FIELD GUIDE TO THE GEOLOGY OF RED ROCK CANYON
AND THE SOUTHERN EL PASO MOUNTAINS,
MOJAVE DESERT, CALIFORNIA

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Red Rock Canyon, with its colorful and scenic cliffs, has been an area of public curiosity for over 100 years. The geologic and paleontologic significance of the area began to be realized with detailed studies by geologists in the early part of this century (Baker, 1912; Merrian, 1919), a process that continues (Cox and Diggles, 1984; Burbank and Whistler, 1985, 1986; Loomis and Burbank, 1987; Whistler and Burbank, 1987).

The following guide highlights some of the more obvious features of areas which are accessible by paved highways. Several side trips are also described, and considerably more awaits those who venture off the main thoroughfare. Much of the area described is within Red Rock Canyon California State Park, thus collecting, even hand specimens, is prohibited. Geographic place names are in a state of flux, however, the names currently applied by the California State Park are used in this report.

Road distances are given in miles in deference to United States auto odometers; all other measurements are metric. The data presented is taken from observations and extensive geologic mapping by the author and published and unpublished reports (Masters and Doctoral theses). All photographs are by the author.

**GENERAL GEOLOGY**

The geology of Red Rock Canyon and the southern El Paso Mountains is fairly straightforward, although it spans an interval of time from Late Precambrian to Holocene (Dibblee, 1952; Carter et al., 1981). Major depositional episodes occurred in the later Paleozoic, Paleocene, Miocene and Quaternary, and plutonic intrusion occurred during the latest Permian and Mesozoic (Dibblee, 1952; Cox and Morton, 1980). The area is tectonically active and arid, thus exposures are excellent.

The bulk of exposures in Red Rock Canyon, and those described herein, document the later Miocene through Holocene history of the area (Whistler, 1982; Loomis and Burbank, 1987). The area is under major structural control by the Garlock and El Paso Faults (Carter, 1980; Loomis and Burbank, 1987).

![Figure 1. Typical exposures of Ricardo Formation at Red Cliffs Natural Preserve east of California Highway 14. Section is interbedded channel sandstones (dark beds), overbank deposits (light, thin-bedded bands) and massive, floodplain deposits (gray). Cliff is capped by resistant pink lapilli tuff breccia.](image)
The oldest rocks exposed in the El Paso Mountains are the highly metamorphosed chlorite-quartz-albite-sericite Mesquenite Schist. This Precambrian schist forms the basement on which the slightly metamorphosed, Late Paleozoic, marine Garlock Formation has been deposited (Dibblee, 1952; Christiansen, 1961). The Garlock Formation is composed of shales, cherts, quartzites, limestones, conglomerates and submarine volcanic flows that are not exposed in Red Rock Canyon, but they are the dominant lithologies in the northeastern El Paso Range.

The Garlock Formation and the Mesquite Schist have been intruded by a complex of plutonic rocks ranging in composition from hornblende-quartz diorite to granite. One of these intrusive units, a highly fractured and jointed granophyre plug, surrounds the gorge at the entrance to Red Rock Canyon.

The Paleozoic and Mesozoic rocks are deeply eroded and are unconformably overlain by the continental Goler Formation of Paleocene age (Cox, 1982), a thick succession composed primarily of conglomerates and sandstones. Occasional finer-grained rocks in the Goler Formation have produced sparse, but diagnostic, vertebrate fossils (McKenna, 1960), which are the oldest records of fossil mammals in California. The Goler Formation is not exposed in Red Rock Canyon, but some thin exposures are present on the eastern side of Scenic Canyon (called Iron Canyon on Figure 1).

The dominant exposures in Red Rock Canyon are Middle and Late Miocene volcanics and clastics lumped together as the Ricardo Formation by Dibblee (1952). More current interpretations would subdivide the older, dominantly volcanic rocks and the overlying, dominantly fluviatile rocks into two formations (Loomis et al., 1983; Loomis and Burbank, 1987). Because the new formal names have not yet been published, the term "Ricardo Formation" will be used here for all these rocks.

The Middle Miocene volcanic rocks at the base of this sequence (Ricardo Members 1 and 2 of Dibblee) are coarse pyroclastics and andesite flows that are most prevalent in Last Chance Canyon in the west-central El Paso Mountains. They also form most of the rocks of Black Mountain in the northwestern El Paso Mountains (including the Black Mountain Basalt which Dibblee considered Quaternary). Radiometric age determinations from interbedded basalt and andesite flows yielded a range of dates from 15 to 19 million years (Cox, personal communication). These volcanic rocks are probably related to the Middle Miocene Tropico Group volcanics which blanketed much of the western Mojave Desert at that time (Dibblee, 1967).

The Middle Miocene volcanics are overlain by 1800 m of primarily fluviatile and lacustrine, later Miocene sediments (Ricardo Formation Members 3-8 of Dibblee, 1952). These form the scenic, multicolored badlands in Red Rock Canyon (Figure 1). The lower 800 m of this succession contain numerous volcanic ash falls, two thick lapilli tuff breccias and two basalt flow sequences (Whistler, 1969). A volcanic ash near the base of Dibblee's Member 3 yielded a radiometric date slightly in excess of 10 million years (Evernden et al., 1964), but subsequent radiometric and paleomagnetic analyses support an older age of at least 12.5 million years (Loomis and Burbank, 1987; Whistler and Burbank, 1987). The fluviatile sandstones and conglomerates in this part of the section have an easterly source area (Loomis, 1984). The common pebbles and boulders are nearly all porphyritic volcanics and dark metamorphics, not plutonics, which would be expected because of the dominantly granitic nature of the source area today. The upper 1000 m of later Miocene sediments are generally coarser grained and, in them, Sierran-derived plutonic clasts become more common.

The later Miocene part of the Ricardo Formation has yielded a diverse vertebrate fossil record spanning over 5 million years based on radiometric and paleomagnetic studies (Whistler, 1969; Burbank and Whistler, 1986). This fossil assemblage is currently being
proposed as a biostratigraphic standard for the Clarendonian North American land mammal age in southwestern North America (Whistler and Burbank, 1987).

The Ricardo Formation is overlain by several episodes of Quaternary alluvial deposition derived primarily from the emerging Sierra Nevada. These deposits demonstrate a complex history of down-cutting and terrace and pediment development, all probably related to periodic uplifts in the Sierra Nevada. Unpublished radiocarbon evidence from the author's files suggests an age of approximately 10,700 years for at least some of these deposits.

**STRUCTURAL CONTROL**

The dominant structural feature of the area is the Garlock Fault and its major splay, the El Paso Fault. The Garlock Fault is a major transform fault which separates the relatively stable Mojave Block to the south from the major crustal extensional area of the Basin and Range Province to the north (Davis and Burchfiel, 1973). Both the Goler and Ricardo formations were deposited in elongated troughs, similar in morphology to the Fremont Valley today, that probably formed along the trace of the Garlock Fault. A cumulative left-lateral displacement of 48 to 64 km has been demonstrated for the Garlock Fault zone (Smith, 1962; Chen and Moore, 1979). Alluvial fans that are offset from their source canyons along the

Figure 2. Index map of the Red Rock Canyon area showing stops discussed in text.
front of the El Paso Mountains indicate at least 18 km, or roughly one-third of the cumulative displacement, has occurred during the past 1.5 million years (Carter, 1980).

Major uplift of the El Paso Mountains, with a cumulative total in excess of 15 km, has taken place primarily on the El Paso Fault and this movement is responsible for uplifting the rocks exposed in Red Rock Canyon. This fault forms the eastern boundary of the range. There are a few minor faults which traverse diagonally across the El Paso Mountains and cut the overlying Miocene clastics and volcanics, but none appear to have been active in the Quaternary.

Figure 3. View looking northwest from top of El Paso Mountains of lower Scenic Canyon and part of Red Rock Canyon. Sierra Nevada on horizon with pediment fans extending eastward from base. Hogback ridges in middle distance are formed by basalts interbedded within Ricardo Formation (Tb1 and Tb2). Large white arrow points to Dove Springs Wash. Closer, light colored ridges are capped by pink lapilli tuff breccia (Ttb) which displays offset from faulting in right center of view (see Figure 8 also). Alluvial infilling (Qoal) of ancient stream valley shown in detail in Figure 4 in middle distance with Sullivan Springs (Spr) at eastern end. Unconformity between flat-lying Quaternary deposits (Qs) and underlying Ricardo Formation (Tr) prevalent in middle foreground (see Figure 7).

FIELD TRIP ROAD LOG

Figure 2

STOP 1—Starting point is at the Red Rock Canyon State Park Headquarters about one mile west of Highway 14 on Abbott Drive. The ranger station is adjacent to ridges formed by a sequence of basalt flows interbedded within the Ricardo Formation. These flows are clearly exposed in the road cut on Abbott Drive where vugs and veins are filled with white opal, chalcedony, and zeolites and a green alteration mica, celadonite. From the Ranger Station, walk south about 1 km on the Campground Road and up the nature trail to the top of the basalt ridge for a panoramic view of the entire southern El Paso Mountains, southern Indian Wells Valley, Red Rock Canyon, Fremont Valley and Mojave Block beyond to the south. The lower portion of the Nature Trail traverses pebble and boulder conglomerates. Note that the pebbles, cobbles and boulders are mostly well rounded volcanics and metamorphics, not plutonics. Further up the hill, the trail traverses a dip-slope on top of the
basalt flow sequence which is highly vesiculated and displays some rudimentary columnar jointing.

To the northwest is the southern end of the Indian Wells Valley covered with alluvial fans spreading eastward from the granitic Sierra Nevada (Figure 3). The Sierra Nevada is uplifted along the high angle Sierran Front Fault that is evident to the southwest where there is an escarpment at the foot of the steeper granitic hills. Badlands in the near distance are formed in clastics of the upper portion of the Ricardo Formation. To the east is the crystalline core of the El Paso Mountains which has been uplifted and tilted to the west. Beyond is the deep trough of the Fremont Valley which formed between the Garlock Fault on the west and the Cantil Valley Fault on the east. Beyond the Fremont Valley is the elevated, flat, granitic Mojave Block which extends 50 miles to the south where it is truncated by the San Andreas Fault and the San Gabriel Mountains (only visible on a clear day).

The El Paso Mountains extend to the northeast where their western slopes are covered with western-dipping deposits of Middle Miocene volcanics. These volcanics also form most of Black Mountain, the high peak on the horizon directly to the north. In the near distance are dissected badlands in the western-dipping homocline of the interbedded clastics and volcanics of the lower portion of the Ricardo Formation. Note that the lower of the two basalt flow sequences in the foreground pinches out before crossing Abbott Drive and starts up again north of the main highway. Both basalt sequences thin and eventually pinch out to the northeast.

Return to the Park Headquarters and proceed southeast (right) on Abbott Drive. At 0.3 miles the road crosses the lower basalts. On the right at 0.5 miles is a thin, white ash bed interbedded within orange and light gray channel sandstones and siltstones of the Ricardo Formation. This ash thickens dramatically to the northeast and becomes the 6 m thick ash in upper Last Chance Canyon that was mined for abrasives for the first half of this century by the Dutch Cleanser Company. Turn north (left) on Highway 14. On the right is a dip slope within a massive pink lapilli tuff breccia, at 1.3 miles are badlands in channel sandstones and conglomerates overlying the tuff breccia. At 1.7, miles turn out at a small siding on the right, opposite a sand dune flowing down from the basalt-capped ridge on the left.

STOP 2—Walk north on the right side of the highway and observe dissected Quaternary sands and conglomerates partially filling the canyon which was cut into the Miocene Ricardo Formation (Figure 4). Note that the upper surface of these deposits is flat and that the interbedded boulders are mostly light-colored granites derived from the Sierra Nevada, not basalt boulders derived from the immediately adjacent ridges. These bouldery sands were deposited in an ancient stream course that traversed directly eastward through the resistant ridges of the underlying Ricardo Formation and then drained down Scenic Canyon. The sediments directly in front of you represent localized thickening that occurred in a pond that developed behind the pink tuff breccia. The uppermost deposits are white to yellow calcareous tufa indicating a fluctuating water level and evaporation in this pond. Sullivan Springs drains from the east end of these Quaternary deposits and serves as a major waterhole for wildlife in Scenic Canyon. Subsequent stream capture in lower Red Rock Canyon has formed the current drainage which is now rapidly removing these poorly consolidated Quaternary deposits.

Return to the highway and drive north. The highway traverses a long projection of Quaternary fan sediments overlying the Ricardo Formation. At 4.4 miles you pass gently dipping white beds on the right that are paleosols and authigenic siliceous (opal and zeolites) hardpan deposits common in the upper part of the Ricardo Formation (Figure 5). Turn out to the right at 4.6 miles at a sign that says "Opal Canyon" (or just "Opals").
STOP 2—Infilling of alluvium (Qoal) into an older Quaternary channel cut into Miocene Ricardo Formation. This alluvium is part of fan, stream and pond deposits which blanketed area between Sierra Nevada and El Paso Mountains except for high-standing ridges of Ricardo Formation volcanics (Tb₁ and Tb₂). Note the angular unconformity between Ricardo Formation (Tr) on left and alluvium on right. This alluvium has been dissected by latest Quaternary and Holocene erosion caused by stream capture in Red Rock Canyon and continued uplift of El Paso Mountains and Sierra Nevada.

STOP 3—From this vantage point there is a good overview (to the south) of the flat, upper surface of the pediment fans extending eastward from the Sierra Nevada. It is apparent that the present-day badlands of Red Rock Canyon are dissecting these fans. From here a side trip can be taken down Opal Canyon. The road traverses the upper part of the Ricardo Formation down to the upper basalt where it turns north toward the opal mines. The Ricardo Formation is finer grained and contains many interbedded cherts in this general area because you are close to the center of the Late Miocene depositional basin. The fire opal mines are privately owned, but open to the public for daily mining on a fee basis. The opals are formed in vesicles, vugs, and veins where a small fault crosses the basalt flows.

Figure 4. Field trip STOP 2—Infilling of alluvium (Qoal) into an older Quaternary channel cut into Miocene Ricardo Formation. This alluvium is part of fan, stream and pond deposits which blanketed area between Sierra Nevada and El Paso Mountains except for high-standing ridges of Ricardo Formation volcanics (Tb₁ and Tb₂). Note the angular unconformity between Ricardo Formation (Tr) on left and alluvium on right. This alluvium has been dissected by latest Quaternary and Holocene erosion caused by stream capture in Red Rock Canyon and continued uplift of El Paso Mountains and Sierra Nevada.

Figure 5. Field trip STOP 3—Paleosoil and siliceous (opal and zeolites) hardpan deposits prevalent in the upper 400 m of Ricardo Formation (Tr) on the east side of highway, 3 miles north of Park Headquarters.
Return to Highway 14 and turn left (carefully, the view to the right is restricted). Drive to the junction of upper Abbott Drive at 6.2 miles and turn right (west). Follow Abbott Drive back toward Park Headquarters. At 6.9 miles you cross a dry wash (Dove Springs Wash), the major drainage from the Sierra Nevada into Red Rock Canyon. Flash floods are common in this drainage, as may be evident from the freshly plowed piles of sand where the road crosses the wash. On the right (west) are sandstones and siltstones of the Ricardo Formation that produced the earliest vertebrate fossil collections between 1906 and 1920. Continue down Abbott Drive past Park Headquarters, retracing your earlier travel, but turn right (south) on Highway 14. Turn left (east) across the highway at 9.3 miles at Red Cliffs Nature Preserve.

STOP 4—The colorful bluffs surrounding the parking area are stream channel and overbank deposits of the lower part of the Ricardo Formation (Figure 1). The bluff is capped by a massive, pink, lapilli tuff breccia containing many angular lithic fragments. A prominent break (and color change) in this unit in the cliffs to the west represents a baked zone between two successive falls. These tuff breccias are over 200 m thick here, but they thin rapidly and pinch out 4 km to the northeast. Walk west around the base of the cliffs to observe a small fault which offsets the contact between the tuff breccia and the underlying clastics (Figure 6). From this stop there is an easy side trip by foot up Scenic Canyon and Nightmare Gulch, the latter name applied to the upper drainages of Scenic Canyon (see Figures 7 and 8). This hike will provide close-up views of the sediments and volcanics of the lower part of the Ricardo Formation in a spectacular setting of deeply dissected cliffs and badlands.

Figure 6. Field trip STOP 4—Small fault cutting pink lapilli tuff breccia in Ricardo Formation immediately east of Highway 14 at west end of Red Cliffs Natural Preserve.
Return to the highway and turn left (south). Clearly visible on the right (west) side of the canyon are the basal conglomerates of the Ricardo Formation lapping onto older crystalline rocks. The planed-off upper surface of the crystalline basement on which the Ricardo Formation is deposited appears to dip to the west at the same angle as the overlying sediments and to project eastward toward the top of the El Paso Mountains. The road crosses the bridge and proceeds through a deep gorge cut through highly jointed, fine-grained, quartzose granophyre. Directly after leaving this gorge turn right (west) into a Tamarisk grove at 10.6 miles.

Figure 7. Part of flat-lying Quaternary sands and clays (Qs), an extension of same deposits described in Figure 4, unconformably overlying basal Ricardo Formation (Tr). View is in lower Scenic Canyon (see Figure 3 also).

Figure 8. Faulting and landsliding in lower part of Ricardo Formation at Scenic Cliffs. Note offset of pink tuff breccia (Ttb) capping cliffs and landslide block (Qls) of tuff breccia extending to flats in foreground. Actual plane of fault is nearly vertical and it strikes parallel to bluff face. This fault can be traced several kilometers up Scenic Canyon where it offsets and repeats Middle Miocene volcanics underlying the Ricardo Formation. Photo taken from top of stabilized sand dune (Qds) formed in wind gap in tuff breccia to west.
**STOP 5**—Walk about 200 m to the west to the top of a small alluvial terrace extending (south) from the hills on the right. The view to the east across the mouth of Red Rock Canyon displays the steeply dipping plane of the El Paso Fault between crystalline rocks on the left (north) and younger clastics to the right (south) (Figure 9).

The El Paso Fault can be traced through a series of fresh escarpments across the base
of the steep hills to a point directly under foot. The older, clastic sediments (possibly Ricardo Formation - Samsel, 1962) south of the fault dip 25 degrees toward the fault. The overlying Quaternary deposits have developed a nearly flat upper surface, indicating a period of depositional stability prior to the erosion that formed Red Rock Canyon. You are standing on a remnant of the same Quaternary sediments.

The view to the west (Figure 10) shows the continuation of the El Paso Fault with the Ricardo Formation on the right and a flat alluvial plane on the left. The fault can be traced nearly to the base of the granitic core of the southern Sierra Nevada to the west where it is truncated by the Sierran Front Fault. The latter is clearly visible near the mouth of Jawbone Canyon, 4 miles south on Highway 14. The steeply dipping sandstones directly in front of you are bounded by two branches of the El Paso Fault. Drag folding of interbedded orange and white conglomerates of the Ricardo Formation is clearly visible in middle distance. The dark ridge in the distance is capped by the lower of the basalts within the Ricardo Formation.

Return to Highway 14 and turn right (south). At 11.4 miles, the road climbs through a ridge (the local name is "Windy Gap", an apt name if it is at all windy) which is capped by a flat-topped remnant of Quaternary fan deposits. From this vantage point there is a good view to the south of the Fremont Valley, with the Garlock Fault occurring at the base of the eastern face of the northern Tehachapi Mountains on the right. The eastern side of Fremont Valley is limited by the fault-bounded Rand Mountains. In certain low-angle lighting, there is an obvious escarpment tracing this fault that is visible between the crystalline rocks of the southwestern Rand Mountains and the outwash alluvial plane to the southwest. Turn hard left at 13 miles at Randsburg-Red Rock Road. The highway traverses perched Quaternary terraces and then along the bases of alluvial fans extending eastward from the El Paso Mountains on the left. Note fresh scarps of the Garlock Fault along the base of the El Paso Mountains on your left. Koehn (or Kane) dry lake, a basin of internal drainage in the fault valley of the Garlock Fault, is on the right. Until the late 1950's, salt (halite) was mined at the abandoned site of Saltdale by evaporating concentrated lake waters. Continue north on Randsburg-Red Rock Road to Mesquite Canyon Road at 24.2 miles.

STOP 6—On the left are dissected, Late Quaternary, lakebed and alluvial fan deposits that have been uplifted on the Garlock Fault (Figure 11). These fine-grained muds were originally flat lying and probably were deposited near the present level of Koehn Lake on the right. Nearly 80 m of uplift has led to a 10 degree upslope dip in these sediments. There are several small springs at the base of these outcrops along the trace of the fault. Continue northward on Randsburg-Red Rock Road 1.1 miles (25.3 miles from start) and turn left on Garlock Road.

You pass the old townsite of Garlock at 26.1 miles. The El Paso Mountains on your left now contain nearly vertical sediments of the Late Paleozoic marine, Garlock Formation composed of partly metamorphosed, fine-grained clastics, limestones and submarine volcanic flows. Continue until you pass the road to Goler Gulch and a distinct elevated escarpment will appear on the left at 30.9 miles.

STOP 7—On the left, below the scarp representing the recent trace of the Garlock Fault, is an un-drained depression (graben) which emphasizes the recentness of faulting activity (Figure 12). The northeasterly trace of the fault is clearly visible on the horizon as a notch part way up the slope of the El Paso Mountains. From here, proceed to Highway 395 and return to Ridgecrest.
Figure 11. Field trip STOP 7—Quaternary lake and alluvial fan deposits (Qc) uplifted by Garlock Fault at mouth of Mesquite Canyon. Due to fault uplift, sediments which were originally dipping gently to right are now dipping 10 degrees to left.

Figure 12. Field trip STOP 7—Graben (white arrows) formed in alluvium along trace of Garlock Fault below Goler Gulch. Note fresh escarpment on left in alluvium (Qal). Mountains in left background formed in Late Paleozoic Garlock Formation (Pg). Notch in hill in background continuation of trace of Garlock Fault.

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