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The Garden of the Gods and basal Phanerozoic nonconformity in and near Colorado Springs, Colorado

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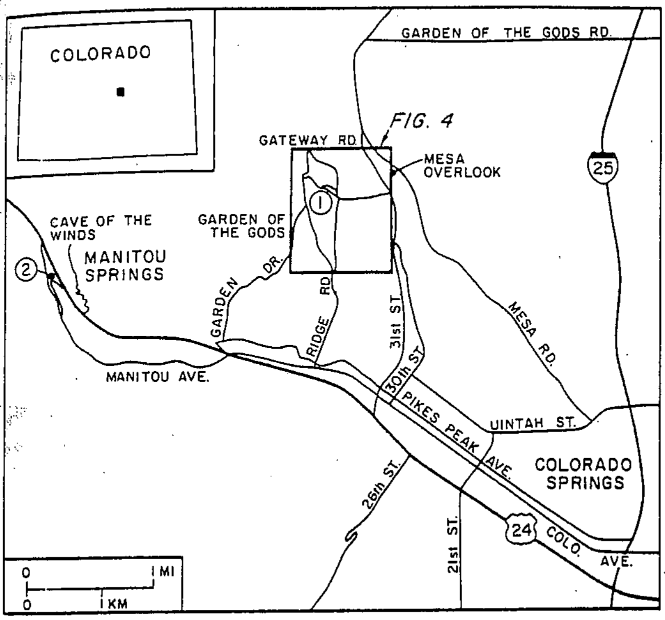

Figure 1. Map of the Colorado Springs/Manitou Springs area showing locations of Stops 1 and 2 and of the Mesa overlook.

LOCATION AND ACCESS

The Garden of the Gods, a city park within the Colorado Springs city limits, is located on the eastern flank of the Colorado Front Range (Fig. 1). It can be reached by following the Garden of the Gods Road (exit 146 from I-25) west 2.4 mi (3.8 km) until it curves to the south and becomes 30th Street. Continue south 1.5 mi (2.4 km) to an unnamed road marked by a small sign (Garden of the Gods) and turn right (west) into the park. Mesa Road, which veers uphill from 30th Street 0.8 mi (1.3 km) north of the turnoff to the park, crests at a spectacular overview of the park and surrounding areas. Several U.S. Geological Survey 7½-minute quadrangle maps cover this region. The Garden of the Gods lies mostly within the Pikeview and Cascade Quadrangles; with its southern part in the Colorado Springs and Manitou Springs Quadrangles. The two stops described here are all on public land and can be reached by passenger car.

SIGNIFICANCE OF THE SITES

Precambrian metamorphic and granitic rocks (1.75 Ga and younger), and also rocks from every geologic period except the Silurian, are exposed within the city limits of Colorado Springs (Grose, 1960; Scott and Webus, 1973). The rock record includes evidence of a variety of sedimentary environments, involving two marine transgressive cycles. Three periods of Phanerozoic uplift are also recorded. A simplified cross section from Pikes Peak across I-25 shows the major units and structures in Colorado Springs (Fig. 2). The Garden of the Gods is an unusually well-exposed display of late Paleozoic and Mesozoic stratigraphy characteristic of the Colorado Piedmont, and of structures associated with Laramide orogenesis. The rocks were deposited in sedimentary environments, including alluvial fan, lacustrine, aeolian, and shallow marine. The primary structure is that of a faulted monocline (Rampart Range fault) with numerous smaller reverse faults, strike-slip faults, and complicated fracture systems. The Manitou Springs locality (Stop 2) is one of the more accessible and well-exposed views of the Precambrian/Phanerozoic contact near the axis of the Transcontinental Arch. The sedimentary sequence of beach sandstone, tidal flat dolomite, and marine limestone is a spectacular one-stop cross section of the early Paleozoic marine transgression. These rocks are cut by a strand of the Laramide-age Ute Pass fault. Noblett (1984) discusses six additional stops of interest in the Colorado Springs area and presents a brief summary of the historical geology.

STOP 1: THE GARDEN OF THE GODS

Exposed Rock Units. The units in the park include the Pennsylvanian Fountain Formation through the Cretaceous Pierre Shale (Fig. 2). Because so many schools use the park as a mapping problem, we do not here present a finished geologic map, but reference the more interesting features to a topographic map (Fig. 3). The units are generally younger to the east, but have been offset by extensive faulting. The oldest unit in the park is the Pennsylvanian (post Morrowan) Fountain Formation, which is composed of conglomerates, arkosic sandstones, siltstones, and shales deposited under alluvial fan and fan delta conditions. Lithic fragments are common; fluvial structures, indicative of deposition under braided stream conditions, are ubiquitous. Such structures are particularly apparent at a vertical outcrop just west of the Gateway Rocks (Fig. 3a). Elsewhere in the park, extensively reworked, planar and low-angle cross-bedded sands suggest deposition in beach and shoreface environments, whereas marine fossils occur in some shaly facies to the northwest. The Fountain Formation is up to 3,000 ft (900 m) thick in the Manitou Springs Embayment to the west, but wedges out rapidly to the east, grading from nonmarine alluvial fan deposition to a coastal marine, fan delta facies. This formation is the primary evidence for the beginning of the orogenic event that created the ancestral Rockies in Late Mississippian–Pennsylvanian times.

The Lyons Formation (Permian) lies in conformable and occasionally interfingering contact with the Fountain Formation. In the Garden of the Gods, the Lyons Formation consists of three

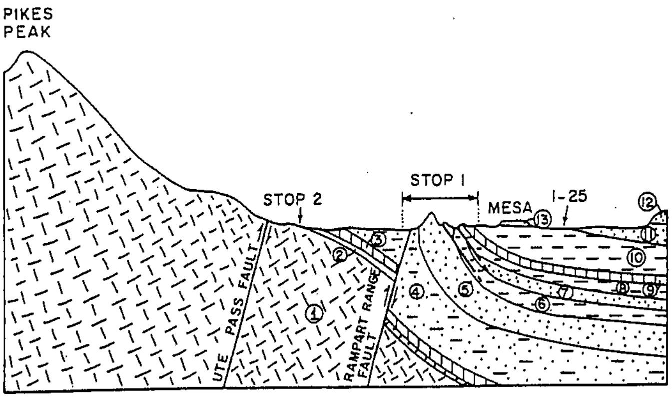

Figure 2. Schematic west-east cross section from Pikes Peak across I-25 showing relative locations of Stops 1 and 2. 1, Pikes Peak Granite; 2, Upper Cambrian Sawatch Sandstone and Peerless Dolomite; 3, Ordovician Manitou Limestone and Harding Sandstone, Devonian-Mississippian Williams Canyon and Hardscrabble limestones; 4, Pennsylvanian Fountain Formation; 5, Permian Lyons Sandstone; 6, Triassic Lykins, Jurassic Morrison, and Cretaceous Purgatoire formations; 7 to 11 are Cretaceous: 7, Dakota Formation; 8, Benton Group; 9, Niobrara Formation; 10, Pierre Shale; 11, Fox Hills and Laramie formations; 12, Tertiary Dawson Arkose; 13, Quaternary gravels.

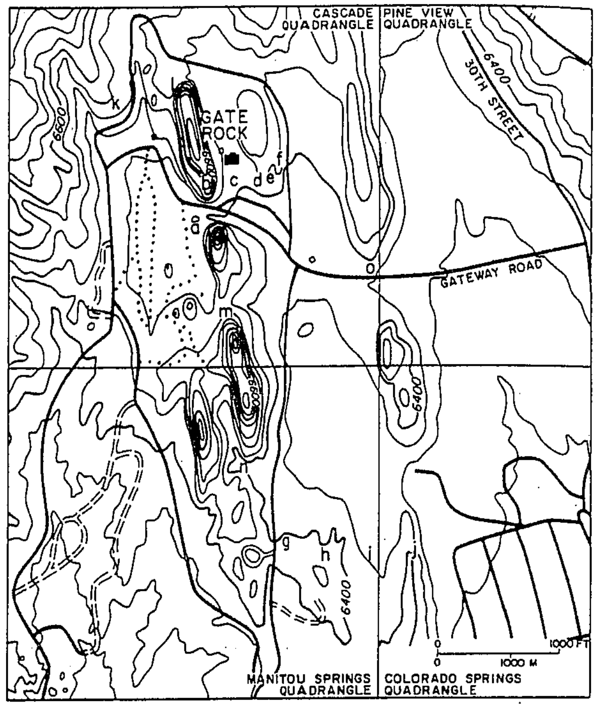

Figure 3. Topographic map of the Garden of the Gods. Contour interval is 40 ft. a, interfingering Fountain and Lyons formations with four facing indicators; b, lower Lyons; c, middle Lyons; d, upper Lyons; e, Lykins Formation; f, Morrison Formation; g, Purgatoire Formation; h, Dakota Formation; i, Benton Group; j, Fort Hays Formation; k, breccia zone in Rampart faults; l, m, and n, northern, middle and southern reverse faults; o, strike-slip fault.

members: a lower and upper hogback-forming sandstone (the big ridges in the park), and a middle valley-forming arkosic conglomerate, which is nearly identical to some of the conglomeratic facies of the Fountain Formation (Fig. 3b, 3c, 3d). In this locality, the two sandstones are distinguishable by color; the lower sandstone is red, and the upper is white. Both sandstones are fine-grained, rounded, moderately well-sorted quartz arenites, with occasional potassium feldspar. The most notable features in outcrop are thick (up to 33 ft; 10 m) high-angle cross-beds. Good exposures of these structures are visible on the south side of the Gateway Rocks, and in Bear Creek Park to the south. Depositional environment was apparently dune fields, which were locally reworked by intermittent streams, as suggested by occasional small-scale low-angle cross-beds and planar beds found at the base of the upper Lyons. The middle, Fountain-like unit indicates that there may have been continuous dynamic interaction between dune and stream environments, possibly as a result of episodic tectonism in the ancestral Rockies through much of Lyons time.

The valley-forming Lykins Formation disconformably overlies the upper Lyons unit (Fig. 3e); it is probably Permo-Triassic in age, and consists of unfossiliferous red shales, siltstones, sandstones, and stromatolitic dolomites. Siltstones are thin bedded to very thin bedded. Stromatolitic bedforms generally show positive relief, and are best seen near Bear Creek Park. The unit shows local mudcracks, which suggest periodic desiccation. Possible depositional environments include both sabkha and playa lake settings.

The Upper Jurassic (Kimmeridgian?) Morrison Formation lies in disconformable contact with the Lykins Formation (Fig. 3f). It consists mostly of variegated pastel purple and green shales and siltstones, with local limestones, chert pebble and bone fragment conglomerates, sandstones, and bedded gypsum. The gypsum unit (up to 100 ft; 30 m thick) is placed at the base of the formation. A meter or two above the gypsum is a thin (few cm) but prominent limestone. This is mostly micritic, with local oolitic, pisolitic, and stromatolitic lenses. The formation was deposited in a mosaic of fluvial, alluvuial plain, and lacustrine environments.

In the Colorado Springs region, the Purgatoire Formation separates the Morrison and Dakota Formations (Fig. 3g). The Purgatoire is a Lower Cretaceous formation, and contains two members. The lower Aptian member (Lytle) is a coarse, poorly cemented, white conglomeratic sandstone, with a basal chert pebble conglomerate. Thin sets of planar, low-angle cross-beds indicate deposition under beach conditions. The upper member, the Glencairn Shale (Aptian-Albian) is a black shale of probable lagoonal origin. Both members of the formation are best exposed in Bear Creek Park, and along Colorado 24 west of 31st Street.

The Dakota Formation (Fig. 3h) in the Colorado Springs region is probably Albian-Cenomanian in age. Dakota sands consistently are organic-rich quartz and quartzofeldspathic wackes. Trace fossils, small channels, and herringbone cross-stratification are occasionally found, while dinosaur footprints occur in a small outcrop just south of Colorado Springs. The Dakota Formation

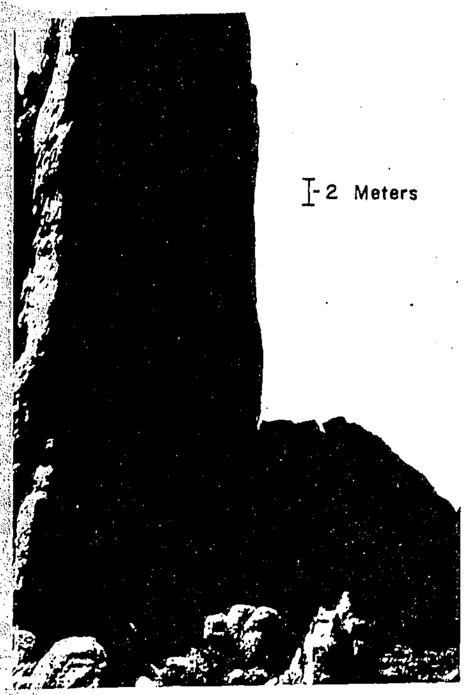

Figure 4. View, to south, of reverse fault at locality "1" of Figure 3; Lyons faulted up over Fountain. Note bending of the Fountain layers.

at the Garden of the Gods appears to have been deposited under alternating tidal flat-lagoonal conditions. Lateral facies thicknesses vary considerably throughout the park. At the north end of the Garden of the Gods, the Dakota forms the typical lichen-covered, pink, fine-grained sandstone hogback that is prominent all along the Front Range. Near the Visitor's Center in the south part of the park, the formation consists of three thinner ridges (8 to 10 ft; 2 to 3 m thick) separated by 33 ft (10 m) of siltstone and shale beds. Through most of the park, the Dakota Formation is present only as tiny outcrops. While an east-dipping reverse fault could explain the missing section and the overall thinning of units to the north, a lateral facies change cannot be ruled out.

The Late Cretaceous Benton Group (Fig. 3i) consists of three shallow-marine formations: the Graneros Shale, the Greenhorn Limestone, and the Carlile Shale (Scott, 1969). These form a valley just east of the Dakota sandstones. The Cenomanian Graneros Formation is a black marine shale. The Cenomanian-Turonian Greenhorn Formation is a marine shale that contains thin beds of lime mudstones and is exposed on the small hill just east of the Dakota ridge at the north end of the park. The Turonian Carlile Formation is primarily a black shale, but the uppermost portion, the Codell Sandstone Member, is a thin (8 to 10 ft; 2 to 3 m) well-sorted, subrounded, calcareous quartz arenite containing trace amounts of petroleum. All of the Benton Group is fossiliferous; sharks teeth, ammonites, and pelecypods (especially *Inoceramus* sp.) may all be found. Numerous thin bentonitic layers serve as useful marker beds.

The Cretaceous Niobrara Formation is divided into two members. The Fort Hays Limestone (Coniacian) forms a prominent white hogback (Fig. 3j) together with the Codell Sandstone. Limestone units in the Fort Hays Member are interbedded with thin shale units; all are fossiliferous, with a fauna similar to that found in the Benton Group. The upper member, the Smoky Hills Chalk (Coniacian-Santonian) is exposed on the eastern edge of the hogback as a yellow fossiliferous chalk. The Smoky Hills Member underlies much of the valley east of the Garden of the Gods.

The thickest unit in the Colorado Springs area is the Pierre Shale (Campanian). It is a black marine shale that contains thin layers of organic-rich feldspathic wackes, lithic wackes (with abundant detrital chert and amphiboles), and limestone. The Pierre Shale is fossiliferous, containing pelecypods, foraminifera, and ammonoids (*Baculites* sp.). The Pierre Formation is very widespread and thick (to 5,000 ft; 1,500 m); it is a shallow marine deposit laid down under conditions that frequently were anoxic. A small exposure of Pierre Shale is visible at the intersection of 30th Street and the east entrance to the park; a better view is obtained under the mesa on Uintah Street west of I-25, where the Pierre forms an angular unconformity with the overlying Mesa gravels.

Structures. The hogback ridges that dominate the scenery in the Garden of the Gods are the vertical to overturned limb of a faulted monocline of Laramide age. The major fault associated with the monocline, the Rampart Range fault, passes immediately west of the large Lyons and Fountain hogbacks, and trends north-northwest. The fault plane dips to the west; its relatively straight trace suggests that the dip is fairly high angle. In the park, the fault separates low-dip Pennsylvanian and older sediments in the hanging wall from the vertically dipping younger footwall sediments; farther north, the fault has superposed Precambrian rocks of the Rampart Range over Paleozoic and Mesozoic sediments. At the south end of the park, most of the fault displacement has occurred on a single plane, which dies out in a monocline farther south. The width of the fault zone increases northward until, at the north end of the park (Fig. 3k), the fault zone may be as much as 330 ft (100 m) wide, and structure becomes unclear.

At least three eastward-dipping reverse faults cut across the hogbacks and offset hogback-forming units. Most spectacular is the northernmost of these (Fig. 3l), which is seen at the north end of North Gateway Rock (Fig. 4). A second fault, passing south of South Gateway Rock, may be seen from the road east of the hogbacks (Fig. 3m). This fault truncates upper (white) Lyons and Morrison ridges immediately north of the Gateway Road, and juxtaposes the continuation of these two units against lower (red) Lyons at the south end of South Gateway Rock. A third east-dipping reverse fault occurs farther to the south (Fig. 3n), but is less conspicuous from the road. It is probable that one or more of these reverse faults has eliminated the Dakota ridge from the park.

STOP 2: THE NONCONFORMITY, WEST END OF MANITOU SPRINGS

To reach the second stop at the western edge of Manitou

Springs, proceed south from the Garden of the Gods to Colorado 24 (Fig. 1), go west on Colorado 24 to the exit opposite the Cave of the Winds. Turn left (south) off the highway until the road curves sharply, at the Ute Trail stone marker. Several cars can be parked in the pullout by the trail mark. Start by looking at the wall of rocks to the north, from a point west of the marker (Fig. 5). The Pikes Peak Granite is the lowest rock exposed to the west. The nonconformity is almost planar here, and is overlain by three east-dipping formations: the basal Sawatch Sandstone, the dark red and green Peerless Dolomite, and the thin-bedded white Manitou Limestone (best seen in fallen blocks). Some deformation that is present may be related to the Ute Pass fault, which cuts through the valley to the south.

The Pikes Peak Granite (1030 Ma) is exposed along the Front Range and Rampart Range from about the latitude of Castle Rock (40 mi; 65 km north of Colorado Springs), through the southern limits of Colorado Springs. Aeromagnetic mapping suggests that the batholith continues subsurface to the east for another 50 mi (80 km); the granite is visible in outcrop for 40 mi (65 km) west. Total surface exposure is some 1,500 mi^2 (3,900 km^2). The Pikes Peak Batholith is a complex anorogenic granite, with rocks ranging in composition from gabbro to syenite to fayalite granite, along with the more typical granites and granodiorites (see articles in Epis and Weimer, 1976). Textures may vary from inequigranular to porphyritic, fine-grained equigranular, pegmatitic, and microlitic. The granite as exposed here is a coarse-grained, red, hypidiomorphic-granular rock composed of potassium feldspar, quartz, and biotite. The bulk of the batholith is similar in composition to the rock in this location.

The Pikes Peak Granite is directly overlain by the Late Cambrian (Dresbachian) Sawatch Sandstone, a 14 ft (4.5 m) thick unit of well-sorted quartz-quartzofeldspathic arenite. No metamorphism is present at the basal contact; this clearly shows that the contact is not intrusive, but is a nonconformity. At this locality, much of the Sawatch Formation consists of graded units with 1.5 to 3 ft (0.5 to 1 m) thick cycles of rounded to subrounded quartz pebble conglomerates, which fine upwards into massive or trough cross-bedded sands, and finally grade into planar-wavy laminated sands and silty sands. The upper surfaces of subcycles are often scoured and may be bioturbated. Minor glauconite occurs in the upper part of the formation. The glauconite, the well-sorted sands, small areal extent, and the lack of fluvial features all suggest that the Sawatch Sandstone is a shallow subtidal, transgressive sand. The graded cycles and hummocky cross-beds (best seen in nearby Williams Canyon) are probably the result of frequent storm activity.

The Sawatch Formation grades conformably into the overlying Late Cambrian (Franconian) Peerless Formation. The formation boundary is marked by the appearance of dolomite crystals; the Peerless Formation at this location is 51 ft (15.5 m) thick, and strikingly colored in red and green. This is a texturally complex unit that contains deeply embayed, moderately sorted, angular clastic grains of quartz, feldspars, and chert, together with rounded glauconite grains, in a coarsely crystalline dolomite matrix. At its base, the Peerless Formation is medium to coarse sand, and shows low-angle planar and trough cross-bedding; individual cross-bed sets are up to 4 in (10 cm) thick and 28 in (70 cm) wide. Higher in the formation, the large-scale cross-beds become thin-bedded to massive, and commonly are burrowed. Bedding surfaces may be scoured. The depositional environment is thought to have been a shallow subtidal setting, with the transition from large-scale cross-beds to planar-bedded, finer sands representing continuing deposition in progressively deeper water.


Figure 5. View of the four units at the Precambrian nonconformity. a, Pikes Peak Granite; b, Sawatch Sandstone; c, Peerless Formation; and d, Manitou Limestone. Contacts are shown by short black lines.

The thin-bedded Early Ordovician (Canadian) Manitou Limestone here overlies the Peerless Formation in minor disconformity. It appears high above the old quarry at this stop, and may best be seen by examining fallen blocks, or by walking downhill to the bridge over Fountain Creek, and then west along the creek to a small cave. The Manitou Limestone is a thin-bedded lime wackestone, which contains abundant skeletal and intraclastic grains in a lime mud matrix. Locally the formation may be dolomitic, cherty, shaly, or oolitic. Wackestone beds are normally separated by wavy, very thin-bedded lime mudstone partings. Numerous gastropods, ostracodes, nautiloids, and horizontal feeding traces are present as fossils. This shallow intertidal-subtidal limestone completes a marine transgressive cycle at this outcrop.

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