



Canyonlands

***A Guide to the Geology
of the Colorado Plateau***

Tony Waltham

Geophotos 2020

Canyonlands: a Guide to the Geology of the Colorado Plateau

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Note for the Second Edition

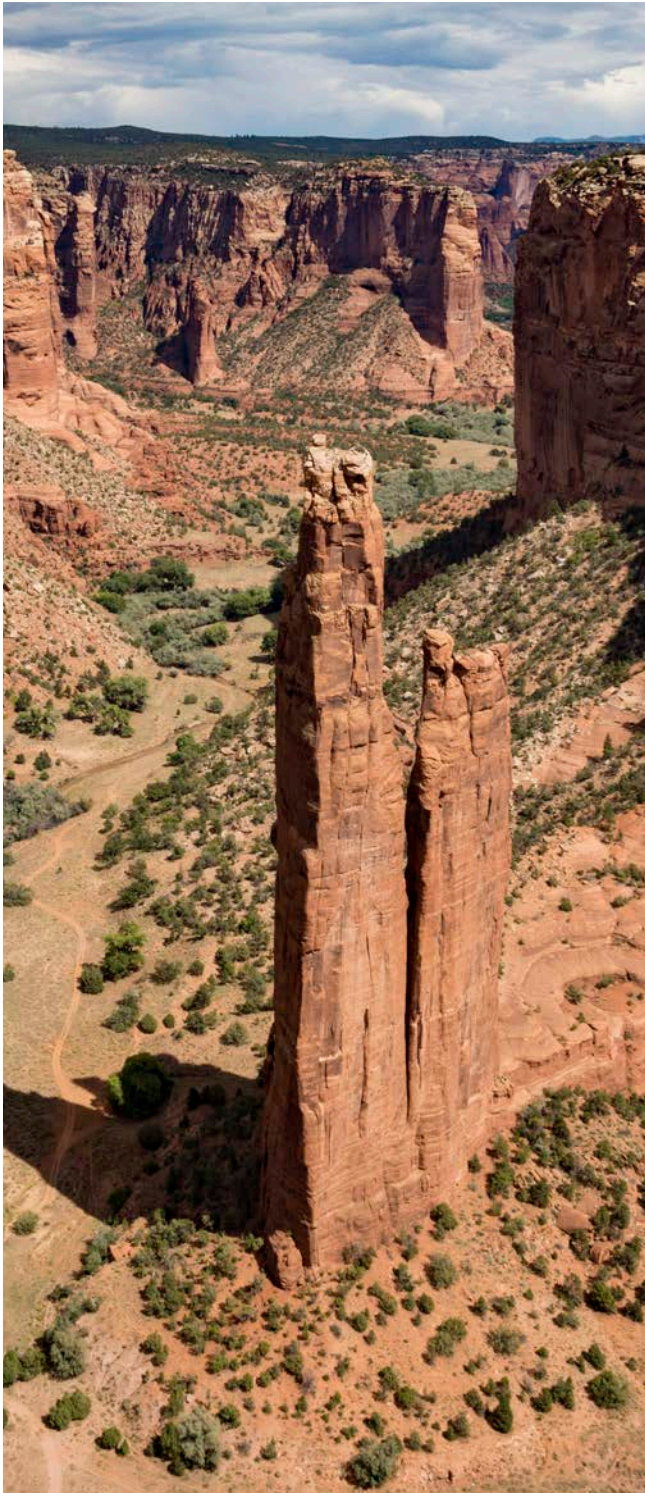
This guidebook was developed from the notes prepared for geological tours of the western United States in the late 1990s. It was then printed without colour for a limited edition that was published as an A5 booklet by Nottingham Trent University.

The text is largely as written in 1998. Though the geology of the sites has not changed, as there are no active volcanoes in the region, details of access have changed at some of the sites, and these have not been up-dated for this edition.

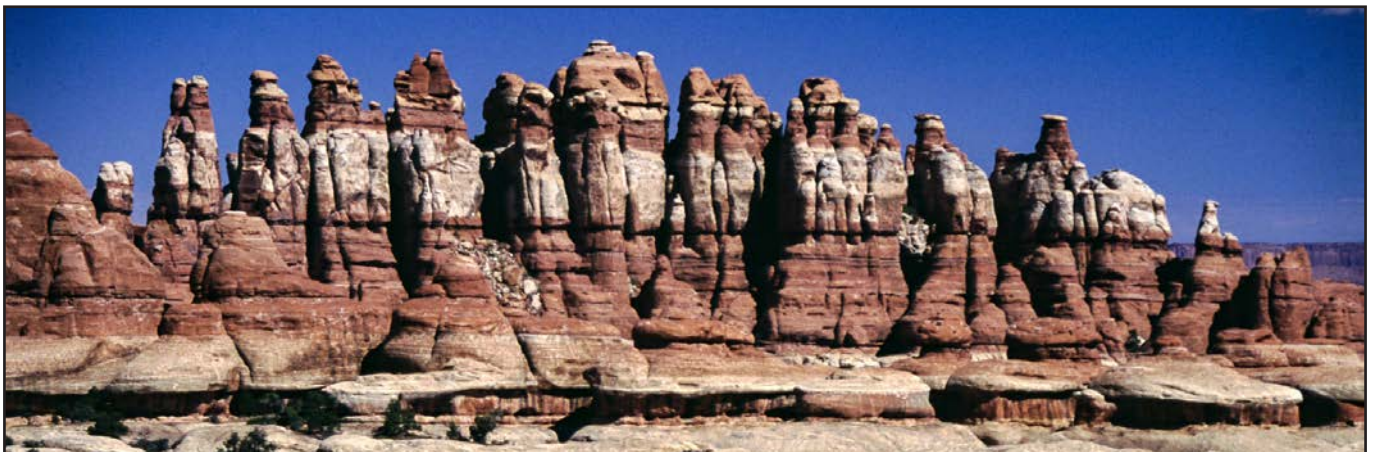
Material has been re-formatted for this e-edition, with coloured versions of the maps and the addition of appropriate photographs. All photographs, except one, are by the author. Maps have been compiled by the author from numerous sources, to which and to whom due credit is afforded.

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A guide to the geology of the Colorado Plateau, USA



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The American West

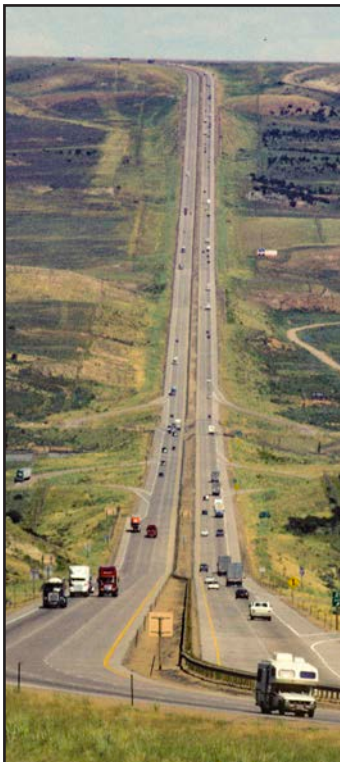
The great mountain chain which traces the Pacific margins of the American continents splits into two distinct units in the segment though the USA. The American Rockies loop more than 500 miles inland, while the Western Cordillera has even higher peaks in its line stretching from Mexico's Baja California nearly to the Canadian border. Between the two mountain chains, semi-arid basins and plateaus constitute a scenic wonderland which is a geologist's delight.

Pacific and Atlantic drainage systems are separated by the continental divide, which follows the watershed of the Rockies. To its west there are just two great river systems. The Colorado drains all the dry lands of the south but to the Gulf of California (though it probably flowed into the Gulf of Mexico, only about five million years ago). The northern interior is drained by the Snake-Columbia river system, flowing in its gorge through the Cascades mountain chain. Between the Colorado and the Snake, much of Nevada and Utah loses its drainage to evaporation in closed desert basins. Within the southern sector, the Colorado Plateau is a terrain unit more complex than a single plateau; it becomes a recognisable entity by way of its huge extents of nearly horizontal red sandstones. It houses a unique collection of canyons, cliffs, pinnacles, arches and bridges which make it one of the world's great rock landscapes.

Within the shelter of its two fringing mountain chains, the interior has a climate which is definitely continental. Summer temperatures frequently exceed 35°C, but most areas freeze in winter. Annual rainfall varies between 100 and 600 mm, closely related to altitude, and this includes winter snow and August thunderstorms. Little of this is really conducive to productive farming, and many areas remain as almost untouched wilderness. Population density is generally low,

but there are scattered cities which owe their origins to the urge for land ownership in the opportunistic climate of America's very recent settlement. Between these cities, the great outdoors is on a magnificent scale. Semi-deserts of bare rock, thin soils and sparse vegetation typically occupy the interiors of many of the great continents. In central Asia, northern Africa and Australia, these remain hostile environments, where access and even mere survival can be seriously challenging. But the American culture of freeways and McDonalds has made its own deserts uniquely accessible.

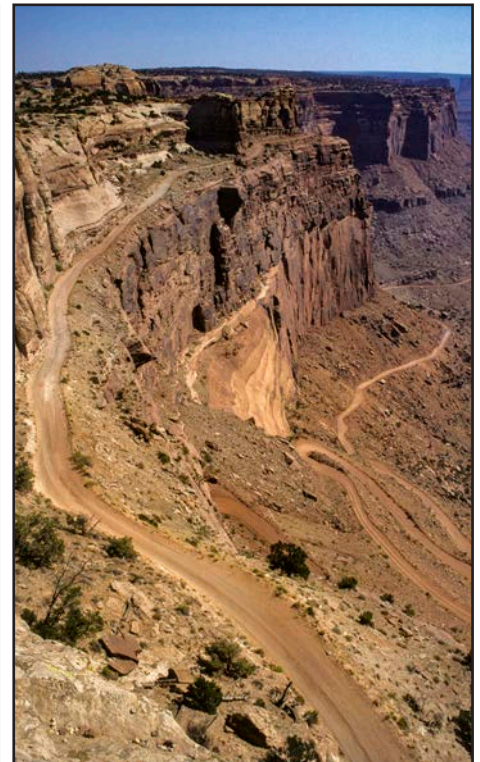
For thousands of years, the American West had its thin spread of people, variously known as Native Americans or Indians, or by their cultural names of Navajo, Apache, Pueblo and many others. They successfully adapted to their environments in ways which led to simple lifestyles -which were no match for the eventual influx of European expansionists. First to arrive were Spanish explorers who ventured north from their Mexican territories; in 1540 Coronado was the first European to see the Grand Canyon, and the Dominguez-Escalante expedition crossed the canyonlands to reach the Great Salt Lake in 1776. But the real discovery of the American West only took place out of St Louis and Kansas City during the next century. In pursuit of beaver fur, the solitary mountain men were the first into most regions, but they were mainly further north, where the Lewis and Clark expedition made its legendary traverse from the Missouri to the Columbia River in 1806. The Santa Fe trail opened across the southwest in 1821, but was only useable by wagons after 1846. Further north, the Oregon trail was opened in 1843, and the Mormons arrived at Salt Lake in 1847. John Wesley Powell explored the Grand Canyon in 1869, and the Hayden expedition explored Yellowstone two years later. By 1869 the railway had crossed the continent, and further progress and development were unstoppable.



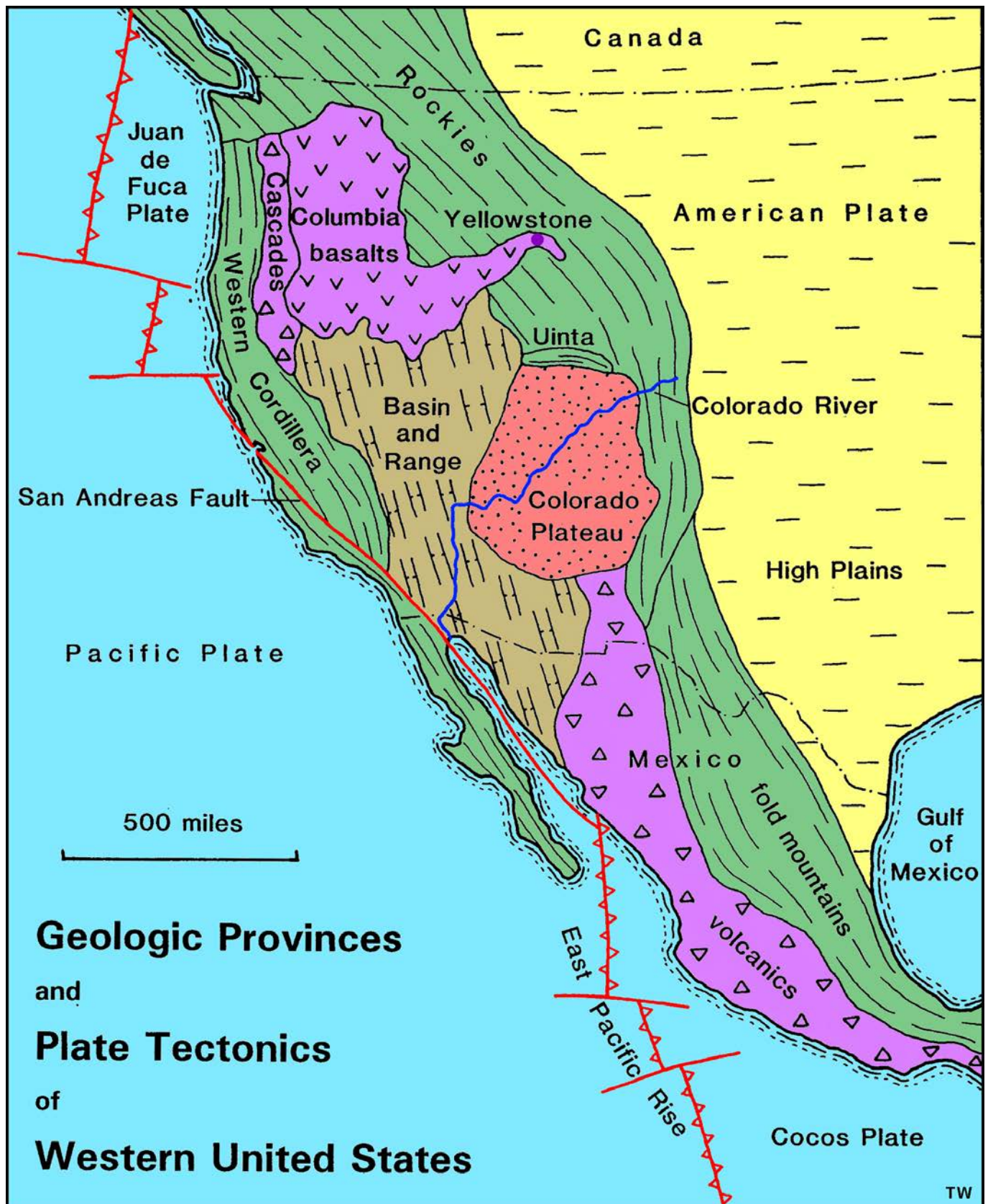
Western Interstate



Utah Truckstop



Shafer Trail



Geology of Western America

Reflected in the landscape units, the American West can be broken into a number of discrete and distinctive geological provinces. These evolved through long and varied geological histories which were influenced throughout by the convergent boundaries between the American and Pacific plates. Waves of orogenic activity climaxed in the Laramide orogeny which straddled the Cretaceous/Tertiary time boundary (though there is no implied link to the dinosaur extinction).

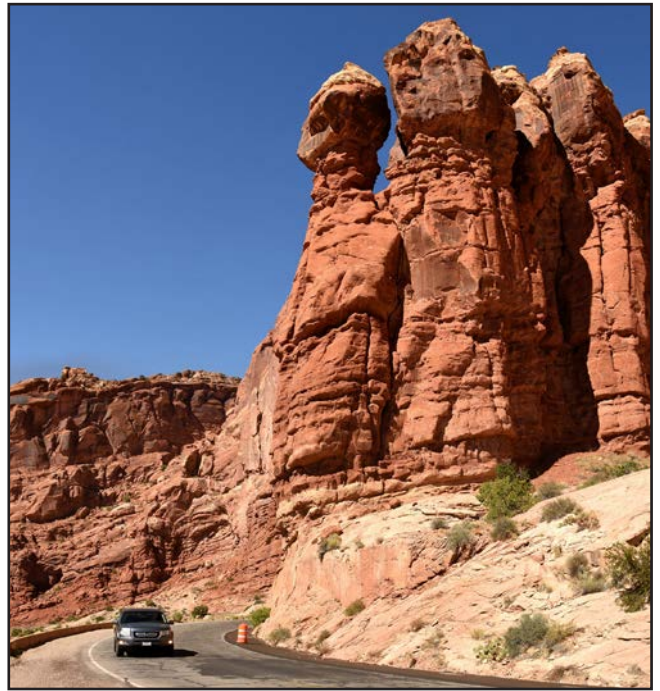
Much of the Rockies is a typical mountain chain convergence zone of fold belts and thrust sheets, though there is little exposure of high grade metamorphism within the root systems. The province includes the uplifted fault blocks of the Tetons and Wind River Range, and also the late sedimentary basins of the Green River and Wind River. The mountains continue north into the greater complexities of the Canadian Rockies, and south into gentler fold mountains of Mexico's Sierra Madre Oriental. To their east, the High Plains are little disturbed sedimentary rocks overlying basement.

A multitude of sub-regions comprise the Western Cordillera; these include the huge granite batholiths of the Sierra Nevada, the sedimentary basin of the Central Valley also in California, and the accretion terranes of the coastal Klamath Mountains. In the north, the andesitic volcanoes lie above the subduction zone of the last remnants of the Juan de Fuca plate, while in the south the earthquake-prone San Andreas Fault forms a passive section of the boundary between the Pacific and American plates.

Between the two mountain chains, the Basin and Range province is a complex of fault-defined blocks. The relative vertical displacements now define mountain blocks of Precambrian rocks scattered between desert basins with partial fills of young sediments. Many of the faults are normal, so defining tensional horst and graben structures, but there are also features of compressional tectonics through parts of their later history.

The Colorado Plateau appears to have retained its integrity over a massive block of more stable basement. It is not purely a positive area, as it was a zone of massive sedimentation through much of the Mesozoic, and tectonic uplifts and sags of smaller units within its block have created many local variations and structural features. It now rises above the Basin and Range country to its west and south, but is overlooked in the east and north by the Rockies and the Uintas, the latter a narrow zone of uplifted basement.

The Columbia basalts are huge spreads of Tertiary flood lavas, with their younger components forming the Snake River basalts just to the east. Within the last few million years, the volcanic activity continued westwards into the explosive centres of Yellowstone, which were erupting until 70,000 years ago and still maintain their geothermal role today.



The road into Arches National Park, beneath a pinnacle that is currently stable.



View east from Dead Horse Point in the winter, with La Sal Mountains in the distance.

Plate tectonic evolution of the region

The Rockies, Cordillera and Cascades all owe their origin to plate convergence over the subducting margins of the Pacific and its associated smaller plates. This convergence zone is distinguished by the rapid westward advance of the American plate, which appears to have overrun the less powerful divergence zone of the East Pacific Rise, whose main output is basaltic material despatched westwards as the Pacific Ocean floor. The horst and graben tensional tectonics within the Basin and Range province may therefore be ascribed to stresses generated within the American plate crust by the mantle divergence still active underneath.

Consequences of the westward advance of the American plate may also be seen further north. The Columbia basalts are best interpreted as the product of a rising mantle plume. The trailing plume tail then produced volcanism on a declining scale, represented by the Snake River basalts, as the earlier flood basalts moved west on the American plate. The explosive andesitic volcanics of Yellowstone were then produced from within the continental crust by heat energy from the remains of the underlying mantle hot-spot.

These broad concepts are very attractive, but may be simplistic; their total acceptance awaits more conclusive field evidence. In the Basin and Range, the picture is clouded by phases and zones of compressional tectonics which could have more shallow origins developed purely within the overriding plate. And within this whole zone of plate margin activity, the Colorado Plateau appears to have survived as an almost intact slab of continental crust.



Needles of sandstone in Canyonlands.



Part of The Maze in western Canyonlands.

Geological framework of the Colorado Plateau

The Precambrian basement of the Colorado Plateau appears to be broken and partly bounded by NE-SW and NW-SE conjugate fractures developed by north-south compression; these fractures define the positions of the Hurricane faults and the Mogollon Rim along the northwest and southwest edges of the modern plateau. From early Cambrian to early Carboniferous times it was largely a positive area subject to erosion and lacking in sedimentation, while thick Lower Paleozoic sediments accumulated in subsiding basins to both east and west. A Carboniferous shelf sea was then broken by movements on the basement weaknesses to create areas of land, and also the isolated Paradox basin where thick salt deposits accumulated.

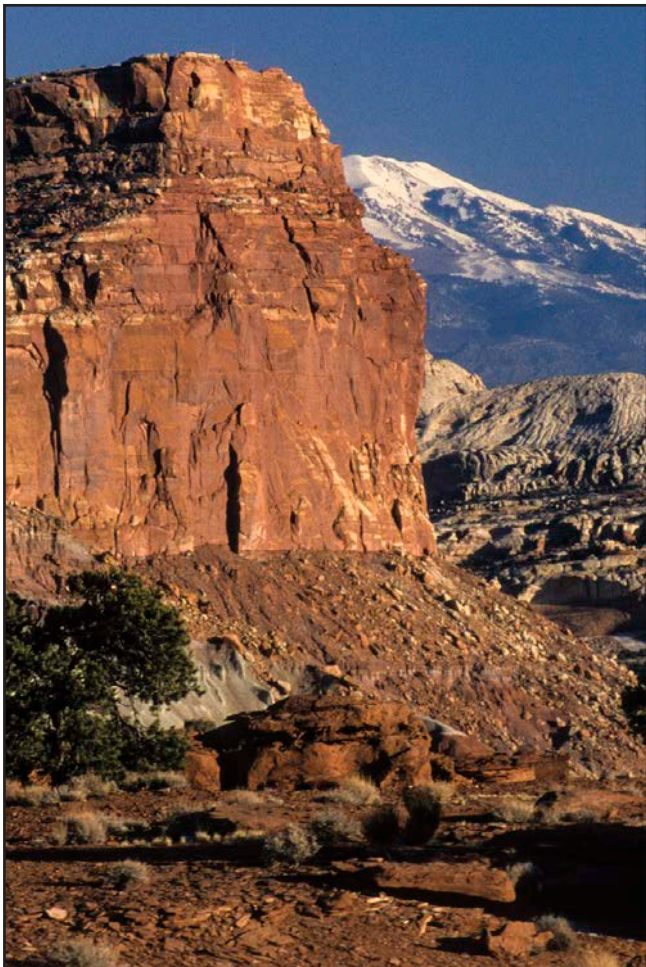
From Permian to Cretaceous times, there was major elastic sediment deposition across most of the region now forming the Plateau. Conspicuous were the massive, aeolian, red sandstones of the Jurassic and Triassic. Basins fluctuated in extent, and many marginal facies changes overlaid the basement fractures, indicating reactivation of the latter. Tilting of the basement blocks is indicated by the Navajo Sandstone which thins from 600 m thick along the western margin to only 50 m in the east. Diapiric rises of the underlying Paradox salt created distinctive local tectonics.

Starting in late Cretaceous times, the Laramide orogeny then reactivated all the basement fractures and older structures, creating the folding seen today which commonly coincides with the facies changes. These structures defined the shallow basins and uplifts which are the elements of the Plateau today, each eroded so that the fold patterns of the stronger sandstone units dominate the landscape patterns. During the Eocene, both the Uinta and Sevier Mountains (a southern continuation of the Wasatch, just west of the Plateau) stood high enough to provide sediment to the Uinta basin and into contemporary lake basins in the Bryce region; later uplift of the western Plateau took the Bryce region way above the Sevier Range. The Tertiary uplifts were accompanied by volcanic activity, mainly around the Plateau margins, but also including the central Navajo volcanic field and the scattered dolerite laccoliths.

Landscapes of the Colorado Plateau

Following the Laramide uplifts of the early Tertiary, most of the Plateau has been subjected to continuous erosion and debris removal. During the Eocene, sediment transport was towards the northwest, to contribute to deposition of the Green River Formation within the Uinta basin. Stripping of the Plateau was by a sequence of scarp retreats, mainly where the strong sandstone units were undercut by removal of underlying shale beds; after the orogenic uplift, erosion rates were high in a wet climate, and scarps retreated by up to a mile per million years.

Miocene uplift of the northwestern part of the region terminated the Eocene deposition, and saw the establishment of the Colorado river system draining to the south; the Grand Canyon sector was not yet established, and the Colorado headed southeast to join the Rio Grande. Scarp retreat continued to be the major feature of erosion, but retreat rates decreased by an order of magnitude as the climate changed to semi-arid. Tectonic disturbance continued to accentuate the gentle domes and basins within the Colorado Plateau, and total Tertiary uplift exceeded 2000 m in the plateaus of the western rim. About five million years ago, a major river capture created the new outlet for the Colorado River through the Grand Canyon. The rejuvenation of the main plateau drainage system made canyon incision into a major component of subsequent landscape evolution in the continuing semi-arid environment.



Capitol Reef National Park.



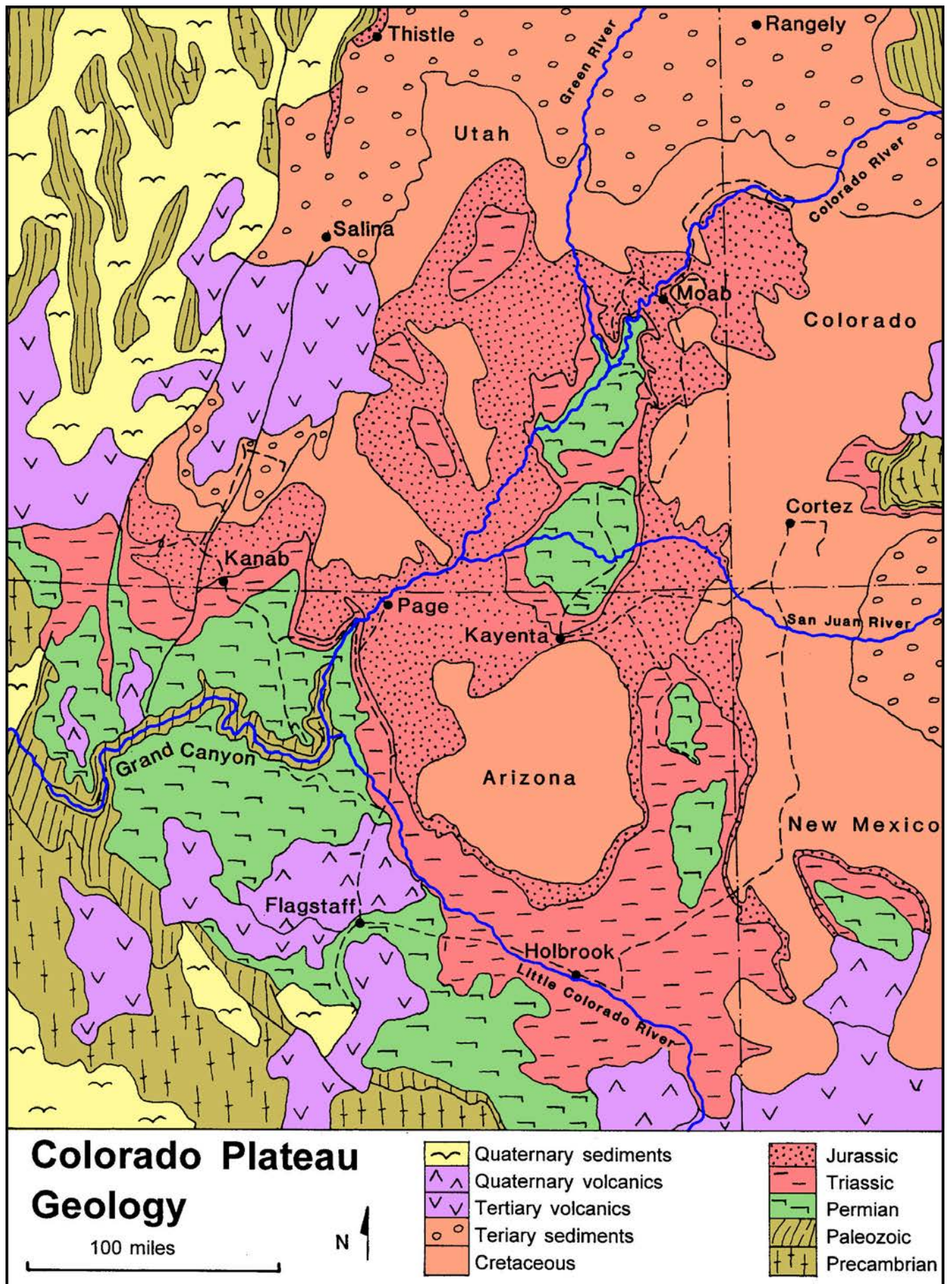
Navajo farmers in Monument Valley.

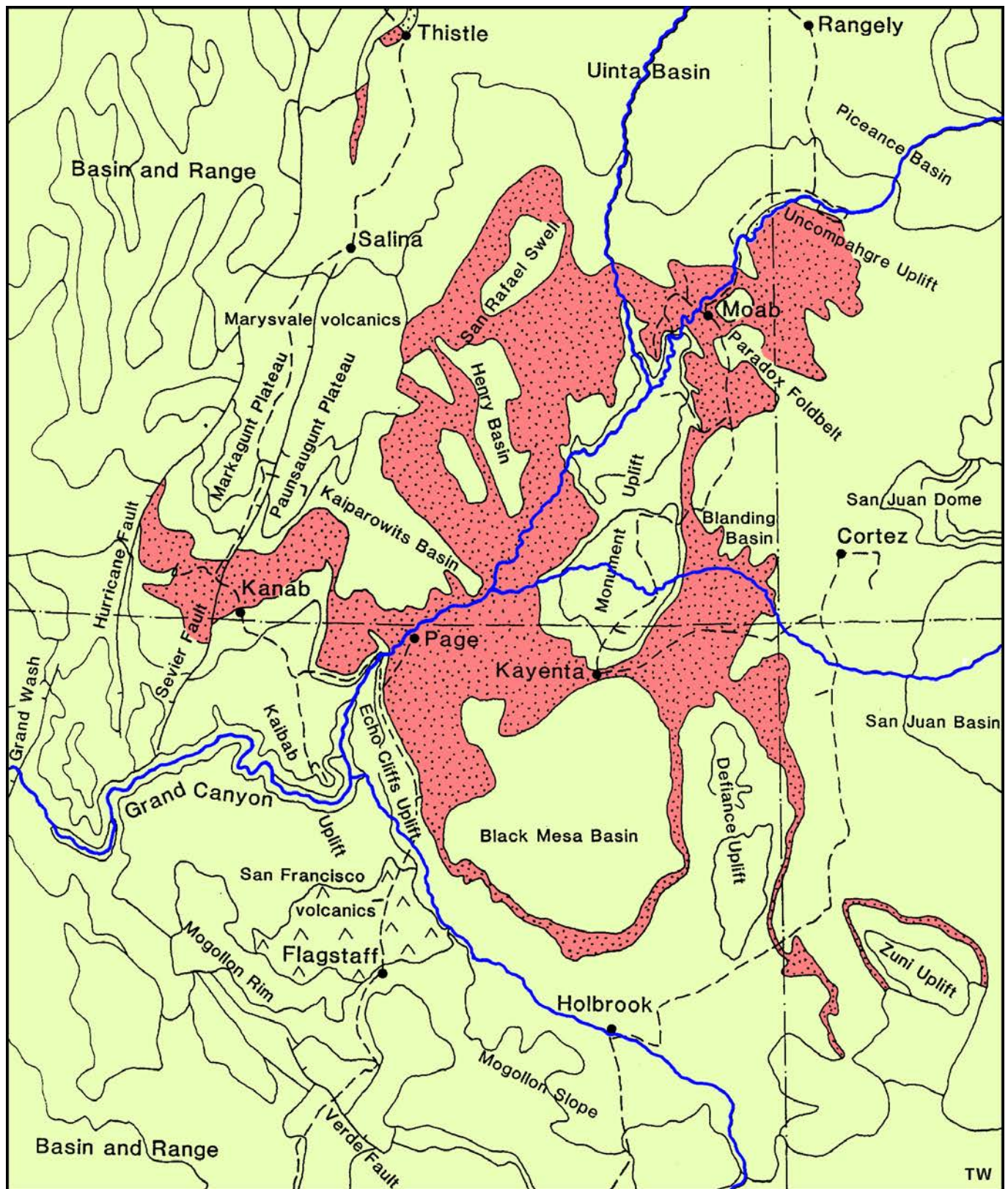
The scarp retreats which have characterised the erosion of the Colorado Plateau have left a series of stripped surfaces on the tops of the stronger sandstones and limestones; as these erosion surfaces therefore follow the stratigraphy, they are known as stratimorphs. The greatest succession of sandstone scarps forms the Grand Staircase, where the Vermillion, White and Pink Cliffs rise northwards from the Grand Canyon to Bryce Canyon; the bottom step is the most conspicuous of all the stratimorphs on the top of the Kaibab Limestone, unmistakable where it forms both North and South Rims of the Grand Canyon.

Higher parts of the modern Colorado Plateau are of three styles. Some are anticlinal stratimorphs over the Tertiary uplift structures, and the limestone Kaibab Plateau is the finest. Others are gently synclinal mesas of strong sandstone surviving in the cores of the Tertiary basins, and Black Mesa is the largest. Then there are the smaller mountains and escarpments formed of stronger rocks; these include mountains cored by Tertiary laccoliths, crags on single volcanic plugs, and hogbacks on the strong Navajo Sandstone.

The Permian, Triassic and Jurassic red sandstones form many of the plateau's most spectacular landscapes; they form vertical cliffs round the mesas and buttes of Monument Valley and elsewhere, and also the walls of many deep canyons. They are soft enough to be easily eroded, yet are massive enough to span undercut voids, so they form the world's greatest collection of natural arches and bridges; bridges are undercut by rivers through the necks of incised meanders, while arches are created by weathering through narrow joint-bounded fins of sandstone.

Pleistocene icecaps developed on the Uintas, the Wind River Range and the Yellowstone mountains, all to the north, but there were only small glaciers on a few of the highest peaks within the plateau. Consequently the landforms of the Colorado Plateau have been carved almost entirely by fluvial action, and then preserved in the semi-arid environment. Combined with the variety of strong and weak rocks, and the sparsity of the modern vegetation, these factors have made the plateau into a geomorphological spectacular without equal.





Colorado Plateau Structural Features

100 miles



- | | |
|--------------------------|--------------|
| — geological boundary | — river |
| — fault | — state line |
| ■ Jurassic red sandstone | — GA route |

TW

Guide to the Canyonlands sites

These notes have been derived largely from the guidebooks produced for Geologists' Association tours in 1997 and 1998. These tours included Great Salt Lake, Bingham Canyon, Thistle, Rangely, Dinosaur, Yellowstone, Madison Canyon, Tucson and Salt River Canyon, besides all the sites in this volume except for South Rim of Grand Canyon and Canyon de Chelly, which have been added to complete the picture of key sites and sights in the red sandstone country.

Some timings and comments from the GA tours remain in this text, where they are useful. A photostop is brief with no walking, and is derived from bus tour planning.

Terminology - The notes use a mixture of American and British stratigraphy in an attempt at achieving the most reader-friendly text; American terms are used where they relate to maps and other literature. Mississippian and Pennsylvanian are the Lower and Upper Carboniferous respectively, but the British term is sometimes retained as a convenient grouping. Similarly, Archean and Proterozoic refer to the Lower and Upper Precambrian. There are few references to the

Pleistocene subdivisions, so the British terms are retained. Paleogene and Neogene are used where convenient for the Lower and Upper Tertiary, though the subdivisions of Eocene to Pliocene are applied where practicable.

Units - In line with modern British conventions, units have been converted to metric throughout this volume, except that road distances are kept as miles, because all American maps and posts refer to miles. Similarly some of the figures retain Imperial units where they have been reproduced directly from the field guides; for use alongside American maps in the field, conversion factors are:- 1 foot = 0.305 metres, and 1 mile = 1.6 kilometres.

Distances - Numbers in the left margins of the notes refer to roadside mileposts, and each locality occurs within the mile after the mile number in the direction of travel, whether this is up or down the numbering. Milepost numbers start and end at road junctions or state boundaries. Numbers in brackets are road distances where mileposts are absent; these are also in miles, as kilometres are just not used in America. Road numbers are used in signposts, all maps and these notes. 1-70 is an Interstate freeway, where even numbers are east-west and odd numbers are north-south. US89 is a national highway, crossing state boundaries, and is generally a fast open road. #46 is a state highway, and is a better through route than county roads which are generally unnumbered on maps.

Logistics - The outline road log in the end section traces a route which was largely used by the GA tours, and offers days of travel which start and end where hotel accommodation is available. In the summer months, advance booking would normally be essential in some of the popular places, notably Kayenta, Grand Canyon South Rim and Page.

Lunch breaks are usually no problem, but some days are out in the wilderness where a snack or picnic lunch must be taken. Water is best carried and is essential on many of the walks; also have a cooler or ice box with chilled drinks in the car.

There are entrance fees for all the National Parks and Monuments. Anyone intending to visit more than about five parks is best advised to buy a Golden Eagle Pass at their first park entrance. Visitors are given brochures with excellent topographic maps at each park entrance, so finding sites, tracing routes and following these notes is not a problem.

Time - The region is on Mountain Time, 7 hours behind British time. All states are on Daylight Saving Time, except Arizona, which is therefore 1 hour behind Utah and the others in the summer. But the Navajo Nation does have DST, so is on Utah time, even where it is within Arizona.

Pleistocene	Sunset Crater volcanics		
Neogene	Verde Limestone		
	San Francisco volcanics		
Paleogene	Navajo volcanics		
	Wasatch Formation Cedar Breaks sandstone		
Cretaceous	Mesaverde Group	Cliff House Sandstone	
		Menefee coal measures	
		Point Lookout Sandstone	
	Mancos Shale	Wahweap Formation	
Dakota Sandstone			
Cedar Mountain Formation		Tropic Shale	
Jurassic	Morrison Formation		
	Curtis Formation		
	Entrada Sandstone	Slick Rock Sandstone	
		Dewey Bridge Sandstone	
	Carmel Formation		
	Temple Cap Sandstone		
Triassic	Navajo Sandstone	Glen Canyon Group	
	Kayenta Formation		
	Wingate Sandstone		
	Chinle Formation		
	Shinarump Conglomerate		
	Moenkopi Formation		
Permian	Kaibab Limestone	De Chelly Sandstone	Park City Phosphate
	Toroweap Sandstone		White Rim Sandstone
	Coconino Sandstone		Cutler Group
	Hermit Shale		Shafer Limestone
Pennsylvanian	Esplanade Sandstone	Cedar Mesa Sandstone	Elephant Canyon Gp
	Schnebley Hill Sst	Halgaito Shale	
		Hermosa Group	Honaker Trail Group
			Supai Group
			Weber Sandstone
Mississippian	Redwall Limestone		
Cambrian	Muav Limestone		
	Bright Angel Shale		
	Tapeats Sandstone		
Proterozoic	Shinumo Quartzite		
	Hakatai Shale		
	Bass Limestone		
	Zoroaster Granite		
	Vishnu Schist		

west and
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Logistic
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of travel
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Kayenta
Lunch
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Water
also have
There
Monument
parks in
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Outline stratigraphy of the Colorado Plateau
encountered at localities with
Some correlations are compiled from
Units of the Glen Canyon Group

Outline stratigraphy of the Colorado Plateau that is incomplete as it includes only beds encountered at localities within this guidebook.

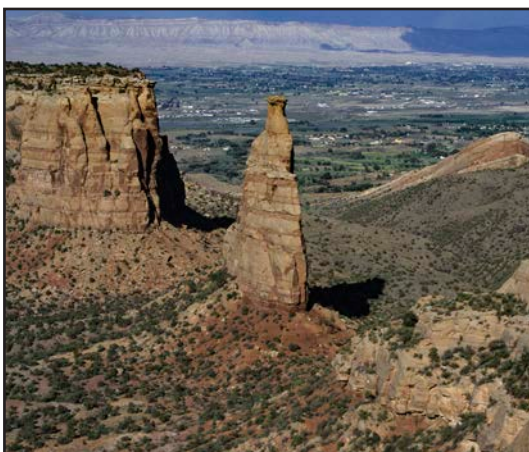
Some correlations are complicated by major facies variations across the region.

Units of the Glen Canyon Group are variously ascribed to the Triassic and/or the Jurassic.

Colorado National Monument

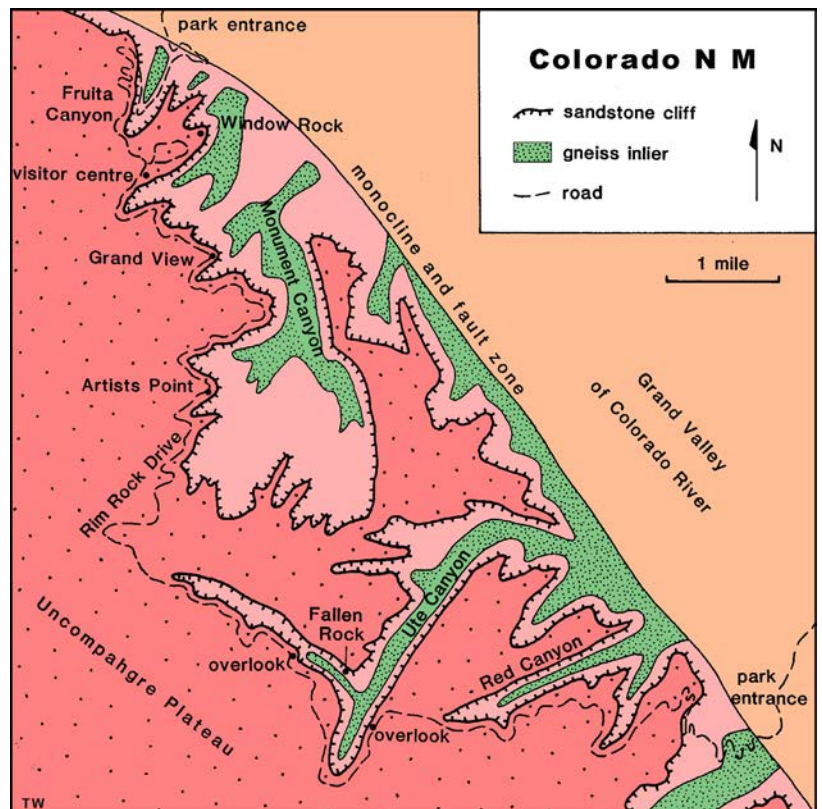
This small national monument includes deeply dissected red sandstone country. It exposes the large monoclinical fold, draped over the basement fault which forms the northern edge of the Uncompahgre Uplift, effectively the northern rim of the Colorado Plateau. The main cliffs are formed in the Triassic Wingate Sandstone and the Jurassic Entrada Sandstone, separated by the softer sandstones and mudstones of the Kayenta; they total about 150 m thick. Beds are nearly horizontal on the plateau, but dip increasingly to the northeast, into the monocline, and are faulted within the steepest zone of flexure; they descend about 1200 m, to continue at depth beneath the nearly horizontal Cretaceous shales of the Colorado valley floor. Precambrian gneisses of the Uncompahgre basement block formed a positive area with no deposition in the late Paleozoic; renewed Tertiary movements on its marginal fault created the monocline and high level faults in cover of Mesozoic sediments. The gneiss is exposed in canyon floor inliers west of the faulted monocline limb.

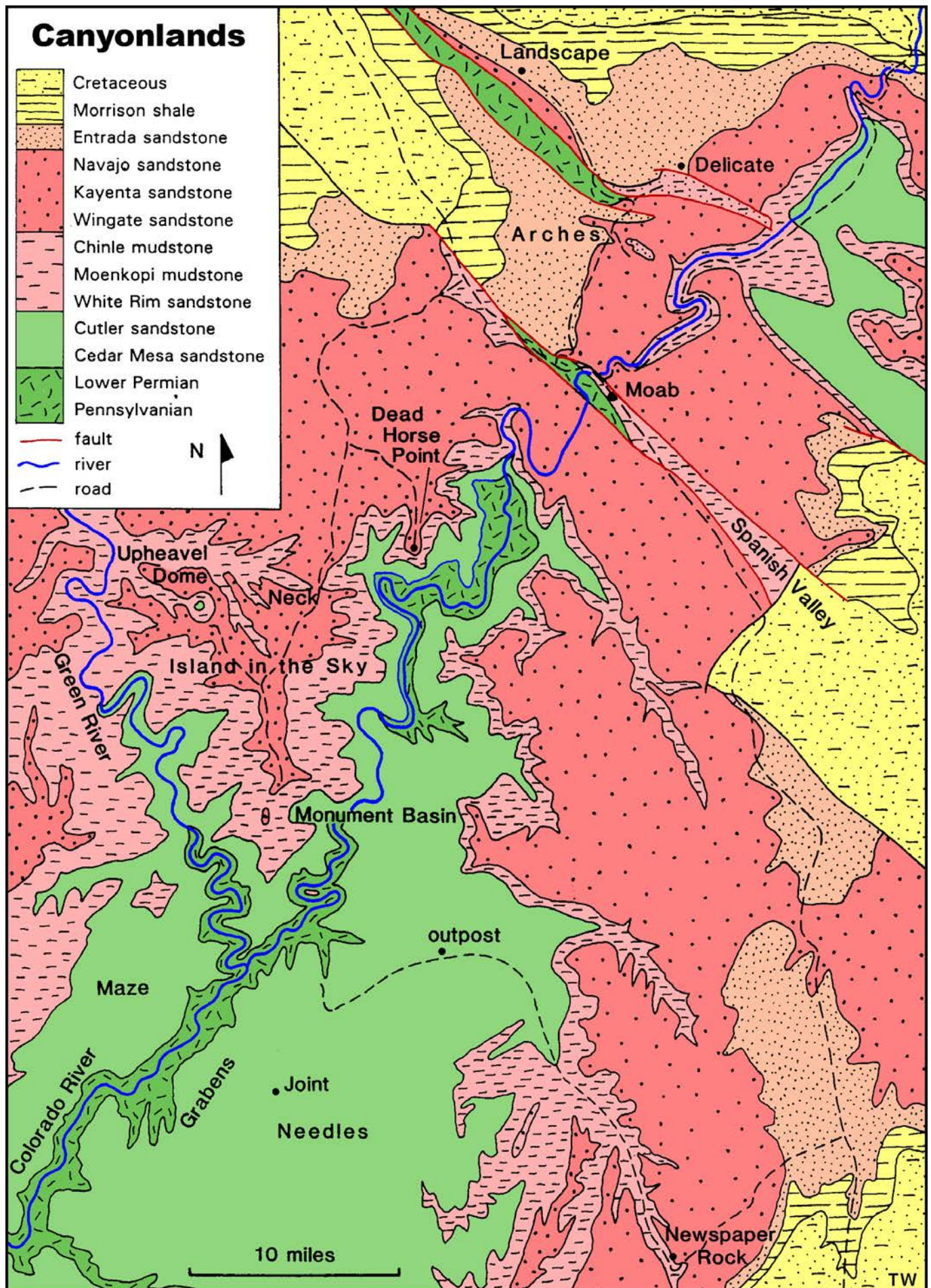
- (0) Enter Monument at southern entrance, up Monument Road from Grand Junction.
- (8) Through entrance station onto Rim Rock Drive, across sandstones in steep limb of anticline. Road crosses fault, and climbs hairpins on inlier of basement gneiss in monoclinical core. Then up onto red Mesozoics, and tunnel on climb through Wingate Sandstone.
- (14) Pass Red Canyon, and others, falling away to right.
- (15) Stop at Ute Canyon turnout; 5 minute walk to overlook. Square box canyon has vertical walls in strong Wingate Sandstone, undercut by erosion of 25 m of soft Chinle Shale above gneiss floor. Fallen Rock and other slabs have failed from canyon walls.
- (17) Photostop at Fallen Rock Overlook turnout on right. Fallen Rock is large slab, which was bounded by vertical relaxation joint within canyon wall created by erosion of canyon and thereby removal of lateral constraint; it failed after water pressure increased in the joint, but it slipped down and did not topple. Road continues in shallow canyons cut in Entrada Sandstone, past Highland View turnout.



Independence Monument sandstone butte.

- (23) Stop at Artists' Point turnout on right, for short stroll to viewpoint. Kayenta Shale is exposed in the roadcut, and overlying Navajo Sandstone is absent across the Uncompahgre Uplift. Coke Ovens and Squaw Fingers pinnacles are erosional remnants of Wingate Sandstone surviving along interfluvies.
- (25) Through Half Tunnel in Entrada Sandstone, where large cliff fall occurred in undercut and overstressed sandstone. Stop at Grand View turnout for short walk to excellent viewpoint over canyons. Independence Monument is largest residual butte, 130 m tall.
- (27) Turn right after visitor centre; and left round loop road to Window Rock trailhead. 10 minute walk to Window Rock, then return to Book Cliff View shelter to rejoin road. Good views of canyons with buttes, sandstone dipping towards monocline fault, and across valley to Tertiary Book Cliffs beyond.
- (28) Continue down Rim Road, with views right down Fruita Canyon. Road then winds down dip slope on top of Wingate Sandstone, and through tunnels in canyon wall of same; views left to proto-arch in far wall, and rockfall down to road on Chinle Shale.
- (29) Short stop at Balanced Rock turnout on Fruita Canyon thalweg. Biotite gneiss is exposed in streambed and in road cuts beyond.
- (30) Road descends through steeper dipping Wingate Sandstone; then crosses fault on hairpin left; monoclinical dip locally 70°. Then re-cross fault (in gully) back onto Chinle Shale at lower dip, and cross again on thalweg.
- (31) Out of Monument, left on #340; over Morrison Formation with derelict Dinosaur Hill site.





Arches National Park

A plateau is capped by gently dipping Jurassic Entrada Sandstone, a red, dune bedded unit 100 m thick. It is broken by the Salt Valley anticline, formed by a rising salt dome core, with subsequent dissolution causing graben collapse along its axis. Tension across the anticline and then the graben created numerous open, vertical joints, aligned NW-SE. Weathering along these created remnant fins of Entrada Sandstone.

Frost shattering and weathering of the porous sandstone in the fins, aided by seepage due to downwards decrease of permeability, causes local retreat of the parallel joint faces into alcoves, until an arch is created through the fin. Most arches form in this way, and there are over 200 within the Park, making it the greatest arch location in the world.

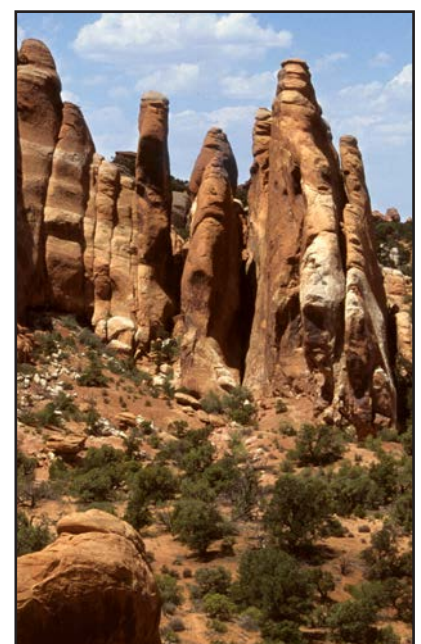
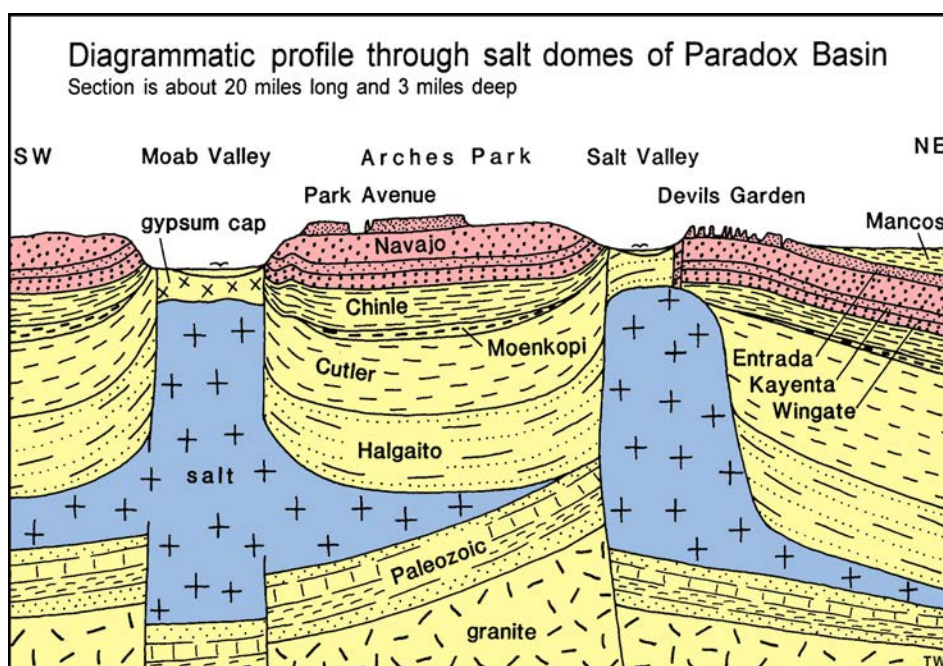
- (0) Past the Visitor Centre, the road climbs steeply on Navajo Sandstone, beneath dubious pinnacle of Entrada Sandstone, with views right into Moab graben.
- (2) Stop in Park Avenue turnout on left. Walk 1.5 km down splendid canyon between vertical walls of red Entrada Sandstone. A pinnacle on the left appears to have been offset by movement along a bedding plane; but the illusion is created by joint blocks which have fallen away from opposite sides. Return by same route, unless someone has driven the car down to meet walkers in the Courthouse Towers turnout at the trail-end.
- (4) Pass Courthouse Towers buttes on left, then long cliff formed of Entrada Sandstone. Main face is in its upper Slick Rock member, overlying its Dewey Bridge member. Latter is a softer red sandstone with distinctive wavy bedding; origin is debatable, but may be uneven compaction due to water expulsion in seismic events, flow within underlying clay unit, or collapse over dissolution of salt or gypsum.
- (6) Pass signposted Petrified Dunes; good dune bedding in Navajo Sandstone, forming bench below and to right.

- (9) Pass Balanced Rock and Windows junction.
- (11) After Panorama Point, road descends into Salt Valley graben; view to left across to joint zone and numerous fins forming Fiery Furnace in Entrada Sandstone along far rim. Then past Delicate Arch junction, and along east rim of graben with splendid fins on right.
- (19) Stop at Devils Garden at end of road. Walking for 3 hours lets everyone reach Landscape Arch, and the fins which lie a little further on, while faster walkers can easily reach the splendid Double O Arch and some of the add on extras. Returning by outward route, do not inadvertently head for Navajo Arch.

Paradox Basin salt tectonics

The Pennsylvanian Paradox Formation lies about 3000 m beneath the valley floors in the Moab region. It is a massive salt sequence at least 150 m thick, containing 29 evaporite cycles with dolomite, gypsum and shale; formed in a marine embayment linked to the open sea over a shallow sill, it extends at depth between the Uncompahgre uplift and a line just west of the Colorado River. Subsequently, over 3000 m of sediment accumulated over the salt, which was squeezed up into anticlinal domes aligned over basement faults. These linear salt diapirs rose through the entire cover; they started to flow in Triassic times, causing erosion above them which left local unconformities. Salt flow continued to, create flank anticlines in the Jurassic rocks, but the Cretaceous cover was not deformed by salt tectonics.

Late Tertiary and Quaternary groundwater dissolution of the salt anticlines caused collapse of the Cretaceous cover into grabens; rift valleys along these (the Moab valley is the finest) are unrelated to the regional drainage, and were regarded as paradoxes by the early explorers - hence basin name. Lesser collapse has created the fissures in Arches and Canyonlands Parks. Oilfields are exploited in fault blocks in Paleozoic basement, beneath the salt.



Fins in Arches National Park.

Landscape Arch

A good, easy trail into the Devils Garden passes excellent sandstone fins on the way to Landscape Arch, which is best seen in morning light. This has a span of 93 m, the longest in the world, and is incredibly fragile as it is only 5 m thick and wide at its narrowest. Weathering along stress fractures cause large chunks to break away; the crescentic scar under the right buttress was formed when 1300 tonnes of rock fell away in the winter of 1941. In September 1991, a 21 m long slab fell away from the underside of the centre of the arch; in June 1995 a slab, 7.5 m long, 1.2 m high and 0.6 m thick, was one of three that broke away from the front of the span. The arch is currently shedding rock at a rate of nearly 1% of its bulk per year. Its collapse is ultimately inevitable, and the side trail beneath is now closed as a precaution.



Above: Turret Arch.

Below: Landscape Arch.



The main trail beyond Landscape is rougher, and divides after passing Wall Arch. Follow signs for Double O Arch, as this includes a superb stroll along the crest of a fin, with splendid views of fins all around; it is worth walking down to and through the Double O. The Private Arch primitive trail is a slightly more energetic way back from Double O. Navajo Arch and/or Pine Tree Arch are worth the diversions for those with time on the return.

- (9) Return across Salt Valley, and stop for stroll around Balanced Rock, which is a 17 m high remnant of Entrada Slick Rock Sandstone, standing on an undercut plinth of Dewey Bridge Sandstone 22 m high. The stump just to the right had a smaller balanced rock (also of Dewey Bridge Sandstone) until it toppled in 1976.

Turn onto Windows spur road, and stop after 2 miles on loop at end. Time for gentle strolls to various arches. Best is Double Arch with 50 m span; this is a pothole arch (as opposed to fin arch) formed by stream scour and pothole erosion behind an exposed face. The loop trail round North and South Windows is also excellent.

Return to main Park road, turn right and down into Salt Valley graben again.

- (11) Turn right to Delicate Arch; stop after 2 miles at Wolfe Ranch trailhead.

Delicate Arch

Energetic walkers leave around 4.00pm, to catch the late sun on Delicate Arch, reached by a hot walk which climbs 150 m, a round trip of at least 90 minutes. Valley floor is on green glauconitic sandstones, and a fluvialite siltstone of Morrison Formation with many chalcedony nodules; trail rises to cross graben margin faults onto older red sandstones. Delicate Arch is splendid in its isolation, as it appears to be a fin remnant standing on an unjointed bed; it is 26 m high and 20 m wide, and the view through it to the La Sal Mountains is magnificent.

Relaxed alternative is to drive 1 mile to the end of the road; then follow the trail for a 40 minutes stroll to the upper viewpoint, with Delicate Arch in distance.

Return out of Park, and back to overnight in Moab.



The view from Dead Horse Point; the Colorado River flows left to right, between wide benches on the Shafer Limestone, with the Shafer Trail just visible on the nearer bench at the bottom centre.

Dead Horse Point

Head through the entrance station into the State Park, then past the fence which was used to close the corral across the narrows known as The Neck, where horses were rounded up by driving them onto the headland rimmed by cliffs.

Stop in carpark at end of road, for 45 minutes lookabout, from the Dead Horse Point overlooks, which are two minutes walk from the tarmac. This promontory provides the most spectacular single view in the whole Canyonlands region. Colorado River is entrenched through almost horizontal rocks forming vast steps and terraces; the river is almost exactly 600 m below the viewpoint.

To the right (west) across the U-bend in the river, the exposed succession extends from the red Triassic Navajo Sandstone down to the mixed sequence of the Permian Elephant Canyon Group. Though forming the main bench within the northern Canyonlands, the White Rim Sandstone is locally thin. The main bench here is on the Shafer Limestone. To the left (east), the Cane Creek anticline lies over a linear salt dome; brine is pumped from wells into the lagoons for precipitation by evaporation of salt and potassium minerals.



Thelma and Louise depart from the Shafer Trail below Dead Horse Point.

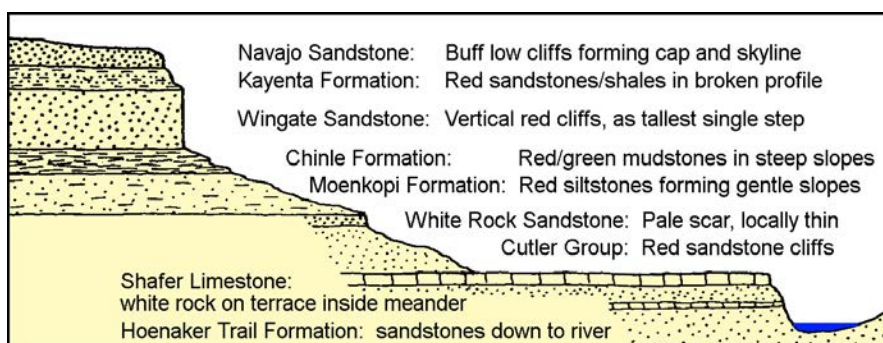
Shafer Trail

Visible across the White Rim bench far below Deadhorse Point, this jeep trail round the White Rim terrace was put in to encourage exploration and development of small zones of uranium ore in thin sandstones within the green Chinle mudstones. A drive along its northern sector is a grand way to see the red sandstone wilderness of Canyonlands.

Companies in Moab run tours along the trail in 4WD jeeps, but an adventurous driver can traverse the trail in a 2WD car with a bit of care. Allow at least half a day to enjoy the trail, also to have time to turn back if a gully has been washed out; and do not attempt the trail if there has been recent rain.

The Trail leaves the tarmac just before the Island in the Sky visitor centre, west of Dead Horse Point, and edges round a bench on the Kayenta shales. It then descends zigzags cut into the Wingate Sandstone cliffs, into the south fork of Shafer Canyon far below the Neck. The gradient eases onto the red Chinle mudstones. Keep left at the trail junction, to descend the wadi floor down onto the Shafer Limestone bench. Follow this east, along the rim of cliffs above the Colorado River on the hairpin bend below Dead Horse Point.

Continue on the benches over the gentle Cane Creek anticline, and then pass the plastic-lined potash evaporation lagoons with their intensely blue brines. Tarmac is regained before the road follows the Colorado River upstream between vertical cliffs of Wingate Sandstone, which end at the fault edging the Spanish Valley graben just north of Moab.



Canyonlands National Park North

This sector covers a magnificent wedge of red sandstone terrain, between the converging Green and Colorado Rivers. Nearly all of it is formed in the almost horizontal sequence of rocks which were seen from Dead Horse Point. Navajo and Kayenta sandstones merely form the cap on a plateau bounded by unbroken vertical cliffs of Wingate Sandstone. Headward erosion by tributaries to both rivers has cut niches into the plateau, and Taylor Canyon has almost isolated it from high land to the north, so that it is known as “Island in the Sky”. The Island plateau stands above a vast platform formed on White Rim Sandstone; the rivers have entrenched this, to reach Pennsylvanian rocks at their confluence. The one break in the structure is Upheaval Dome, on its western margin.

- 5 Stop at Canyonlands Visitor Centre on right, and also just beyond at Shafer Canyon Overlook, on left. Walk out on neck for view down Navajo, Kayenta and Wingate cliffs, with switchback trail down to White Rim. Dead Horse Point is above and left of river bend. Green shale at eye-level on end knoll, has sand columns formed by seismic, upward water blows; some appear to have been ptymatically folded in diagenesis.
- 5 Road continues across The Neck, narrow rib of Navajo Sandstone remaining between heads of canyons cutting back on both sides, and the only route onto the Island in the Sky plateau. Further erosion will leave this as a mesa.
- 13 Turn right to Upheaval Dome, and after 5 miles stop at end of road at Dome trailhead. Short walk rises to viewpoint; the energetic can climb to the higher rim to the right.

Upheaval Dome

Site is a textbook example of an inlier with concentric outcrops on an eroded dome, with almost symmetrical radial dips of about 15° on the conspicuous outer scarps. The dome is 3 km across with a structural rise of about 250 m. Rim of Navajo Sandstone surrounds Kayenta shale valley and Wingate ring – with viewpoints over circular valley in green Chinle and red Moenkopi shales around jumbled core of White Rim Sandstone. In the undisturbed plateau, dome cannot be due to compressive tectonics. It was thought to

lie over a small salt dome. Fieldwork has found explosion and impact structures in the core zone, and has also found locally high iridium values; these finds suggest an origin by meteorite impact followed by a deep explosion. Blast debris has been eroded away: a shallow concentric syncline can fit either the salt dome or the meteorite impact hypothesis.

- 13 Return to junction, and turn right to Grand View.
 - 14 Stop at unsigned Candlestick Tower Overlook on right. Short stroll over dunes in Navajo Sandstone to viewpoints looking west over Green River, entrenched below White Rim.
 - 19 Stop at Orange Cliffs Overlook for good views to west. White Rim platform is magnificent; rim is deeply indented where dendritic channels on the platform shale cover drop over sandstone edge so that waterfall retreat, aided by spring sapping, forms lower canyons.
 - 19 Grand View Point Overlook is at end of road. Monument Basin has spectacular interfluvial aretes and remnant buttes in Cutler red sandstones just below White Rim Sandstone.
 - 13 Return to junction, go right towards Park exit, and shortly stop in Mesa Arch turnout on right. Short loop trail reaches Mesa Arch formed in Navajo Sandstone on rim of cliff. Fine views east through arch to Colorado River and La Sal Mountains.
- Return out of Park, and back to overnight in Moab.



Above: Monument Basin.

Below: Upheaval Dome.



Canyonlands National Park South

- 20 West from US191 at Church Rock, the spur road into the Park descends from the plateau of Navajo Sandstone, down through the Wingate Sandstones into Indian Creek canyon.
- 8 Newspaper Rock is on the right, and is best seen in afternoon light. A cliff of pale red Wingate Sandstone has dark red, desert varnish - a weathering veneer of iron oxides. Generations of Indians made petroglyphs by scratching away the dark crust. This mass of rock art may have items dating back 2000 years, but drawings of horses postdate their introduction by the Spanish in about 1530.
- 0 Pass the Dugout Ranch in a fine box canyon with walls of Wingate Sandstone undercut in Chinle shales.
- (3) Photostop for excellent table-mountain mesas and narrower tower-shaped buttes on left; remnants of the plateau to the east, they are formed of Wingate Sandstone, with their tops over 350 m above valley floor. Road descends gently through Chinle, Moenkopi and Organ Rock shales to reach bench on top of Permian Cedar Mesa Sandstone.
- (12) Into the National Park, with Needles profiles on left.
- 14 Needles Outpost off to the right has food and drinks.
- 15 After entrance station, small visitor centre on the right.

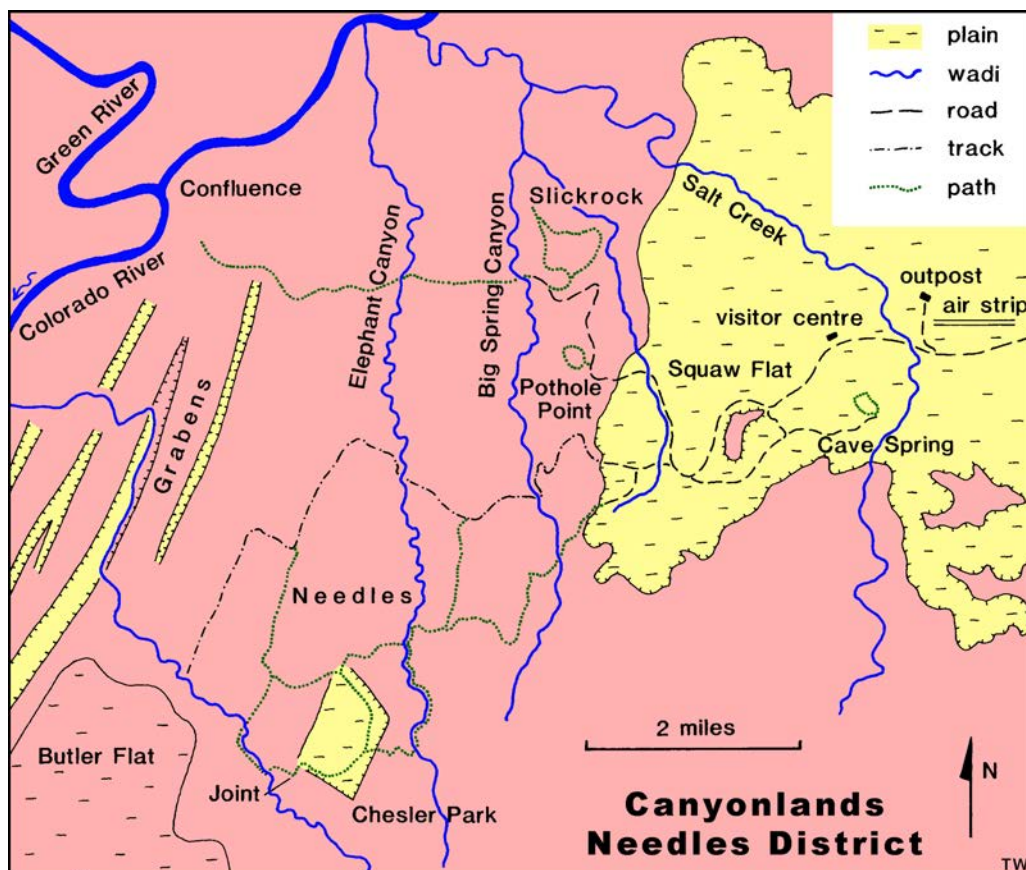
This sector of the Canyonlands National Park covers the Needles district, east of the deeply incised confluence of the Green and Colorado Rivers, formed in a wide bench of almost horizontal Cedar Mesa Sandstone. The red and buff

sandstone was deposited in a beach environment, largely as beach dunes but partly as sand bars in shallow water; both types are cross bedded. This unit is a facies of the Permian Cutler Group, contemporaneous with the soft red sandstones seen the day before in Monument Basin, just to the north. Dissolution and plastic flow of the underlying Pennsylvanian Paradox Salt created major systems of fractures in the Cedar Mesa Sandstone; erosion along the joints has left remnants of sandstone as rounded pinnacles and some as sharper needles, which form the jagged skylines throughout the area. Some fins survive, penetrated by arches. Meandering canyons are incised into the fractured bench; most are wadis, only active in flash floods.

Between the Needles and the Colorado River, the Grabens are long, narrow, straight rift valleys formed on blocks downfaulted into the salt; they are aligned NE-SW along the main tension fractures. The crests of salt domes are exposed at five places along the floor of the Colorado River canyon downstream of its confluence with the Green River.

The magnificent landscapes are best appreciated by walking through them. The Joint Trail walk is a classic, but is rather demanding, especially on a hot summer's day. From the end of the tarmac by the Squaw Flat campground (3 miles from the visitor centre), there are 3 miles of dirt road through Big Spring Canyon to the trailhead, but this is easily reached by normal 2WD cars. A walk on just the first part of the trail is also memorable.

Shorter and easier walks include the Slickrock and Cave Spring loop trails.



Joint Trail.

Slickrock Foot Trail

Loop trail, well marked for 4 km over Cedar Mesa Sandstone, bench takes 90 minutes; best walked anti-clockwise; finest of many views is the end overlook of the convergence of Big and Little Spring Canyons, both cut 150 m into the plateau.

Pothole Point Trail

This shorter loop trail is not so well marked, but wandering is ok and it is difficult to get lost on the open bench. High point has splendid view of Needles. Trail passes many small potholes in Cedar Mesa Sandstone; these are enlarged by dissolution of mineral cement when temporarily filled with rainwater before wind removes sand grains when dry.

Cave Spring Trail

Short loop trail gives 40 minutes' stroll, mostly level except for two short ladders. Trail passes low cliffs with wide rock shelters created by weathering around seepage springs on less permeable horizons. Return trail is down shallow canyon with overhanging cliff on left; the sandstone at the rear of the undercuts has vertical fractures and rock spalling where it is overstressed by the weight of the projecting bed above.

Joint Trail (distances in miles)

- 0 Trail starts at foot of Elephant Hill, and is generally well marked; at all junctions follow signposts to Chesler Park and Joint Trail Start with climb onto wide ridge, with remnant pinnacles in Cedar Mesa Sandstone containing fine beach dune structures.
Cryptobiotic soils are lumpy black crusts of algae and lichen binding mineral sand; they form on flatter areas of ground, and are thin, slow-forming and very fragile - keep to the trails and do not tread on them.
- 1.5 Right at trail junction, then shortly down gully to steep descent into Elephant Canyon.
- 2.1 Floor of canyon is dry wash on bed of white calcareous sandstone, transitional to underlying sandy limestones; rise steeply up far side, and steady ascent to gap through pinnacled ridge.
- 2.9 Into Chesler Park and take trail to left.
Park is gently sloping grassland basin surrounded by low sandstone cliffs. Its margins are defined by fractures, with one set parallel to grabens; sandstone on buttes within basin show that it is not a downfaulted block. Basin appears to be due to selective erosion of zone of locally dense systems of intersecting joints.
- 4.9 Easy trail around Park leads into Joint Trail.
Trail descends into spectacular joint fissure, the only way through a sandstone ridge. Joint has opened by tension, parallel to grabens over flowing salt at depth; its walls are vertical, straight and uneroded. Sandy floor is flat except for a few steps, and has carried an ephemeral stream, but fluvial widening of the fissure is minimal. Continue down boulder climb and onward to intersection of another joint, on right, which has been fluvially eroded as it has large undercuts beneath a very narrow skylight slot (an ideal lunch stop).

Return to trailhead by same route; don't miss the obscure right turn to scramble up the rock step out of Elephant Canyon. Should be back at trailhead 5-6 hours after leaving.

Alternative route for walkers not taking the flights is to take the right turn out of Chesler Park midway round the loop trail; this adds only 400 m, but is rougher and slower; potholes are passed on some of the benches, and there is an interesting descent down joint fissures into Elephant Canyon, before a long hike down the wash to rejoin the outward trail at the sign-boarded crossing. The loop round to the west of Chesler Park has no real benefit.

Canyonlands flightseeing

Commercially available flights give one hour of fantastic sightseeing over the great wilderness of Canyonlands. Various companies advertise flights, which are likely to start from Monticello or Green River airfields. Features seen along the flight routes generally include:

Needles District, with joint fissures, needles, and meandering canyons in Cedar Mesa Sandstone. The Grabens, parallel rift valleys in the sandstone.

Canyons of the Colorado and Green Rivers, downstream and upstream of confluence, entrenched into Pennsylvanian shales below the sandstone, with salt domes exposed in canyon floor. Maze District, with deepest joint canyons, highest sandstone fins, and deepest incised meanders. White Rim terrace, where the thin, strong, pale sandstone is developed north of the Confluence. Cliffs of red Wingate Sandstone, above the benches on the White Rim and Cedar Mesa Sandstones. Upheaval Dome, with its concentric sandstone outcrops.

Island in the Sky above its perimeter of sandstone cliffs.

Monument Basin, with buttes formed in the softer, dark red Cutler sandstones, inside terrace of White Rim sandstone.



Canyonlands west of the rivers.

Natural Bridges National Monument

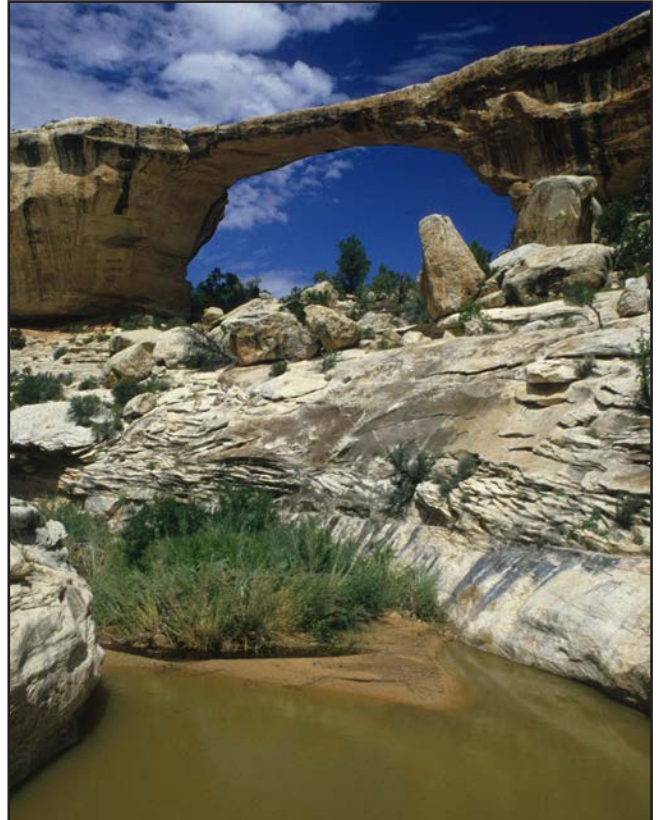
Cedar Mesa is capped by the almost horizontal Cedar Mesa Sandstone, and its northern sector is dissected by various deeply entrenched meandering canyons.

Natural bridges are formed where flash floods on the ephemeral streams cut through the narrow necks of tight meanders in the deep, steep-walled canyons. Bridges survive where strong rock can span the openings above the level of stream erosion, and then suffer minimal weathering and face retreat in the desert environment; their spans become wider and higher as rock spalls from beneath the bridge, until they ultimately collapse. The strong, cross bedded Cedar Mesa Sandstone has few fractures to weaken it, and its incised canyons provide ideal conditions for the formation and preservation of natural bridges.

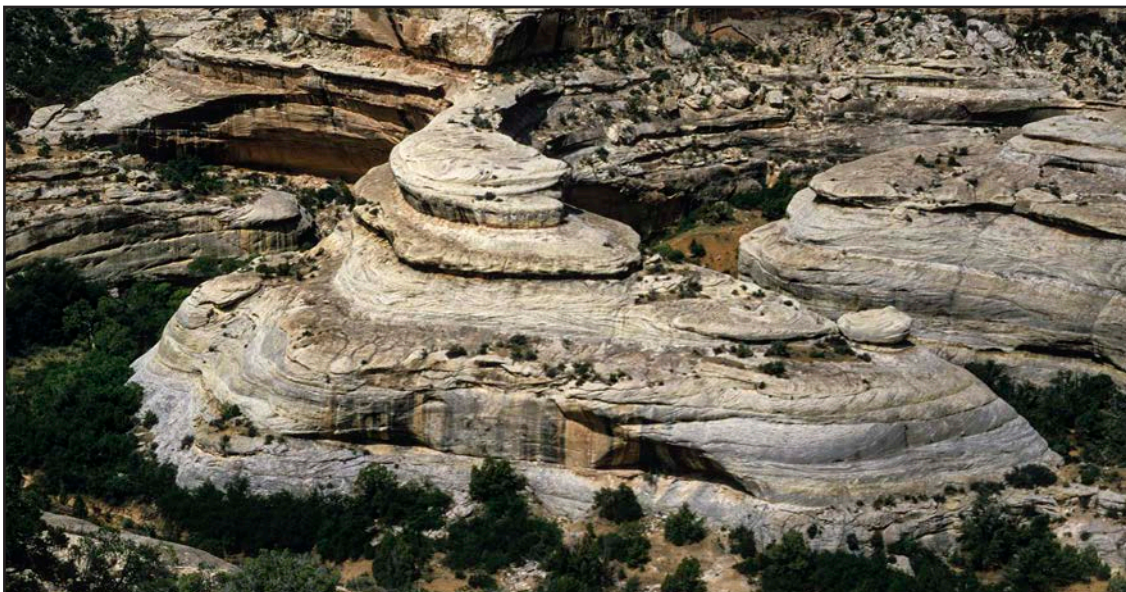
The National Monument has three splendid natural bridges in different stages of maturity in two converging canyons. They are accessible by short walks from a loop road.

- (0) Into Monument by visitor centre with its solar power source, and then head right onto the one-way loop road. that passes the three main bridges
- (2) Stop at Sipapu Bridge viewpoint turnout. Walk 100 m to viewpoint overlooking White Canyon. Sipapu Bridge spans 81 m, reaches a height of 67 m, and is 16 m deep. It is the classic bridge, clearly located in a well preserved meander neck, with the canyon streambed passing through it without causing any further erosion.
- (4) Stop in unmarked turnout on right. Walk out across sandstone bench for 100 m to excellent view of White Canyon's incised meander round the Kachina Bridge.
- (4) Stop at Kachina Bridge viewpoint turnout. Walk 200 m across the bench to an overlook where the bridge is clearly seen. Kachina spans 64 m, beneath a sandstone bridge member which is 28 m deep. Its relatively small opening is an immature feature which is still being enlarged by flash floods passing through it.

- (7) Stop at Owachomo Bridge carpark. Good trail descends 60 m and warrants 45 minutes walking; it descends into Armstrong Canyon and passes beneath the natural bridge. Owachomo is the smallest of the three Monument bridges, but it is the most mature. It spans 55 m of space, 32 m above the dry streambed, and its elegant rock bridge is less than 3 m thick; so it will be the first of the three to collapse. Those who continue along the streambed under the bridge will find it at its most photogenic when viewed from a canyon junction where there may be a small pool of water.
- (9) Continue round loop road back to visitor centre and out of the Monument exit.



Owachomo Bridge.



The meander incised into the sandstone; its neck is breached by Kachina Bridge, which cannot be seen in this view.

Monument Valley Navajo Tribal Park

An eroded plateau edge of nearly horizontal red sandstone has retreated to leave a selection of mesas and buttes which create one of the world's most dramatic and recognisable landscapes. The mesas and buttes stand about 330 m above the surrounding desert floor, their profiles determined by the Permian and Triassic stratigraphy.

Shaping of the mesas and buttes has been by subaerial weathering and rainwash, with face retreat due to rockfalls controlled by the vertical joints in the strong sandstone cliffs undercut in the weak shale, and fluvial excavation and transport in the intervening valleys. Processes have been very slow and selective in the semi-arid environment, and wind erosion has played a minimal part in landform maturation. There are many natural arches in the valley, mostly pothole arches which have been enlarged by streams falling through them.

Forming all vertical cliffs on the mesas and buttes, the De Chelly Sandstone is the lateral equivalent of the White Rim Sandstone in Canyonlands; it thickens south into Arizona, and is missing in the Needles District. Shinarump Conglomerate is a basal member of the Chinle mudstones which form a residual cap on the largest mesas. The Organ Rock unit is a mixed facies contemporary with the Cutler Sandstone. Flooring the lower Valley, the Cedar Mesa unit changes from thick sandstone over the Monument Uplift to thin sabkha mudstones in the Blanding Basin; the facies change coincides with the position of the intervening monocline, indicating control of the Laramide folds by basement disturbances which were also active in the Permian.

Monument Valley has been a Navajo Park since 1958. Visitors in cars should drive round the loop road to the classic viewpoints; travel beyond the loop road is only possible with Navajo guides.

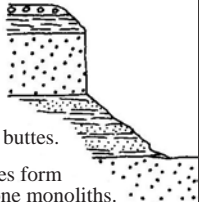
The mesas and buttes of Monument Valley, in the classic view from Artist Point.

Monument Valley tour

All the classic features and viewpoints are reached on the loop road. In the southern part of Monument Valley, the walls of De Chelly Sandstone rise directly from a broad floor of Organ Rock sediments. The car route is via Three Sisters buttes, Rain God Mesa, Totem Pole (the thinnest of the buttes), the sand dunes around Gypsum Creek, and Artist Point and North Window, both of which give superb views north to the Mitten Buttes and the mesas beyond.

Hunt's Mesa walk

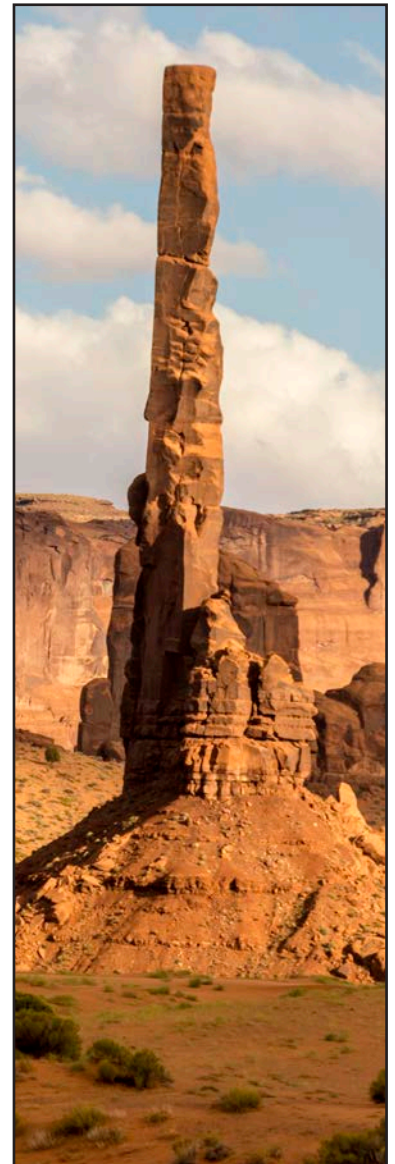
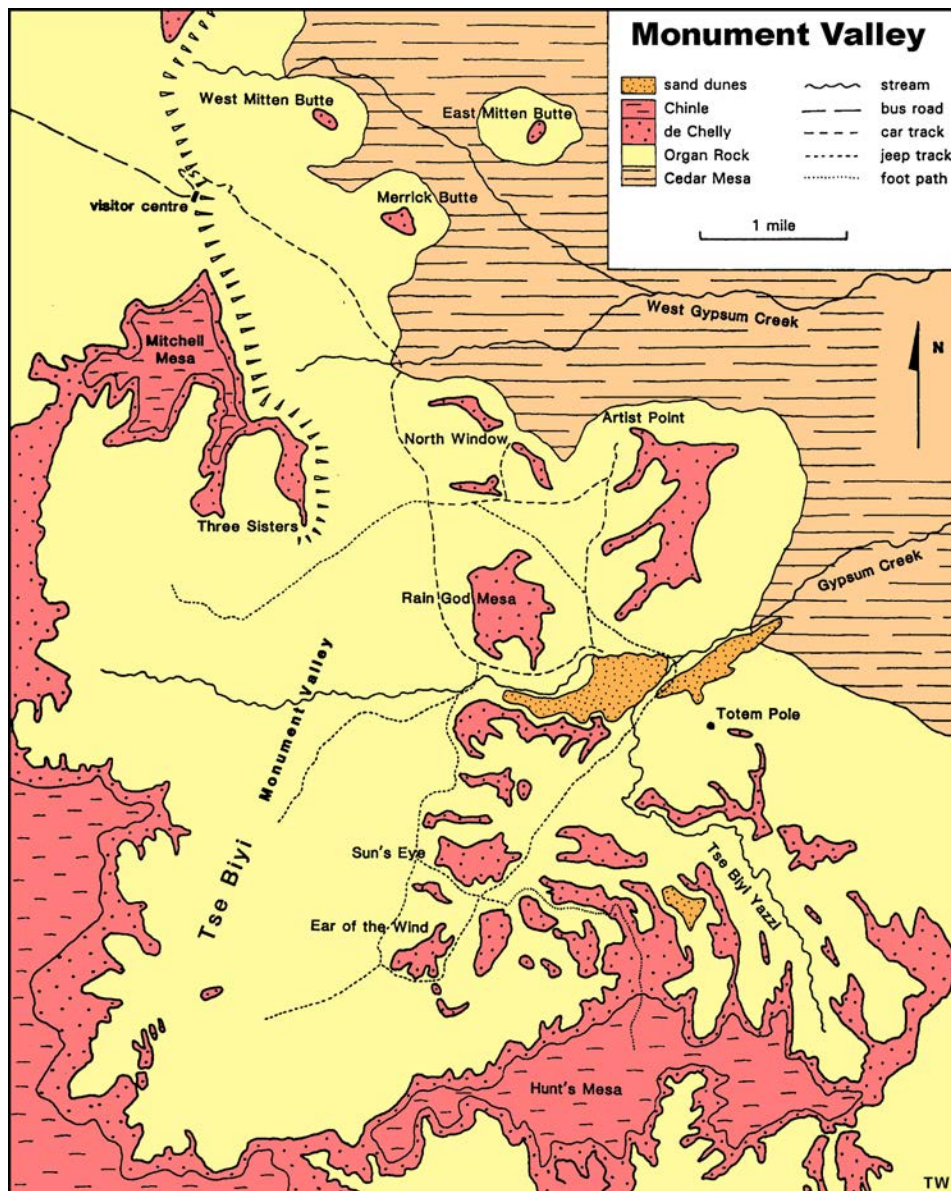
Hunt's is the large mesa across the south end of the valley; it rises 120 m above the smaller mesas. It therefore offers views over the buttes and mesas within the main valley. Navajo companies at the visitor centre offer trips onto the mesa - with a rough jeep ride to the base, followed by a spectacular and energetic walk. The jeep follows first half of the valley tour route; it then goes off onto rougher tracks and stops in wash east of Hidden Arch. Walk is along dry wash, then up rock slopes which provide the only route up the De Chelly Sandstone. There are small steps cut into some steeper rock sections, but the rock is broadly terraced so that there is no serious exposure; a rope ladder can be installed by the guide at one place, to avoid the only rather scary ledge. The route then rises steadily up a wide ridge onto the Shinarump and Chinle caprocks. Continuing south, an easier trail rises to the summit ridge, giving ever-improving panoramas back over the whole valley. The return jeep route is via the rest of the loop road, passing Totem Pole and North Window.

Shinarump Conglomerate	Fluvial pebble beds form thin caprock.	
Moenkopi Shale	30 m of marine shales form rounded shoulders.	
De Chelly Sandstone	140 m of massive, red aeolian sandstones have vertical joints to maintain vertical cliff faces.	
Organ Rock Formation	170 m of thinly bedded shales and sandstones form the stepped plinths for all the mesas and buttes.	
Cedar Mesa Sandstone	Cyclic beach sandstones and sabkha mudstones form the main surface above which rise the sandstone monoliths.	

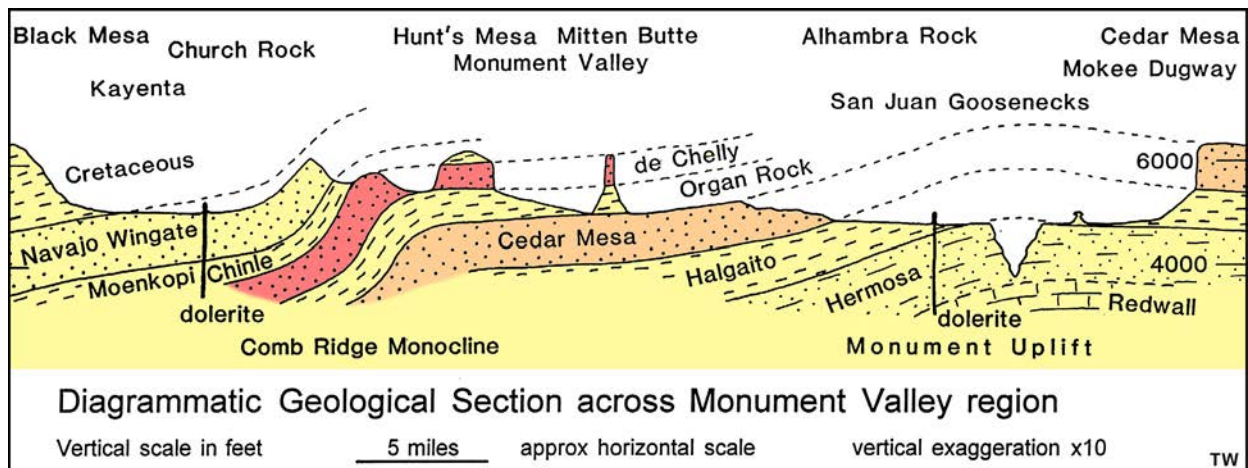




Monument Valley seen from the top of Hunt's Mesa.



Totem Pole in sandstone.



Valley of the Gods

This section of desert lies between the Cedar Mesa cliffs and the San Juan River just north of Mexican Hat. It is best approached from the north, on the road across the cedar covered mesa, south from the Natural Bridges National Monument. The end of the mesa is marked by the sudden drop-off that is descended by the Mokee Dugway dirt road.



Above: Mokee Dugway.

Below: San Juan Goosenecks.



Mokee Dugway

The first and highest overlook provides a spectacular view from the edge of the Cedar Mesa plateau out over the Valley of the Gods, 350 m below. Upper half of cliff is Cedar Mesa Sandstone, overlying ramparts of Halgaito Shale. Platform below is on top of thinly bedded, marine limestones and shales of Pennsylvanian Hermosa Group, exposed in core of the Monument Uplift. San Juan Goosenecks can be seen entrenched into the Hermosa platform.

Skyline is profile of mesas and buttes around the northern edge of Monument Valley; these are in De Chelly Sandstone rising above platform of Cedar Mesa Sandstone. Ruplee anticline lies left of and beyond Goosenecks, and dolerite monolith of Alhambra Rock can be picked out.

San Juan Goosenecks

These famous and spectacular incised meanders are seen from the overlooks on their northern rim, at the end of a short spur road from #261. The San Juan River is a tributary of the Colorado; it originally meandered across a plain cut in the Halgaito Shales, and then became deeply incised across the Monument Uplift, in response to the lowering of base level as the Colorado River entrenched ever deeper. At the same time, the weak Halgaito Shales were stripped down to the impure limestones at the top of the Hermosa Group. The river is now about 310 m below the rim. Walk left along the rim, over grey limestone outcrops with small dissolution features, for the best views of the meanders and the cyclic sediments exposed in the canyon walls.

Canyon de Chelly National Monument

Canyon de Chelly (pronounced *shay*) is a mature fluvial feature draining west, down-dip; its thalweg is almost flat, but the canyon rim rises upstream, creating the deepest sections of canyon towards the east. Its walls are mostly close to vertical, as they are cut in the strong red Permian De Chelly Sandstone; this is locally about 250 m thick, and dips gently off the Defiance Uplift to disappear beneath the Chinle shales to the west. Clean walls in the sandstone reveal spectacular dune bedding, though the rock is structurally massive.

- (0) Into the Monument, take the South Rim Drive, which climbs the dip-slope on top of the De Chelly Sandstone. Remnant outliers of Chinle Shale and Shinarump Conglomerate can be seen on the sandstone dip-slope.
- (2) Stop at Tsegi Overlook. Canyon is about 85 m deep between vertical walls. Navajo farms and hogans on its flat floor take water from alluvium, where the summer water table is only about 1 m down.
- (16) Stop at Spider Rock Overlook at end of Monument road, and walk 200 m to canyon rim. View is upstream with canyon floor 300 m below. Spider Rock is a splendid butte 252 m high left behind where tributary canyons coalesced around it. Canyon floor is just cut down into thinly bedded Organ Rock clastics, beneath walls of vertical De Chelly Sandstone. Black Rock, on the skyline, is the erosional remnant of a Tertiary plug.
- (10) Turn right to Sliding Rock Overlook, and walk 200 m from end of road to canyon rim. Trail is over Shinarump Conglomerate, which lies unconformably on the sandstone. Numerous potholes are enlarged by dissolution of the rock cement in ephemeral pools of trapped rainwater, followed by wind deflation when they are dry. Sliding Rock Ruin is a Pueblo Indian stone house built on a sloping ledge in the sandstone cliff. Excellent dune bedding in the cliffs shows that paleowind was from the northeast.



Canyon de Chelly downstream from Spider Rock.

- (7) Turn right to White House Overlook. View from roadhead is over canyon 160 m deep. White House Ruin is in a cave in the opposite cliff, best seen in afternoon sunlight. The cave formed by weathering on a seepage horizon in the sandstone, and also may have been enlarged by river erosion when the canyon floor was at its level. The cliff above is streaked by blue-green algae on the lines of water runs.

The walk to the canyon floor is excellent for the energetic; it is best done in the afternoon when the sun is on the White House cliff, and should be given 2 hours as it climbs 160 m on the return. Trail descends to the right of the meander core below the roadhead overlook, and passes below some of the most perfect exposures of dune bedding in the cliffs. The main canyon floor may have a shallow flowing stream; paddle across and walk on soft sand downstream to the White House Ruins – which were occupied about 1060–1275 AD. The houses in the overhang cave were reached by ladders from the lower building, which used to stand higher than what remains today.

- (0) Return down South Rim Drive to visitor centre and Monument exit.

Spider Rock in Canyon de Chelly.



Mesa Verde National Park

The mesa plateau is about 15 km square sloping south at about 10°. It is capped by two sandstones of the Cretaceous Mesaverde Formation, each 100 m thick; the tan Cliff House Sandstone lies above the buff Point Lookout Sandstone, and they are separated by 100 m of Menefee marine shales and coal measures. The sandstones cap the Mancos Shales which form the mesa foot-slopes and surrounding valleys. At the northern up-dip tip of the scarp, Cliff House Sandstone has been removed, and Point Lookout Sandstone forms the caprock at its type locality, high above the road. Remnants of the Cliff House Sandstone form down-dip ridges which peak at high points along the North Rim, including Park Point. It also forms the main mesa cap to the south, where it is dissected by long canyons draining down-dip; Cliff House Sandstone rims are undercut by slopes in Menefee shales. Variations of permeability within the sandstone, and its shale floor, create lines of seepage within the canyon walls; these become foci of weathering, frost shattering and stress failure, which create alcoves receding into large rock shelters, that became the Anasazi cave villages.

From about 550 AD, Anasazi people (Navajo for *ancient ones*) now known as the Basketmakers lived on the mesa, in wooden huts and pit houses. They became known as the Pueblo when they started masonry building around 1050, and they soon started building houses and villages inside the cliff caves. By 1200, there were over 5000 people living in the cliff settlements, but by 1300 they had all left, driven out by 20 years of drought. Cowboys rediscovered the Cliff Palace village in 1888, and the Park was designated in 1921.

- (2) Mancos Shale exposed in roadcuts on hairpins.
- (3) Road crosses landslide in Mancos Shales, active in 1990; stabilisation for road includes rock anchors to hold wall supporting road, inclined boreholes into landslide draining out of concrete wall just above road, diversion ditches round top of slide. Photostop in Mancos Valley Overlook turnout on left, for view back to landslide.
- (4) Down dip valley in sandstone, through tunnel, and onto cap of Point Lookout Sandstone.
- (9) Roadcut in Menefee coal measures, and onto cap of Cliff House Sandstone, past Park Point.
- (15) If early in the morning, stop at visitor centre to buy tickets to Cliff Palace and/or Balcony cliff houses; tickets for the cliff house tours sell out by midday.
- (20) Ahead at X-roads to Museum parking on Chapin Mesa; stop for 2 hours.

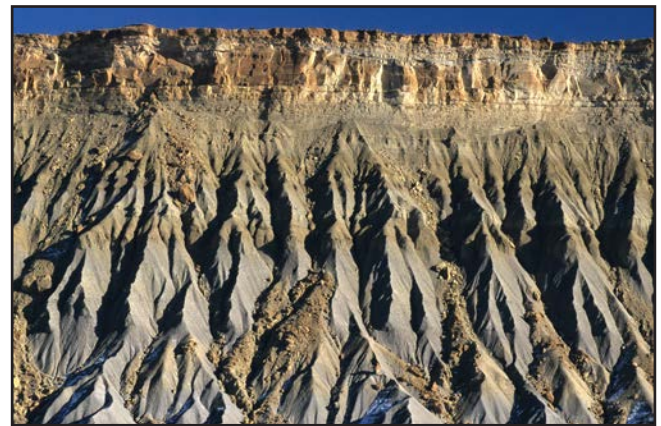
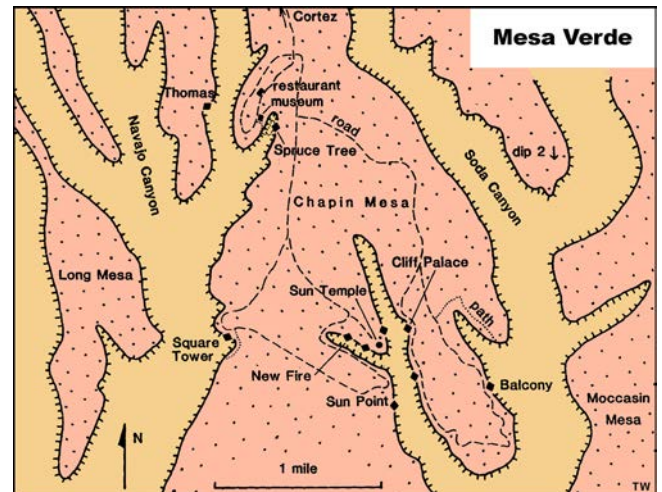


Spruce Tree House

Visit the very good displays in the Chapin Mesa Museum.

Spruce Tree House is reached in 5 minutes on trail behind museum. The spectacular settlement has 114 rooms and 8 kivas in cave 65 m wide reaching back 18 m from the overhang 6 m above. Kivas are spirit holes – ceremonial, painted underground rooms lined with masonry and roofed with timber and clay; Hopi Indians still use them on their reservation. Masonry houses and unroofed kivas are in excellent shape, and this is the one large cave settlement with unrestricted access.

Spruce Tree Terrace has cafe and shops across from museum. Drive through the Museum area, keep ahead at junctions, onto one-way loop road passing all the sites on Chapin Mesa.



Gullies in Mancos Shale below the Point Lookout Sandstone that forms the caprock on much of the Mesa Verde plateau.

Ruined dwellings in one of the many smaller caves along the cliffs of Cliff House Sandstone that line the southern canyons of Mesa Verde.

- (23) Stop at Square Tower House. Short stroll for view into Navajo Canyon, and down to the Square Tower House with its 80 rooms built into a cave.
- (24) Stop at Sun Point. View across canyons, with 12 sets of ruins visible in caves and alcoves.
- (25) Photostop at New Fire House; two levels and steps between cut into opposite canyon wall.
- (25) Stop at Sun Temple. Surface temple, not completed and with an unknown purpose. From rim of Cliff Canyon, there is view of Cliff Palace cave in far wall.
- (27) Turn right onto Cliff Palace road, to one-way loop.
- (29) Stop at Cliff Palace Overlook, best after 3.30pm for sunlight. Cliff Palace is the largest and most spectacular of the cliff dwellings, with 217 rooms up to four storeys high and 23 kivas. The cave is 100 m long, 30 m deep and nearly 20 m high. Some of the buildings stand on a huge slab of fallen roof; the slab has been stabilised by masonry placed by both the Anasazi and the Park Service. Excellent view from canyon rim, 90 m above.
- (31) Pass Balcony House, which lies below the road. Large cave village is only reached by ladders, a tunnel and steps cut in the rock. Tickets from Visitor Centre are needed.
- (32) Stop for walk on short level trail to the only viewpoint for Balcony House; best in the early morning when the sun lights the canyon wall with the cliff house.
- (43) On return to park exit, turn left to Park Point. Few minutes' walk to both viewpoints, to see dip slope, scarp face exposing both Mesaverde sandstones, Mancos Shale valley, Ute Mountain, and Ship Rock (ahead on return). Elevation of 2612 m, 700 m above valley, accounts for local relief rainfall and the green tree cover which gave Mesa Verde its name.

Ship Rock

Known to the Navajo as *Sa-bit-tai-e* (the rock with wings, the great bird that brought them from the north), Ship Rock is in reality the erosional remnant of an Oligocene plug which is the root of a vent within the Navajo volcanic field. It rises 500 m above the almost flat surrounding plain formed largely of Mancos Shale.



The exhumed dyke from Ship Rock, which is 5 km away in this view.

Ship Rock can be seen from the main roads west and south out of the town of Shiprock. It is best seen from the Red Valley road which leaves US666 westwards, 7 miles south of Shiprock.

Seven miles from US666 stop at the junction of a dirt road on the right, immediately before the south dyke. Ship Rock is still 5 km from this viewpoint, but the views are impressive, and the dyke features can be examined. Various dirt roads do reach closer to the rock itself, but their condition can be poor, and they are often impassable after rain except with 4WD vehicles

The igneous rock is minette, a type of lamprophyre with biotite and diopside instead of plagioclase due to the low aluminium content; its isotope profile and eclogite xenoliths suggest that it is mantle derived, with some contamination from crustal rocks. Ship Rock is formed largely of vent breccias, with collapse structures and airfall debris in its upper part; this suggests minimal erosion of its summit since the Oligocene, while the shale plains have been greatly denuded. The dykes have fewer wallrock xenoliths, representing a quieter phase of magma upwelling, during a phase of crustal tension, after the explosive activity of the vent.

The south dyke is 9 km long. Where it is crossed by the road it forms a wall up to 20 m high; this has been left standing by more rapid erosion of the shale country rock. It is about 3 m thick, spheroidally weathered, and breached by many holes. Mica phenocrysts and many small xenoliths can be seen in the minette, which had multiple phases of intrusion and contains some flow banding. There is some marginal breccia and a porous alteration zone, and the grey shale wallrocks show contact baking over about a metre.

Explosion and slump breccias in the upper part of Ship Rock (not detectable from this location) indicate that the surviving plug originally reached to close to its contemporary surface level. Surface lowering of the area has therefore been about 500 m in the subsequent 30 million years, at a mean erosion rate of 17 mm per 1000 years. This is typical of erosion rates in desert environments of low relief; it is much slower than the mean rate of 120 mm per 1000 years recorded (by cave stalagmite dating) for the Yorkshire Pennines through their Pleistocene sequence of glacial ice excavations and interglacial phases of fluvial erosion.

Petrified Forest National Park

Fluvial sandstones within the nearly horizontal Triassic Chinle Formation contain the famous silicified tree trunks. Most of the Chinle are red, grey, purple and pink clays, shales and siltstones, which provide the colours in the Painted Desert. They were deposited in marshes and on floodplains of rivers draining to an inland sea from Triassic highlands to the southeast. In warm tropical climate, trees grew to 60 m tall in marshes and swamps; the main logs are *Araucarioxylon*, (similar to pines of the modern south Pacific region), with lesser *Woodworthia* and *Schilderia*. Distribution of the fossil logs suggests that many fallen trees were washed down the river channels, until log jams formed against sandbars. There are four log horizons in the sequence.

Rapid burial by fluvial sand in the reducing swamp environment minimised decay of the wood, which therefore retained its structure. During early diagenesis of the sandstone, mobile and soluble sodium silicate was created with sodium from alkaline lakes above; there is no known volcanic association. Silicification was in stages, replacing the cell walls of the wood and also infilling the cell cavities, so that much of the structure is perfectly preserved. The silica that replaced the wood structure is cryptocrystalline chalcedony, or agate, coloured by trace elements, commonly reds (jasper) with iron, yellow with iron or uranium, or black with manganese. Cavity infills are of amethyst or smokey quartz, now rarely seen. Most logs are fractured by tension joints at 90° to their lengths, which developed perpendicular to vertical stress during burial compression.



Petrified logs tumbled into a gully within the National Park.



Coloured agate forming a petrified log beside the Giant Logs trail.

The National Park was created in 1907 to protect the logs. Collecting of petrified wood (even tiny chips) is forbidden, and cars may be searched on leaving the Park.

- (0) Enter the Park at the north end, off I-40.
- (2) Kachina and Lacey Points are the best for views of the Painted Desert in the multi-coloured Chinle clays. Gully erosion has created classic badlands terrain, and low mesas are capped by Pliocene basalt lavas at Pintado Point and Pilot Rock.
- (14) Photostop at turnout on right after the Tepees, conical hills in Chinle clays.
- (15) Turn left onto 3 mile spur road, up to loop on Blue Mesa. Stop in first or second turnout on loop. Pebble beds with petrified logs lie over clays which are deeply gullied; some logs stand on low clay pedestals protected from rainwash, and others have been undercut and have slid into gullies. Also stop in viewpoint turnout, after trailhead turnout. The badlands have gullies cutting through banded Chinle clays. White log chips show cell structure under handlens (the loop trail round the valley floor is an optional extra for those with the time)
- (17) Up onto main low mesa. Above gullied rim, mesa top is at main log horizon. Pass Agate Bridge (single log spanning undercut gully, now supported by concrete beam), Jasper Forest (red logs) and Crystal Forest (where early collectors blasted the logs apart in search of amethyst geodes), amid many logs scattered across the mesa. Flattops mesa is capped by sandstone above main mesa and log horizon.
- (26) Turn left to Long Logs. Excellent loop trail winds past numerous photogenic logs, some over 30 m long. Logs are both *in situ* and weathered out of soft sandstones and silty clays. Walk to Agate House is of marginal value.
- (26) Stop at Rainbow Forest Museum. Do not miss the Giant Logs trail, reached through the museum; various loop trails with many logs of large diameter with some of the best mineral colouring in the Park, in silts and clays at two levels separated by channel conglomerates. Good museum displays; shop across road sells mineral specimens collected outside Park.

Craters and cones around Flagstaff

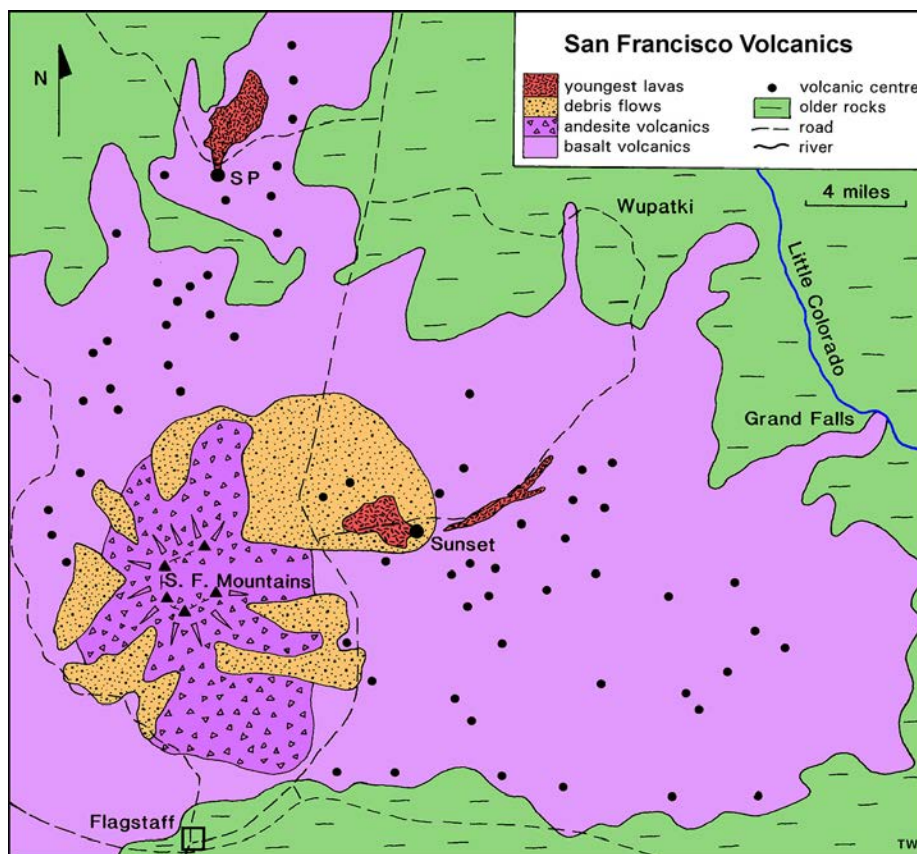
The San Francisco Peaks are the remains of a large late Pliocene composite volcano created by mildly explosive eruptions of andesitic lavas and pyroclastics. Originally about 2500 m tall, expansion during its last phase of magma intrusion (in the Pleistocene) caused massive collapse of its slopes; debris flows spread outwards, and 1000 m was lost from the summit height. The Peaks of today are erosional remnants around an interior basin; this opens towards the east, and appears to be largely a landslide scar, broadly comparable to the well-known and fresher 1980 feature on Mount St Helens, though it has been glacially and fluvially modified.

The main andesitic volcano stands on a sheet of Miocene basalts which cover an area 60 km across; growth of the large andesitic cone was followed into Holocene times by a dying basaltic phase which produced the scattered small cones.

Sunset Crater

A loop road east of US89 passes by Sunset Crater and the Sinagua Indian ruins of Wupatki. There is no access onto the Sunset cone, but it is best seen by walking up the smaller cinder cone from the roadside picnic area 4 miles east of the cone. There is also a sign-posted trail out on the Bonito lava flow which flowed west from the Sunset vent in 1180 AD.

Sunset Crater is the youngest feature in the volcanic field. It is a basaltic cinder cone 300 m high, with a 120 m deep explosion crater inside its summit rim; the bare slopes are coloured by fumarolic silica, limonite and gypsum, to give it its name. Eruptions began in 1064 AD; cone growth continued intermittently for about 150 years, with lava flows produced in both 1064 and 1180 from the same vent.



SP Mountain cinder cone and lava flow

A good dirt road leaves west over a cattle grid from US89 at mile 447.7; it is then 7 miles to SP, approaching the cinder cone past the flow (on the right) of blocky lava from the same vent. The road then crosses the lava where it is over 15 m thick with spectacular levees just beside its emergence from beneath the later cinder cone.

In the classic style of a parasitic basaltic vent, SP was first effusive, producing a lava flow 6 km long about 71,000 years ago; it then became explosive, building a large cinder cone with a summit crater. Its cone is 1200 m across and 250 m high, with a crater 400 m across and 120 m deep; its shape provides its name derived from the vernacular for a chamber pot. The magma was a basaltic andesite (with andesine feldspar in place of basalt's labradorite), its viscosity accounting for the flow's blocky surface, steep margins and high channel levees.

Stop just beyond the lava, for a refreshing walk up to the saddle west of the cone for fine views of the cone and the lava flow, passing deep gully erosion initiated in tracks of 4WD vehicles. The view of the flow is a volcanic classic (well-known from the splendid and widely reproduced air photograph of the cone and flow). Patterns of dark lava show the multiple lobes of the lava flow, including two escapes into a graben valley to the west.

An energetic scramble from the saddle up loose tephra to top of the cone offers finer views, but the crater itself is unexciting except for its rim of welded spatter.

Meteor Crater

Lying 5 miles south of I-40, this is the world's most clearly preserved example of a crater formed by meteoric impact. Originally thought to be volcanic, its impact origin was only proven by Daniel Barringer early in this century. It is 1265 m across and 170 m deep, with an upturned rim rising 50 m above the plain of Moenkopi red sandstones; blocks of white Kaibab Limestone strewn across the plain were ejected from the depths of the impact explosion crater. The crater was formed 50,000 years ago by impact of a meteorite about 40 m across travelling at about 20 km/sec. Fragments of nickel-iron meteorite have been found on the surrounding plain and in boreholes drilled in the crater floor. Boreholes and geophysical surveys suggest that no large mass of the meteorite survives. Pleistocene lake sediments on the crater floor obscure breccia which continues to around 200 m deep. The crater is most spectacular, and best photographed, from the air, and the view from the rim is only gained by entry to a very expensive museum complex.

Mogollon Rim

The southern rim of the Colorado Plateau has features worthy of a detour south of Flagstaff.

Oak Creek Canyon

Old highway #89A follows the canyon down a minor fault which cuts through the rim escarpment.

- 391 Stop in scenic view on left; short stroll to canyon rim overlook. View is south down the Oak Creek fault and its eponymous valley; a cap of columnar Neogene basalt on the Kaibab Limestone on left (east) is down-faulted and lower than the Kaibab Limestone cap on Coconino Sandstone on right (west).
- 390 Down into the basalts, with red tephra deposited between successive lava flows.
- 389 Down into limestone below the basalts, then across the fault with 200 m upthrow onto Coconino Sandstone exposed in roadcuts on hairpin bend. Then cross fault again, back onto Kaibab Limestone, and down more hairpins, past scree debris from overlying basalts.
- 377 Below Coconino Sandstone, roadcuts in grey Mississippian Redwall Limestone dipping 45°, within the fault disturbance zone. Midgley Creek gorge is also entrenched in the limestone.
- 375/314 Continue down into Sedona, a seriously trendy community; head out southeast on #179.
- 299 Under freeway and soon turn right onto a good dirt road for 3 miles.

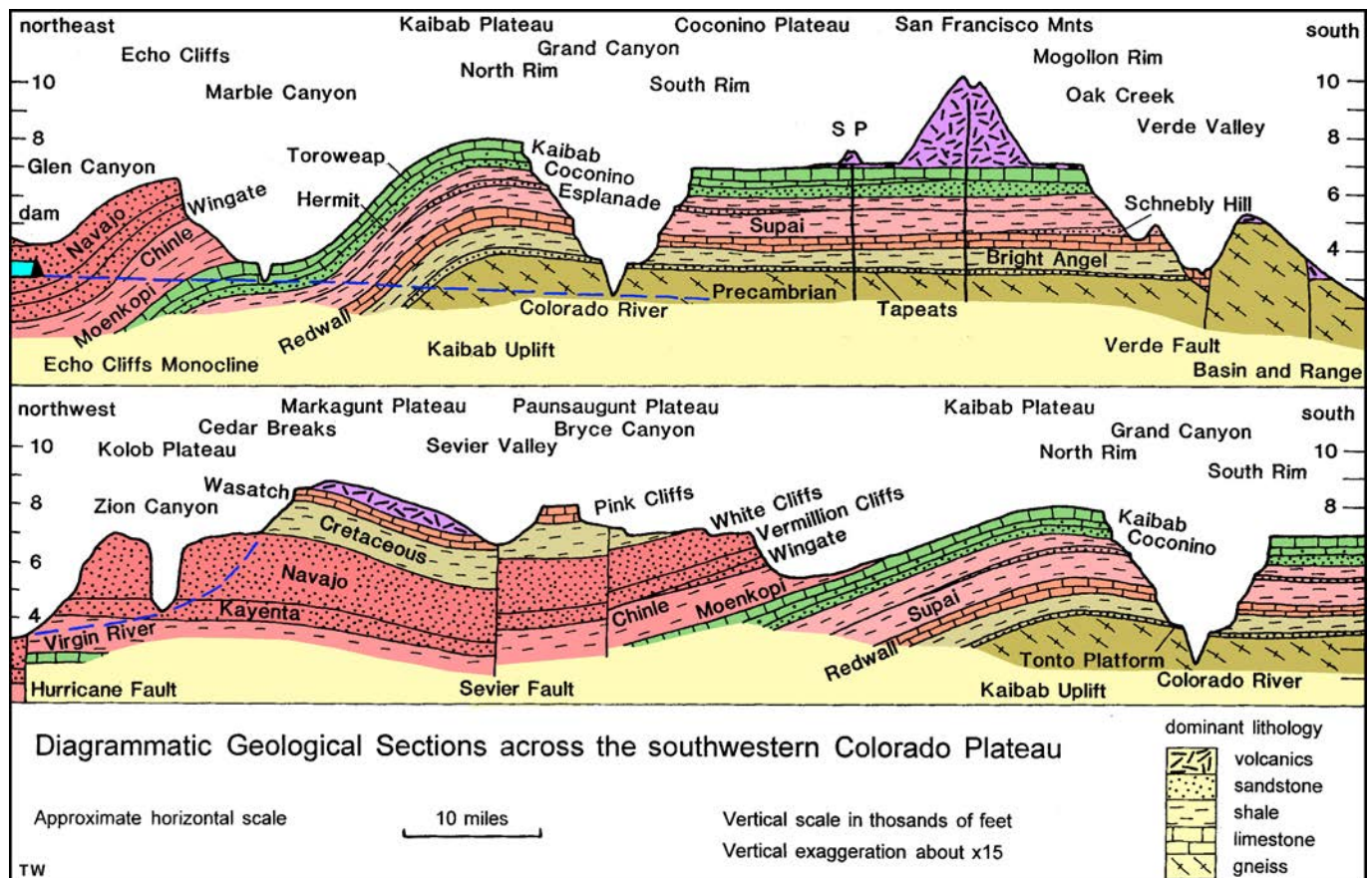
Montezuma Well National Monument

Verde Valley lies between Mogollon Rim of Colorado Plateau and horst block of basement uplifted on Verde Fault to southwest. Drainage was blocked in Neogene by lava flows from Hackberry Mountain, 30 km to south, and the dammed basin lake filled with thick tufaceous limestones, with minor clays and evaporites. Tufa was formed in very shallow, lime-saturated water due to algae extracting carbon dioxide; it is not a normal skeletal limestone. Source of the carbonate may have been plateau of Redwall Limestone to north, low enough to have precluded detrital transport while carbonate was moved in solution.

Erosion of the Verde's outlet has led to entrenchment in the valley, leaving limestone terraces with marginal scars, and has instigated karstic groundwater flow. Well is a cenote, formed by dissolution and collapse of the roof of a chamber within a cave below the water table; it has a lake 110 m across and 17 m deep, draining via a cave through the rim to the adjacent valley. Some new tufa is being deposited from the lime-saturated karst water. Story about fish and carbon dioxide makes no sense; absence of fish is probably due to other salts in the water.

Take the short loop trail to the cenote rim, to see the collapse features. Also take spur trail to the cave resurgence, to see the best of the banded Pliocene tufa. This contains basalt boulders which appear to be flash flood deposits, though isolated boulders could be vegetation dropstones.

Montezuma Castle is a Sinagua Indian ruin under overhang of limestone cliff, 10 km west.



Grand Canyon National Park

The Grand Canyon of the Colorado (in the state of Arizona) has spectacular dimensions. It is 440 km long and 3–28 km wide; its deepest part is through the Kaibab uplift, where the North Rim is 1750 m above the river and 300 m above South Rim. Though valleys in the Himalayas are deeper, and some other gorges have greater depth/width ratios, the Grand Canyon's accessibility, and the clean vertical walls along its rim, make it one of the world's best known natural wonders.

The geology exposed in the canyon walls is a suite of sub-horizontal Paleozoic sedimentary rocks lying unconformably on Proterozoic basement. The main cliff units are the Permian limestones and sandstones for nearly 300 m down from the rim, and the 120-m-thick Mississippian Redwall Limestone lower down. The Inner Gorge is cut into Vishnu Schist, locally overlain by red Unkar sediments, and intruded by granites. Above the Inner Gorge, the Tonto Platform formed where Cambrian Bright Angel Shale has been stripped from the Tapeats Sandstone. The Esplanade Sandstone thickens to the west to form wide benches in the downstream part of the canyon.

Origin of the Grand Canyon

There is still debate over the formation of the Grand Canyon, but it is a largely Pliocene feature. In Miocene times, the Mesozoic red sandstones formed the surface of the Colorado Plateau, and were being stripped off the southwestern sector to expose the Permian Kaibab Limestone.

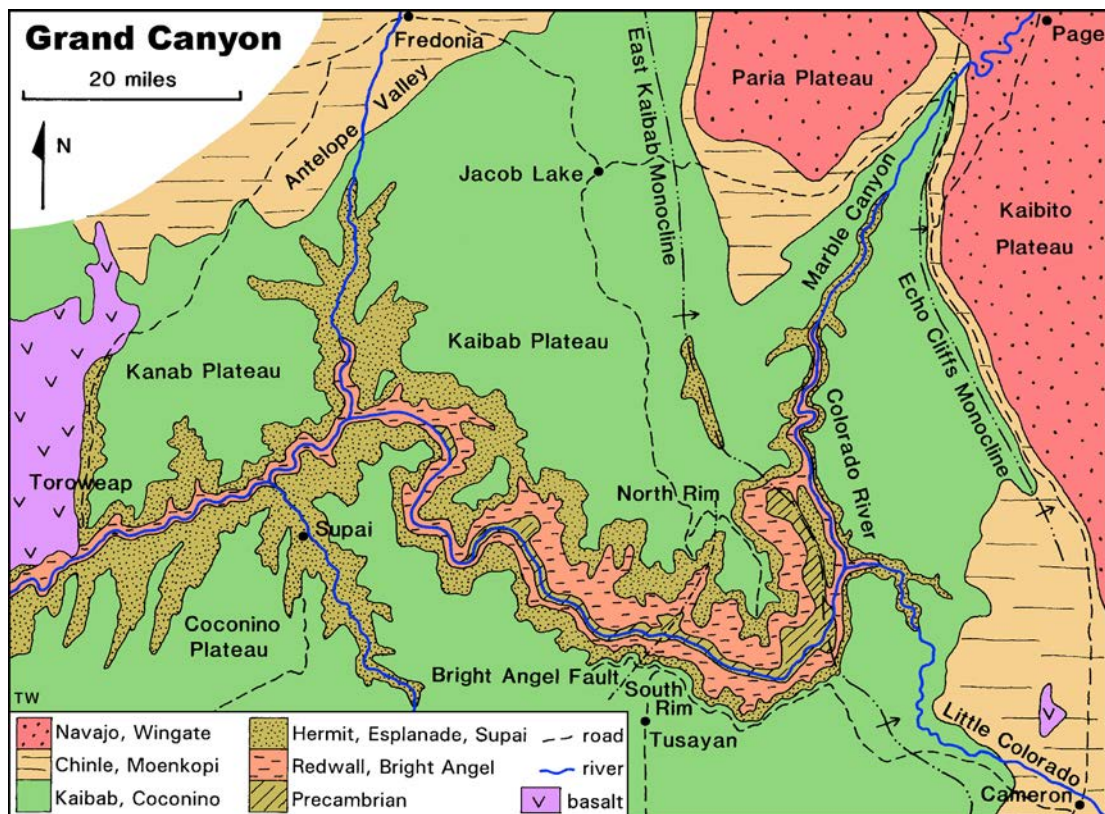
The Colorado River formed as a drainage system off the west slopes of the Rockies, with roughly its present course down to the area south of Page. Its initial route from there was probably southeast, forming a tributary to the Rio Grande in New Mexico. This route may have been the overflow from a

Lake Bidahochi, ponded in a basin east of the Kaibab uplift; though topography suggests the existence of this lake, no sediments from it have yet been recognized. Contemporary drainage west off the Kaibab uplift, and over the fault scarp of the Grand Wash Cliffs, formed the Hualapai River which then flowed south to the Gulf of California.

Headward erosion by the Hualapai cut the initial Grand Canyon back through the limestone uplift, until the upper Colorado River was captured at the elbow bend now wrapped round Cape Royal. This capture occurred around 5.5 Ma, recorded by a change in the valley sediments and incision to the west, where the little Hualapai became the giant lower Colorado. The increased river flow and descent to the foot of the Grand Wash Cliffs caused rapid incision of the Grand Canyon. A knick point retreated up the Colorado to entrench back into Marble Canyon. Any Lake Bidahochi then disappeared, and the Little Colorado River was entrenched by its reversed flow to the northwest and into the Colorado.

The breach through the Kaibab uplift allowed erosion of the Mesozoic shales from the East Kaibab syncline. The same limestone stratigraphic cross the Kaibab uplift creates the highest rims over the deepest part of the Grand Canyon; Pliocene rise of the uplift may have aided canyon incision.

Survival of the Grand Canyon, as opposed to flaring out into a broader valley, is due to the classic gorge-forming situation; down-cutting by the powerful river fed from distant mountains is more effective than degradation of the walls in the desert environment of minimal erosion. Pleistocene volcanoes within the western canyon exhibit little modern erosion, though contemporary lava piles over 300 m high once dammed the Colorado and have since been largely removed by river scour. The high permeability of the rim limestones and sandstones has further aided the canyon wall preservation.



Visiting the Grand Canyon

There are six approaches for visitors to the Grand Canyon:

South Rim is the popular access with massive visitor facilities. A series of viewpoints is currently accessible by car, but a light rail and shuttle bus system is planned to replace car traffic for all day visitors to South Rim by the year 2000, and the only cars to South Rim will be for those reaching hotels or campgrounds. Shuttle buses already run from Bright Angel trailhead west to Hermits Rest (cars are not allowed on West Rim Drive), and east to Yavapai Point.

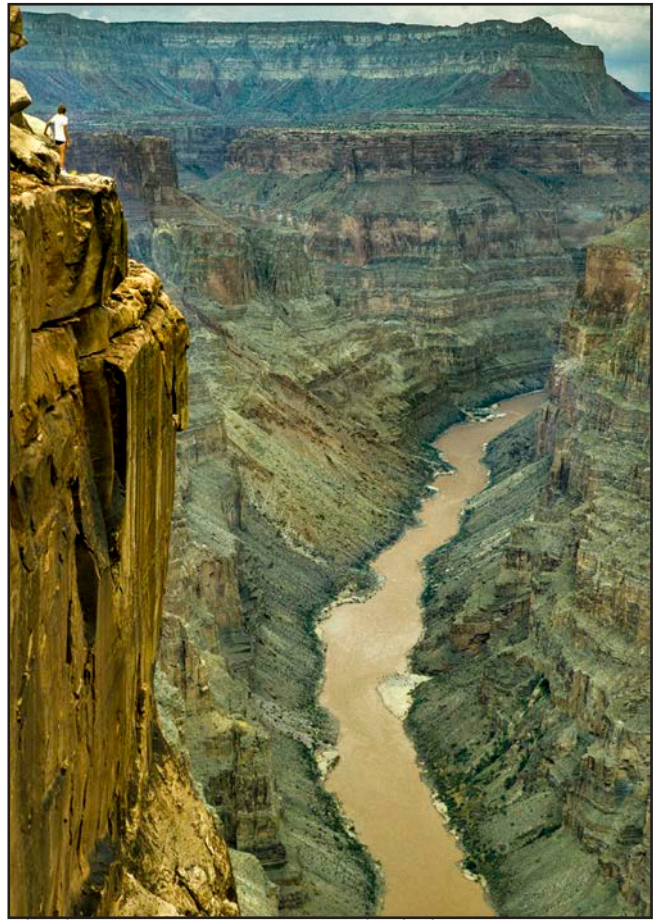
South Rim is the only place where walkers can reach the river and return in the day; for the very fit, the hike down Kaibab Trail and back up Bright Angel Trail is one of the world's classic walks. Shorter day walks, which still demand fitness, are down the Bright Angel Trail to the Plateau Point overlook on the Tonto Platform above the Inner Gorge, or down the ridge section of the Kaibab Trail as far as Skeleton Point.

North Rim is higher and much quieter as it receives fewer visitors and is closed by snow in winter; the rim views encompass more of the subsidiary canyons and residual buttes within the main feature. There are few walking opportunities except for the two-day hike to South Rim via the North Kaibab Trail, stopping over at Phantom Lodge close to the river.

Havasupai lies 60 km west of South Rim, and is approached by a long drive from the surviving loop of old highway 66 between Seligman and Kingman. From the isolated roadhead carpark at Hualapai Hilltop, a trail descends to the Indian village of Supai, and continues beyond to the travertine waterfalls of Havasu (30 m high) and Mooney (60 m high), both on Havasu Creek. The travertine is deposited by slightly warmed geothermal springwater emerging from the Redwall Limestone through a fault in the Supai Group shales, and then degassing its carbon dioxide as it flows down Havasu Canyon. Mooney Falls lie about 1000 m below the canyon rim; to reach them and return in a single day is a very hard walk of 33 km; but it is very rewarding. Food and drink can be bought in Supai, but the trail is otherwise waterless.



Havasupai Falls and travertine barriers.



The classic view at Toroweap, on a cloudy day.

Toroweap lies 90 km west of North Rim. Reaching it is an all-day experience (or camp at the rim) on a long dirt road through very empty desert south from Fredonia; the dirt roads in from the northwest are poorer and are not normally passable by 2WD cars. The road ends beside the famous overlook on the top of an almost vertical drop to the river, 900 m below - the finest single view of the Grand Canyon. The cliff is capped by 200 m of Permian Esplanade Sandstone, and the Redwall Limestone maintains the verticality in the lower part of the cliff; Precambrian basement remains below river level. The downstream view includes two cascades of black lava that poured into the canyon from vents on the north rim, at the southern end of a Pleistocene volcanic field along the Toroweap Valley. The lavas temporarily dammed the Colorado to a depth of 300 m; remnants survive on the south wall of the canyon, and also create the rapids of Lava Falls; a small cinder cone stands on the Esplanade bench.

Rafting trips reveal the Canyon from its depths. Various companies offer full and partial rafting trips, but most take over a week; some splendid side canyons and travertine falls are notable features not seen by any other approach. A raft ride right through the canyon is more popular than the monumental walk through, largely along the Tonto Platform.

Flight-seeing reveals the Canyon from above. Charter flights over the canyon are offered from various airstrips (most conveniently just south of South Rim). The benefits are undeniable, but the options are now reduced, and are likely to be further restricted on justifiable environmental grounds; helicopter flights are no longer permitted over the Canyon.

Grand Canyon South Rim

- (0) From the eastern Park entrance, East Rim Drive heads west to Grand Canyon Village.
- (1) Stop at Desert View, where the canyon is 1370 m deep for a good first view. Canyon walls show in descending order:— Kaibab Limestone rim; Toroweap shales in ledged profile; conspicuous pale cliff of Coconino Sandstone; ledged slopes of Hermit and Supai shales; Redwall Limestone forming the lower major cliff; Bright Angel Shale down to the Tapeats Sandstone above the clear angular unconformity; the Inner Gorge is cut in dipping Precambrian sandstone.
- (3) Stop at Lipan Point for the best view down the Canyon, with the wide Tonto Platform above the Inner Gorge cut in Vishnu Schist.
- (12) Road rises 120 m up dip onto Grandview Monocline.
- (23) Yaki Point has the views of the Kaibab Trail directly below, and of the trail out across the Tonto Platform from Bright Angel Trail to Plateau Point.
- (25) Join South Entrance Road from the left, and head right into Grand Canyon Village.
- (26) Yavapai Point has a repeat of the Yaki Point views.

Bright Angel Trail

Well graded and sometimes too crowded, this offers a memorable walk down the fault-guided tributary canyon and out to Plateau Point on the Tonto Platform. It involves a descent and climb back of 950 m, in a return length of 20 km, and needs 6 hours of steady walking. A shorter walk on the trail is not as rewarding as a comparable short descent on the Kaibab Trail. Its advantage is its easier gradient and the three conveniently spaced rest-houses where water is available. The trailhead is 200 m west of the Bright Angel Hotel.

First steep section and tunnel are in Kaibab Limestone, then trail eases onto Toroweap elastics. Just before the second

tunnel, cross the Bright Angel Fault with 58 m downthrow to the east. Second tunnel and following zigzags are in dune-bedded Coconino Sandstone.

Easier descent on weaker Hermit and Supai sediment ends at Three Mile Resthouse, at top of Jacobs Ladder zigzags down the Redwall Limestone, stained by leachates from above, and then the grey Muav Limestone.

Trail levels again over Bright Angel Shale, to Indian Garden which was once farmed with the aid of spring-water from the overlying limestones. Water supply is now out of pipeline from Roaring Springs at same horizon beneath North Rim.

Fork left for Plateau Point, on a level but very exposed and hot, trail across the Tonto Platform on the Tapeats Sandstone. From the trail-end viewpoint, the Colorado River can be seen tumbling over the Horn Creek Rapids, 420 m below the overlook. The Inner Gorge is cut largely in Precambrian rocks beneath the conspicuous unconformity at the base of the Tapeats Sandstone; Vishnu Schist is dominant, but the bright red Hakatai Shale is also exposed in the canyon walls.



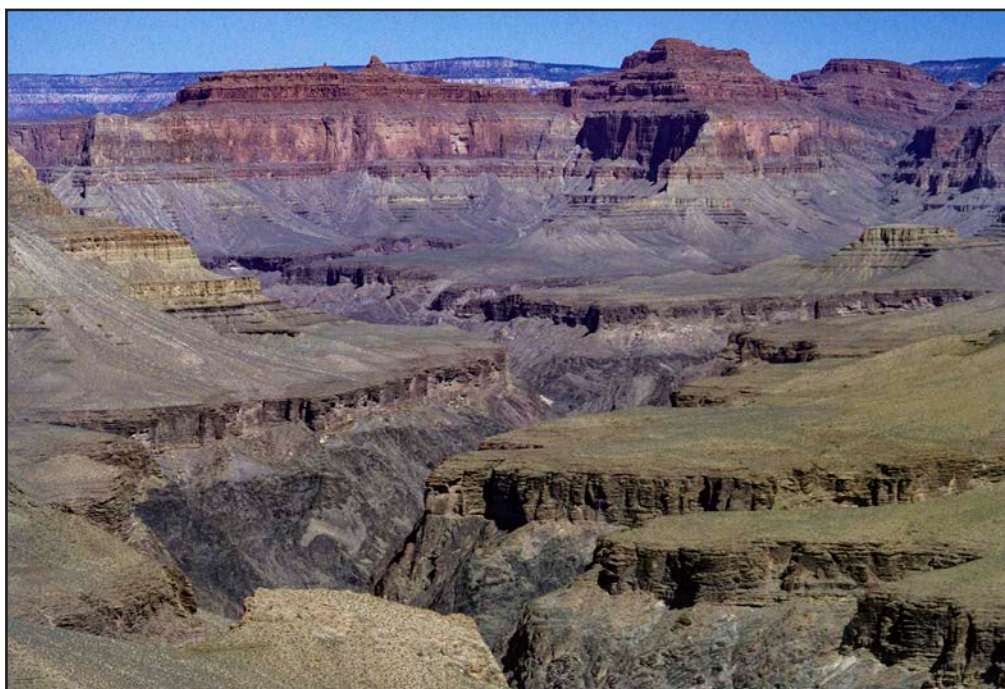
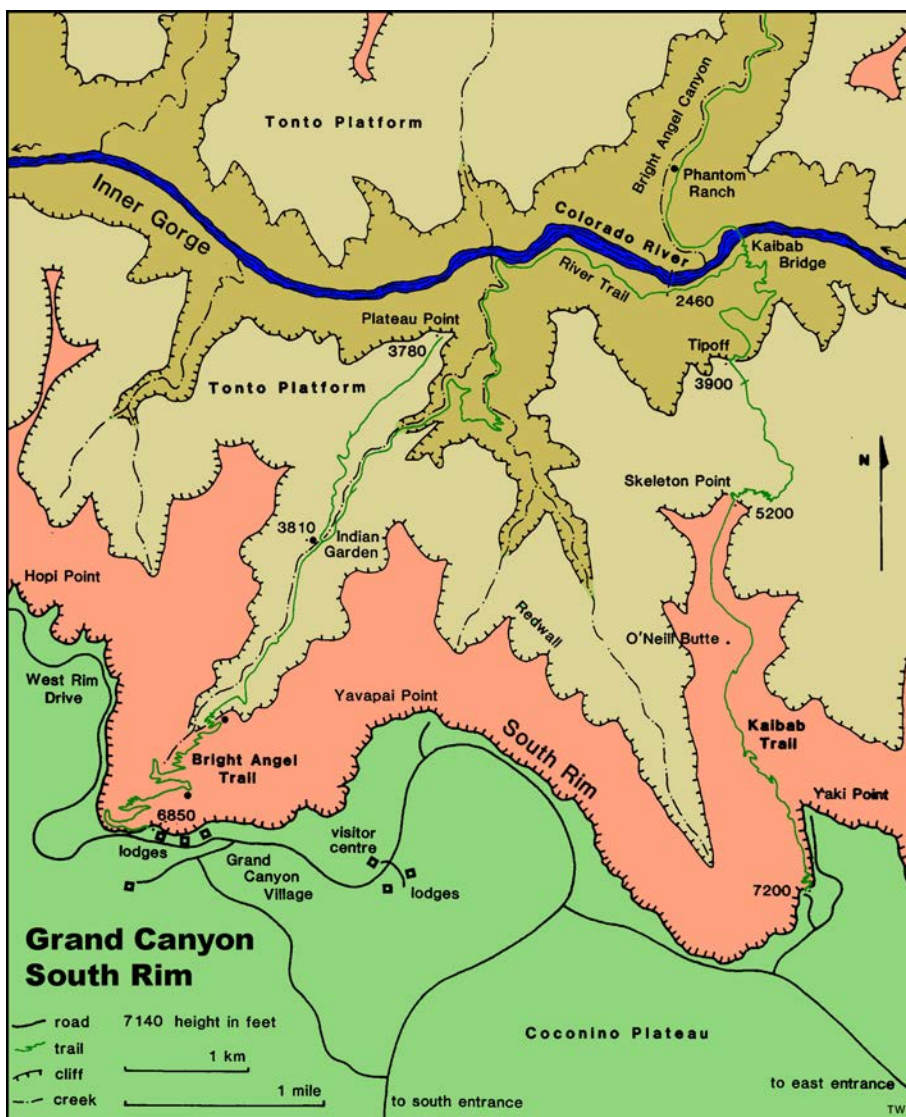
Grand Canyon, from Desert View, with dipping Precambrian sandstones beneath the almost horizontal Tapeats Sandstone.



Grand Canyon from Hopi Point, with the Bright Angel Canyon guided by a fault in its descent from the North Rim skyline.



Supai resident in Havasu Canyon.



Tonto Platform and the Inner Gorge, downstream of the Havasupai Trail.

West Rim Trail

This offers the only level walk, westwards from Bright Angel trailhead, with the choice of returns on the shuttle bus. Maricopa Point has a view down to the Orphan Mine, worked 1893–1966 first for copper then for uranium. Hydrothermal ore is in breccia pipe through the Hermit Shale, filled with blocks of Coconino Sandstone, formed by karstic collapse into the Redwall Limestone. The Abyss has an untypical single vertical wall through both the Kaibab and the Coconino. Granite Rapids (over granite within the Vishnu Schist) in the Colorado River can be seen from Pima Point.

Kaibab Trail

Steeper, more remote and less crowded than Bright Angel, the Kaibab Trail offers a splendid walk of 3-4 hours (round trip) down to Skeleton Point 650 m below the rim; it mostly follows along an interfluve ridge, affording fine views in both directions. The trailhead is just upstream and south of Yaki Point; unlike Bright Angel, there is no water on the Kaibab Trail. There are geological signboards along the trail.

First zigzags descend 60 m of cliff in Kaibab Limestone, containing chert and brachiopods. Trail levels onto mixed Toroweap sequence, with fallen blocks of Kaibab Limestone on slopes. Second set of zigzags are down buff dune-bedded Coconino Sandstone.

Hermit Shale extends down to level col on Cedar Ridge; display case on left has Permian ferns, and O'Neill Butte ahead is outlier of Esplanade Sandstone. Trail steepens onto mixed, thinly bedded Supai Group; reptile tracks are exposed in sandstone a metre above the trail where it passes below the top of O'Neill Butte.

Almost level platform out to Skeleton Point is on top of Redwall Limestone. Trail steepens down through the limestone, past karstic dissolution pockets in walls stained by iron oxides from the overlying shales.

It is worth going down to the third hairpin bend, where there is an excellent view of the Tonto Platform and Inner Gorge; do not go further down unless prepared for the total descent.



Horseman and his pack animals coming up the Kaibab Trail after supplying Phantom Lodge.

Day hike to the floor of the Canyon

This is best done by going down the shorter and steeper Kaibab Trail, then along the River Trail for 2 km and back up the Bright Angel Trail. The distance is 25 km and the climb out is 1360 m. Walkers should enjoy the sunrise on Yaki Point, and then descend immediately afterwards; they should reach the river in a few hours, but the total walk takes 8 to 12 hours; it is only for those who are very fit. There are no water supplies until Indian Gardens is reached on the ascent. Any variations from this single loop are much harder, and are not advisable in summer heat.

Below the zigzags from Skeleton Point down the Redwall and Muav Limestones, the gradient eases onto the Bright Angel Shales.

Tonto Platform extends to the Tipoff on the rim of the Inner Gorge, where a few metres of Tapeats Sandstone is exposed above the very uneven unconformity with Shinumo Quartzite beneath. Zigzags descend the quartzite, and then cross a fault onto the dipping, bright red, Hakatai Shale with the Bass limestone (with algal banding) beneath it.

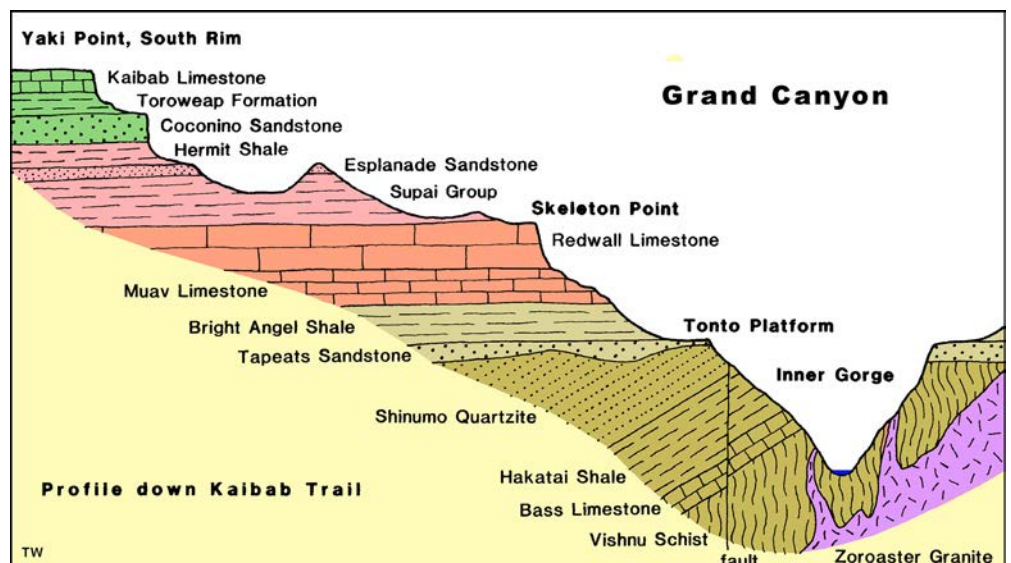
Trail descends onto dark Vishnu Schist with mica and hornblende, intruded and stoped by dykes of gneissic Zoroaster Granite with pink feldspar; both are early Proterozoic.

The Colorado River is about 100 m wide and 5 m deep. It is crossed by the Kaibab footbridge and the Silver Bridge with its water pipeline from Roaring Springs. Follow the River Trail downstream, without crossing the river, and pass opposite the outlet of Bright Angel Canyon which comes down from North Rim.

At Pipe Creek, continue up the Bright Angel Trail and up the Devils Corkscrew zigzags, still in dark Vishnu Schist.

An easier gradient continues through a narrow canyon entrenched in the Tapeats Sandstone, and the trail follows the thalweg up out of this to emerge on the Tonto Platform for an almost level walk to Indian Garden.

The route up then follows the return leg of the Bright Angel walk to Plateau Point, and water is available at Indian Garden and the two resthouses higher up the trail.



Simplified profile of the geology of the Grand Canyon, drawn roughly along the line of the Kaibab Trail.

Grand Canyon North Rim

- 0 Through entrance to Grand Canyon National Park, at elevation of 2690 m.

Road then descends plunge of anticline crest towards canyon rim.

- 9 Pass Cape Royal junction; roadcut in Toroweap sandstone, beneath Kaibab limestone.

- 12 Stop for 90 minutes at Grand Canyon Lodge.

Take the trail from the eastern side of the lodge, walking for 5 minutes along limestone arete to Bright Angel Point. Roaring Springs, in canyon to east, can be seen and heard from bridge onto Point; these large karstic risings at base of Redwall Limestone drain much of the Kaibab Plateau.

View from Point is along terraced walls of Bright Angel Canyon, formed on fault which extends right across main canyon. Buff cliffs below rim limestone are Coconino Sandstone, with some recent rockfalls. Lower down, red cliffs are of Redwall Limestone, a grey limestone stained by iron oxides from above. Dipping basement metasediments and schist, lying below unconformity, are exposed in inner gorge of Bright Angel Canyon, with thin Tapeats Sandstone along the rim.

River is 11 km away and 1740 m below; South Rim is 16 km away. On far wall, Tonto Platform has trail visible from Plateau Point to patch of greenery at Indian Garden fed by springs in limestone above. Skeleton Point is promontory on Redwall Limestone. Bright Angel Fault is clearly visible, with downthrow of pale Coconino Sandstone on east (left). Volcanic San Francisco Mountains rise far beyond rim.

- 9/0 Turn right onto Cape Royal road, out across the Walhalla Plateau.

- (9) Brief stop at Vista Encantadora picnic site. View north is of start of monoclinial dip off

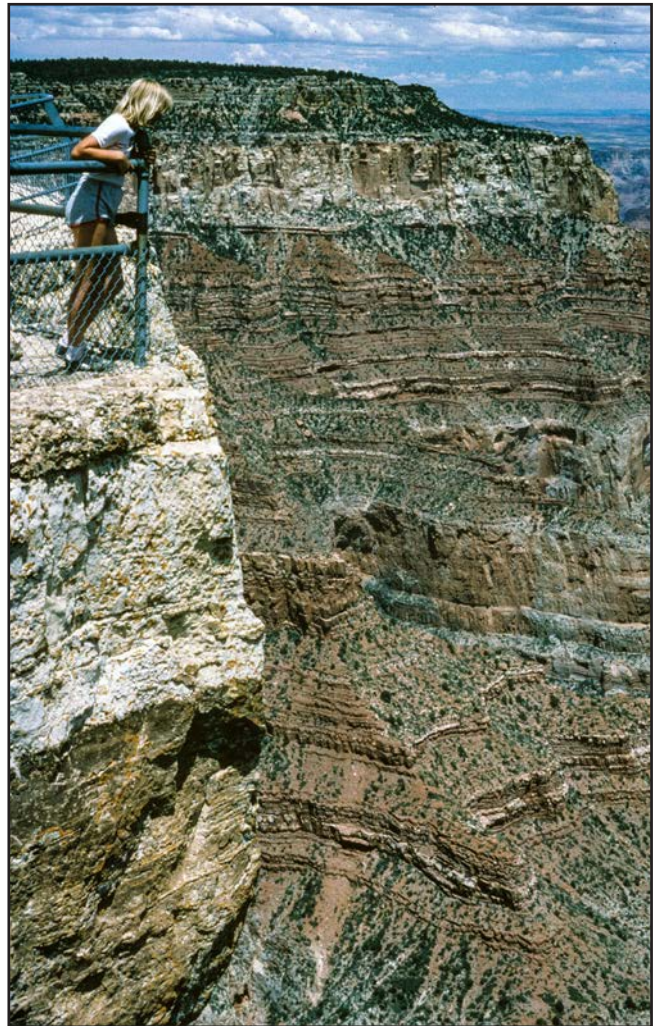
Kaibab uplift and eastwards into East Kaibab syncline, with Echo Cliffs in the distance. Down below, the Precambrian inlier in the monocline core has the Butte fault along its far boundary; beyond it narrow mesas of buff Mesozoic sandstone border the lower end of Marble Canyon, and river is visible through gap at its left end.

- (16) Pass Roosevelt Point, with extensive flat floor of syncline seen beyond canyon.

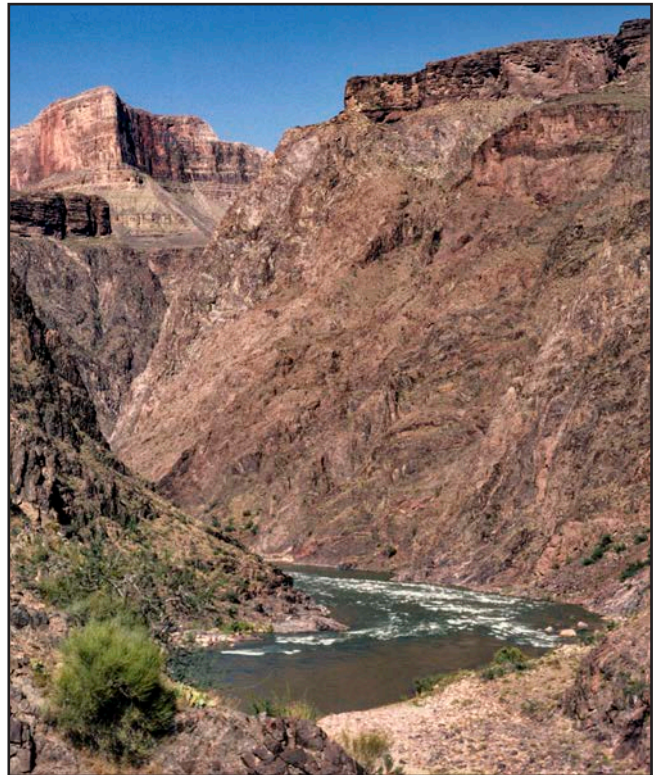
- (20) Stop at Cape Royal, at end of road, for 75 minutes.

Walk short trails to viewpoints. See the river through the Angel's Window, natural arch formed by weathering and block failure from thin arete of fractured Kaibab Limestone. View east from above Angel's Window, to river (1560 m below) in red Unkar sandstones dipping north beneath clear unconformity.

View south from Point Royal, along arete of Coconino Sandstone leading out to butte of Wotan's Throne with Kaibab Limestone cap.



Lookout above the Angel's Window on the North Rim.



Colorado River in the Inner Gorge at the foot of the Kaibab Trail.

Glen Canyon and Lake Powell

The Colorado River is impounded by the dam in Glen Canyon, to form the reservoir known as Lake Powell, a key element in the Colorado River Storage Project. This regulates springtime meltwater floods, to provide a steady flow for supply and irrigation downstream in Nevada, California and Mexico. All the Colorado water is used, and none reaches the sea; it provides power at the Glen Canyon and Hoover dams.

First site planned for the dam was at north end of Echo Cliffs, but sandstone was too fractured in fold zone. Glen Canyon was a better dam site, between nearly vertical walls in strong, horizontal Navajo Sandstone; its permeability allows leakage that is acceptable. The concrete dam is 215 m high, including foundations 40 m below river level, and is 475 m along its curved crest. With 90 m of thickness at its base, it is both a gravity and an arch dam. Strong aggregate was extracted from quarries beside Wahweap Creek, concealed when the reservoir covered them. Construction was in 1959-63, and the reservoir reached full capacity for the first time in 1980.

Lake Powell is 298 km long, with 3135 km of shoreline. It holds 3 years of flow on the Colorado, and each year loses 2.5% of its volume to evaporation. Deposition of river sediment will fill the lake in about 750 years. To keep outflow constant, the lake level rises (normally by about 10 m) in May to July each year, and falls for the rest of the year. Short flood-flow pulses have been released to regenerate natural washlands down the river. The dam drowned the beautiful Glen Canyon, but created a uniquely spectacular recreation area. A wilderness for the few gave way to a park for the many; but the Sierra Club now want to empty the reservoir.

US89 crosses Glen Canyon just downstream of the dam, on a steel-arch bridge spanning 313 m, 210 m above the river; the Carl Hayden Visitor Center is adjacent on the west rim.

Glen Canyon Dam

View the dam from the visitor centre, and from walkways on bridge. Note the grid of rock anchors in the sandstone wall just right of the dam; each up to 23 m long, these prevent spalling (and potential rock bursts) on stress relief fractures parallel to the canyon wall, and nearly parallel to the compressional stress from the arch dam. Moss marks a seepage line on a bedding plane over a less permeable unit in the sandstone.

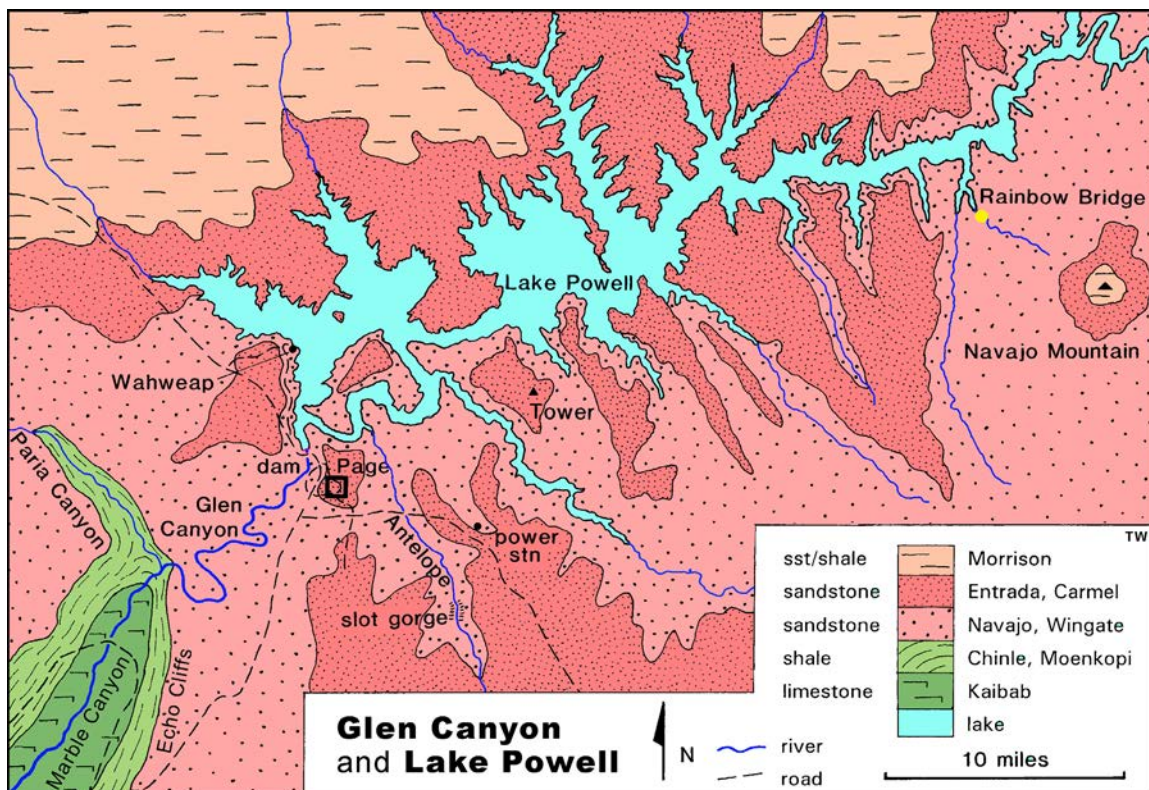
The visitor centre has an excellent model of the region, on which many of the structures of the Colorado Plateau may be identified.

Take an hour for the self-guided tour of the dam. First lift goes down to crest of the dam, with good views all around. Second lift descends 161 m inside dam, ending 30 m horizontally from the bottom of Lake Powell. Bridge leads to the powerplant, with information boards and visual displays in visitor gallery. Third lift goes down to the turbine pit and governor gallery; the scale is large – each of the eight turbines has a rotor weighing over 500 tons. From the transformer deck outside, the rock anchors in the canyon wall can be seen; there is one on the parapet for inspection.

The best single view of Glen Canyon and its dam is from the rim overlook on Scenic View Drive, west of Page.

The town of Page was only converted from a construction camp in 1975 when the dam was completed. It stands on a low mesa overlooking Glen Canyon.

A luxurious way to enjoy the half-drowned sandstone canyons of Lake Powell is to rent a houseboat for a few days or a week from any of the three marinas on the lake. Most of the narrow canyons are open to visiting boats, and the finest are mostly near the upper lake marinas.





The southern, upstream, side of Rainbow Bridge.

Lake Powell boat tour

In the morning and the afternoon, boats cruise 80 km up the lake to Rainbow Bridge, and return by roughly the same route. The captains give out bits of information along the way, and free iced lemon squash is available.

Two wide sections of lake, including all of Wahweap Bay, are formed where water lies over low benches between canyons, while narrower canyons have deeper water between higher walls. Maroon sandstones and mudstones, thinly bedded, shallow water sediments of the Jurassic Carmel Formation, form the ground around Wahweap.

Most of the lake walls are red, tan and buff, massively jointed, dune bedded sandstones. The younger Entrada Sandstone forms most of the western cliffs along the north side of the lake, where it is brought down by the gentle northerly dip into the Kaiparowits basin; proto-arch alcoves form in cliffs above seepage horizons. The older Navajo Sandstone forms the low benches to the south, and nearly all the canyon walls upstream in the Rainbow Bridge area.

Distinctive Tower Butte to the south is Entrada Sandstone, with a small Morrison cap and a Carmel plinth above the Navajo plateau; more in sunlight on the return journey. Far northern skylines are Morrison and Cretaceous sandstones.

Navajo Mountain, rising 2000 m above lake level to the east is an outlier of Entrada and Morrison sandstones draped over a barely exposed dolerite laccolith.

About 70 km from Wahweap, the boat turns into the narrower tributary canyons south of the Colorado. These are truly dramatic, with the water level part way up vertical walls of Navajo Sandstone. The high point of the cliffs on the left is 330 m above lake level.

Part of Rainbow Bridge is seen ahead before the boat docks.

Rainbow Bridge National Monument

Walk for 10 minutes along good trail to the foot of Rainbow Bridge (walking up trail beyond is discouraged, to avoid damage and desecration of site which is held sacred by the Navajo). Rainbow Bridge is formed in Navajo Sandstone. It spans 85 m and is 88 m high above the flooded canyon floor where lake water can now reach 15 m deep; its top is 13 m thick and 10 m wide, and rock spalling has progressed until a very stable profile has been created.

Like all natural bridges (as distinct from arches), it was formed by river erosion undercutting the sandstone on the outside of bends around a deeply incised meander. When the two sections of riverbed converged, the river took the short route beneath the bridge, and has since entrenched a further 20 m to form a narrower canyon (now partly flooded) within the Kayenta Sandstone bench. The abandoned meander is left of the bridge, above the bench and behind a bluff.

Antelope Canyon

A section of dry creek, 200 m long, has formed a narrow twisting slot canyon, cut in Navajo Sandstone. It is a classic fluvial feature, cut by fast flowing stream during flood pulses, with no weathering or erosion of walls in desert environment; bends were emphasized during entrenchment, partly as moulins enlarged and coalesced. A sand floor provides an easy walk right through this section of slot canyon. Upstream, a wide valley is cut in badland sediments with remnant terraces, comparable to the downstream end; these appear to fill buried valleys cut into the sandstone and lying across Antelope Creek. The slot canyon may have been entrenched through an interfluvial ridge or a meander core, when it was superimposed from a sediment cover, perhaps after a northward tilt due to uplift of Kaibito Plateau.

This site is an essential visit. With a risk of flash floods from afternoon thunderstorms, it is best seen in the morning, and can be followed by a boat trip to Rainbow Bridge. Antelope can be visited on a jeep tour from Page, or on a more casual basis from the Navajo facility at the site. For the latter, drive out from Page, past religious pick'n'mix of churches on left, for 3 miles along the Kayenta road (#98) towards chimney stacks of Navajo Power Station (burning coal from Black Mesa). The Canyon parking is signposted beside road; it is a 3 miles jeep ride up the wash for 1 hour at the slot canyon.



The upper entrance to the slot canyon on Antelope Creek.

Zion National Park

The main feature of Zion is the series of deep canyons cut by the Virgin River and its tributaries into the massive, dune-bedded Navajo Sandstone. This unit is 600 m thick at Zion, red lower down and paling up to a buff top. Above is grey Temple Cap Sandstone, and beneath are weaker, thinly bedded red Kayenta and Moenave mudrocks and sandstones.

Due to rapid runoff from its catchment largely on bare rock, the Virgin River is flood-prone, and shows the geomorphic importance of catastrophic events. Base flow through the canyon is 3 cubic metres per second (cms), which moves about 150 tonnes of sediment per day past any one point. Flood flows of 30 cms move 350,000 tonnes of sediment per day.

Canyon walls in the Navajo Sandstone are almost vertical, as fluvial down-cutting is rapid during the flood pulses, while wall degradation is negligible in the strong, permeable rock. The Narrows, upstream of Zion Canyon, are giant slot gorges. Where the rivers cut down to the weaker Kayenta beds, lateral erosion by the river undercuts the Navajo Sandstone walls, aided by spring sapping at the contact. Walls therefore retreat, but slab failures, caused by water pressures in vertical relaxation joints, maintain their verticality, and thereby creates the large box section of the main Zion Canyon.

- (1) Photostop in turnout on right for Checkerboard Mesa, fine rock face of buff Navajo Sandstone scored by weathering niches along bedding planes and joints.
- (2) Many exposures of buff Navajo Sandstone, some with angular bases to the dune bedding.
- (4) Through short unlined tunnel in strong sandstone.
- (5) Parking for head of trail to Canyon Overlook. This is a good short walk for those not aiming to climb to Angels Landing before the sun hits the canyon; it passes through various overhangs and caves formed by weathering along seepage horizons in the sandstone, and ends directly above the Great Arch with fine view down to cliffs beyond the main canyon.

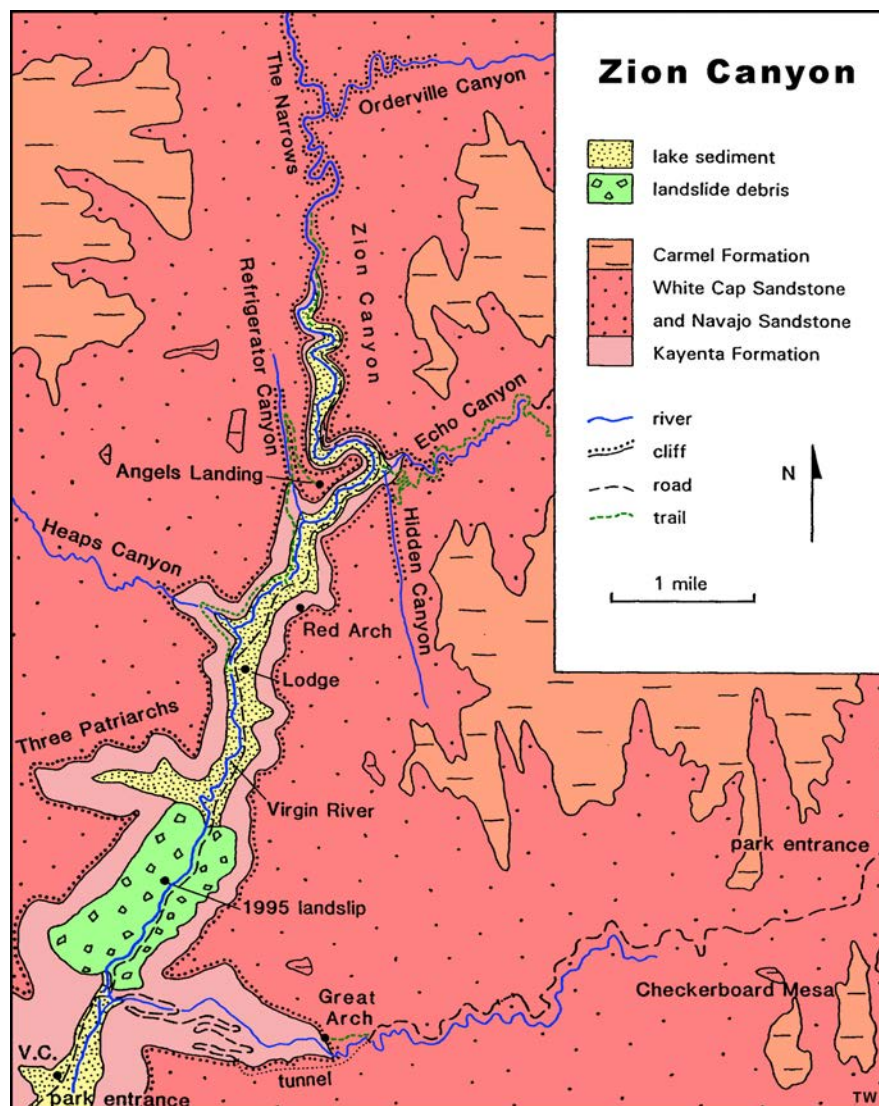
- (5) Road enters long tunnel lined with concrete, descending through Navajo Sandstone, against easterly dip of 2°, to emerge at base of vertical cliff in south wall of Pine Creek Canyon.
 - (6) Road switchbacks down slope of Kayenta beds, with veneer of rockfall debris, with views to Great Arch in Navajo Sandstone wall at head of box canyon.
 - (10) Turn right, to go up Zion Canyon (visitor centre is short way to left). NB: a shuttle bus system should replace all car traffic on the canyon road by the year 2001.
 - (11) Road follows river trench 100 m deep through landslide debris. Navajo Sandstone and underlying Kayenta mudstones failed in deep rotational slide from the high Sentinel cliff (downstream of the conspicuous Three Patriarchs cliffs) on west side of canyon, about 4000 years ago. The slide mass lies along 2 km of the canyon floor, and originally dammed the river, so that a lake extended up to the Narrows. The inevitable spillover was followed by scour and entrenchment through the slide debris, so that lake was drained, but only after lake sediments had created the flat floor along the upper canyon.
- After a very wet winter, a shallow rotational failure of old slide debris fell from the western trench wall in April 1995. This dammed the river to a height of 6 m; it was overtopped after 90 minutes and the spillover scoured 3 m from the debris dam, causing a small flood-pulse which washed out 150 m of the road downstream. Below scar, slide debris toe has rock armour, under section of road rebuilt with red sandstone wall along edge.
- (12) Pass Zion Lodge on right.
 - (13) Stop in Grotto picnic area on right. Red Arch, on high cliff to south, was left above scar of rockfall in 1880, when slab of sandstone peeled away from relaxation joint just behind and parallel to original cliff face.



The approach along the narrow rib of sandstone that leads to Angels Landing, some 300 metres above the floor of Zion Canyon, which loops round its meander on the left and extends into the distance, downstream on the right.



The Narrows of Zion Canyon.



Angels Landing walk

Energetic option is to leave from Grotto, for 4 hours walk. This is one of the finest short walks anywhere in the world, but it is a steep climb, and is sensibly done early in the morning when most of the ascent is then in cool shadow. Well-made trail crosses river, then climbs towards the north; it eventually turns into joint fissure of Refrigerator Canyon, and doubles back up zigzags to Scout Lookout. This is on lip of wall which drops 275 m vertically to canyon floor; excellent views into the Narrows and down Zion Canyon, and also of the core of the incised meander which is Angels Landing. The walk to the Landing is dramatic and vertiginous, on trail with 300 m drops on each side, and sections of chain to assist progress on exposed sections. Summit is 420 m above canyon floor, with spectacular views all around, including down to the lower incised meander to the east. Return by same route to Grotto car park.

- (13) Continue up canyon road towards the Narrows.
- (14) Pass Weeping Rock where water seeps from base of Navajo Sandstone.
- (15) Stop at end of road, where trail continues into Narrows. Parking for cars is limited and it can be easier to use the shuttle bus up from the Lodge.

Narrows walk

Easier option is to walk, paddle or wade along the riverbed through canyon of the Virgin River. Good trail continues up canyon for 1.5 km, past small slab falls from walls. Upstream, canyon walls are entirely of Navajo Sandstone, as Kayenta Formation is below river level. Consequently there is no wall retreat, and canyon narrows upstream into true slot gorge. Trail ends where river occupies most of floor width; way on involves frequent paddling across river between available gravel banks. The Narrows become more and more narrow upstream, notably after the junction with Orderville Canyon, 90 minutes upstream; the shaded confines of the very deep canyon are impressive. Some sections of canyon are clearly joint defined; others have travertine banks on walls deposited by seepage from bedding planes in sandstone with calcite cement.

Time and energy dictate how far to go before returning by same route. The hike right through the Narrows is a two-day trek downstream, requiring fitness and stable weather.

A shorter stroll is offered by the loop trail round the Lower Emerald Pools below Heaps Canyon. Take the lower trail, to the lower pool, then climb to the middle pool above the waterfall, and return on the upper trail along the sandstone shelf at that level. The hike to the Upper Pool is less rewarding.

Bryce Canyon National Park

Bryce is one of a series of natural amphitheatres, all within the National Park, cut back into the fault-line scarp along the eastern margin of the Paunsaugunt Plateau. They form the headwater bowls of small canyons that feed into the Paria River on the upthrow side of the Paunsaugunt Fault; its valley lies on the weak Tropic shales, and is entrenched downstream into Paria Canyon in the underlying sandstones.

The amphitheatres of Bryce Canyon are cut into rocks of the Eocene Claron Formation (previously known as the Wasatch). These are thinly bedded impure limestones and mudrocks, about 200 m thick in total, which were deposited in semi-arid lake basins; nearly all are red due to hematite content. Fluvial dissection of amphitheatre has left narrow interfluvial ridges, whose vertical walls are guided by joints. Ridges are broken by cross joints, where dissolution and weathering create open fissures; these enlarge below stronger caprock beds to leave remnant pinnacles, or hoodoos. Headwall retreat and downcutting in the steep gullies are faster than decay of exposed rock, so ridges and hoodoos emerge to great heights.

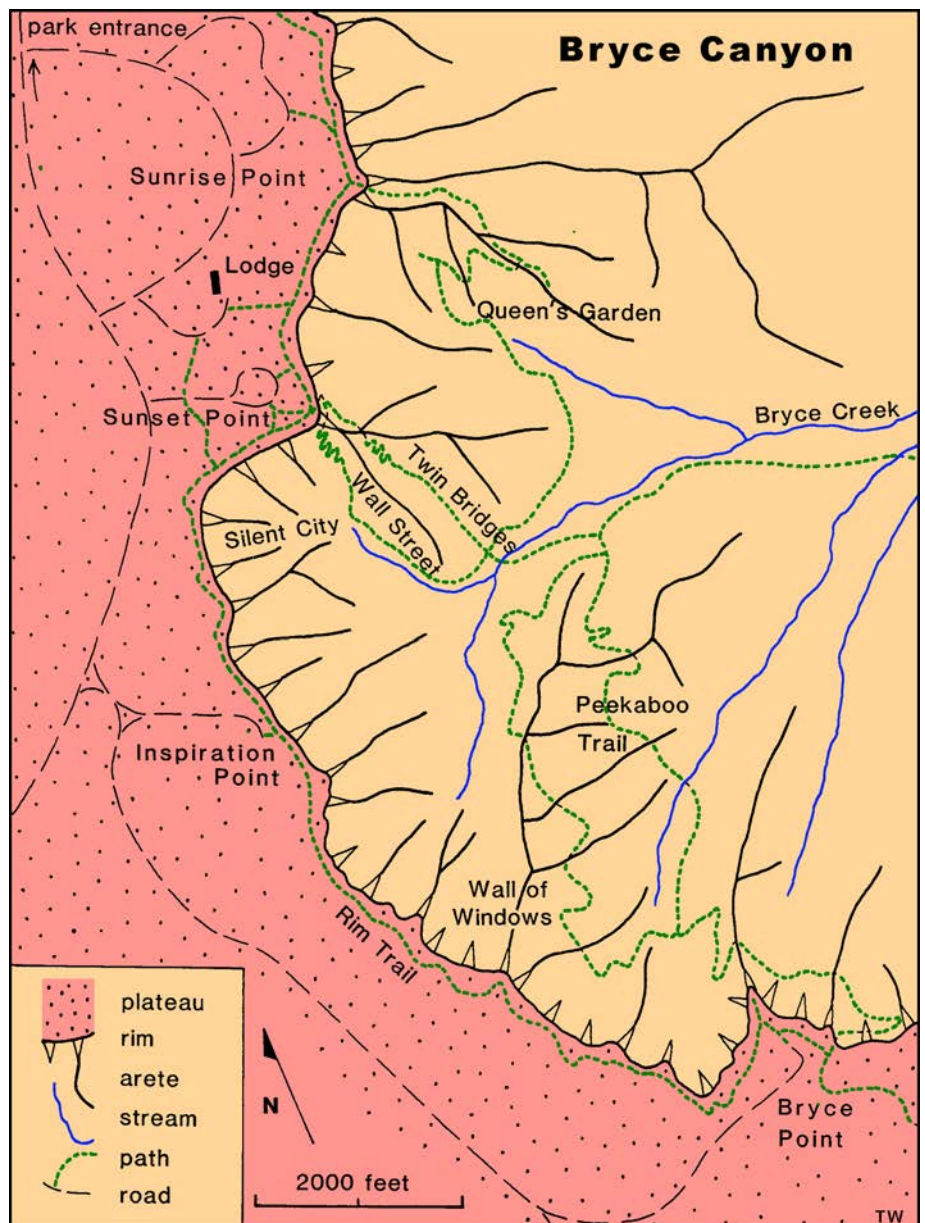
Amphitheatre rims recede at about 0.6 m per 100 years, and they show an evolution from north to south. Those north of Bryce Creek, on upstream Paria tributaries, are immature and have not yet developed many hoodoos. Those south of Bryce Creek are older and deeper; spring lines on the underlying Cretaceous shales are foci of numerous landslips, which cause rapid cliff retreat and few hoodoos survive. Gullies and hoodoos have maximum relief in the Bryce amphitheatre.

First stop at Bryce Point, for a spectacular view across the amphitheatre. Softer sandstones and clays form sloping segment below rim, above limestones dissected into hoodoos; ridges, fins and hoodoos have their crests at just a few levels defined by stronger beds which form caprocks; highest hoodoos are on steepest slopes where gully incision is fastest.

Return to Sunset Point for a choice of walks, best in the morning when it is cooler and also has the sun shining into most of the canyons.



Morning sunlight reaches into a narrow section of the Wall Street canyon, one of the tributary canyons inside Bryce Canyon.



Walks into Bryce Canyon

The rim is at an elevation of 2400 m, and a walk to the canyon floor beneath the main hoodoos incurs a return climb of at least 200 m, but the experience of being down among the hoodoos, on the very good trails, is unforgettable and should not be missed.

Alternative walks are available, listed in ascending order of energy demand; those taking the shorter loops may stroll gently and also have time to visit the Lodge for indulgence.

- 1 Rim Trails - lazy strolls along the rim, north to Sunrise Point and south to overlook Silent City canyons. Note trees with exposed roots on rim, which have been dated to determine erosion rates.
- 2 Navajo Loop, 2 km - taking the easiest loop down Wall Street and back up Twin Bridges Trail, deep canyons which hide a few Douglas firs between colourful vertical walls.
- 3 Navajo - Queen's Garden Loop, 5 km - a rewarding hike down Wall Street canyon, with longer gentler climb through Queen's Garden, up to Sunrise Point.



Part of the view of Bryce Canyon from Inspiration Point.

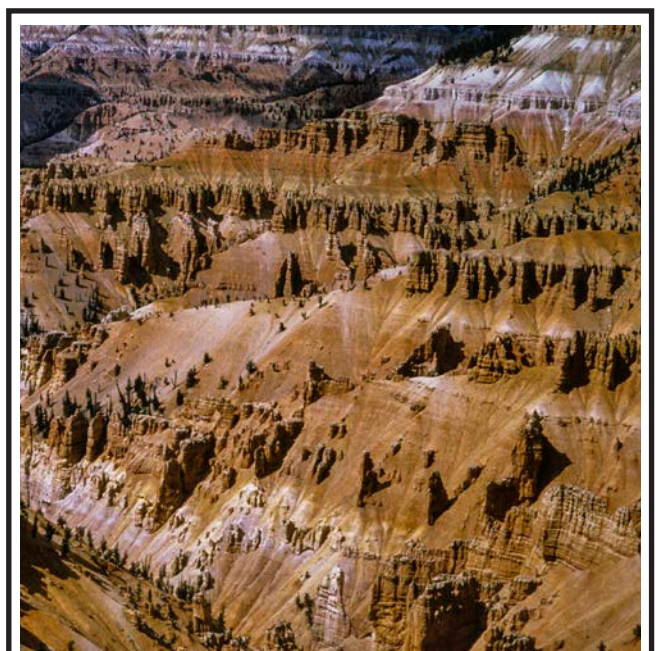


On the Peekaboo Loop Trail, deep inside Bryce Canyon.

- 4 Peekaboo Loop, 8 km - an energetic hike with more up and down, memorable for the fitter walkers; start down Wall Street, across Bryce Creek, then either way round Peekaboo Loop to pass the Wall of Windows, and back up Twin Bridges Trail; fitter walkers could add 2 km to return via Queen's Garden and Sunrise Point.

Before leaving the Park, stop at Inspiration Point for the finest single panorama over canyons and hoodoos of the Bryce amphitheatre.

Rim Road continues south for 14 miles to Rainbow Point; there are fewer people around, but the escarpment edge is less dissected and generally less spectacular; note that Natural Bridge is actually a natural arch.



Panorama of Cedar Breaks National Monument, which is cut into the western margin of the Colorado Plateau, almost as a mirror image 100 km west of Bryce Canyon, but with fewer hoodoos and more variegated colours in the same sequence of rocks.

Road Log for the Colorado Plateau

The sparse network of roads across the heart of the Canyonlands region means that there is a limited choice in routes that take in the major parks and features described in this guide. The following log is perhaps the natural route for a clockwise circuit, and is largely the route that was followed by the Geologists' Association tours. It starts and ends in Salt Lake City, which is probably the ideal for arrivals from Britain, but it could be picked up anywhere.

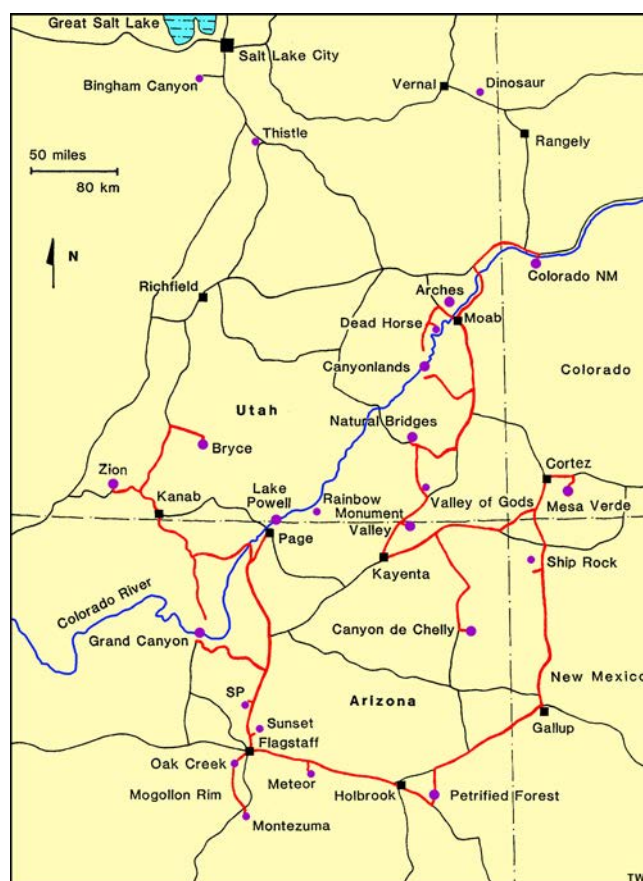
Numbers in the left margin refer to the roadside mileposts immediately preceding the site. Mileages also define the junction numbers on the Interstate freeways. Numbers in brackets are distances. The suggested overnight stops give time in the intervening days to see everything without rushing, but also provide an active schedule for visitors from Britain who do not have unlimited time. On many sectors there are few alternative places with hotels, for those without tents or camper vans.

Salt Lake City to Moab

To join the Colorado Plateau loop, head east out of Salt Lake City on 1-80, and onto US40 to Vernal for an afternoon visit to the spectacular fossils in Dinosaur National Monument, then back to a hotel in Vernal for the night.

Next morning continue east into Colorado, and turn south in Dinosaur onto #64, through the Rangely oilfield, then onto #139 up Canyon Pintado and over Douglas Pass, 2520 m high. Descend Book Cliffs to the Colorado Valley; monoclinical rise of red sandstone to the south is northern rim of the Uncompahgre Plateau, 600 m above. Through Grand Junction, head for the southern entrance to Colorado National Monument (page 13).

- 19 Out of the Monument, turn left on 1-70.
- 2 Leave freeway, and right to Dinosaur Trail at road end. Mygatt Moore Quarry has been excavated for fossils in Jurassic Morrison Formation. Adjacent "Trail through Time" has signboards on geological sites. Board 1 is by exposures and cross sections of *Camarasaurus* vertebra and ribs; find the brass plates, and the excellent preserved bone texture. The other nine sites round the loop trail are less exciting, and only for those with plenty of time; board 4 is on conglomerate in which plant fossils are not easily found, board 5 is on expansive bentonite clay, and board 8 marks vertebrae and fragments of *Diplodocus*.
- 0/229 Cross into Utah. Then leave freeway at exit 212; through metropolis of Cisco, on old road for 6 miles; then left on #128, signposted to Moab (at mile 42).
- 30 Over Colorado River bridge, then canyon with cliffs in Triassic red Wingate Sandstone overlying Chinle shales, Moenkopi shales and Permian Cutler sandstone, all red. Sediment sequence between basement and Wingate is over 5000 m thick in Paradox Basin, compared to 25 m of Chinle shales seen in Colorado National Monument over Uncompahgre uplift.
- 22 Into wide basin where Wingate Sandstone cliffs have retreated over core of Fisher Valley anticline. Fisher Towers are buttes in Cutler Sandstone. Off to the left, the rough Onion Creek road is 5 miles long, through 18 fords across the shallow creek, to an exposure of the salt dome beside the road. The outcrop is mainly gypsum, clay and carbonates, as the salt has been leached out by near-surface groundwater.
- 11 Unconformity at base of Chinle shales, across river, is due to Triassic salt tectonics which led to erosion of Moenkopi shales and siltstones over rising dome (p.15).
- 3 Wingate Sandstone is at river level in Courthouse Syncline, before the beds rise towards the Moab salt anticline.



0/129 Turn left on US191, south along Spanish Valley.

126 Overnight in Moab, a lively vacation town with many hotels and restaurants.

An alternative route is direct to Moab in one day, thereby saving a day. Head out of Salt Lake City south on 1-15, and onto US6 at Spanish Fork. Pass the 1983 Thistle landslide where the road goes through a massive new cutting, then continue over Soldier Summit and down past the coal mines at Price. At Green River, join 1-70 east for 24 miles, and leave it on US191 south into Moab.

Use Moab as a base for one day, or preferably two days, in Arches National Park, Dead Horse Point State Park and the northern part of Canyonlands National Park (pp.17-20). On the western edge of Moab, a low roadcut on Kane Creek Boulevard has a roadside exposure of the evaporite cap of the salt dome. Material is mainly fine grained gypsum, with dissolutional residue of clays and some carbonate crusts.



The one fossil that can be touched in Dinosaur National Monument.

- 126 Head north out of Moab on US 191.
- 131 Turn right into Arches National Park (pp.15-16).
Or continue up Moab Canyon on floor of Pennsylvanian limestone and shale; right wall of canyon is Jurassic Entrada Sandstone, beyond Moab Fault with 600 m displacement created on edge of linear salt dome. Borehole was drilled near road; it reached the top of the salt dome at a depth of 710 m, and continued down through 2150 m of salt and potash.
- 136/22 Turn left to Dead Horse Point and Canyonlands National Park on #313. Road climbs through Wingate and Navajo Sandstones, with exposures in pre-split road cuts.
- 16 Entrada Sandstone on right; dune bedded Slick Rock sandstone unit is above the wavy bedded Dewey Bridge unit, above dune-bedded Navajo Sandstone at road level.
- 8 Turn left to Dead Horse Point, on plateau of Navajo Sandstone.
- 5 Nodding donkey on right produces oil from block-faulted Mississippian reservoir rocks beneath the Big Flat dome.
- 0 Into Dead Horse Point State Park (p. 17).
- 7/0 Return to junction, left to Canyonlands National Park (p.18).

Moab to Cortez

- 126 Head south out of Moab, on US191, along Spanish Valley graben between fault line cliffs.
- 112 Out of graben; minor fault in sandstones on left, on descent into Entrada Sandstone, in which Hole-in-the-Rock is an artificial cave house.
- 108 Over wash, with wavy folding in Dewey Bridge Sandstone in cliffs on left.
- 101 Pass Wilson Arch on left, again in Entrada Sandstone; then Abajo Mountains, formed by diorite laccoliths, are seen ahead on right.
- 87 Turn right to Canyonlands National Park (see pages 22-24). Church Rock on left is remnant butte of Entrada Sandstone. Return from National Park to same road junction.
- 80 Over pass into Blanding Basin, in Cretaceous Dakota Sandstone and Mancos Shale. Sandstone aquifer is fed by rainfall on Abajo Mountains laccoliths. Monticello Airport offers sightseeing flights over the canyonlands.
- 72 Overnight in one of the few hotels in Monticello.
Leave Monticello to the south, still on US 191.
- 48/122 Turn right onto #95, after Blanding.
- 109 Photostop in gravel turnout on left at end of deep cut through red sandstone hogback of Comb Ridge. This is monocline between Blanding Basin and Monument Uplift. View north of Navajo and Wingate Sandstone scarp overlooking valley in Permian and Triassic shales with Cedar Mesa Sandstone levelling out of monocline towards west. Rockfall scars in roadcut show good dune bedding in Wingate Sandstone.
- 101 Pass Mule Canyon ruins, then good beach dune cross bedding in sandstone cliffs on right.
- 88 Turn right into Natural Bridges National Monument (p.21).
- 94/33 After returning 6 miles from the Natural Bridges junction, turn south onto #261, a long straight featureless road across Cedar Mesa Plateau on eponymous sandstone.
- 10 Stop in viewpoint turnout on right shortly after end of blacktop, for spectacular view across the Valley of the Gods (p.24). Then drive down the Mokee Dugway road below.
- 2 Spur road on right to the Goosenecks overlook (p.24).
- 0/25 Turn right on US163.
- 24 Photostop on shoulder at gravel road junction, or drive down side road for closer views of sandstone butte which has the distinctive profile of a Mexican in a big Hat. Raplee anticline, away to left, appears as a monoclinical rise of the Hermosa limestones, shales and sandstones, which form excellent flatirons between gullies cut into the dipslope. Beneath the butte, the Mexican Hat syncline lies between the Raplee anticline and the Cedar Mesa anticline (all within the Monument Uplift); it is a producing oilfield, unusual in that the oil is in a synclinal trap because there is no intergranular groundwater on which it can float and thereby rise into normal anticlinal traps.
- 22 Through Mexican Hat, and over San Juan River, into Navajo Nation, semi-autonomous Navajo Indian Reservation.
- 19 Photostop in small gravel turnout on right, on upgrade just past Alhambra Rock. Tertiary dolerite dyke forms monolith on right, with smaller dykes intruded into Hermosa sediments exposed in gully. Distant uranium mine tailings from 1970s were covered in 1997.
- 14 Road climbs through Halgaito Shale and then Cedar Mesa Sandstone, which thins with a southeasterly facies change into sabkha gypsiferous mudstones and so no longer forms a major scarp. On the gentle climb towards Monument Pass, the classic view ahead of the mesas and buttes in profile, is into the afternoon sun.
- 1 Turn left to Monument Valley Navajo Tribal Park (p.22-23). Stop for night in Gouldings Lodge (book ahead in summer), across US 163 from park exit, or head south to Kayenta.
- 0/417 Cross into Arizona, still in Navajo Nation, therefore with no time change.
- 403 Photostop in gravel turnout on right. Agathla Peak (also known as El Capitan) is 350 m high erosional remnant formed of a Tertiary diatreme; lamprophyre (micaceous dolerite) dykes lace through vent breccias and contact metamorphosed sandstone.
- 400 Photostop in gateway on right immediately after electric cables. Chaistla Peak is a monolith formed by a single lamprophyre plug, with surrounding sandstone eroded away.
- 394 Into Kayenta, probably for the night (hotels must be booked in advance in summer).
Leave Kayenta to the east on US160. Series of lamprophyre plugs form crags on left, projecting from Navajo Sandstone. Black Mesa, to south, is broad plateau of Cretaceous rocks; base is Dakota Sandstone, which forms the Hopi mesas on the far southern rim. Cap is Mancos Shale and Mesaverde Group; latter has thick coal seams which are opencast mined, and taken by automatic railway to large Navajo power station near Page.



Agathla Peak, an exhumed plug south of Monument Valley.

- 401 Photostop on wide shoulder on right at top of hill. Church Rock is another monolith formed of dykes laced through the sandstone. Beyond, Comb Ridge is a hogback formed by monoclinical upwarp of Navajo Sandstone along edge of Monument Uplift.
- 407 Pass Baby Rocks on right, hoodoos in soft Morrison sandstones.
- 434 Choice of routes at junction.
- Straight ahead on US 160 is towards Cortez for Mesa Verde National Park and Ship Rock, before continuing south towards Petrified Forest and reaching Holbrook in two days from Kayenta, as in the following road log.
- Right on US191, Chinle is reached after 64 miles, at the entrance to Canyon de Chelly National Monument (p.25). South from Chinle on US191, Petrified Forest can be reached more directly, and so into Holbrook one day earlier than via Cortez.
- 465 Turn left at Teec Nos Pos, still on US160, and shortly pass Four Corners, the only place in USA where four states meet (now developed as a tourist site of little appeal).
- 472/0 Cross into Colorado (and out of Navajo Nation), and over San Juan River.
- 12 Through badlands with gully erosion in shales. Ute Mountain on left is Tertiary laccolith in core of a dome. Mesa Verde is ahead; broad sandstone plateau dips 10° south.
- 18 Turn left, still on US160. Heading north, views to right of Mesa Verde with 100 m of Point Lookout Sandstone in cliffs above 350 m of gullied slopes in Mancos Shale.
- 41 Through Cortez, down Main Street, keeping on US160; both the Mesaverde sandstone units are clearly seen in the high scarp face on the right.
- 48 Take sliproad right, into Mesa Verde National Park (p.26). Return to a choice of hotels in Cortez for the night.

Cortez to Flagstaff

- 41 Leave Cortez west on US 160.
- 19/7 Ahead onto US666. Chimney Rock on left is sandstone butte above Mancos Shale.
- 0/108 Cross into New Mexico and Navajo Nation.
- 93 Turn right in Shiprock onto US64 and US666; then ahead on US666.
- 85 Turn right onto Red Valley road to the Ship Rock dyke (p.27). Return to US666, to continue south.
- 80 Pass more plugs of the Oligocene Navajo volcanic field, which extends south for 30 km.
- 79 Table Mesa on right is in sandstones of Mesaverde Formation, which continue in basin most of the way to Gallup. Coal measures within them have small mines.
- 64 Road passes between Ford and Bennett plugs, with dykes between them and close to the road; all weathered to sand colour. Hills of red Triassic Chinle shales and sandstones on right horizon are exposed in anticline of Defiance Uplift.
- 0/20 Through Gallup, and turn right onto 1-40. This is the rather unromantic modernisation of Route 66 - which was the much loved highway to the west, from Chicago to Los Angeles; known as Main Street of America, it ended as Sunset Boulevard down to the Pacific Ocean.
- Descend stratigraphy against the dip (except for one monoclinical step) through Mesaverde Sandstone, Mancos Shale and Dakota Sandstone.
- 0/360 Cross into Arizona. Watches go back 1 hour (onto Arizona

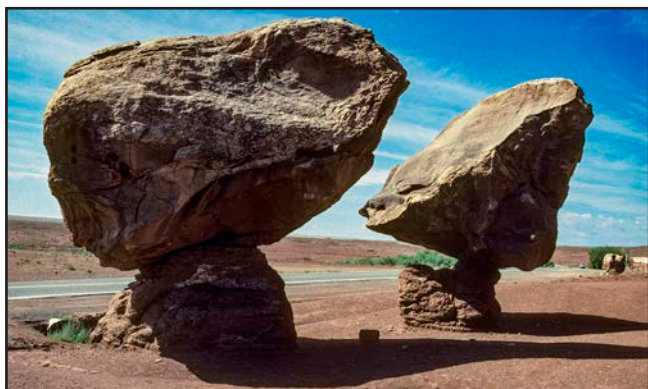
time without Daylight Saving).

Descend stratigraphy through Dakota and Navajo sandstone, and past cliffs of Wingate Sandstone, followed by wider valley in underlying Chinle clays.

- 311 Exit freeway into Petrified Forest National Park (p.28). Out of south entrance of Park, onto US 180, into Holbrook with many hotels for the night.
- 286 Leave Holbrook west on 1-40, across flatlands on Chinle and Moenkopi shales.
- 233 Freeway exit for Meteor Crater, 5 miles **to** the south (p.29).
- 198 Into Flagstaff, for a choice of onward routes.
- A loop south to the Mogollon Rim (p.30) is best down Oak Tree Canyon on US89A, through Sedona, via Montezuma Well, and back up 1-17 to Flagstaff (with many hotels). Grand Canyon lies to the north, with options for visits (p.32).
- The most direct route to the Canyon is on US 180 round the western edge of the San Francisco Peaks, and then across the Coconino Plateau to the hotel village of Tusayan, at the south entrance to South Rim (pp.31-35).
- Otherwise follow the road log to pass through the San Francisco Peaks volcanic field on the way to either the east entrance to South Rim, or to the North Rim.

Flagstaff to Kanab

- 415 Leave Flagstaff out to the north on US89; old town centre is on Route 66.
- 420 Quarry on right in the first of many cinder cones within San Francisco Peaks volcanic field (p.29); main andesite mountain rises on left, and Sunset Crater lies ahead.
- 430 Loop road on right passes Sunset Crater (p.29).
- 432 Long downgrade is on debris flow from volcano behind; with no roadside exposures. Then onto flatter ground on Miocene flood basalts, with scattered Pleistocene cinder cones.
- 444 Road on right is end of the loop from Sunset Crater via Wupatki, the ruins of an Indian village probably abandoned because of the adjacent volcanic eruptions.
- 447 Good dirt road on left to the SP Mountain volcanics (p.29).
- 456 Road now on red Triassic sandstones. Monocline capped by Permian limestone to left is edge of the Kaibab uplift, through which Grand Canyon is cut.
- 465 Just before Cameron, #64 extends west for 29 miles to the east entrance to South Rim of Grand Canyon (p.33).
- Along the way, there are various views right to the canyon of the Little Colorado River; the best overlook is up a short spur road 15 miles from the start on US89. There, the canyon is 500 m deep, with most of its very steep walls in Kaibab Limestone above Toroweap and Coconino sandstones; the Little Colorado is normally dry in summer.
- About 9 miles further on, soon after entering the Kaibab National Forest, there are good views left to the Grandview Monocline, the final rise of the Kaibab Limestone plateau to its maximum height over the Kaibab Uplift, where it is cut through by the deepest part of the Grand Canyon - which is a few miles ahead.
- 465 North of Cameron on US89, cross over intermittently dry channel of Little Colorado River, and pass Shadow Mountain cinder cone on left.
- 470 Through grey then pink badlands of Painted Desert in Chinle shales and clays.
- 480 Turn right onto US 160 for 5 miles to a signposted short dirt road on the left to the Moenave Dinosaur Tracks. Short walks



Balanced rocks at Mile 547 below Vermillion Cliffs.

west and north from the parking area, reveal (to the observant or to the Navajo guides at the site) various dinosaur footprints and tracks preserved in Chinle mudstones and sandstones of lake and tidal flats, now exposed on desert surface. Nodules exposed along return trail are claimed to be (or to have cores of) eggs and coprolites, but evidence is vague.

- 486 Echo Cliffs ahead to north. Glen Canyon Group of red sandstones (Navajo at top, down through Kayenta to Wingate) forms scarp face on monocline with 10° dip to east; the Kayenta is a strong sandstone in this area, unlike its mixed mud/sand facies seen at Dead Horse Point. For 30 miles, road is along dip slopes of sandstones and silicified limestones within Chinle and Moenkopi Groups, at foot of main scarp.

- 523 Keep right for Page on US89, and climb obliquely up Echo Cliffs. Views to left across Marble Platform to Vermillion Cliffs are good in morning light (p.37). Then deep roadcut in Navajo Sandstone, to rise onto red sandstone plateau.

- 548 Town of Page is just off to the right; it has many hotels, but all rooms are normally sold out before midday in the summer months. Turn left after 1 mile onto Scenic View Drive to parking turnaround, for short trail down to overlook with excellent view up Glen Canyon to its dam. Keep north on US89 for 2 miles to Glen Canyon bridge and dam.

Use Page as a base for at least one full day to visit Lake Powell, Rainbow Bridge and Antelope Canyon (p.38).

- 548 Leave Page to the south on US89.

- 528 Through deep cutting in Navajo Sandstone to emerge on scarp face; stop for scenic turnout on right (which normally has some good stalls selling Navajo turquoise jewellery).

View is across the gently sloping Marble Platform, a bench of Permian Kaibab Limestone entrenched by the Colorado River in Marble Canyon; this limestone is a strong unit which forms wide stratimorphic surfaces all around the Grand Canyon. Rising beyond the Marble Platform, Vermillion Cliffs are the same red sandstones as the Echo Cliffs behind. Retreat of the sandstone cliffs has widened the limestone bench. The Colorado Plateau landscape has largely evolved by a series of scarp cliff retreats, each exposing a lower stratimorph. Typical rate of scarp retreat is 1.5 km per million years; rates were higher soon after uplift, and are lower in today's dry climate.

To the north (right), the Vermillion and Echo Cliffs converge at the exit of Glen Canyon, round the plunging nose of the asymmetrical Echo Cliffs anticline (which continues away to the south as a monocline, with Echo Cliffs on its steep east limb). To the southwest, the Colorado runs into the gentle East Kaibab syncline. Beyond it, the Kaibab uplift is formed by the Kaibab Limestone, creating the high ground on the rim of the Grand Canyon.

- 524 Turn right onto US89A on soft red Chinle and Moenkopi shales. Descend onto Marble Platform, and continue gently down plunge of anticline towards convergent red cliffs.

- 538 Stop in one of the turnouts before or after Navajo Bridge, 140 m above the Colorado River. View from old bridge into Marble Canyon, with Permian Kaibab Limestone forming rim above cliffs of Toroweap sandstones and limestones. West side has small visitor centre.

- 546 Stop in turnout on right past small bridge amid the many balanced rocks. Fallen blocks of strong buff sandstone, from the Moenkopi above, stand on plinths of soft *in situ* shale that are protected from rainfall erosion; some plinths are near failure in unconfined compression (factor of safety is under 2, if rock's unconfined compressive strength is taken as 10 MPa and is multiplied by a rock mass factor of 0.1 to allow for rock fracturing).

- 557 Monoclinical rise of Kaibab Limestone ahead is eastern rim of Kaibab uplift. Historic marker recalls Escalante expedition, first Spanish explorers in the area in 1776.

- 566 Road starts climb up limestone dipslope, leaving strike valley in Chinle and Moenkopi shales to north. Roadcut has small fault with limestone against red shale. Road then winds up entrenched dry valley which descends the dip slope of Kaibab Limestone.

- 579 Turn left at Jacob Lake onto #67, towards North Rim of Grand Canyon (p.36). At elevation 2414 m, Jacob Lake is 1310 m above the bridge over Marble Canyon. Road continues south through forest of ponderosa pine on Kaibab Plateau, which is Kaibab Limestone stratimorph over anticlinal pericline of Kaibab Uplift; the highest part has a cover of spruce forest broken by some meadows with blue lupins. Forest at canyon rim has more pinon pine and juniper. Plateau is high enough to have annual rainfall of 600 mm, with 3 m of winter snow; floor of Grand Canyon has one third the rainfall and no snow.

- 590 West from Jacob Lake, US89A descends monoclinical dip slope and fault scarps following the Kaibab Limestone off western side of Kaibab uplift. Vermillion Cliffs of sandstone rise beyond the broad shale valley which loops north round the nose of the uplift. Pink Cliffs rise to Bryce Canyon rim on distant skyline. Zion Canyon is on far side of red cliffs to the left, which rise above platform on the Kaibab Limestone.

- 594 Limestone surface extends for a few miles, then dips gently beneath cover of red Moenkopi shales forming Muggins Flat, in Antelope Valley.

- 613/0 Cross into Utah. Watches go forward 1 hour (onto Mountain time with Daylight Saving).

- 3 Into Kanab for the night in a choice of hotels.

Do not miss visit to the Wonderstone Shop, on outside of road bend at west end of town. It produces cut slabs of cross-bedded Shinarump Sandstone, worked from a bed just 2 m thick in quarries 30 km southwest of Kanab. Sandstone has spectacular Leisegang rings; these are due to deposition of various iron oxides and hydroxides on redox fronts within slowly circulating, intergranular groundwater.

Kanab to Salt Lake City

- 65 Leave Kanab to the north on US89.

- 70 Pass Mogul Cave, tourist trap in artificially modified, undercut seepage cave in Jurassic sandstone, embellished with a plastic Cretaceous dinosaur.

- 71 Photostop in gravel turnout on left at top of incline just beyond small ponds. Spectacular dune bedding in Navajo Sandstone in old quarry wall.

- 72 Side roads lead to Coral Pink Sand Dunes, small field of dunes coloured pink because all their sand grains are hematite coated from their source in the Navajo Sandstone.
- 81 Turn left at Carmel Junction onto #9, for 15 miles to Zion National Park (pp.39-40).
Cross grey shales containing coals (which are not seen) of Cretaceous Tropic Formation, then red shales and sandstones of Carmel Formation, before faults bring underlying Navajo Sandstone to outcrop shortly before park entrance.
Return from Zion back to Carmel Junction, and continue north on US89.
- 86 Through Orderville. Sevier Fault along line of valley has downthrow to west where Cretaceous shales and sandstones are level with red Jurassic Cannel sandstones on east.
- 87 Cretaceous Wahweap Sandstone, in cliff on right, has red and buff colouring clearly due to leaching, as colour does not follow bedding.
- 92 Tufa bank on left lies below springs from Wasatch limestones.
- 96 Pinnacles in Eocene Wasatch limestones, high on the left, are a foretaste of Bryce Canyon.
- 113 View right to pink cliffs of Wasatch limestones along rim of Paunsaugunt Plateau, which has Bryce Canyon on its far side. Markagunt Plateau to west has cap of Oligocene basalts, at lower level due to 300 m downthrow west on Sevier Fault.
- 114 Pleistocene basalts on valley floor in Sevier basin.
- 124/0 Turn right on #12, towards Bryce.
- 2 At mouth of Red Canyon, cross Sevier Fault along east side of basin, where black Pleistocene basalt lavas in the basin are faulted against red Cedar Breaks sandstone which forms the hillside to the east.
- 3 Up Red Canyon in soft sandstones of Cedar Breaks facies of Eocene Wasatch Formation, and through short tunnel where inadequate sprayed concrete is peeling off.
- 7 Out onto gently synclinal Paunsaugunt Plateau; view ahead to pink Table Cliffs on next plateau to east, uplifted beyond Paunsaugunt Fault.
- 13 Turn right onto #63, towards Bryce Canyon National Park (pp.41-42).
Best to visit park in morning, after overnight stop at Ruby's Inn on park entrance road (or at hotels at Hatch or Panguitch, back on US89).



The landslide of 1983 that blocks the valley at Thistle.



Bingham Canyon Copper Mine.

The more relaxed alternative is to stay on US89 all the way north; with an overnight stop most easily in Richfield, this should take about two days into Salt Lake City, including the morning in Bryce Canyon. As it lies parallel to 1-15, this route has little traffic. Between Panguitch and Sevier, there are some spectacular roadcuts in vent rocks and structures of the Marysvale volcanic field, which is rich in hydrothermal mineralisation in areas away from the road.

US89 joins US6 just after crossing the site of the lake which drowned the town of Thistle when the Spanish Fork valley was blocked by a landslide in 1983; the lake was later drained through an outlet tunnel around the landslide dam. Just after the very large cutting on the new US6, a turnout on the left gives a fine view of the landslide source zone on the far side of the valley. US6 then joins 1-15 into Salt Lake City.

These alternative routes converge south of exit 298 on 1-15, where 9000 South Street heads due west to the Bingham Canyon Copper Mine - the world's largest open pit mine which has visitor access to a viewing area; this should not be missed off any tour itinerary. North from the mine, the Great Salt Lake is most accessible from the junctions and frontage road along 1-80 on the western edge of Salt Lake City; the lake beside the freeway may appear as shallow water at beach resorts or as a dry salt flat, depending on rainfall patterns in the preceding winter.

The state of the Great Salt Lake varies with the weather conditions in the previous year or so. The landscapes of the Colorado Plateau have evolved over the last ten million years or so, in a series of rocks that date back through much of geological time. Short on mountain chains and orogenic belts, the Plateau more than compensates with its bold structures laid bare in a semi-desert environment amid a host of splendid geomorphological features. A tour through the region provides one of the finest geological field trips in the world. It is there to be appreciated and enjoyed.

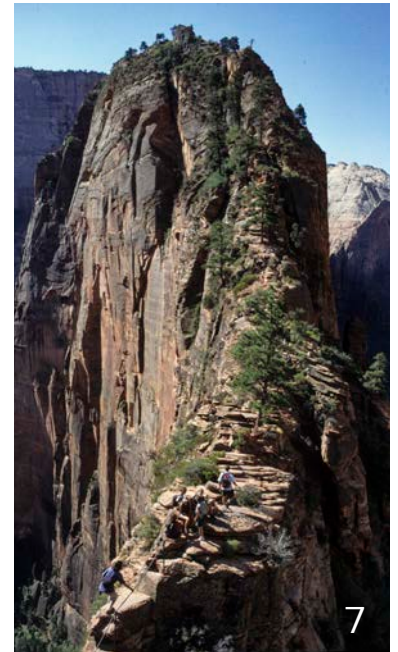
Some further reading

- Baars D L, 1993. Canyonlands Country - geology of Canyonlands and Arches National Parks. University of Utah Press, 138 pp (an easy read for the areas around Moab).
- Beus S S, 1987. Rocky Mountain Section. Centennial Field Guide, Vol 2. Geological Society of America, Boulder, 475 pp (series of field trip guides, including many key sites).
- Beus S S & Morales M, 1990. Grand Canyon geology. Oxford University Press, 518 pp (the book with everything on the Grand Canyon, by many authors)
- Redfern R, 1980. Corridors of time. Orbis, 198 pp (historical geology through panoramic photographs of the Grand Canyon).
- Prinkel, A S, 2000. Geology of Utah's Parks and Monuments. Utah Geological Association, 644 pp (geology of the state's sites).

Highlights of the Colorado Plateau

This list of highlights, in no special order, is based on visual impact. For history one could add Mesa Verde, and the keen geologist might include Petrified Forest, but the list is perhaps a pointer for those planning their first visit to enjoy the best of the desert landscapes and geomorphology of the spectacular Colorado Plateau.

1. Watch sunrise from Yaki Point before hiking the Grand Canyon.
2. The panorama west from Orange Cliffs in Canyonlands North.
3. The view from White House Overlook in Canyon de Chelly.
4. Sit down and gaze from Inspiration Point, Bryce Canyon.
5. Rainbow Bridge seen from the approaching boat.
6. Delicate Arch first glimpsed after the walk up.
7. The walk to Angels Landing, in Zion Canyon.
8. The panoramic view from Dead Horse Point.
9. Valley loop drive in Monument Valley.
10. Reflected light in Antelope Canyon.



**Top
Ten**

