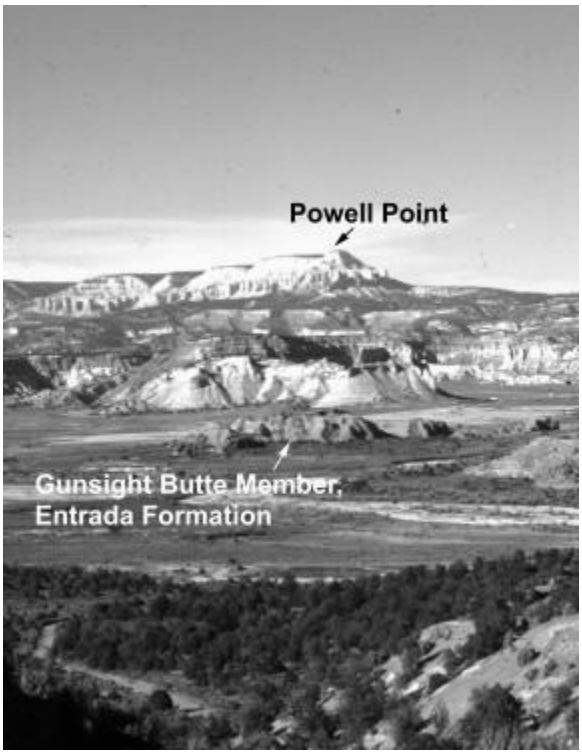
1.0 186.2 Cross wash. The yellow Thousand Pockets Tongue is visible ahead at 1:00 overlying the reddish or brownish Crystal Creek Member of the Carmel Formation.

0.9 187.1 The road joins the Bull Run drainage, affording more views of the various members of the Carmel Formation. The road continues in the Co-op Creek Member.

0.5 187.6 Note the thin gypsum beds in the Co-op Creek Member in the road cut at 9:00.

0.4 188.0 **STOP 10**. Cross Bull Valley Gorge, an impressive slot canyon in the top of the Navajo Sandstone. Park another 0.1 mile up the road. The Co-op Creek Member is at road level, overlain by the Crystal Creek Member of the Carmel and the Thousand Pockets Tongue of the Page Sandstone. After stop, continue on main road.

0.4 188.4 View at 12:00, Powell Point in the Pink Cliffs (composed of Claron Formation) and the underlying Gray Cliffs (composed of [descending stratigraphic order] the Kaiparowits, Wahweap, Straight Cliffs, Tropic Shale, Dakota, Entrada, and Carmel Formations).



Mile 188.4 Looking northeast at the Pink Cliffs and Powell Point.

1.3 189.7 Drop into Willis Creek drainage through the Thousand Pockets Tongue, Crystal Creek, and Co-op Members. Cross Willis Creek at Carmel Navajo Contact. Willis Creek cuts some modest (about half a mile long) narrows in the Navajo Sandstone just east of the crossing.

1.7 191.4 Climb out of the wash to **STOP 11**. We are parked on gypsum of the Paria River Member of the Carmel Formation. Walk to the canyon edge and view the Thousand Pockets Tongue across the canyon.

1.4 192.8 Road crosses Sheep Creek (concrete spillway), which lies in the lower members of the Carmel Formation. Thousand Pockets Tongue is visible above the drainage.

1.9 194.7 View at 12:00 of Powell Point. Looking into the Paria River Valley with the Carmel to Entrada transition visible at 12:00.

0.8 195.5 Grand Staircase - Escalante National Monument boundary.

0.1 195.6 Carmel to Entrada transition visible at 1:00 across Yellow Creek.

0.1 195.7 Cross Yellow Creek.

0.1 195.8 Turn left at stop sign toward Cannonville, Utah on asphalt.

0.3 196.1 Junction, stay on pavement toward Cannonville.

0.5 196.6 View at 3:00, half way up ledge of the contact between the Carmel Formation and the Gunsight Butte Member of the Entrada Formation.

Mile 196.6 Looking east at the Carmel Formation - Gunsight Butte Member, Entrada Formation contact.

0.6 197.2 Orange-brown slickrock at 3:00 is Gunsight Butte Member of the Entrada Formation, and is locally called Promise Rock. According to local folklore, it served as the site for many pioneer marriage proposals.

1.7 198.9 Entering Cannonville, Utah.

0.4 199.3 Junction with SR 12. Turn left toward Tropic, Utah. View at 12:00 is the Cannonville Member of the Entrada Formation and the overlying Escalante Member, Cedar Mountain and Dakota Formations.

Mile 199.3 Looking east at (in ascending stratigraphic order) the Cannonville and Escalante Members, Entrada Formation, and the Cedar Mountain and Dakota Formations.

2.2	201.5	View at 9:00 is the contact of the Dakota Formation and the overlying Tropic Shale. The Grey Cliffs occupy the view.
1.0	202.5	Entering Tropic, Utah.
1.2	203.7	View at 1:00 is the contact of the Tropic Shale and the overlying Straight Cliffs Formation. In the distance is Powell Point where the pinkish colored Claron Formation sits on the Kaiparowits Formation. Claron Formation at Powell Point shows the division of the lower pink and upper white members.
1.5	205.2	View at 3:00 of the contact between the Tropic Shale and overlying Tibbet Canyon Member of the Straight Cliffs Formation.
0.7	205.9	Trace of the Paunsaugunt fault at 3:00. Claron Formation on the left is on the downthrown block. The Paunsaugunt fault separates the Tropic Valley to the east from the sculpted buttress of the Paunsaugunt Plateau to the west. The fault passes through the center of Bryce Canyon National Park, which owes much of its existence to this fault. The spectacular hoodoos and fins carved into the pastel limestone and siltstones of the Claron Formation are preserved on the downthrown west side of the fault. The topographically low Tropic Valley on the upthrown east side of the fault seems illogical but its existence is due to the relative differences in erosion rates of the rocks on either side of the fault. On the upthrown block, the soft limestones and siltstones of capping Claron Formation and less resistant shales and sandstones of the underlying Cretaceous age rocks were quickly eroded and removed to form Tropic Valley. The Claron on the downthrown side of the fault is partially volcanic capped and has only experienced lateral erosion and gullying along the edge of the Paunsaugunt Plateau.
0.4	206.3	Pink member of the Claron Formation visible on both sides of the road. The Claron is a lacustrine (freshwater lake) limestone deposit.
2.1	208.4	View at 9:00 of Claron Formation hoodoos in the Bryce Canyon amphitheater.
0.7	209.1	View at 1:00 is the top of the Paunsaugunt Plateau with volcanics of the Mount Dutton caldera acting as a cap.
0.7	209.8	Junction of SR-62 with SR-12. Turn left to Bryce Canyon National Park.

2.4	212.2	Ruby's Inn at 3:00. Driving along the top of the Paunsaugunt Plateau, on top of the Claron Formation. We will spend the night here, at Ruby's Inn, and continue the road log tomorrow from this point.

End of Day 1 Road Log

Bryce Point overlook with the Table Cliffs plateau in the background.

Day 2

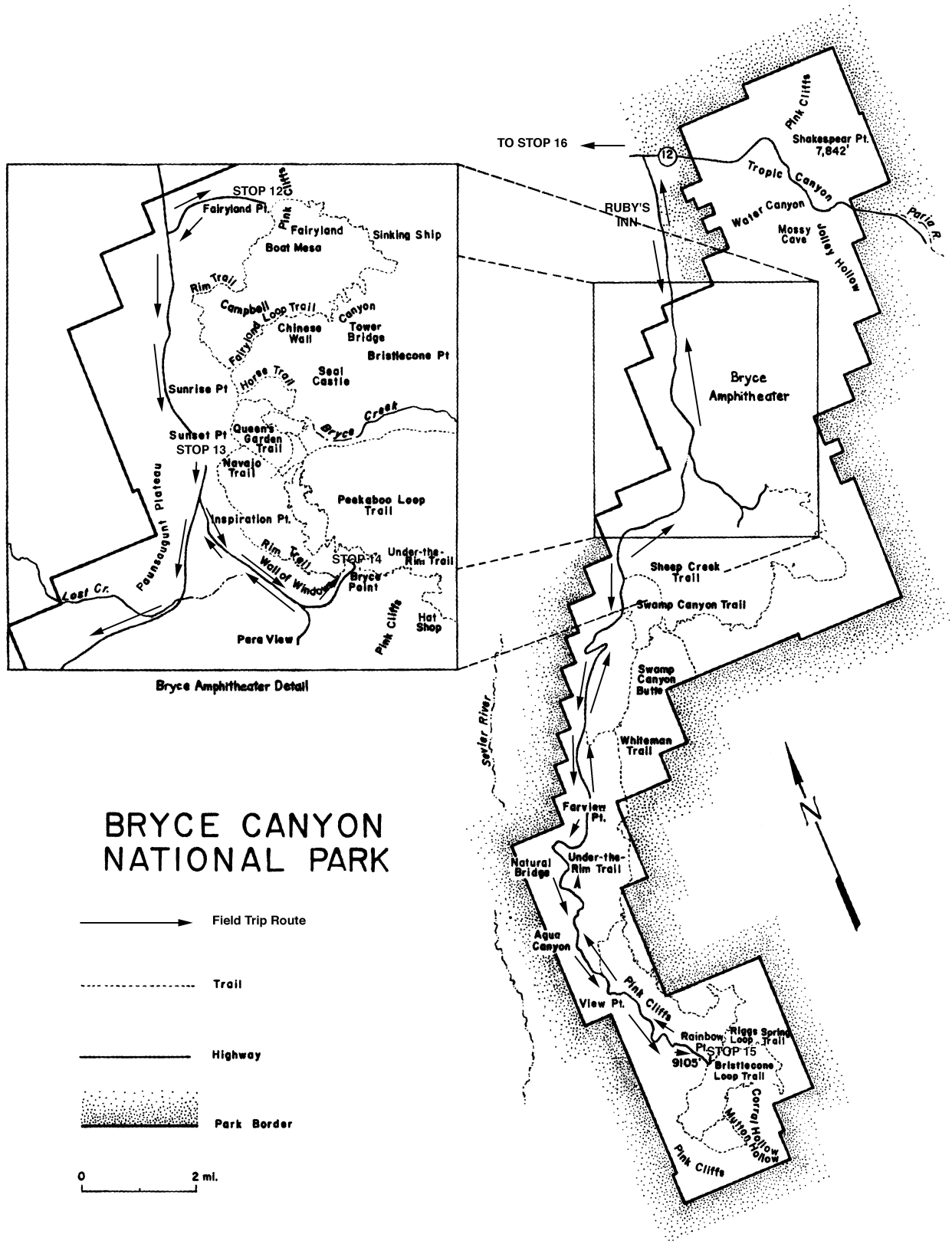


Figure 11. Sketch map of the field trip route for Day 2 (from Harris and others, 1997).

We will spend most of the day in Bryce Canyon National Park. The field trip will proceed south along the scenic drive to the Fairyland, Sunset Point, Bryce Point, Rainbow Point, and Yovimpa overlooks. These viewpoints will allow us to view the hoodoos and spires of the Claron Formation, and overlook much of the Skutumpah Terrace, the area we drove through yesterday. Once we leave Bryce Canyon, we will proceed west on SR-12, through Red Canyon to the Sevier fault scarp, and return to Cedar City via US 89 south and SR-14 west.

MILAGE

Interval	Cum	Description
0.0	0.0	Leave Ruby's Inn parking lot, turn left (south) toward Bryce Canyon National Park.
1.3	1.3	Entering Bryce Canyon National Park. Bryce Canyon National Park (BCNP) lies along the high eastern escarpment of the Paunsaugunt Plateau. Its special geological features include the rock chimneys (hoodoos), fins, and windows all carved by nature into the pink and white Claron Formation. BCNP is 56.2 mi^2 in area and has an elevation range of 7,600 to 9,100 feet. The earliest people in the area arrived approximately 12,000 years ago, but left little record of their existence. Paiutes were living throughout the region when the first Europeans arrived. Paiute legend refers to Bryce Canyon as "the ruins of a great city, buried in red mud and now partly excavated, the work of Shin-away, a Paiute demigod of great power. Before there were any Indians, the To-whon-an-ung-wa lived in that place. There were many of them. They were of many kinds - birds, animals, lizards, and such things - but they looked like people. They were not people; they had power to make themselves look that way. Because they were bad, Shin-away turned them all into rocks; some standing in rows, some sitting down, some holding on to others. You can see their faces, with paint on them just as they were before they became rocks. The name of that place is Angka-ku-wass-a-wits ['red-painted faces']" (Gregory, 1951, p. 17). Other Paiutes have called Bryce "Unka-timpe-was-wince-pock-ich", meaning 'red rock standing like men in a bowl-shaped recess.'
0.3	1.6	Turn left to Fairyland Point.
1.0	2.6	**STOP 12**. Fairyland Point parking, elevation 7,758 ft. Walk down the Fairyland Trail to observe cycles in the lower pink member limestone member of the Claron Formation.
1.0	3.6	Junction of Fairyland Point road and main park road. Turn left.
0.8	4.4	Entrance Station and Visitor's Center, Bryce Canyon National Park.
0.9	5.3	Entrance to Bryce Canyon lodge.
0.2	5.5	Entrance to Sunset Point. Turn left.
0.2	5.7	**STOP 13**. Sunset Point parking area. Good views of the upper, white member of the Claron Formation.
0.3	6.0	Junction of Sunset Point road and main park road. Turn left.
0.4	6.4	Entrance to Bryce Point. Turn left.
0.1	6.5	Road forks, turn right toward Bryce Point.
0.3	6.8	Road forks, turn left toward Bryce Point.
1.6	8.4	**STOP 14.** Bryce Point parking lot. Exit Bryce Point parking lot and return.

0.6	9.0	Bear right at Paria View fork.
1.2	10.2	Bear left at junction to Inspiration Point.
0.1	10.3	Stop sign. Bear left toward Rainbow Point.
0.1	10.4	Bear left to Rainbow Point. Stop at main park road and turn left. Driving on top of Claron Formation.
7.7	18.1	Turn for Farview Point. Do not turn. Continue 8 miles to Rainbow Point.
7.3	25.4	**STOP 15**. Rainbow Point parking lot. Take trail to Yovimpa Point. Overlook of Grey and White Cliffs to the south and the Skutumpah and Wygaret Terraces, over which we have just driven.
20.3	45.7	Return to Bryce Canyon Park entrance by same route. Junction of SR-63 and SR-12. Turn left on SR-12 west.
0.5	46.2	View at 3:00 of Tertiary Mt. Dutton volcanics. Another splay of the Sevier fault is apparent and expressed by the cliffs of the lower pink member of the Claron Formation at 11:00.
6.1	52.3	Entering Red Canyon, administered by the U.S. Forest Service. Lower pink member of the Claron Formation exposed on west side of Paunsaugunt Plateau.
1.6	53.9	Passing through two sharp ridges in the lower pink member of the Claron Formation.
1.7	55.6	View at 2:00, Claron Formation capped by Quaternary volcanics.
0.5	56.1	**STOP 16**. Looking north you can see an exposure of the Sevier fault on the west side of the Paunsaugunt Plateau. The fault is dipping steeply to the west and is normal. This segment of the Sevier fault has up to 3,000 feet of offset (Reber and others, 2001). The gray volcanics are andesite, and they dominate the visible hanging wall portion. The footwall is composed of Tertiary Claron Formation. Best and others (1980) date the volcanics in this road cut at 560,000 years.
2.5	58.6	Cross the Sevier River.
0.4	59.0	Junction of SR-12 and US 89. **END OF ROAD LOG**. Turn left to return to Cedar City, Utah.

GLOSSARY

Albite	A sodium-rich member of the plagioclase feldspar mineral group.
Alluvial	Of or pertaining to all deposits resulting from the operations of modern streams; including sediments laid down in riverbeds, flood plains, lakes and fans at the foot of mountain ranges.
Ammonite	One of a large, extinct, group of Mollusks (Class Cephalopoda) related to the living chambered nautilus.
Ammonoid	An inclusive term for all ammonite-like organisms (Goniatites, Ceratites, and Ammonites).
Bentonite	A clay formed from the decomposition of volcanic ash. The mineral has a great ability to absorb water and swell accordingly.
Biostratigraphic	Bodies of strata containing recognizably distinct fossils.
Biotite	A mineral, a dark brown, to green, member of the mica group.
Biozone	The fundamental biostratgraphic unit: defined by its fossil content.
Calcareous	Containing calcium carbonate (calcite).
Calcite	A mineral, calcium carbonate, $CaCO_3$.
Carbonaceous	Pertaining to, or composed largely of, carbon.
Caldera	A large depression typically caused by the collapse or ejection of the summit area of a volcano.
Chert	A compact, siliceous rock formed from cryptocrystalline varieties of silica (quartz).
Concretion	A nodular or irregular concentration of mineral constituents in sedimentary rocks; developed by localized deposition of material from solution, generally about a central nucleus.
Coquina	A coarse-grained, porous, variety of limestone chiefly made up of cemented shell fragments.
Cyclicity	Tendency of some sedimentary processes to repeat over time, resulting in repetitive, stacked strata.
Eolian	A term applied to the erosive action of the wind, and to deposits which are due to the transporting action of the wind.
Evaporitic	Climatic conditions leading to the formation of evaporates; sedimentary rocks formed by material deposited form solution during the evaporation of water.
Felsic	A general term applied to light-colored igneous rocks containing an abundance of feldspar and quartz.
Fluvial	A term referring to streams, stream action, and the deposits of streams.

Formation	The basic litho(rock)stratigraphic unit; a unit of strata that is mappable and that has distinctive upper and lower boundaries.
Intraformational conglomerate	A conglomerate developed by the breaking up of a partially consolidated bed and the incorporation of the fragments in new strata nearly contemporaneous with the original beds.
Intertonguing	A series of jagged pinchouts between laterally adjacent rock bodies; form in response to rapid changes in the shoreline.
Lacustrine	Produced by, or belonging to, lakes.
Lithology	The physical characteristics of rocks.
Marine	Of or belonging to, or caused by, the sea.
Marl	A calcareous clay, or intimate mixture of clay and particles of calcite or dolomite, usually fragments of shells.
Member	A subunit of the lithostratigraphic formation; multiple members make up a formation.
Molluscan	Of, or pertaining to, the phylum Mollusca.
Orogeny	The process of forming mountains, especially by folding and thrust faulting; an episode of mountain building, e.g., the Laramide orogeny.
Orthoclase	A potassium-rich member of the feldspar mineral group.
Oxidation	The loss of electrons by an element or ion, due to chemical interaction (weathering). So named because the elements commonly combine with oxygen.
Pangaea	The name proposed by Alfred Wegener for a supercontinent that existed at the end of the Paleozoic Era and consisted of all of Earth's landmasses.
Playa	The flat central area of an undrained desert basin.
Quartzite	A coarsely crystalline metamorphic rock consisting essentially of the mineral quartz.
Reduction	The gain of electrons by an element or ion, due to chemical weathering: contrasted with oxidation.
Regression	The opposite of marine transgression; the withdrawal of the sea from a continent or coastal area resulting in the emergence of land as sea level falls or the land rises with respect to sea level.
Resistant	Less susceptible to the forces of weathering and erosion. Resistant strata tend to form cliffs and rock faces.
Sabkha	A tidally produced salt flat.
Subaerial	Formed, existing, or taking place on the land surface; contrasted with subaqueous.

Subarkosic	A clastic sedimentary rock containing abundant quartz and lesser amounts of feldspar.
Topography	The physical features of a district or region, such as are represented on maps; the relief and contour of the land.
Transgression	Refers to the migration of a marine shoreline. The invasion of coastal areas or much of a continent by the sea resulting from a rise in sea level or subsidence of the land.
Unconformity	An erosion surface that separates younger strata from older rocks.
Volcanic arc	Mountains formed in part by igneous activity associated with the subduction of oceanic lithosphere beneath a continent. Modern examples include the Andes and Cascade Mountains.