Geology

OF

RED ROCK CANYON

STATE PARK

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GEOLOGY OF RED ROCK CANYON STATE PARK

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Location and Topography

Red Rock Canyon State Park (cover photograph) is located along U.S. Highway 281 just south of Hinton, in northeastern Caddo County, Oklahoma (Fig. 1). The park is dissected by a south-flowing tributary of Sugar Creek, which in turn flows south–southeast into the Washita River. The elevation of the highest point in the park is about 1,650 feet above sea level; that of the lowest point is about 1,450 feet above sea level. Red Rock Canyon itself is about 150 feet deep; locally, the vertical canyon walls and overhanging cliffs are as much as 60 feet high, but generally they are about 45 to 50 feet high.

Red Rock Canyon is only one of several beautiful canyons in northeastern Caddo County and extreme southwestern Canadian County. Some of the streams that have formed these canyons drain south into the Washita River, or into Sugar Creek, which also drains into the Washita; others drain northeast into the Canadian River.

Bedrock Geology of the Park

Red Rock Canyon is a beautiful canyon that has eroded into sandstone that is part of the Rush Springs Sandstone formation of Late Permian age (Fig. 2). The Late Permian extended from about 270 to 250 Ma (million years ago). (For definitions of geologic terms and names, see the Glossary, based in part on Bates and Jackson, 1987.) Most of the surface rocks in this part of Oklahoma are Permian; in general, if the rocks (and soil that has developed on the rocks) are red, they're Permian. Older to younger Permian formations are exposed from the northeast to the southwest, respectively, because the rock layers are tilted gently to the southwest, about 10–20 feet per mile, into the Anadarko basin. (The Anadarko basin is described more fully below in the section on Regional Geology.)

The total thickness of the Rush Springs Sandstone in the Hinton area is about 300 feet, and about 150 feet of the middle part of the formation is exposed in the park. The next older formation, the Marlow Formation, can be seen beneath the Rush Springs Sandstone along the stream that forms the canyon about 2 miles south of the park, and along Sugar Creek north of Binger. The upper part of the Rush Springs Sandstone and the overlying Cloud Chief Formation (Fig. 2) have eroded away in the area.

The Rush Springs Sandstone is reddish brown to orangish brown in color; it is mostly very fine grained to fine-grained sandstone, although layers of siltstone and thin layers of shale are present in places. The sandstone consists of small sand grains (0.06–0.25 mm in diameter), mostly of translucent quartz, but also of feldspar and some dark iron-magnesium silicate minerals. These sand grains are loosely cemented together by iron oxides, gypsum, and calcite. (The "cement" in sandstone is natural and consists of one or more minerals that precipitate or crys-

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tallize out of ground water that slowly moves through the rocks. At first, these minerals form a thin coating on individual sand grains. As minerals continue to precipitate from ground water, the coatings on adjacent grains grow together. In this manner, sand becomes sandstone.) In places, the cement is concentrated along fractures in the Rush Springs Sandstone, imparting a "webbed" appearance to some outcrops.

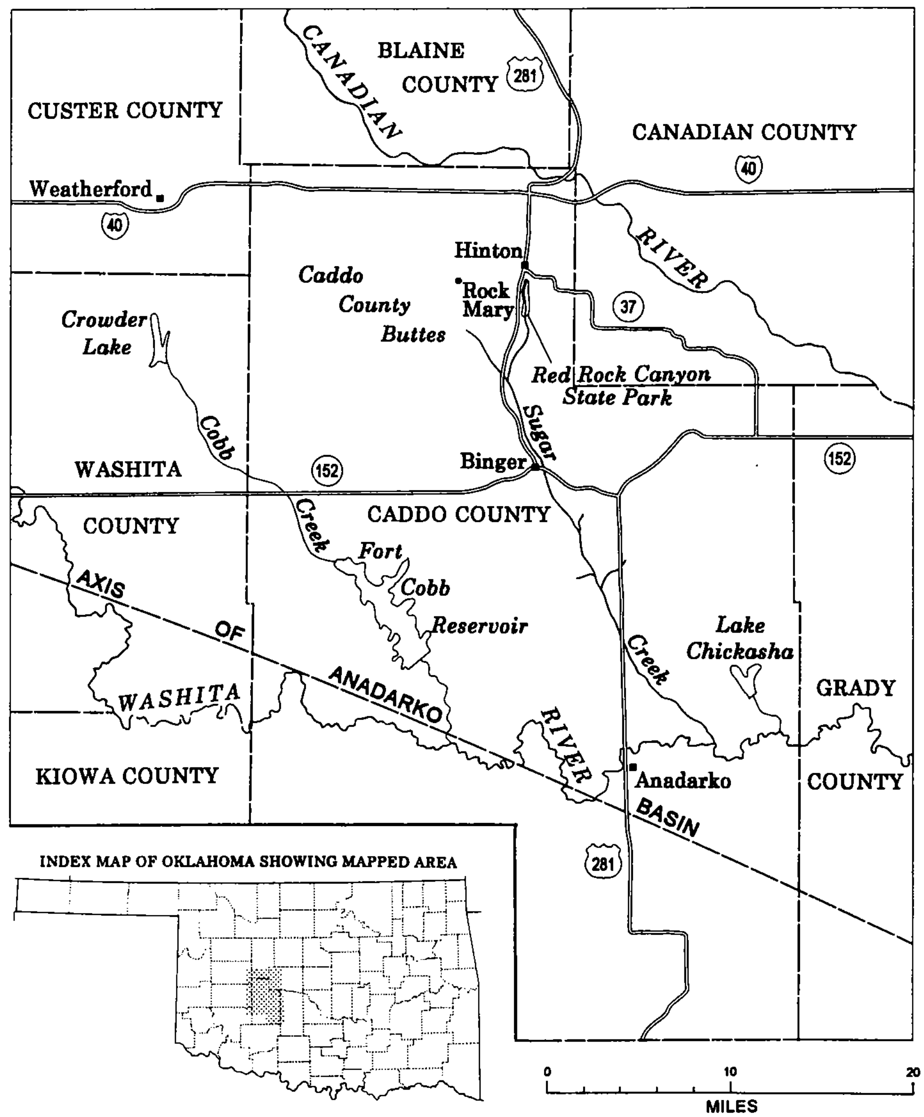

Figure 1. Map showing location of Red Rock Canyon State Park and local geologic features.

GENERALIZED STRATIGRAPHIC COLUMN

PERIOD/ EPOCH		FORMATION	FEATURES
PLEISTOCENE		"CANYON FILL"	*RED ROCK CANYON STATE PARK*
PERMIAN	UPPER	ELK CITY SANDSTONE	
		DOXEY SHALE	*HILLS WEST OF CLINTON*
		CLOUD CHIEF FORMATION	*CADDO BUTTES*
		RUSH SPRINGS SANDSTONE	*ROCK MARY*; *RED ROCK CANYON STATE PARK*
		MARLOW FORMATION	
		DOG CREEK SHALE	
		BLAINE FORMATION	*ROMAN NOSE STATE PARK*
		FLOWERPOT SHALE	
		DUNCAN SANDSTONE	
	LOWER	HENNESSEY GROUP	*OUTCROPS NEAR OKLAHOMA CITY*
		GARBER SANDSTONE	*ROSE ROCKS NEAR NOBLE*

Figure 2. Stratigraphic column showing relative ages of geologic formations near Red Rock Canyon State Park and local geologic features in these formations. The double line between "canyon fill" and Elk City Sandstone represents an unconformity—a break or gap in the geologic record separating rock units of very different ages.

Perhaps the most spectacular feature of the Rush Springs Sandstone is its red color. The color results from a thin coating of oxidized iron minerals (mostly hematite) that stains individual sand grains in the rock. Iron oxide generally makes up only 2–3% of the rock, but just a little red stain goes a long way in coloring a rock that consists mostly of otherwise colorless and translucent quartz grains. It is uncertain whether the sandstone in the Rush Springs Sandstone was red when it was

Figure 3. Two cross-bedded layers in the Rush Springs Sandstone in the canyon wall near Group Camp. These layers are in the lower, mostly non-cross-bedded part of the exposed sandstone. Note rock hammer (13 inches long) at lower right, for scale.

deposited, or whether the red color is due to chemical changes after deposition. Most geologists think that the sediment was red when deposited: the red color, salt, and gypsum in Permian-age sediments throughout the world is evidence for widespread arid conditions, and supports the theory that these sediments were oxidized (red-colored) before they were deposited. The red color extends back behind the canyon walls, and this formation, like most Permian formations, is red throughout western Oklahoma.

A feature of the Rush Springs Sandstone, which can be seen in the park as well as in other locations, is that the red rocks appear to be stained with vertical stripes of darker material. Most of these stripes are surface coatings of manganese dioxide (MnO_2), which form as a result of weathering. Some of the dark stripes in the canyon walls are encrustations of lichen (a plant composed of an alga and a fungus that rely on each other to live). The manganese stain and lichen tend to occur where water has seeped out of the sandstone and trickled down the canyon wall. Over time, the lichen breaks down the sandstone into sand, contributing to the erosion of the canyon walls.

Cross-bedding is another conspicuous feature of some of the sandstone beds in the Rush Springs Sandstone (Fig. 3). The cross-bedding is particularly evident in layers that are 3–10 feet thick and about 20–30 feet above the canyon floor (Fig. 4). This feature resulted from wind transport and deposition of sand grains when the Rush Springs Sandstone was being deposited in this part of Oklahoma. Although

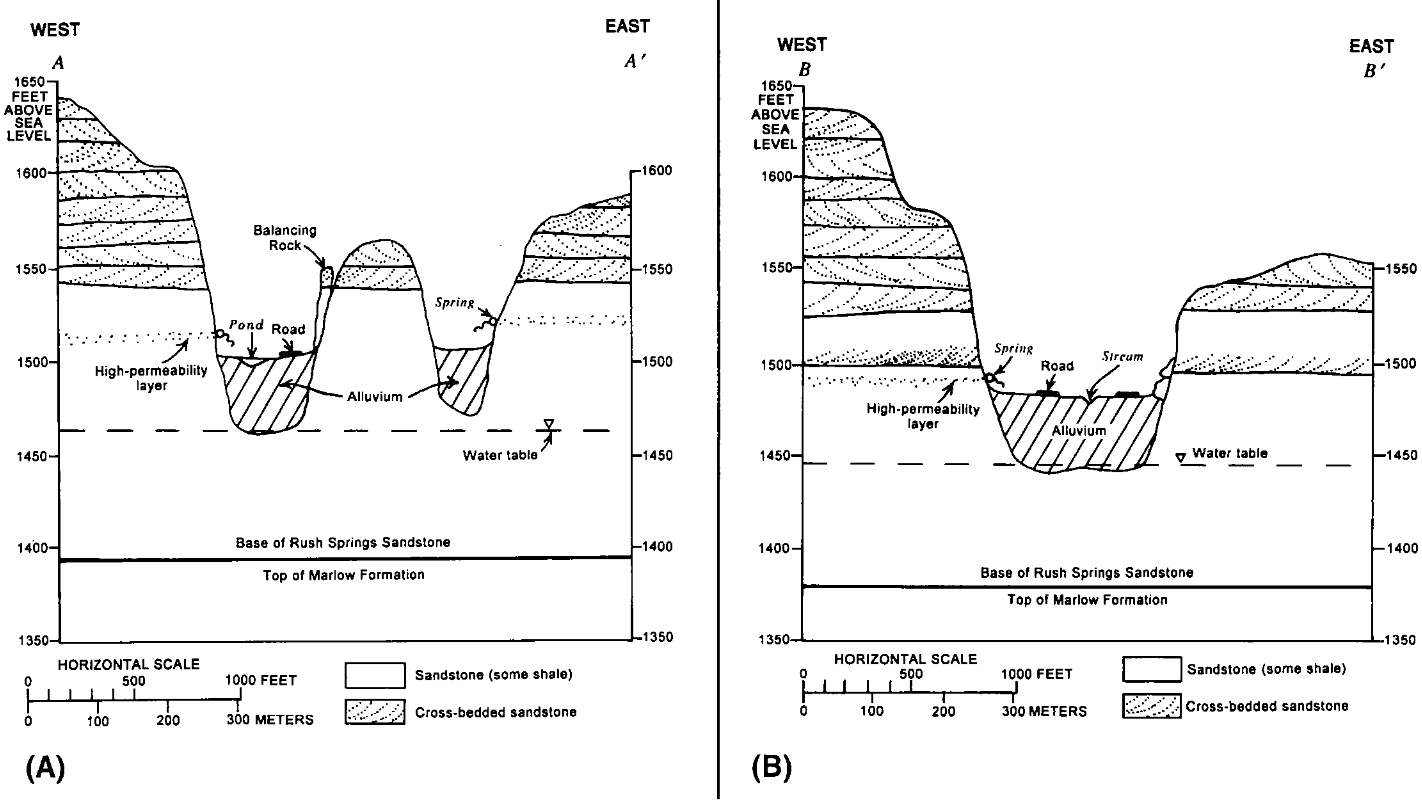

Figure 4. (A) East–west cross section across Red Rock Canyon State Park near Canyon Campground. (B) East–west cross section across Red Rock Canyon State Park near Group Camp. Both A and B show the canyon fill (alluvium) and features of the Rush Springs Sandstone. (Location of cross sections are shown in Figure 6.)

Figure 5. Cross-bedded sandstone layers along the California Road Nature Trail. The cross-bedding in the sandstone makes the rock layers appear steeply tilted. Regionally, however, the Rush Springs Sandstone in Red Rock Canyon is nearly horizontal.

the sand grains were transported to the park area by streams (see section on Geologic History), sediments in the cross-beds (exposed in the upper part of the canyon walls) were reworked during, and shortly after, deposition. A series of sand dunes were created and they migrated across the area, in the same way that sand dunes are now forming and migrating at Little Sahara State Park, near Waynoka. The cross-bedded layers are well exposed in cross section in the upper canyon walls and in three dimensions in the bare, bedrock exposures above and back from the canyon walls (Fig. 5).

Geomorphology of the Park—Canyon Cutting and Filling

Red Rock Canyon is about 2½ miles long and averages 80 feet wide at its head and 750 feet wide at its mouth. In the northern part of the park, the canyon walls are vertical to overhanging. Downstream, toward the southern end of the park, the canyon walls are steep but no longer vertical. Farther downstream, they become less steep and eventually lose their character as walls altogether, where the soft, more easily eroded Marlow Formation is exposed.

The physiography of the park can be divided into three areas: the upland prairie, the box-head area, and the canyon. The upland prairie consists of fairly level to gently rolling farmland and is the dominant landform in west-central Oklahoma. The rolling farmland can be observed as you approach the park from any direction.

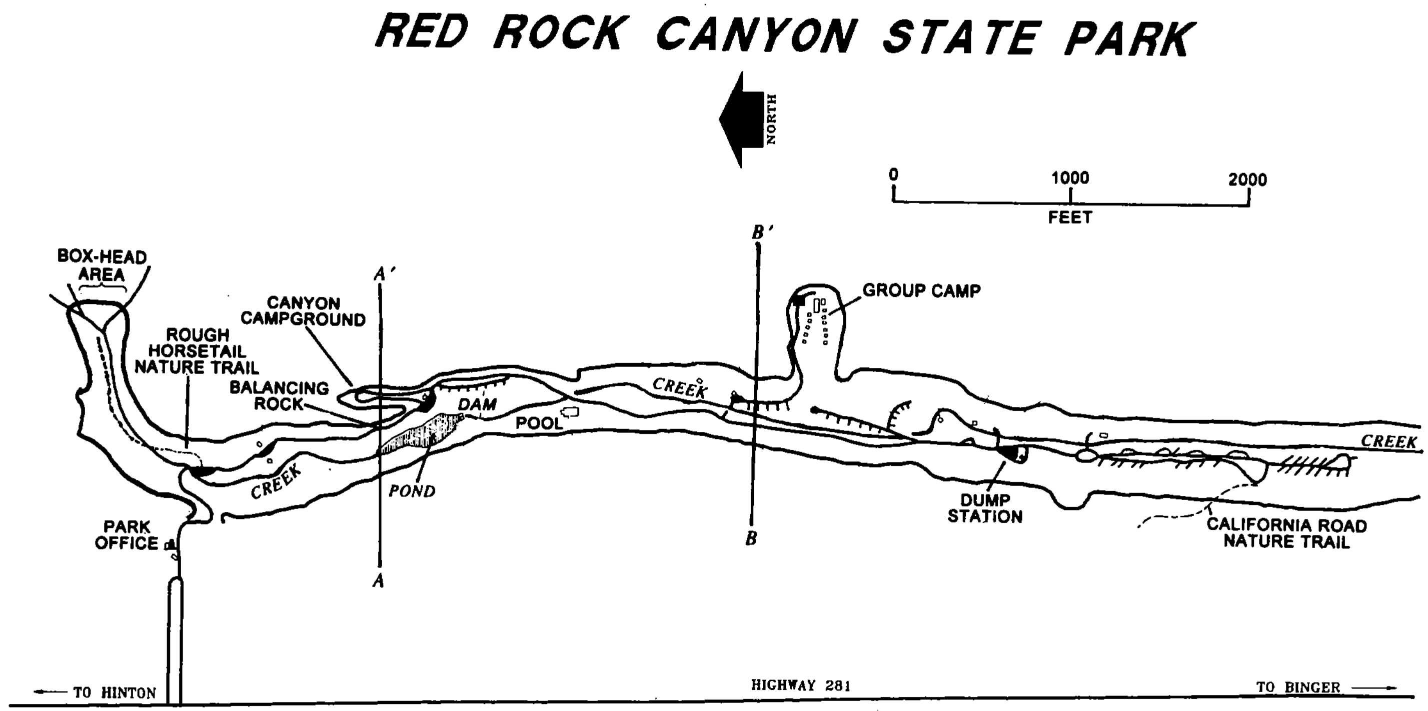

Figure 6. Map of Red Rock Canyon showing features mentioned in text and locations of the two cross sections depicted in Figure 4.

Figure 7. One of the box-heads at the end of Rough Horsetail Nature Trail. The V-shaped notch and vertical to overhanging cliff are characteristic features of box-heads.

In the park, itself, the upland prairie occurs between the canyon rim and the park boundary.

The box-head area of Red Rock Canyon can be seen at the end of the Rough Horsetail Nature Trail, at the northern end of the park (Fig. 6). It actually is three box-heads at this site, each of which consists of a vertical to locally undercut, semicircular cliff; a V-shaped notch at the top of each cliff is the present-day stream channel (Fig. 7). Beneath each box-head, a plunge pool is excavated below the general level of the soft sediments that fill the canyon. Two other box-heads have developed elsewhere in Red Rock Canyon State Park, each where a major stream enters the canyon from a side. One is at the head of the Canyon Campground facility and the other is at the head of the Group Camp facility (Fig. 6). Like those at the end of the nature trail, their cliffs are semicircular in outline, have varying degrees of steepness, and show the characteristic V-shaped notch at the top. Box-heads are a characteristic feature of most of the canyons that are eroded into the Rush Springs Sandstone near the park. The origin of box-heads is described in the section on Geologic History.

The physiography of the canyon, itself, can be discussed in terms of the canyon walls, valley floor, and drainage system. The walls of Red Rock Canyon range in height from a few feet to 60 feet, but generally they are 45–50 feet high. In places, the walls are vertical and nearly planar, which suggests that joints or natural fractures partly controlled the location and direction of the canyon. Just north of the spire named Balancing Rock (Figs. 4A, 8), large vertical joints can be seen in the canyon wall. Eventually, these joints will widen, perhaps forming another spire, which ultimately will collapse, thus widening the canyon. In other places, the walls are vertical to overhanging and curviplanar ("scalloped" in appearance). The curved segments are concave towards the valley and are separated by cusps. The curved parts of the canyon walls probably were eroded by a meandering stream during a time when the canyon was not as deep as it is now. Small, hollow pockets that follow distinct layers within the sandstone high on the canyon walls may be evidence for such stream erosion; or, the pockmarks may merely follow more easily eroded rock layers in the Rush Springs Sandstone. The concept that Red Rock Canyon is currently undergoing a period of erosion, and may have undergone repeated episodes of erosion, filling, and re-erosion, is explained more fully in the section on Geologic History.

Figure 8. Balancing Rock. Erosion and widening of a nearly vertical joint in the canyon wall has formed this feature. Eventually, this spire will collapse and the sandstone rubble will erode to sand that will be carried out of the canyon. In this way, the canyon is gradually widened.

The valley floor of Red Rock Canyon is relatively flat and consists mostly of very fine grained to fine-grained sand derived entirely from erosion of the nearby Rush Springs Sandstone. In places, terraces of canyon-fill material lie above the general level of the valley floor; in other places, there are large spires (for example, Balancing Rock) and piles of broken blocks of sandstone. Locally, the vertical canyon walls meet the valley floor quite abruptly, which suggests that the canyon walls actually extend below the level of the alluvium in the canyon. In other words, Red Rock Canyon actually is deeper than it appears, but it is partly filled with sediment. Borings through the alluvium that partly fills the canyon have proved that the bedrock floor of Red Rock Canyon is about 20–50 feet below the present surface of the canyon fill; the average depth to bedrock is about 40 feet (Fig. 4). The borings also showed that the bedrock floor of the canyon is gently curved to flat.

The small stream that flows through Red Rock Canyon is fed by many perennial natural springs that seep through the sandstone of the Rush Springs Sandstone (see section on Hydrology). During and following rainstorms, additional water is supplied via surface runoff to the main stream and tributary streams. During periods of particularly heavy rainfall, the stream can overflow its banks, close the road into the park, and cause considerable damage.

One question that often is asked is why the direction (orientation) of the Canadian River differs from that of Red Rock Canyon. The answer relates to the age of the river in contrast to that of the canyon. The generally eastward direction of flow of most of the major rivers in Oklahoma, including an ancestral Canadian River, probably was established in the Early Tertiary (from about 67 to 50 Ma), during uplift of the Rocky Mountains. This uplift imparted an eastward tilt to the land surface throughout western Oklahoma. In places where they encounter easily eroded rocks, the rivers are deflected from the generally eastward direction of flow. In contrast, the southerly to southwesterly direction of Red Rock Canyon is the result of erosion during the much more recent Pleistocene (less than about 2 Ma) (see section on Geologic History) and is due largely to the tilt of the rocks into the Anadarko basin. On a more local scale, the remarkably straight courses of Red Rock Canyon and the several canyons near it may be caused by streams following natural joints or fractures in the rock.

Hydrology of the Rush Springs Sandstone

The sandstone in the Rush Springs Sandstone has only a small amount of natural mineral cement between the sand grains. As a result, it is very porous and permeable, which enables water to soak into the sandstone very rapidly; thus, the rock unit is an excellent ground-water aquifer. The Rush Springs aquifer in the Hinton area is recharged entirely from precipitation. Water percolates down through the soil or bedrock until it reaches the water table and thus replenishes the aquifer. As it percolates downward, some of the water encounters local, thin sandstone beds of especially high permeability; in these beds, the water flows laterally to canyon walls, where it is emitted as springs and seeps.

Ground water produced from local wells is of high quality; that is, a liter of water contains less than 500 mg of total dissolved solids. Well yields also are high: 100–500 gallons per minute. The water table probably was near the level of the canyon floor when Native Americans and early pioneers entered the area. A series of springs in the canyon made it a good campground and a welcome stop for travelers along the nearby trail, the California Road (Fig. 6).

Ground-water seepage is seen locally in the canyon walls where small clumps of vegetation grow due to extra moisture. In places, the thicker vegetation may follow a more permeable and water-charged sandstone bed. Above the canyon, vegetation can be seen growing along joints or fractures in the sandstone, because rainwater tends to accumulate and remain there. Also, a thin white mineral crust is present locally where mineralized ground water seeps to the walls; when the water evaporates, it leaves behind principally the minerals calcite, gypsum, and/or thenardite. Lichen, mosses, and algae also occur locally as organic encrustations on the rock surface.

Regional Geology of the Red Rock Canyon State Park Area

Most of the surface rocks in this part of Oklahoma are Permian in age. As you travel east, the rocks generally are progressively older; for example, the rocks near Oklahoma City, which are part of the Hennessey Group and the Garber Sandstone, are Early Permian in age (deposited between about 290 and 270 Ma) (Fig. 2). To the west and southwest of Red Rock Canyon, the rocks are slightly younger. The beautiful reddish-brown hills about 10 miles west of Clinton along Interstate 40 are formed by erosion of the Doxey Shale, which overlies (and therefore is younger than) the Rush Springs Sandstone (Fig. 2).

The rocks at the park are tilted gently to the southwest, toward the axis of the Anadarko basin (Fig. 1). The Anadarko basin is a major tectonic feature in Oklahoma, although it doesn't appear that way on the surface. It is one of the deepest sedimentary basins in the world, and as much as 40,000 feet of sedimentary rocks accumulated in it. The axis, or deepest part, of the basin in western Oklahoma extends southeast from Elk City, through Cordell and Fort Cobb.

The Anadarko basin is a prolific oil- and gas-producing province. Five wells were drilled within 2,000 feet of Red Rock Canyon State Park in the 1980s; the deepest is 13,380 feet deep. All produce oil and gas from Pennsylvanian-age sandstones that are at depths of about 10,000–13,000 feet. These sandstones were deposited about 315 Ma and are considerably older than the Permian rocks exposed at the surface. Pennsylvanian rocks are exposed in much of eastern Oklahoma, beginning just east of Shawnee (on Interstate 40).

There are several other interesting surface geological features near Red Rock Canyon State Park. Rock Mary, located about 4 miles west–southwest of Hinton, is an outcrop of Rush Springs Sandstone capped by a thin, unnamed layer of gypsum (Figs. 1, 9). A plaque on the top of Rock Mary reads:

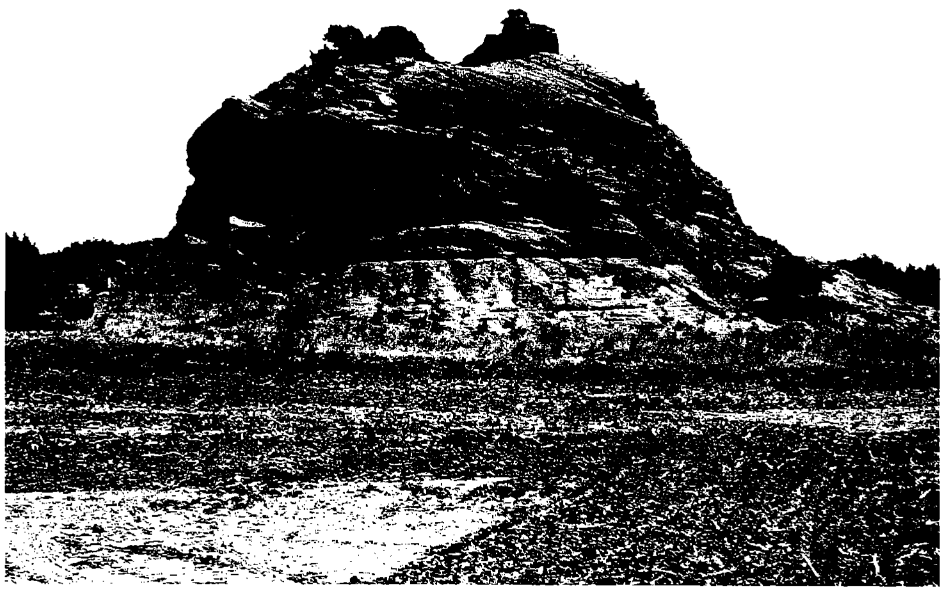

Figure 9. Rock Mary, located about 4 miles west–southwest of Hinton, is an outcrop of Rush Springs Sandstone capped by a thin layer of gypsum. Rock Mary is adjacent to the California Road and was a familiar landmark for emigrants traveling west during the gold rush.

May 23, 1849. This odd and unusual land feature was named on that date by Lieuts. J. H. Simpson and M. P. Harrison when they visited this site, planted a flag on the crest and named the rock for 17-year-old belle Mary Conway, an emigrant. Oklahoma Historical Society, 1960.

Caddo County Buttes cover a large part of northwestern Caddo County (Fig. 1). The buttes are capped by a thin, but locally hard, rock unit called the Weatherford Bed, which lies within and just below the top of the Rush Springs Sandstone. Locally the Weatherford Bed is gypsum, but in many parts of northwest Caddo County it is dolomite. Because dolomite is more resistant to weathering than the surrounding gypsum or underlying sandstone, it forms buttes in those places where it occurs. Eventually, however, the dolomite will erode and the buttes will disappear.

Geologic History of Red Rock Canyon State Park

Geologists can describe, although not always with total agreement, part of the geologic history of Red Rock Canyon State Park. By looking at the surface exposures (the Rush Springs Sandstone and those formations above and below it), they can piece together the history of west-central Oklahoma during Permian times. Similarly, by looking at the sediments that fill Red Rock Canyon, as well as other canyons in the area, geologists can infer something about when and how the canyon was eroded and later filled. (The geologic history of western Oklahoma before the Permian can be determined by looking at the rocks encountered in oil and gas wells; we will not attempt to describe that story here.) What happened between the end of the Permian Period and the time that the canyons were cut (between about 250 and 2 Ma) is unknown—all rocks and sediments deposited during that long time period have eroded away, if they ever were present at all. The evidence is gone (Fig. 2).

In Permian time, an extensive, relatively shallow seaway extended north from western Texas across the western half of the southern Midcontinent, including western Oklahoma (Fig. 10). This sea was bordered on the west by the ancestral Rocky Mountains (precursors to the present-day Rocky Mountains) and on the east by the Ouachita Mountains and Ozark uplift. Several kinds of marine rocks were deposited in the Permian sea, mostly evaporites (halite, gypsum, anhydrite, and dolomite), and some shale. Sand was deposited along the eastern edge of the sea as deltas; these deltas formed where rivers originating in the Ouachitas and Ozarks entered the Permian sea. At times, the area covered by the sea expanded, and marine rocks were deposited over a large area. At other times, the sea shrank, and sand from deltas covered the previously deposited evaporites. In places, the sand was reworked by the wind and formed sand dunes. The Rush Springs Sandstone in the park shows this mixture of stream- and wind-deposited material. The marine muds were compressed and cemented to form shale, and the deltaic and windblown sands became sandstone. The Permian sea expanded and shrank repeatedly, resulting in a complex interbedding of marine evaporites, shale, and sandstone. As time progressed, the Rush Springs Sandstone was buried by younger sediments.

Red Rock Canyon, itself, is much younger than the Permian rocks exposed in its walls (Fig. 2). Geologists know that the present-day small stream in the canyon bottom is not capable of cutting such a large canyon; clearly, the stream must have been much larger at one time. This suggests that Oklahoma had a wetter climate at some time in the past. Most likely, this time period was the Pleistocene Epoch (the Ice Age). The continental glaciers that once covered much of North America never

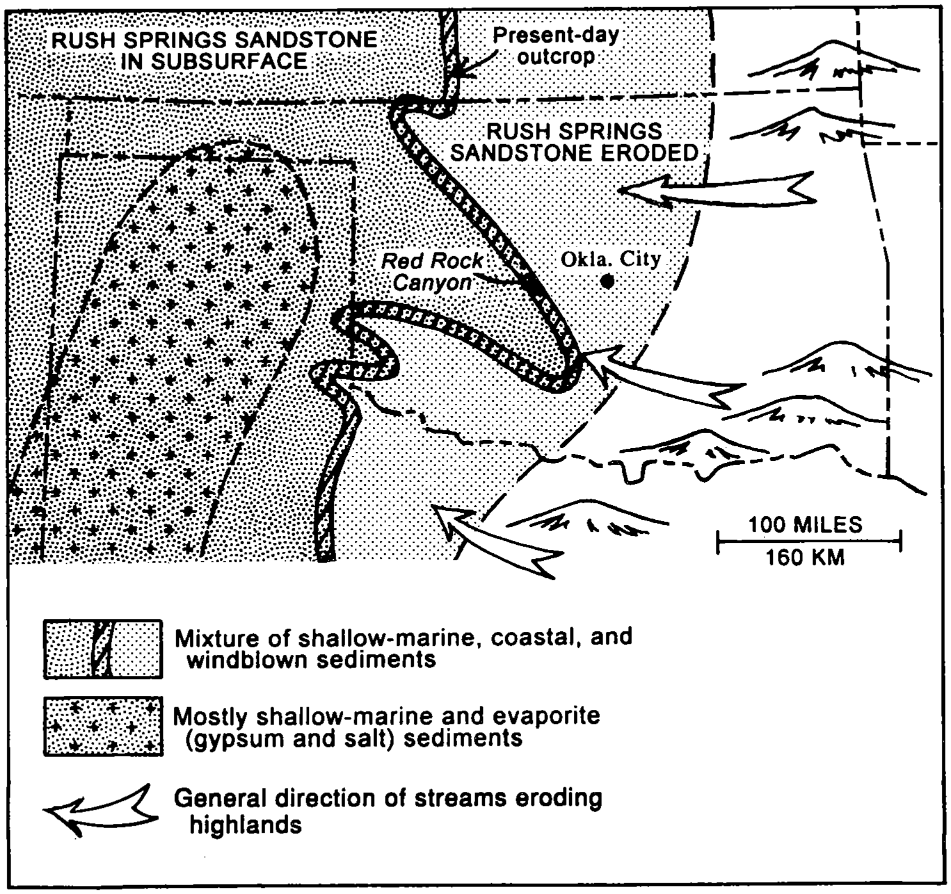

Figure 10. Paleogeographic map of Oklahoma in the Permian, when the Rush Springs Sandstone was being deposited. The stippled area shows the probable extent of the Permian sea. The Rush Springs Sandstone has been eroded east of the present-day outcrop, and the eastern margin of the sea can be located only very approximately.

extended into Oklahoma; they came only as close as the northeast corner of Kansas. However, the climate in the Rock Red Canyon area undoubtedly reflected the glacial periods. The average temperature was cooler, summers were shorter, and the amount of precipitation was greater than today.

Geologists agree that the canyon was cut by a process known as headward erosion. During the Pleistocene, streams (larger than those today) cut channels as they flowed down the south-sloping Rush Springs Sandstone. When water flowed over softer rocks, like the underlying Marlow Formation or shales within the Rush Springs, it eroded them more quickly and the stream channels steepened. A "knickpoint" formed where, during storms or other periods of high rainfall, water would rush over the southern edge of outcrops of sandstone in the Rush Springs. At first, the knickpoint probably was a short series of rapids. Over time, the relatively soft shale at the foot of the rapids eroded and the rapids developed into a waterfall. Subsequent floods continued to erode the shale at the base of the waterfall; undercutting resulted and large sections of sandstone collapsed, broke down, and eventually were carried downstream as individual sand grains. Then, the whole cycle of erosion, undercutting, and collapse started over. In this way, the waterfall migrated upstream, a process known as headward erosion. The site of the waterfall is called a box-head.

Geologists disagree, however, on exactly when canyon cutting began. Some think that it began during the first glacial period, known as the Nebraskan Stage, about 1 Ma. (The four glacial stages of the Pleistocene Epoch lasted from 1 Ma to about 10,000 years ago; each glacial stage was followed by a warm interglacial stage.) A precursor to Red Rock Canyon was cut by headward erosion, but later was filled by sediment and largely buried during the subsequent interglacial stage. The sediment that filled the canyon compacted slightly relative to the bedrock on either side of the canyon. This caused a minor depression to form over the filled canyon, setting the scene for a period of renewed canyon cutting and headward erosion during the next (Kansan) glacial stage. The canyon that was eroded during the Kansan glacial stage was at about the same site as the older Nebraskan canyon, but it was slightly deeper and longer. The Kansan canyon was filled during the subsequent interglacial, only to be re-eroded, deepened, and lengthened during the later Illinoian glacial stage. It was refilled during the next interglacial, and eroded, deepened, and lengthened during the last (and most recent) glacial stage, the Wisconsinan. Red Rock Canyon subsequently was partly filled by sediments (canyon fill); currently it is undergoing a period of mild erosion.

Other geologists are not convinced that canyon cutting began during the Nebraskan glacial stage; rather, they think that most of it occurred during the Wisconsinan, or Illinoian, at the earliest (within the last 115,000 years). Unfortunately, the process of canyon cutting, itself, removes the evidence geologists need to determine with certainty when it occurred. Thus, unless uneroded remnants of the older valley fills can be found, opinions about the geologic history of Red Rock Canyon probably will continue to differ.

Sources of Information

Much of the information presented in this brief overview of the geology of Red Rock Canyon State Park is based on the published and unpublished (mostly student theses) reports listed in the References Cited section. Four of these reports were particularly helpful and we have used them extensively: Howery (1960) and Trapnell (1961) provide excellent descriptions of the regional geology; Norris (1951) has studied the geology, particularly the Pleistocene geology, of Red Rock Canyon; and Johnson and others (1988) describe the physical setting of Oklahoma in the Permian. We have borrowed extensively from these authors. Reports on other aspects of the regional geology near Red Rock Canyon State Park include Ireland (1949), Branson and others (1962), Vining (1963), Bond (1968), and Carr and Bergman (1976).

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Glossary

alluvium—a general term for unconsolidated material (for example, silt or sand) deposited during recent geologic time by a stream or other body of running water.

Anadarko basin—a large sedimentary basin in western Oklahoma. It formed mostly during the Pennsylvanian Period (from about 330 to 290 Ma). Sedimentary rocks in the Anadarko basin are as much as 40,000 feet thick; equivalent rock strata are much thinner to the northeast and southwest outside the basin.

anhydrite—a mineral, $CaSO_4$, similar to gypsum but without water in the crystal structure. Anhydrite commonly is associated with gypsum and halite in evaporite deposits.

aquifer—a permeable rock or deposit that is water-bearing.

bedrock—a general term for the rock, usually solid, that underlies soil or other unconsolidated, superficial material.

box-head—the upper end of a steep-walled canyon that is closed upstream with a similar wall; a "dead-end" canyon.

butte—a conspicuous, usually isolated, generally flat-topped hill or small mountain that has relatively steep slopes or precipitous cliffs, and often is capped with a resistant layer or rock; it represents an erosional remnant carved from flat-lying rocks.

calcite—a common rock-forming mineral, $CaCO_3$. It is the principal constituent of limestone and commonly is the principal cement of sandstones.

cement—chemically precipitated mineral material that occurs in the spaces between the individual grains of a sedimentary rock, thereby binding the grains together. It may be derived from the sediment or its entrapped waters, or it may be brought in by solution from outside sources.

Cloud Chief Formation—a formation of Permian age, composed mostly of reddish-brown shale and minor siltstone, sandstone, dolomite, and gypsum. It underlies the Doxey Shale and overlies the Rush Springs Sandstone.

Cretaceous—the final period of the Mesozoic Era ("age of the dinosaurs"); it extended from about 140 to 67 Ma.

crop out—see *outcrop.*

cross-bedding—the internal arrangement of the layers in a sedimentary rock, usually sandstone, in which minor beds are more or less regularly inclined at various angles (typically 10°–40°) to the principal layers in the rock. Cross-bedding is produced when the sediments are deposited by a moving current of air or water.

cross section—a diagram or drawing that shows geologic features as if viewed in the vertical plane. A "cut-away" drawing of surface and subsurface features.

delta—the low, nearly flat area of land consisting of sediments deposited at or near the mouth of a river, perhaps extending beyond the general trend of the coast, and resulting from the deposition of sediment supplied by a river where it enters a larger body of water (usually a sea or lake).

dolomite—a sedimentary rock consisting mostly of the mineral dolomite, $CaMg(CO_3)_2$, formed from dolomite muds and fossil fragments or, more commonly, by alteration of limestone.

Doxey Shale—a formation of Permian age that is mostly reddish-brown shale and siltstone. It underlies the Elk City Sandstone and overlies the Cloud Chief Formation.

erosion—the natural processes of weathering, disintegration, dissolving, and removal of rock and earth material, mainly by water and wind.

evaporite—the general name for a sedimentary rock composed of minerals that precipitated out of a saline solution that became concentrated by evaporation. Evaporites often form in restricted or enclosed bodies of seawater or in salt lakes. Examples are gypsum and rock salt (halite).

feldspar—a common rock-forming mineral of the general formula $MAlSi_3O_8$, where M = K, Na, or Ca. Feldspars make up 60% of the Earth's crust.

formation—a formal unit in the classification of rocks that allows geologists to map, describe, and interpret the geology of an area. A rock unit usually is given a formation name if all the rocks in that unit are similar, contain similar fossils, or show the same repetitions of different kinds of rocks. Formations can be combined into groups or subdivided into members.

fracture—a general term for any crack or break in a rock, whether there has been movement along that break (in which case, it is called a fault) or not.

Garber Sandstone—a formation of Permian age in central Oklahoma that is mostly orangish-brown to reddish-brown sandstone and minor shale. It is a major aquifer for Oklahoma City and surrounding cities and locally contains barite rosettes (rose rocks, Oklahoma's State Rock).

geologist—a scientist who practices or participates in geology.

geology—the study of the planet Earth, including the origin of the planet; the material and morphology of the Earth; the history of the planet and its life forms; as well as the processes that acted (and act) upon the Earth to affect its historic and present landforms.

geomorphology—the science that treats the general configuration of the Earth's surface, especially the development of present landforms and their relationship to local geology.

glacial—pertaining to the presence and activities of ice or glaciers.

ground water—that part of subsurface water that is in the zone of saturation, in which all the spaces between rocks and the particles that make up the rocks are filled with water.

gypsum—a sedimentary rock consisting of the mineral gypsum, $CaSO_4{\cdot}2H_2O$, formed by chemical precipitation from evaporating seawater. The mineral gypsum forms a cement in some sandstones.

halite—a mineral, NaCl; large deposits or rock layers of halite are called salt or rock salt.

headward erosion—the lengthening and cutting back upstream of a valley or gully, caused by erosion of the upland at the head of the valley.

hematite—a common iron mineral, Fe_2O_3. It often occurs in deep red or reddish-brown earthy forms, and is the main source of red color in rocks.

Hennessey Group—several formations of Permian age in central Oklahoma that consist mostly of reddish-brown shale, siltstone, and sandstone. The Hennessey Group overlies the Garber Sandstone and underlies the Duncan Sandstone.

hydrology—the science that deals with continental water, its properties, circulation, and distribution, on and under the Earth's surface and in the atmosphere. In recent years the scope of hydrology has been expanded to include environmental and economic aspects.

Illinoian—pertaining to the third glacial stage (of four) of the Pleistocene Epoch in North America, beginning about 115,000 years ago. It is named after excellent deposits in Illinois left by glaciers of that time period.

interglacial stage—a subdivision of a glacial epoch separating two periods of glaciation, characterized by a relatively long period of warm or mild climate.

iron oxide—a general term referring to weathered iron minerals. Hematite is a common iron oxide mineral and forms the cement of many red sandstones.

joint—a fracture in rocks along which no movement has occurred.

Kansan—pertaining to the second glacial stage (of four) of the Pleistocene Epoch in North America, beginning about 400,000 years ago. It is named after excellent deposits in Kansas left by glaciers of that time period.

knickpoint—a point of abrupt change or inflection in the profile of a stream or its valley; generally forms where a rock that is not easily eroded crops out.

Ma—abbreviation for "millions of years" or "millions of years ago."

Marlow Formation—a formation of Permian age, composed mostly of orangish-brown sandstone, siltstone, and shale, about 120 feet thick; contains two gypsum and/or dolomite beds near the top. It underlies the Rush Springs Sandstone and overlies the Dog Creek Shale.

meandering—said of a stream or river that has regular, tightly curved bends, loops, turns, and windings.

Nebraskan—pertaining to the first glacial stage (of four) of the Pleistocene Epoch in North America, beginning about 1,000,000 years ago. It is named after excellent deposits in Nebraska left by glaciers of that time period.

outcrop—that part of a geologic formation that appears at the Earth's surface. The verb to "crop out" means to appear exposed and visible at the Earth's surface.

paleogeography—the study and description of the geography of the Earth in the geologic past, such as the historical reconstruction of the Earth's surface or of a given area at a particular time in the geologic past.

Pennsylvanian—a period of the Paleozoic Era; it extended from about 330 to 290 Ma. Most of the rocks that crop out in eastern Oklahoma are Pennsylvanian in age.

permeable—said of a porous rock that easily transmits a fluid, such as water or oil. A rock can be porous but not permeable if the pore spaces between the grains are not connected.

Permian—the last period of the Paleozoic Era; it extended from about 290 to 250 Ma. Most of the rocks that crop out in western Oklahoma, especially those that are red, are Permian in age.

physiography—the description of landforms. It is similar in meaning to geomorphology, except that physiography is descriptive, whereas geomorphology is interpretative.

Pleistocene—an epoch of the Quaternary Period, which is the most recent period of the Cenozoic Era. The Pleistocene Epoch occurred from about 2 million to 10,000 years ago and is generally referred to as the "Great Ice Age"; in fact, it consisted of four glacial stages.

porous—said of a rock having numerous holes or spaces, whether connected or not. In a sandstone, the spaces occur between the individual sand grains.

quartz—a common rock-forming mineral, SiO_2. It is very hard and resistant to weathering, and it is the second most common mineral in the Earth's crust (after feldspar).

Rush Springs Sandstone—a formation of Permian age, composed mostly of orangish-brown, cross-bedded sandstone with some thin dolomite and gypsum beds. It underlies the Cloud Chief Formation and overlies the Marlow Formation.

sandstone—a sedimentary rock consisting of sand grains (mostly quartz) that are cemented together.

sediment—solid fragmental material (for example, sand, gravel, mud) that originates from weathering of rocks and is transported and deposited by air, water, or ice; it forms in layers on the Earth's surface in a loose, unconsolidated form. It includes material that accumulates through other natural agents, such as chemical precipitation.

sedimentary—pertaining to or containing sediment; for example, sedimentary rock.

sedimentary basin—an area of the Earth's crust that contains an unusually thick accumulation of sedimentary rocks compared to surrounding areas. Sedimentary basins usually are downwarps in the Earth's crust that subsequently fill with sediments (for example, the Anadarko basin).

seeps—small areas where water or another liquid (such as oil) percolates slowly to the land surface.

shale—a fine-grained sedimentary rock formed by the consolidation of clay or mud. Typically, it is softer, and more easily eroded, than sandstone.

siltstone—a fine-grained sedimentary rock formed by the consolidation of silt. Silt grains are intermediate in size between clay and sand grains.

spring—a place where ground water flows naturally from a rock or the soil onto the land surface or into a body of surface water.

tectonic—said of, or pertaining to, the forces involved in shaping the broad architecture of the upper part of the Earth's crust.

terrace—any long, narrow, relatively level or gently inclined surface, bounded along one side by a descending slope and along the other by an ascending slope. A terrace commonly occurs along the margin of, and above the present level of, a body of water, and marks a former water level.

Tertiary—the first period of the Cenozoic Era; it extended from about 67 to 2 Ma.

thenardite—a relatively uncommon mineral, Na_2SO_4, that occurs as a white encrustation where water containing sodium and sulfate has evaporated.

tributary—a stream feeding, joining, or flowing into a larger stream or into a lake.

water table—the upper surface of a body of ground water.

Weatherford Bed—a layer of gypsum and/or dolomite in the Rush Springs Sandstone, about 50 feet below the top of the formation.

Wisconsinan—pertaining to the last glacial stage (of four) of the Pleistocene Epoch of North America, lasting from about 85,000 years ago until about 10,000 years ago.

On The Cover —

Red Rock Canyon, Caddo County, Oklahoma

View of Red Rock Canyon looking south from near the top of Balancing Rock across the pond and dam (visible on left side of photo) to the west wall of the canyon. Permian Rush Springs Sandstone makes up the beautifully colored bedrock throughout Red Rock Canyon State Park. Mostly horizontally bedded sandstone is exposed in the vertical cliff face; cross-bedded sandstone is exposed on the tree- and grass-covered slopes above the cliff.

The canyon is partly filled with unconsolidated sediments eroded from the surrounding outcrops of Rush Springs Sandstone. These sediments were deposited during the latter part of the Pleistocene, when Oklahoma's climate was much wetter than it is today. It is possible that Red Rock Canyon was eroded, filled with sediment, and re-eroded four times in the last million years, but the evidence is not conclusive.

Neil H. Suneson

Photograph by Fred W. Marvel
Oklahoma Tourism and Recreation Department

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