AN INTRODUCTION TO SOME GEOLOGICALLY SIGNIFICANT LOCALITIES OF THE COLORADO PLATEAU

The rocks conceal many mysteries, but also reveal many secrets.

AN INTRODUCTION TO SOME GEOLOGICALLY SIGNIFICANT LOCALITIES OF THE COLORADO PLATEAU

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INTRODUCTION

The western region of the United States is well known for its dramatic scenery and an unusual abundance of National and State Parks. The region has the additional benefit of a sparse vegetation cover that provides extensive exposure of the colorful geological layers. These exposures are accentuated by dramatic fault scarps, elongated monoclines and deep canyons such as the Grand Canyon. Furthermore, the colorful geological sequence of the region is quite simple and serves as an easy preamble to the study of geology, which can at times be very complex. There are few places, if any, on the surface of our planet where one can get a better introduction to the geologic past of our Earth.

You will encounter many new terms in this brief treatise. In order to facilitate your reading, we have provided: 1) a glossary of geological terms; 2) a listing and description of the important geologic formations of the region; 3) a standard stratigraphic column to help you identify which part of the geologic column you are in; and 4) a brief introduction to petrology (the study of rocks) to give you some idea of the nature of the rocks encountered. You will find these resources appended at the end of the descriptive section of this guide. You should refer to these whenever you run into an unknown term. It is suggested that these four study aids be examined carefully ahead of time so that you will know where to turn for help.

For two centuries there has been an ongoing conflict between science and the Bible. This has been one of the greatest intellectual battles of all time. The Bible, with its recent creation by God in six days a few thousand years ago, and science with its theory of evolutionary development over billions of years, stand in stark contrast to each other. The Bible, with a publication record which is 17 times that of any secular book, is highly respected. Science, with dramatic accomplishments such as space exploration and genetic engineering, is also highly respected and many are perplexed as to which is correct. This field guide addresses itself especially to issues related to both sides of this controversy.

Very pertinent to the Biblical account of beginnings is the Genesis flood, which reconciles the geologic layers of the Earth and their enclosed fossils to a recent creation by God. Without a worldwide flood, as described in Genesis, it is not possible to explain the fossiliferous geologic layers found on all the continents of the Earth in the context of Biblical history. Without that flood one cannot reconcile the uniqueness of the various fossiliferous layers of the Earth with the six day creation event given by God in the fourth commandment and in the Genesis account of beginnings. At stake here are questions about the integrity of Scripture. This is not a question that can be easily dismissed. The question of the Genesis flood is paramount to the question of the integrity of the Biblical model of origins and of the Bible as a whole. Hence special attention will be given in this treatise to geologic questions about that horrendous event.

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THE COLORADO PLATEAU

GENERAL FEATURES

The geology of the United States has been divided into a number of geographical provinces based on structure and perceived geologic history. Much of the area to be considered in this guide is in what is known as the Colorado Plateau Geological Province. This plateau radiates out from the Four Corners region, the only place in the United States where you can stand on four different states at the same time. It covers major portions of Utah, Arizona, Colorado and New Mexico. The Plateau is not named after the State of Colorado, but after the Colorado River, which courses from the northeast to the southwest of this region.

The varied topography of the Colorado Plateau exposes many easily recognizable, widely distributed and distinctive rock formations. The Plateau is surrounded by major regions of volcanic activity including the high plateaus of central Utah, the San Francisco Mountains of central Arizona, the Datil region of western New Mexico, and the San Juan Mountains of southwestern Colorado. The Colorado Plateau itself is dominated by smaller plateaus, mesas, and buttes that expose a rich array of sedimentary rocks. Volcanic peaks and mountains formed by the intrusion of molten rock between the sedimentary layers can be seen here and there; some form mushroom-shaped bodies called lacoliths. The La Salle, Abaho, Ute, and Carrizo Mountains around the Four Corners area are all such mountains. In the more central part of Utah are the Henry Mountains, where G. K. Gilbert first described and named the lacolith intrusion feature. Other intrusions of molten rock include several well-known residual volcanic necks such as Shiprock, and Cabazon Peak in New Mexico.

The Grand Canyon is one of the most instructive and intriguing features of the Colorado Plateau. The Canyon cuts right through a broad uplifted area with the Kaibab Plateau to the north and the Coconino Plateau to the south. It exposes the Paleozoic layers of the region as well as Precambrian sedimentary, igneous and metamorphic rocks (consult the Glossary, Rock Classification, and the Geologic Column at the end of this guide for explanations of these terms).

THE STANDARD, SLOW, LONG-AGES INTERPRETATION OF THE GEOLOGIC HISTORY OF THE COLORADO PLATEAU

The account begins with the low Precambrian (see Geologic Column in the Reference section at the end of this guide for location in column) rocks which can be seen in the depths of the Grand Canyon. Here rocks of various types, assumed to be in the billion year range, are free of all but the simplest kinds of fossils, and the rare, often poorly preserved examples have sometimes been reinterpreted as not being fossils at all. Rocks that have been metamorphosed by heat and/or pressure can also be seen in the form of dark schists (see: Introduction to Introductory Petrology: The Five Minute Rock Course in the reference section in back for explanation of what a schist is). Thick Precambrian layers of sedimentary deposits are seen especially in the eastern end of the Grand Canyon and there are Precambrian intrusions of molten rock magma into both the metamorphic and sedimentary rocks of the region. All of this suggests a harsh environment devoid of most of the life forms we are familiar with.

The Precambrian period was followed by a time (Cambrian to Mississippian, 550 to 300 million years ago) during which the Colorado Plateau was mainly an ocean, providing a rich marine environment. The deposits we now see are widespread layers of limestone and shale with marine fossils which are locally abundant. Following this period several parts of the Colorado Plateau were moderately uplifted. This facilitated their erosion into the lower sedimentary basins between. This was followed by a period when many of the colorful, bright red or green, iron rich deposits of the region were laid down. This period, which lasted from Permian up to the Jurassic (consult your geologic stratigraphic column in the Reference section), is thought to have lasted around 180 million years.

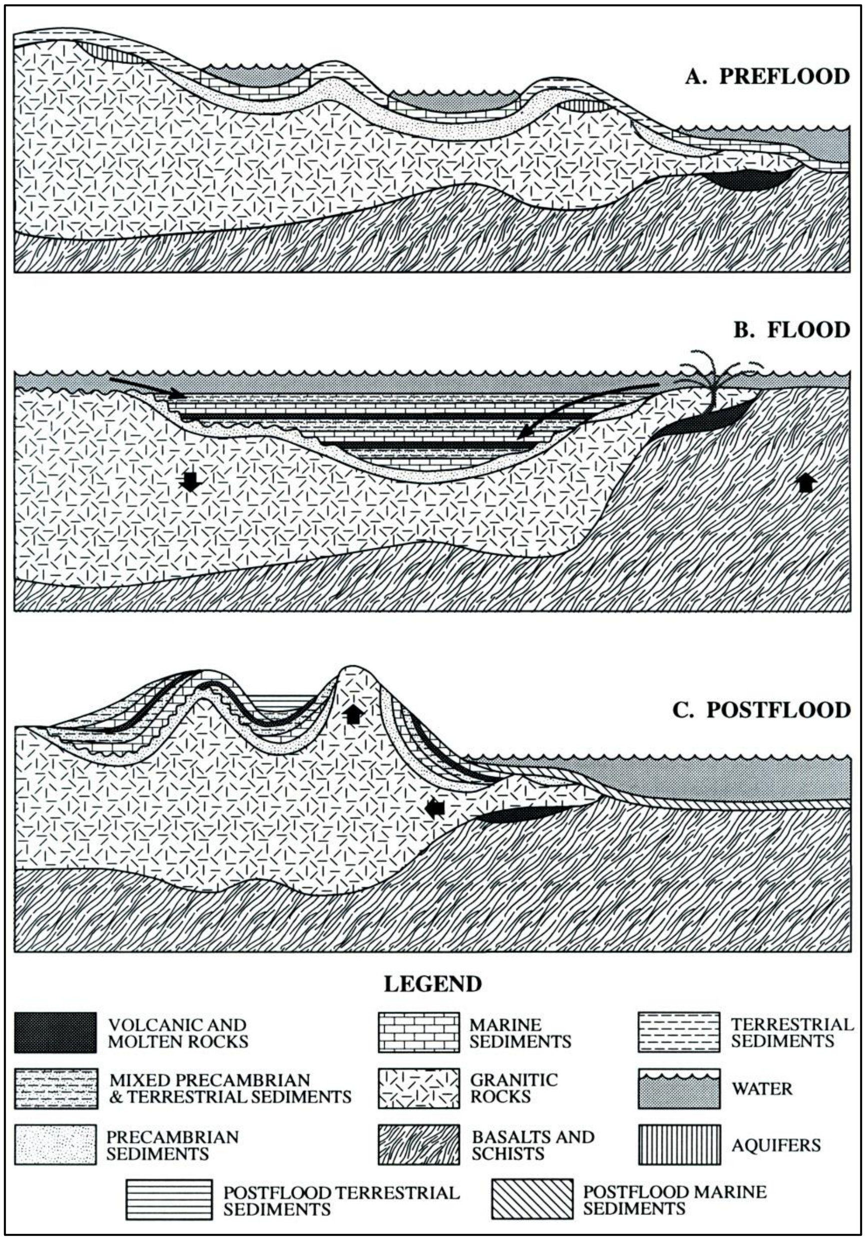

FIGURE 1. An example of a flood model. The diagrams represent cross sections of part of a continent and an ocean before, during, and after the Genesis Flood.

Subsequently uplifts in the east and west served as sources of sediments for the plateau area, which had broad north-south marine troughs in the middle. This combination of factors, which lasted through the Cretaceous (about 70 million years ago) produced wide-spread interfingering marine and land types of deposits. Much of the coal of the region is found in these layers.

A major uplift of the Colorado Plateau, of as much as 3 to 5 kilometers, took place in the late Cretaceous to early Tertiary. This uplift, called the Laramide Orogeny, dramatically modified the landscape. The Grand Canyon region was probably also uplifted at that time and other plateaus and basins were delineated by these events. Many of the notable elongated monoclines of the region, such as Capitol Reef, were formed then. The more recent events include volcanic activity, especially around the edges of the Plateau. The abundant faulting which characterizes the Basin and Range Province which is found to the south and west of the Colorado Plateau had little effect on the Colorado Plateau itself. The faulting did produce major features such as the Rio Grande Rift to the southeast, which cradles the Rio Grande River on its way to the Gulf of Mexico.

Evidence for slow geologic changes, evolutionary time requirements, and radiometric dating are used to support this long ages model.

A CREATION-FLOOD PERSPECTIVE

The following is an example of the history of the Colorado Plateau within the context of the Biblical historical record. It is subject to revision as new information is assimilated.

The Precambrian rocks seen in the deepest rocks of the Grand Canyon represent the geological history of the Earth before the flood and possibly before the six days of creation described in Genesis. This is the Earth "without form and void" of Genesis 1:2, which is dark and covered with water (see also Job 38:9 and II Peter 3:5). Intrusions of molten rock magma, metamorphism of rocks, and the formation of sedimentary layers, would take place before the light appears on the first day of creation week. The microscopic fossils found in these rocks represent microbial life that has infiltrated after the creation of life during creation week. Infiltration could occur before, during, or after the Genesis flood.

The Cambrian through Mississippian layers, with many marine fossils, represent in its lowest parts an epeiric sea over part of a continent. As the continents sank down and the ocean floor rose up to bring about the Genesis flood (Fig. 1) marine deposits and organisms were transported from preflood seas to the continents to form the extensive lower Paleozoic marine layers of the region.

Erosion of the lower land areas of the preflood continents would bring about deposition of Upper Paleozoic land-derived (terrestrial) sediments and organisms. The sedimentary layers of the Plateau alternate many times between marine and land-derived sources as one ascends the geologic column of the area. This would have been brought about by alternation of land and ocean sources for the sediments (Fig. 1B). Erosion of the land-derived source areas would reach well down into uplifted Precambrian sediments. Towards the end of the flood, there would be an abundance of fine sediments suspended in the flood waters. These would serve as a source for the abundant shales found in the region near the top of the geologic column.

As is the case for the long geologic ages model, there would be local uplifts here and there, and there would be the major Laramide Uplift of the Plateau during the late Cretaceous and early Tertiary part of the geologic column. As the continents rose towards the end of the flood, the receding waters which covered the Earth would erode major portions of the flood sediments, leaving great denuded areas and smaller eroded canyons, such as those seen around Bryce, Zion, and the Grand Canyon. The major flood events would have taken about one year, but the lingering effects of this major catastrophe would have lasted for many centuries or for millennia thereafter.

The above is presented only as a suggestion. Several alternative flood models have been proposed. Nevertheless, regardless of the flood model being considered, a significant number of geologic features are difficult to explain if one adopts the usual explanations of billions of years for the formation of the crust of the Earth. Some of these features will be discussed in the following pages.

BALL-AND-PILLOW FEATURES OF HORSE GULCH

LOCATION

Horse Gulch can be easily accessed at the east end of 3rd Street in Durango, Colorado. The ball-and-pillow outcrop is on the north side of the Gulch a few hundred feet along the path to the east (Dunbar 1992, Lucas 1997).

FIGURE 2. Ball-and-pillow structure at the contact between the tan Point Lookout Sandstone above, sinking into the darker Mancos Shale below. Note how the Mancos squeezes up between and almost around the two large balls, which are almost separated from the sand source above. Such features are considered to result from rapid action occurring before the Mancos consolidated.

DESCRIPTION

The overlying tan sandstone is the Cretaceous Point Lookout Sandstone, which lies just above the darker Cretaceous Mancos Shale. The spectacular soft sediment deformation, distorted bedding, and ball-and-pillow features of the overlying Point Lookout (Fig. 2) indicate that it was loaded rapidly over the unconsolidated Mancos Shale. The sandstone, which had a greater density (about 2) than the fresh Mancos "mud" (density about 1.5) sank down, producing the distorted contact. Such features are interpreted as evidence of rapid action having to take place before the mud became compacted and eventually consolidated into shale.

FIGURE 3. Fossil "worm tubes" of various kinds from the Point Lookout Sandstone. Note especially the pattern in the large tube near the top of the rock slab (arrow). Tubes are 1-2 cm in diameter.

There is ample evidence of burrowing by organisms in the upper one-third meter of some of the Point Lookout Sandstone units (Lucas et al. 1997, p 28). The sequence of rocks here has been interpreted as an ancient tidal channel or river mouth bar environment.

A CREATION-FLOOD PERSPECTIVE

The distorted layers and ball-and-pillow features seen are evidence of rapid loading of the Point Lookout over a soft Mancos. Similar and also larger features are abundant in Cretaceous layers around Price, Utah. Such features are what we would expect during relatively rapid flood events. One should not conclude that there was a worldwide flood on the basis of one locality, but every locality is part of the total picture.

The presence of "worm tubes", especially in the upper parts of the sedimentary units is also similar to what is found to the northwest of here around Price, Utah. These latter deposits have been thoroughly studied (Frey and Howard 1985, 1990). It is strange that though the tubular structures are abundant, little is known about the kinds of organisms that produced them: "Body fossils are virtually nonexistent" (Frey and Howard 1990). Over a score of "species" of trace fossils (tubes) have been identified in this region.

Trace fossils are considered to be a problem for a flood model. In a worldwide flood, one would not expect organisms to be producing "tubes." This requires time.

One suggestion to answer this objection is that these tubes really do not represent structures made by organisms. After all, organisms are essentially absent. This may be the case for some; however, for others a biological origin seems almost certain, since a regular pattern of biological activity is reflected in the wall and sometimes the content of the tubes. This is especially conspicuous in the *Ophiomorpha* group, which has a pellet-wall pattern.

An alternative answer lies in the question of the amount of time required by these organisms to produce these tubes. The flood described in Genesis took over a year for its various phases. Could organisms build these tubes within the constraints of that time? During the year of the flood, many things could happen, including tube burrowing. In order to disprove the flood, only events that take longer than the time available should be considered valid. Since the known rate of formation of these tubes can be quite rapid, they may not represent a firm challenge to a flood model after all.

Studies by Kranz (1974) indicate that bivalves burrow between 0.16 and 153.15 cm/hr under an increasing overburden of sediments (anastrophic events). Under normal conditions, rates between 1.84 and 1000 cm/hr are reported by Stanley (1970; also see Table 4 in Kranz 1974). Investigations by Howard and Elders (1970) on small Crustacea from Sapelo Island, Georgia, indicate burrowing rates of 0.7 to 2.8 cm/hr.

Interestingly, Signor (1982) found that fat turritelliform snails buried themselves much faster in sand (about 200 sec) than thinner ones (about 600 sec). The faster ones were assumed to have a more efficient burrowing apparatus. The substrate also affects rate of burrowing (Alexander 1988).

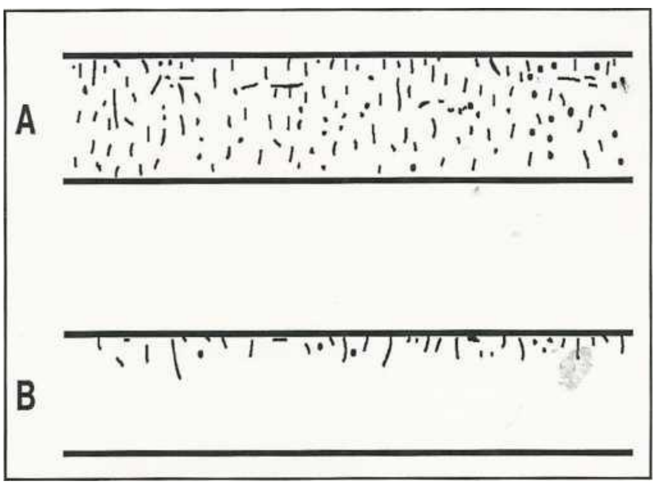

FIGURE 4. Sedimentary layer with trace fossils illustrated as vertical-oblique lines. A = pattern expected under a slow process of accumulation; B = pattern expected under rapid deposition.

The Blackhawk and related formations of the Price, Utah, region are interpreted as a shoreline-type location. The sea was to the east, coarse sediments came from the west. Lagoons, deltas, flood plains, bars, and rivers are assumed to have formed a complex in which “rafted organic material” (Marley 198) served as source for coal. Trace fossils (“worm tubes”) are found at many levels in this complex. Some sediments are assumed to have accumulated slowly (Frey and Howard 1985), while storm deposits are the interpretation for slightly hummocky beds (Frey 1990). The picture is generally similar around Durango.

One suggestion for a flood model is that these “worm tubes” represent escape burrows as sediments accumulated episodically and trapped organisms during the later stages of the flood. Some of the same organisms might even be responsible for escape burrows at various levels as they were repeatedly trapped and escaped. This might help explain the virtual absence of body fossils in these tubes. Brandt (1980) proposes the same kind of process for successions of burrows in the Upper Ordovician around Cincinnati, Ohio.

Many of the units in the region show a preponderance of both horizontal and vertical trace fossils (burrows?) near the tops of the units. Such a pattern is interpreted as instantaneous deposition (Seilacher 1962; Frey and Pemberton 1984). Rapidly deposited turbidites are specifically suggested by Seilacher. This kind of evidence is an argument for rapid action.

The argument is that if the layers accumulated slowly, one would expect a more-or-less even distribution of "worm tubes" throughout a rock unit, as shown in Figure 4A. If accumulation was rapid, tubes would be formed mainly in the tops of the units, as illustrated in Figure 4B. There would not be enough time for the formation of worm tubes throughout the unit during "instantaneous" deposition.

The question of rate of formation of sedimentary units also raises the question of preservation of sedimentary surfaces in the presence of organisms which can destroy such surfaces by "stirring" them up. The term "bioturbation" is used for this process. The main organisms involved in bioturbation in marine environments are fish, crabs, clams, snails, and worms that persistently forage on the bottom of ocean and lakes. Clifton and Hunter (1973) have reported on this process in the US Virgin Islands. They found that sand ripples are totally destroyed in 2-4 weeks. Layering in the upper 2 cm is largely obliterated in the same period of time. These data suggest that in the presence of bioturbating organisms, burial of layers has to be rapid if their structure is to be preserved at all, and the presence of these layers may signify rapid burial.

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WIDESPREAD DEPOSITIONAL PATTERNS

LOCATION

The two formations discussed below are so widespread that they can be viewed from many localities in the western United States. The location for Figure 5 below is from an exposure along U.S. Highway 191 about 8 miles north of the junction with U.S. Highway 666 in Monticello, Utah. Here both the Morrison and Dakota formations are exposed due to erosion of the great Sage Plain.

FIGURE 5. View of the Dakota and Morrison Formations exposed to the east of U.S. Highway 191 north of Monticello, Utah. The bedded layers high in the wooded region just below the skyline are the Dakota Formation. The various colorful layers just above the road are part of the Morrison Formation.

DESCRIPTION

Some formations are small and local; on the other hand some are huge and extremely widespread. Two formations of the Colorado Plateau, found in this location, serve as examples of the latter.

MORRISON FORMATION

The Upper Jurassic Morrison Formation is most famous for its dinosaur remains. Its variegated (multicolored) mudstones and white, tan, and gray sandstones are characteristic. It can reach up

FIGURE 6. Distribution of Morrison Formation

to 450 m (1500 ft) in thickness, although through most of its expanse it is more like 100 m (300 ft) thick. It is spread over 1,000,000 km^2 (400,000 mi^2) (Fig. 6). It has been divided into lateral and vertical subunits (Craig et al. 1956, Peterson and Roylance 1982, Peterson and Turner-Peterson 1987). Stokes (1944) has proposed formational status to the Lower Cretaceous Buckhorn Conglomerate and Cedar Mountain Shale which are similar to, and between, the Morrison and the Dakota in the central-western part of the formation. In the locality of Monticello, formational status has been proposed for a Burro Canyon Formation between the Morrison and Dakota, but this has been disputed.

Fossils are rare in the Morrison. Dinosaur bones are found in localized massed accumulation in some 20 localities, one of which is Dinosaur National Monument. Other animal fossils include: crocodiles, turtles, fishes (primarily lungfish), frogs, salamanders, ostracods, snails, clams, and small primitive mammals. Plants are also rare and include large conifers (mainly logs) and small plant fragments. Palynomorphs (pollen and spores), which are also rare, suggest gingkos, ferns, lycopsids, and algae.

The Morrison is considered to represent a past environment of rivers and floodplains with possibly an increased tendency toward more lakes and deltas in later periods (Peterson and Roylance 1982). Some deposit by wind has also been suggested. There is no agreement as to whether there was a humid, dry, or varied climate in Morrison time (Dodson et al. 1980). Source of sediments for the Morrison is generally considered to have come from hills in the west, which included a volcanic arc. On the other hand, Yingling and Heller (1987) suggest a southwest source.

THE DAKOTA SANDSTONE

(FORMATION OR GROUP)

This Lower Cretaceous formation is very thin, often around 30 m (100 ft) thick, with a maximum up to 220 m (700 ft). It is very widespread (Fig. 7), extending from Iowa to Arizona and from Montana to New Mexico, covering some 815,000 km^2 (315,000 mi^2). It is a mixed marine-and-land formation containing great variety of fossil types such as leaves, coal, wood, dinosaurs, mammals, sharks and invertebrates.

The Dakota Formation is assumed to have been deposited in a variety of environments such as a transgressive sea, river, lagoonal, and tidal. In the southwest it tends to consist of three units, a shale layer between two sandstone layers. It is a very thin layer and represents unusually flat depositional environments. Unusual energy levels may have been involved in such widespread distribution.

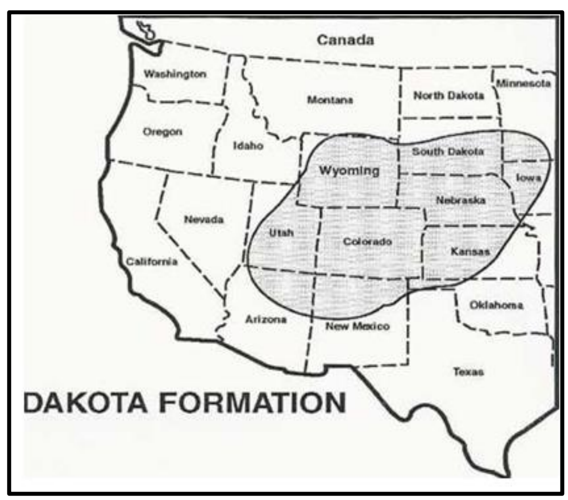

FIGURE 7. Distribution of Dakota Formation

A CREATION-FLOOD PERSPECTIVE

The Morrison poses a number of puzzles which would be alleviated by a catastrophic flood model. These include:

1) For a unique continental (land) deposit the Morrison is very widespread (Fig. 6). Could local deposition produce such a special thin, widespread formation? This seems very unlikely. Dodson et al. (1980) point out:

> *The enormous area covered by the Morrison sediments and the general thinness of the sedimentary sheet (being in most areas less than 100 m in thickness) indicate that the sediments were distributed by widespread flowing water.*

While the authors do not entertain the suggestion of a worldwide flood, their mode of spread reflects the type of activity expected for such an event.

2) Ancient channels of *major* rivers, which would help distribute the sediments over a wide area, have not been found in the formation.

3) The Morrison Formation appears to represent a vast but incomplete ecological system. It has been one of the world's richest sources of dinosaur fossils, yet plants are rare, especially in the vicinity of dinosaur remains (Dodson et al. 1980). What did the behemoths eat? The paleontologist Theodore White (1964) comments that "although the Morrison plain was an area of reasonably rapid accumulation of sediment, identifiable plant fossils are practically nonexistent." He further muses that by comparison to an elephant an apatosaurus dinosaur "would consume 3 ½ tons of green fodder daily." If dinosaurs were living there for millions of years, what did they eat if plants were so rare? Other investigators (Herendeen et al. 1994, Peterson and Roylance 1982, Peterson and Turner-Peterson 1987) have also commented on this lack of plant fossils. Brown (1946) states that the Morrison in Montana "is practically barren of plant fossils throughout most of its sequence," and others (Dodson et al. 1980) comment that the "absence of evidence for abundant plant life in the form of coal beds and organic-rich clays in much of the Morrison Formation is puzzling." These investigators also express their "frustration" because 10 of 12 samples studied microscopically were essentially barren of the "palynomorphs" (pollen and spores) produced by plants. With such a sparse source of energy, one wonders how the large dinosaurs could survive the assumed millions of years while the Morrison Formation was being deposited.

   To explain the dilemma, some have suggested that plants existed but did not get fossilized. This idea does not seem valid, since a number of animals and a few plants are well preserved. Perhaps the Morrison was not a place where dinosaurs lived. Instead, it might have been a flood-created dinosaur burial ground with plants sorted and transported by water elsewhere.

   Paleontologists (Fastovsky et al. 1997) report a similar situation for the dinosaur protoceratops found in the central Gobi Desert of Mongolia. These investigators, studying various aspects of these Cretaceous deposits, conclude that "the abundance of an unambiguous herbivore (protoceratops) and a rich trace fossil fauna [probably tubes made by insects] reflect a region of high productivity. The absence of evidence of well-developed plant colonization is, therefore, anomalous and baffling."

4) Also puzzling for a long-ages model is the general absence of fish remains and diverse molluscan assemblages in deposits interpreted as "clearly lacustrine [lake] in origin" (Dodson et al. 1980).

A model of a worldwide flood with gradually rising and receding waters provides some answers to these questions. The flood-waters provided the widespread distribution of the sediments, and the animals did not live in the inhospitable environment inferred from the fossil picture.

It is difficult to appreciate how widespread these formations are compared to their thickness. This can be illustrated by noting that proportionately for the maps of Figures 6 and 7, each formation would average less than 1/8 the thickness of the sheet of paper on which the map is printed. Such incredibly thin layers, spread over such a wide area, could indicate “widespread flowing water” as suggested by Dodson et al. (1980) for the Morrison. Also on a long-ages model for Earth, one has difficulty thinking of such a stable (flat) environment for the millions of years postulated to accommodate the deposition of these formations. During that time continents would be moving, and uplift and subsidence is suggested around the region to provide a source of sediment for the deposits. Furthermore, one wonders if over many millions of years some erosion through these layers would not tend to break the widespread continuity and sequence we see. Here we see evidence of activity of a different nature and scale than is common at present. High-energy factors may have been involved in such widespread distribution of thin, unique sedimentary units.

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MOAB VALLEY

LOCALITY

The Moab Valley is an elongated valley that runs in a northwest to southeast direction in eastern Utah. It is located mainly to the south of the town of Moab and can easily be seen as high cliffs on either side as one drives along U.S. Highway 191 through the Moab region.

DESCRIPTION

The Moab Valley (Fig. 8) is one of six to eight (depending on subdivision) elongated parallel valleys that run in a northwest-southeast direction in western Colorado and eastern Utah. These valleys are all anticlines (layers convex upward) whose central portions subsided and have been eroded, leaving valleys between opposing cliffs (Baars and Doelling 1987, Chenoweth 1987). These anticlines were formed by the migration of salt to the region below the valleys, mainly along fault lines. Upward migration of the salt caused uplift of the valley regions prior to erosion. The salt, which has a lower density than the surrounding rock, migrated up below the developing valleys along zones of least confining pressure.

FIGURE 8. View from the south end of the Moab Valley looking north. The valley was formed by the migration of salt and by erosion. The gray (Cretaceous) layers in the center and right foreground of the valley used to be much higher above the level of the reddish to tan layers (Jurassic Triassic) forming the sides of the valley. These Cretaceous gray layers, which are stratigraphically higher than the reddish-tan layers, collapsed down due to dissolving of the salt below the floor of the valley

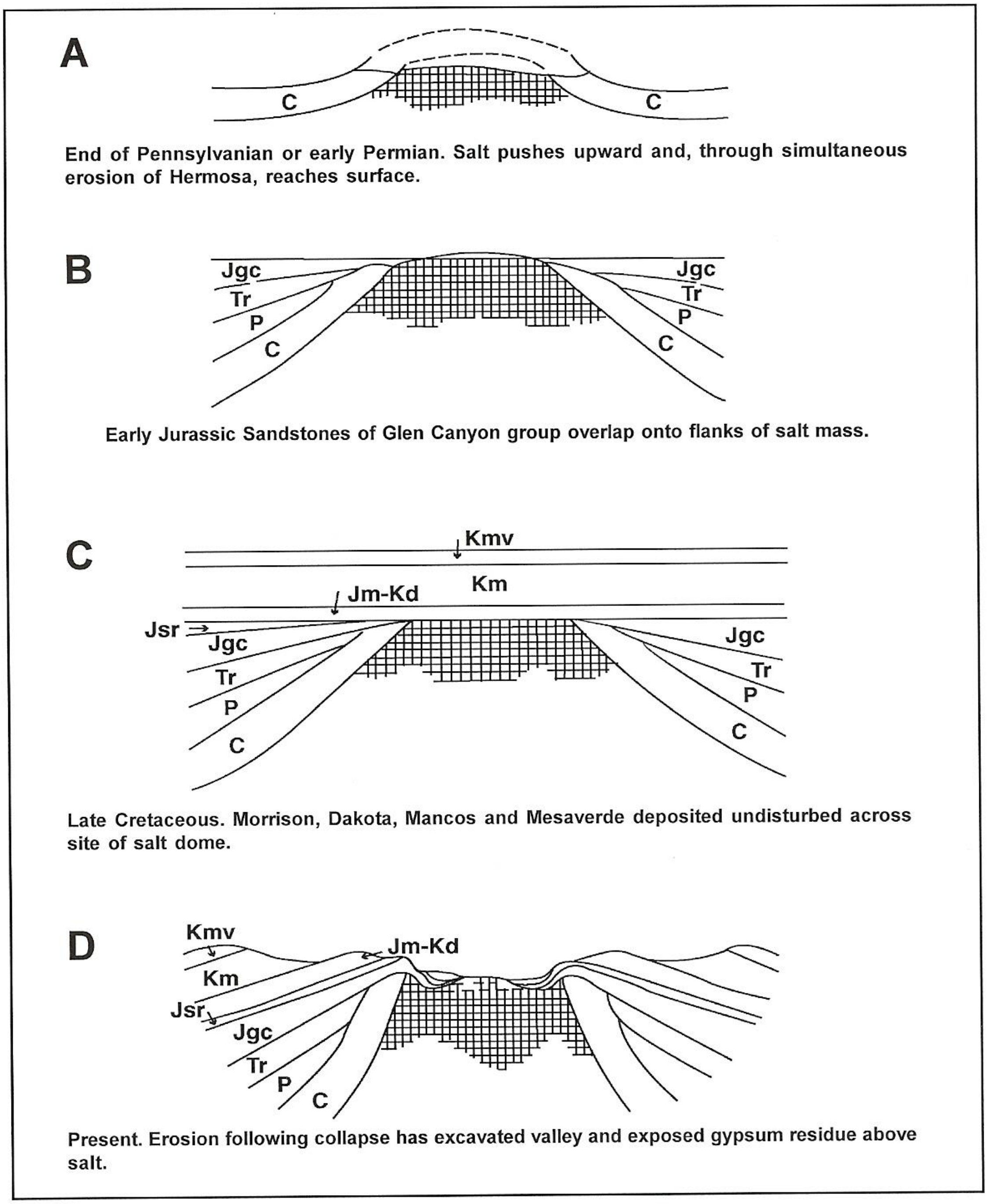

FIGURE 9. Postulated sequence in the formation of salt valleys. Hatched pattern - salt; C - carboniferous (Pennsylvanian); P-Permian; Tr-Triassic; Jgc-Jurassic Glen Canyon Group; Jsr-Jurassic San Rafael Group; Jm-Kd - Jurassic-Cretaceous Morrison to Dakota; Km - Cretaceous Mancos Shale; Kmv - Cretaceous Mesa Verde Group. Modified from Thornbury (1965), p 432.

Movement of the salt occurred mainly from Pennsylvanian through Triassic time (Fig. 9) A little more salt migration may have occurred during the Laramide Oregeny late Cretaceous and early Tertiary time. As the valley regions moved up, it appears that deposition of surrounding formations was restricted over the rising ridges but this is a disputed point. In the late Cretaceous the Mancos Shale completely covered the region (Fig. 9C). This was followed by further accentuation of the anticlines by west-to-east compressional pressure. Solution of the salt caused collapse of the valley floor, and occasionally the Cretaceous layers can be seen much lower (Fig. 8) than the stratigraphically lower valley walls. Erosion of sediments in the central part of the valley accentuated the topography. The Moab Fault on the southwest side of the valley is an apparently normal fault, suggesting expansion of the valley, with a down drop of as much as 793 m (2600 ft) of the northeast side.

The Paradox salt layer, that migrated up and eventually caused the valleys to form, is not pure and contains significant clay, gypsum, and limestone. It is from 610-1830 m (2,000-6,000 ft thick in the surrounding region, but reaches up to 3658 m (12,000 ft) under the Moab Valley and 4572 m (15,000 ft) under the Paradox Valley to the east. There is no salt exposed on the floor of the Moab Valley, but there are associated gypsum outcrops along the southwest side of the valley.

Up to 29 cycles of evaporation have been proposed for the Paradox salts. It would require the evaporation of many kilometers of depth of sea water to produce one cycle, hence a reflux model with repeated addition of sea water in a barred basin is proposed. The sequences of precipitation of various salts from sea water is sometimes normal and sometimes reversed, and various reflux systems have been proposed to accommodate this (Hite 1973).

One of the baffling features of the region is that major rivers cut almost perpendicularly across the long valleys. The Colorado River cuts across the Fisher and Moab Valleys, and the Dolores River cuts across the Paradox Valley. Another question is why are the centers of these elongated anticlines cleaned out while the sides remain? The paradox of rivers flowing perpendicularly to the valleys is the reason for the names: Paradox Valley, the Paradox Formation, which is the source of the salt, and the Paradox sedimentary basin of the region. Several explanations have been proposed and will be considered later in connection with erosion around the Grand Canyon region, which shows somewhat the same paradox.

A CREATION-FLOOD PERSPECTIVE

The traditional view that the salt of the Paradox Formation formed as a result of the evaporation of sea water does not fit easily with the concept for the deposition of most of the Phanerozoic sediments in a one-year flood. On the other hand, one can postulate “original” preflood salt deposits getting involved in these sediments, as the crust of the Earth broke up at the time of the flood. Uplift and erosion of the salt valleys would take place during and after the flood. The traditional evaporation model for the formation of salt is not without problems. It would take around 40 km (25 mi) of sea water to produce 610 m (2000 ft) of Paradox salt. And when you evaporate sea water, calcium and gypsum precipitate out first. Repeatedly replenishing an evaporation basin with sea water is the usual long-age explanation, but requires special fortuitous conditions for a very long time.

The very few natural salt deposits now being formed by evaporation on our Earth are very minute compared to the huge salt deposits found in the sedimentary record of the past. Past conditions seem definitely different from present ones.

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DEAD HORSE POINT

LOCATION

Dead Horse Point, which overlooks the Colorado River, is located southwest of Moab, Utah. Take U.S. 191 for about 8 miles north of Moab, and proceed west on State Highway 213. Follow the signs to Dead Horse Point.

DESCRIPTION

At Dead Horse Point (Fig. 10) the Colorado River has eroded through a dramatic section of Paleozoic and lower Mesozoic rocks. The stratigraphic section given below is assumed to have taken some 100 million years for its deposition. See “Stratigraphic Section” in References section for formation details.

TRIASSIC

Kayenta Formation
Wingate Sandstone
Chinle Group
Shinarump Conglomerate of Chinle

(Unconformity of about 10-12 million years, middle Triassic missing)

Moenkopi Formation

PERMIAN

(Unconformity of about 15-20 million years, upper part of Permian missing)

Cutler Group (top is White Rim Sandstone)

PENNSYLVANIAN

Hermosa Group (Rico)

A CREATION-FLOOD PERSPECTIVE

The contrast between the amount and irregularities of erosion by the Colorado River and the flatness of the sedimentary layers in the region is instructive. Between some of these layers, significant parts of the geologic column are missing. If lots of time occurred between the deposition of some of the layers, one would expect evidence of this in the form of lots of irregular erosion, as the canyon cut by the Colorado River so ably demonstrates here. Yet the layers we see lie flat (on top of each other) as though time, represented by the missing parts of the geologic column, did not occur.

Figure 10 gives the precise location of two significant gaps in deposition. The upper arrow is at the base of the Late Triassic Shinarump. Below this is the Early Triassic Moenkopi. The Middle Triassic (about 10-12 million years) is missing. The lower arrow points at the top of the Early Permian White Rim Sandstone. Between this and the Lower Triassic Moenkopi immediately above it, the Late Permian (about 15-20 million years) is missing. The lack of irregular erosion, that would be expected at these gaps in deposition, suggests that these layers were laid down rapidly on top of each other, as expected during the Genesis flood.

FIGURE 10. Valley of the Colorado River as seen from Dead Horse Point. The top arrow points to an assumed 10-12 million year depositional gap. The lower arrow joints to a 15-20 million year gap. Note the striking contrast between the flat depositional patterns of the layers at these 10 to 20 million year hiatuses and the deep irregular erosion of the canyon by the Colorado River.

The difficulty with the extended time proposed for these gaps is that one cannot have deposition, nor can one see much erosion. With deposition, there is no gap, because sedimentation continues. With erosion, one would expect abundant channeling and the formation of deep gullies, canyons and valleys; yet, the contacts are usually nearly planar. Over the long periods of time envisioned for these processes, erosion would erode the underlying layers and much more. One has difficulty envisioning little or nothing at all happening for millions of years on the surface of our planet. The gaps seem to suggest less time.

This is not an isolated situation (Roth 1988; 1998, p 222-229). Figure 11 illustrates the missing layers in this region of the Colorado Plateau and contrasts the flat sedimentary layers with the present topography illustrated by the dashed and dotted lines superimposed on the diagram. Such pattern contrasts can be found around the Earth.

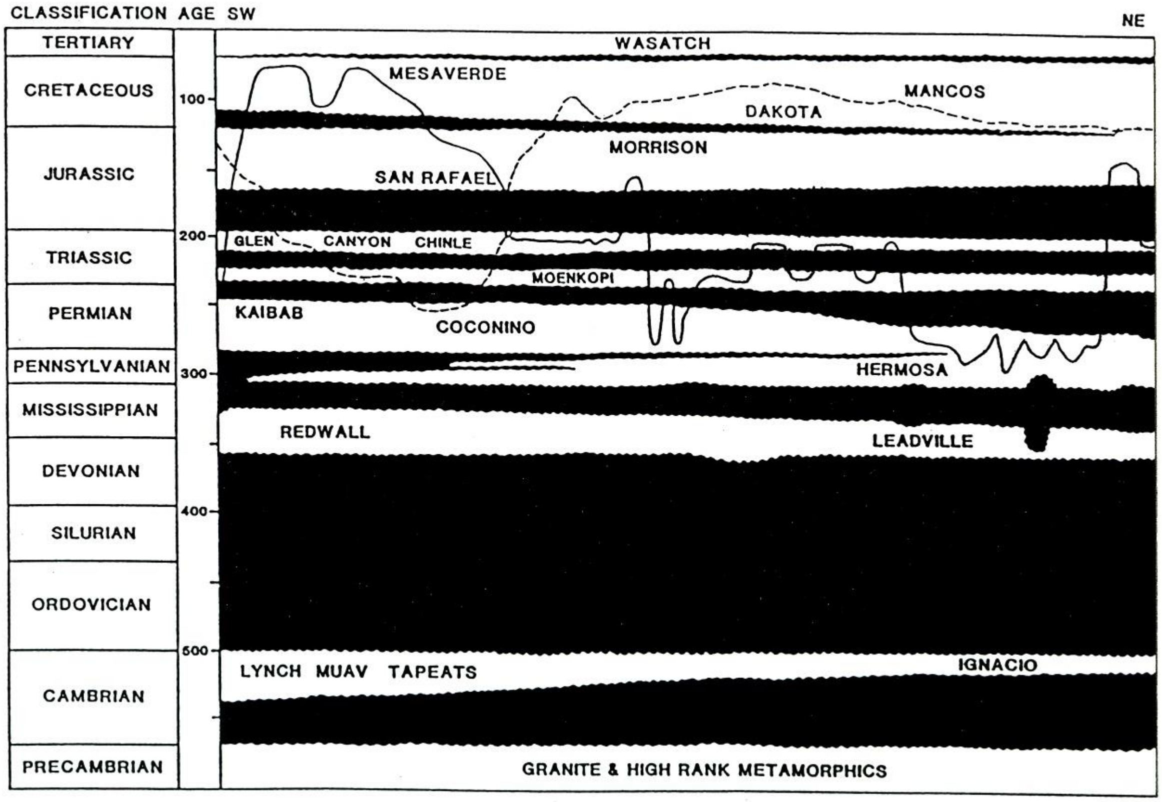

FIGURE 11. Representation of the sedimentary layers in eastern Utah and a little of western Colorado, based on the standard geologic timescale (instead of thickness, although the two are related). The clear (white) areas represent sedimentary rock layers, while the black areas represent the time for the main gaps (hiatuses) between layers where parts of the geologic column are missing in this region. The layers (white areas) actually lie directly on top of each other with flat contact planes. The black areas stand for the postulated time between the sedimentary layers. The irregular dashed and continuous lines through the upper layers represent two examples of the present ground surface in the region as carved by erosion. The dashed line (--) represents one of the flattest surfaces of the region as found along 1-70, while the smooth line (—) is in the hills farther south. This provides evidence for a flood model wherein the layers (white areas) were deposited rapidly in sequence without much time for erosion between. Erosion toward the end of the flood and afterward produced the irregular topography that exists today (dashed and continuous lines). If millions of years had elapsed between the layers (black areas), as postulated by the geologic timescale, we would expect patterns of erosion somewhat similar to the present surface pattern (dashed and continuous lines) between the white layers. The main divisions of the geologic column are given in the left column, followed by their putative age in millions of years. Names in the sedimentary units represent only the major formation or groups. Vertical exaggeration is about 16x. The horizontal distance represents about 200 km while the total thickness of the layers (white part) is about 3 ½ km. (Based on references given below. ©1998, Review & Herald Publishing Association.

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CAPITOL REEF

LOCATION

The features discussed below are located in Capitol Reef National Park. To reach the contact between the Shinarump Conglomerate and Moenkopi Formation discussed below, take the Scenic Drive to the south past Grand Wash and past the Egyptian Temple east of the road. Follow the formations until the contact between the buff colored Shinarump Conglomerate layer and the reddish brown Moenkopi comes down to below road level and is exposed in a creek bed running east of the road (Fig. 12). This is just before the road turns east to go through a narrow passage in the Moenkopi. If you reach the turnaround at Grand Wash you have gone too far! Walk north up the creek bed and examine the Shinarump-Moenkopi contact on the east side of the creek bed.

FIGURE 12. Location of the contact between the Moenkopi and the Shinarump south of the Egyptian Temple in Capitol Reef National Park. The picture is a view to the North. Note that the layers slant down to the east (right). The Moenkopi lies above and below the grey paved road to the left. The Shinarump forms the prominent low cliff in the foreground just above the creek bed.

DESCRIPTION

Capitol Reef is not a typical coral reef in the usual sense of the word. It is called a reef simply because it forms a huge barrier. The barrier is the remains of a 100 mile long north-south monoclinal folding of many geologic layers. Going from east to west the layers of the region are horizontal until they come to Capitol Reef. There they bend up the monocline and then continue to the west in a near horizontal pattern at a higher level. Major parts of the Mesozoic layers west of the monocline have been eroded away up to the monocline, where what remains is a very colorful display of layers dipping down to the east (Fig. 13). This is the "reef", which because of its colors is called by the Navajos the "Land of the Sleeping Rainbow." The name "Capitol" comes from several domes in the Navajo Sandstone, seen in the higher regions of the "reef." They are somewhat reminiscent of the domes of typical government capitol buildings. The monocline is also called the "Water Pocket Fold" because of the many pockets or potholes of water found on the surface of the uplifted "reef."

The colorful formations (Fig. 13) of sedimentary rocks in the region range from the Permian Kaibab on up to the Cretaceous Mancos Shale, spanning some 200 million years according to the standard geological timescale. The main layers exposed in the vicinity of the Visitor Center from bottom to top are the brownish red Moenkopi, the soft multicolored Chinle, with the occasional layer of buff colored Shinarump Conglomerate at its base. These are overlain by the massive buff Wingate Sandstone and higher strongly bedded reddish Kayenta Formation. The pale Navajo Sandstone can often be seen at the top.

FIGURE 13. View of main rock formations in Capitol Reef. The low red-brown layers in the foreground are the Moenkopi Formation. The reddish, gray and white layers above are the Chinle Group. Above is the massive buff Wingate Sandstone, which is overlain by the darker red bedded Kayenta Formation. The Shinarump is not represented at this locality. On the right edge of the figure the Moenkopy forms the lower third. The Wingate and Kayenta form the top quarter. The Chinle lies between.

A CREATION-FLOOD PERSPECTIVE

The widespread nature of the formations seen here is unusual as compared to present depositional patterns on the continents of the Earth, and reflects higher energy transport of unique sources than is common now. The Chinle Group, with its characteristic multicolored layers, is spread over some 800,000 square kilometers (300,000 square miles) in the western United States. Exposures can be seen from Texas to Montana, and from Idaho to Nevada.

FIGURE 14. Contact between the Moenkopi and Shinarump. Note two main kinds of rocks: a harder, lighter colored sandstone, the Shinarump (mainly above), and a darker (arrow) softer shale, the Moenkopi (mainly below). Note the interlayering of the two kinds of rock, suggesting that both were fluid when the Shinarump was laid over the Moenkopi. The Shinarump is assumed to be some 10-12 million years younger than the Moenkopi. Could the Moenkopi remain fluid for that long a time?

The contact between the Shinarump Conglomerate, which is at the base of the Chinle, and the Moenkopi below reflects rapid action and not the putative long geologic timescale. At the creek location described above the sediment deformation (Fig. 14) reflects rapid deposition ball and pillow characteristics. It appears that both formations were soft when the Moenkopi was overlain by the Shinarump. However, long-age interpretations propose that there is a gap of some 10-12 million years between the two. Other formations found elsewhere on the Earth represent that long time period. The Middle Triassic is missing here. Could the Moenkopi which is below the contact remain in a semi-fluid condition for 10 million years before it was overlain by the Shinarump that readily penetrates it? It looks more like we are dealing with little time between the deposition of the Moenkopi and the Shinarump.

CLASTIC PIPES AND DIKES IN KODACHROME BASIN

LOCATION

Kodachrome Basin State Park lies east of Bryce Canyon National Park. From the town of Cannonville, follow the signs to Kodachrome Basin. Take the only paved road going south of town. About 1.8 miles past the bridge over the Paria the road goes up and down through a narrow roadcut pass. This is Shepard Point. The southeast exposure seen to the left just after the pass will be discussed later. Continue on the paved road for about 2 miles to Kodachrome Basin State Park. Many protruding stone pipes and dikes are located in the region. The pipe with exposed striations discussed below is located behind the park store.

DESCRIPTION

In the region of Kodachrome Basin State Park, Utah, are found some unusual vertically oriented, intrusive sedimentary structures. They are called pipes if cylindrical in shape (see Figure 15), or dikes if

FIGURE 15. One of the largest exposed "pipes" in Kodachrome Basin. The surrounding rock, which is softer, has been eroded away, leaving this 50 m (150 ft) "monolith." The surface of the pipe is badly eroded.

flat-like in shape. These structures, which sometimes reach heights well over 50 m (150 ft), have come from the sedimentary layers below (Fig. 16, up arrow). In the same area, there is also indication of collapse (Fig. 16, down arrow; Fig 17) of some sediments into lower layers (Christiansen 1952).

These features in the Jurassic layers raise interesting questions regarding the amount of time involved in their formation. The source layers would have to be soft in order to intrude into other layers. Sediments cannot remain soft forever; they tend to become cemented. Cementation occurs under pressure and/or when dissolved minerals are carried by water into the sediments, hardening them into rocks. Some other features of these pipes also suggest that there was not much time between deposition of these layers and recent (Plio-Pleistocene) geologic activity. The conundrum is that the standard geologic time scale implies well over 150 million years between laying down of these sediments and what appears to be the time of intrusion.

The details of these strata, which are about 600 m (2000 ft) thick, have been worked out by Thompson and Stokes (1970) (see Fig. 16). The Jurassic layers involved have a putative age of 144-208 million years. The Carmel Formation of this group averages around 179 million years, and the Entrada averages around 166 million years. In parts of the area an unnamed Plio-Pleistocene channel and sheet conglomerate (Gregory 1951) covers various formations. It contains basalt pebbles considered to be only 1-6 million years old, and therefore is interpreted to be much younger than the main Jurassic sedimentary formations of the area.

Flornbacher (1984) has mapped and described 67 pipes and many dikes in the area. They are found at various stratigraphic levels, but dominate in the Gunsight Butte member of the Entrada (Fig. 16).

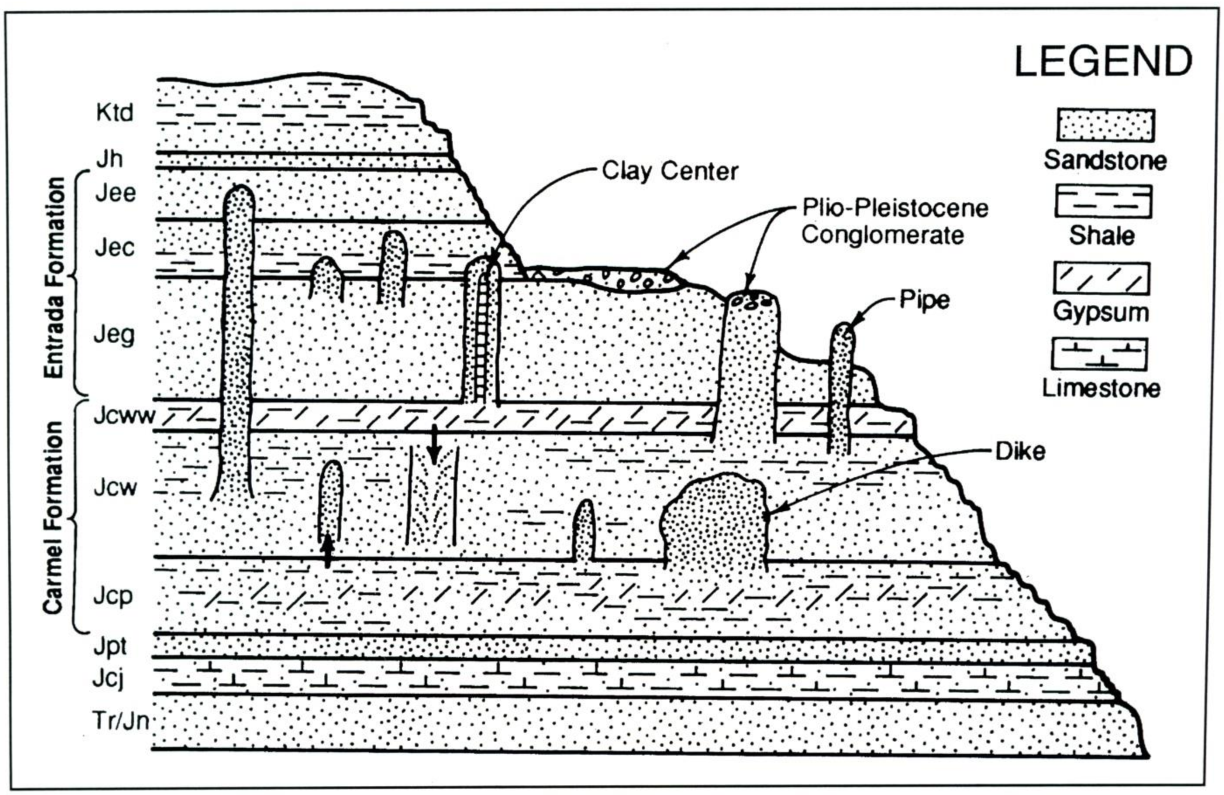

FIGURE 16. Diagrammatic representation of a section through the pipe and dike-bearing strata in Kodachrome Basin. Legend for formations: Tr/Jn —Triassic-Jurassic Navajo; Jcj — Jurassic Carmel, Judd Hollow; Jpt — Jurassic Page Sandstone, Thousand Pockets Tongue; Jcp — Jurassic Carmel, Paria River Member; Jew — Jurassic Carmel, Winsor Member; Jcww—Jurassic Carmel, Wiggler Wash Member; Jeg—Jurassic Entrada, Gunsight Butte Member; Jec — Jurassic Entrada, Cannonville Member; Jee—Jurassic Entrada, Escalante Member; Jh — Jurassic Henrieville Formation; Kdt — Cretaceous Dakota-Tropic Formations undifferentiated.

FIGURE 17. Collapse feature at Shepard's Point along the road to Kodachrome Basin State Park. The area with layers slanting down suggests collapse, which may have compensated for sediments intruding the clastic pipes and dikes in the vicinity.

One intrudes as far up as the Escalante member of the Entrada. The pipes range in exposed height up to 52 m (170 ft) and up to 15 m (50 ft) in diameter. Analysis of the rocks and minerals in the pipes shows similarity, mainly to the upper Paria River and lower Winsor Formations below. They are the most likely source for most of the pipes. Some upper Winsor and Thousand Pockets Tongue of the Page Sandstone (see Fig. 16) and possibly other layers have occasionally also served as a source for the pipes.

The mechanism for intrusion is problematic and may never be known. Hannum (1980) has suggested that the pipes came from cold springs. Hornbacher (1984) favors seismically induced sediment liquefaction and intrusion. The relatively smooth and striated wall pattern of some pipes (Fig 18) favors the latter interpretation. To add to the mystery, there seems to be little or no disturbance of bedding planes or indication of compressive strain in the sediments surrounding the pipes. This suggests that both the pipe material and the surrounding sediments were soft when the pipes formed.

A CREATION-FLOOD PERSPECTIVE

Hornbacher (1984) gives evidence that intrusion took place at the time of the recent Plio-Pleistocene conglomerate deposition. This includes: 1) intimate association of the Plio-Pleistocene conglomerate with the top of one pipe (Fig. 16); 2) fluid escape structures from this pipe into the conglomerate; and 3) the Plio-Pleistocene tectonic activities in the region (i.e., earthquakes, orogenies) needed for the suggested mechanism of intrusion. LeFevre et al. (1987) suggest a Jurassic age for formation of the pipes, but give no direct supportive evidence.

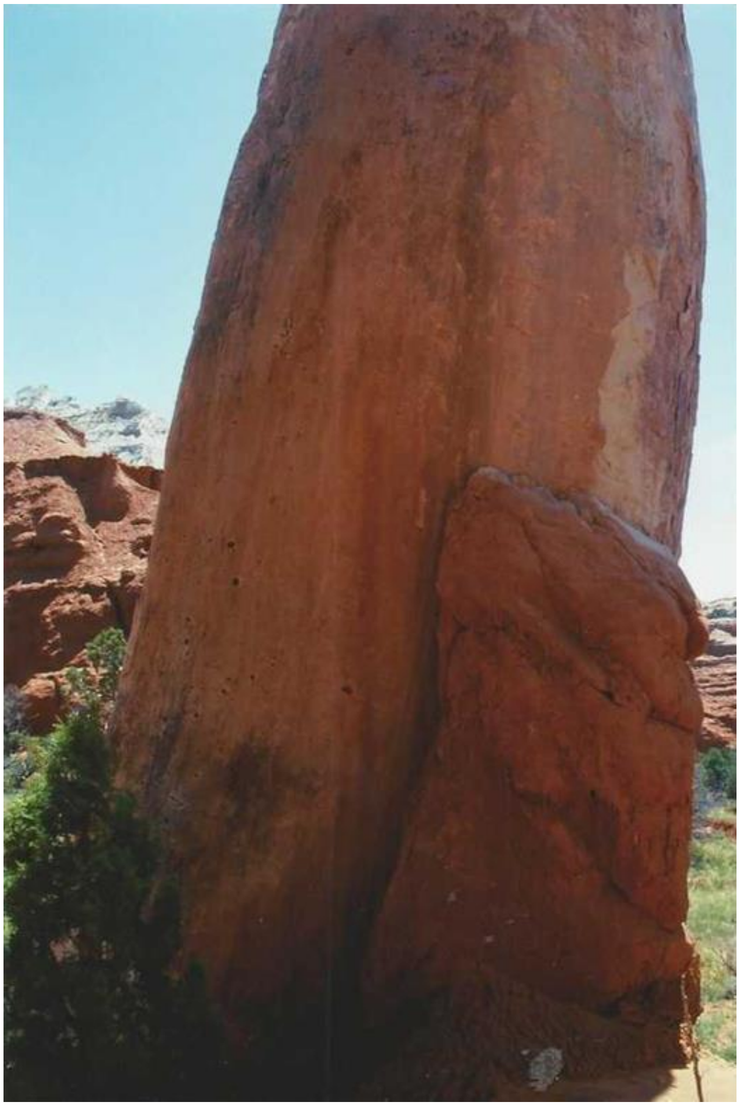

FIGURE 18. Close-up view of the surface of one of the pipes showing vertically oriented striations. The slightly darker vertical rock wedge to the right is not part of the pipe but a remnant of the surrounding "rock" into which the pipe intruded.

These pipes appear to present a problem for the standard geologic time scale, since it would require that the Jurassic formations which serve as source for the intrusions remain soft (uncemented by minerals) for over 150 million years. Considering how easily cementing minerals are transported through sediments by water, this seems highly unlikely. It also seems highly unlikely that a delithification process (dissolving of cement) would take place at the same time throughout the thick and highly varied sequence over the widespread area in which these pipes are found.

Even if one does not take into consideration the evidence for a Plio-Pleistocene intrusion, there is still a problem for the standard geologic time scale. The time, represented by the vertical distance between the source of the pipes and their present location, would be many millions of years (13 million if you use the average Carmel and Entrada ages). It seems very unlikely that the source material could remain uncemented for that length of time. Some of the pipes intrude 100 m (300 ft) of sediment.

One can argue that since there are now soft sediments on the ocean floor which are assumed to be many millions of years old, the sediments producing the pipes and the surrounding rocks could have likewise remained soft for many millions of years. However, the situation associated with these pipes does not appear to be comparable. Some of the layers associated with the pipes are interpreted as being terrestrial instead of marine. We do not now see in the continental crust older layers in a fluid state that could form the pipes. Associated with these pipes and dikes are long fine veins originating from the pipes and penetrating the surrounding layers. These seem to mandate a highly fluid source (i.e., the pipes themselves). However, it seems virtually impossible for the intruding material in these veins to have remained soft for any extended period of time. An overburden of more than 1200 m (4000 ft) of sediment once covered the now-exposed area where these pipes are found. This overburden would create a pressure of 275 x 105 Pascals (4000 lb in.^{2}). After dewatering such pressure would induce rapid cementation, precluding a much-later Plio-Pleistocene intrusion.

These pipes are fascinating structures. The model of formation that seems to best fit the data would be rapid deposition during the recent Genesis flood, with subsequent seismic activity liquefying uncemented sediments which would then intrude into the overlying soft sediments, forming the pipes and dikes.

ACKNOWLEDGMENT

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KANAB CREEK

LOCATION

The erosion of Kanab Creek can be readily seen along Highway 89 just north of the town of Kanab, anywhere between the city limits and the diversion dam built to capture creek water. A good place is about 0.8 miles south of the dam site.

DESCRIPTION

There are only a few records of rates of erosion during storms in the geological literature. Kanab Creek in the vicinity of the town of Kanab, Utah, is an example. Kanab Creek flows from here due south some 80 km (50 mi) to join the Colorado River in the Grand Canyon.

FIGURE 19. Kanab Creek north of the town of Kanab. The whole region used to be a willow-studded plain at the level of the foot of the red rocks in the upper part of the picture (arrow). A flash flood in 1883 eroded a channel 15 m (50 ft) deep and 80 m (260 ft) wide in 8 hours.

The creek (Fig. 19) is reported to have cut down its bed by 12.2 m (40 ft) in the two days during the flood of July 1883 (Brunn 1962). The area occupied by the creek is said to have been mostly a willow-studded meadow before the flood. Cutting is through poorly consolidated alluvial deposits. The steep slopes which these deposits can uphold is also of interest. Gregory (1917) reports that the flood of 29 July 1883 and high waters in 1884 and 1885 cut down Kanab Creek about 18.3 m (60 ft) for a distance of 24 km (15 mi) and widened it to 21.3 m (70 ft). Gregory (1963) further states, “Floods fed by a single downpour lasting an hour and covering a few square miles have been known to remodel the topography to an extent that evenly distributed precipitation could not duplicate in tens perhaps hundreds of years." Gilluly (1968) states that a flood in Kanab Canyon "cut a channel 50 feet deep and 260 feet wide in less than 8 hours." Webb et al. (1991, p 28) references the same figures.

Another example of rapid erosion is the 1976 Teton Dam disaster where water behind the dam eroded through the 91 m (300 ft) newly completed earthen dam in less than one hour. Fortunately, because of early warning, only 11 people died; however, some 3700 homes were damaged or destroyed.

Examples of erosion of harder rocks during catastrophic conditions are rare. One of the outstanding examples is the prehistoric Spokane Flood, or possibly 4-7 floods. The last was the most dramatic. It stripped the southeast quarter of the State of Washington, eroding into the widespread basaltic lava flows. The pattern and forces involved have been carefully reconstructed by geologists and represent one of the triumphs of catastrophism. The breaking of an ice dam released water at the rate of 40 km^3/hr (10 mi^3/hr), traveling over the area at rates up to 100 km/hr (60 mi/hr), moving basalt boulders 10 m (30 ft) in diameter. Conservative estimates would suggest erosion of the basalt layers at the rate of 100 m (300 ft) in a few weeks. Less conservative estimates would put this in a few days or less.

Three processes have been considered responsible for the rapid erosion of hard rock during the Spokane Flood (Baker 1981): 1) plucking of basalt blocks by the fast-flowing water; 2) lifting of the basalt blocks by a type of large vortice called a "kolk" (a Dutch term); and 3) cavitation caused by the collapse of small vapor bubbles a few mm in diameter in the fast-flowing water. Formation is by a sudden drop in pressure and collapse by an increase in pressure. Collapse causes local pressure as high as 30,000 atmospheres (400,000 lbs/in^2) (Barnes 1956). The collapse of the bubbles either by direct contact or shock waves are capable of shattering the surface of nearly any solid material. Cavitation is important only in water flowing faster than 8m/sec (18 mi/hr).

A CREATION-FLOOD PERSPECTIVE

The rapid erosion of Kanab Creek can raise questions about time and average rates of erosion. Is Kanab Creek an exception? It turns out that general rates of erosion also pose a problem for the standard geologic timescale. They are too fast. Geologists have recognized this inconsistency for many years. Using an estimated average erosion rate of 61 millimeters per 1,000 years, a number of geologists (Dott and Batten 1988, p 155; Garrels and Mackenzie 1971, p 114; Gilluly 1955; Schumm 1963) point out that North America could be leveled in a mere "10 million years." In other words, at the present rate of erosion, the North American continent would have been eroded away about 250 times in 2,500 million years. Of course, we cannot take this analogy too literally. After continents have been eroded once, not much remains to be eroded again. The example does, however, permit one to ask the question: Why are the Earth's continents still here if they are so old? B.W. Sparks (1986) at Cambridge, comments: "Some of these rates are obviously staggering; the Yellow [Hwang-Ho] River would peneplain [flatten out] an area with average height that of Everest in 10 million years."

The discrepancy is especially significant when one considers mountain ranges such as the Caledonides of western Europe and the Appalachians of eastern North America, which geologists assume are several hundred million years old. Why are these ranges still here today if they are so old?

Geologists often suggest that mountains still exist because the uplift is constantly renewing them from below. Although mountains are rising, the process of uplift and erosion could not continue long without eradicating the layers of the geologic column contained in them. Just one complete episode of uplift and erosion of the sedimentary layers, some of which, however, would have to be uplifted from their location below sea level, would eliminate them. Present erosion rates would quickly *remove the* sediments of Earth's mountain ranges as well as elsewhere, yet sediments from young to old are still well represented. In the context of long geologic ages and rapid erosion rates, the renewal of mountains by uplift does not seem to be a solution. For further discussion see Roth (1998, p 263-266).

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THE "GREAT DENUDATION"

LOCATION

The "Giant Staircase" and the "Great Denudation" can be seen on a clear day from many vistas as one ascends the north flank of the Kaibab Plateau along U.S. Highway 89A between Fredonia and Jacob Lake. A good locality is about 22 miles south of the Utah-Arizona State line.

FIGURE 20. View to the north from the north side of the Kaibab uplift. The Mesozoic and Cenozoic Formations display the "Giant Staircase." Just below the foot of the middle thick red cliffs, towards the foreground, are the very thin tan over red Shinarump cliffs. Above lie the prominent red "Vermillion Cliffs", which are overlain by the "White Cliffs." The "Gray Cliffs" are faintly displayed on the skyline at the left of the picture, while the highest "Pink Cliffs" form the skyline towards the right. See text and your geologic cross section map for details.

If one looks to the north when ascending the north flank of the Kaibab Plateau, one sees the various units up the "Giant Staircase", where Mesozoic and Cenozoic formations display from bottom to top the Shinarump cliffs (thin buff color), the Vermillion Cliffs (Moenkopi, Kayenta, and lower Navajo), the White Cliffs (mainly Navajo), the Gray Cliffs (Wahweap-Straight Cliffs), and the Pink Cliffs at the top (Wasatch-Claron).

The question posed is, how did all those layers, which were most likely all over the Kaibab Plateau, get washed away? The pioneer geologist, C. E. Dutton (1882, pp 61-77) called this great washout the “Great Denudation.” This is assumed to have taken place over many millions of years. The volume of sediment removed could be dozens of times greater than all the sediment removed from the Grand Canyon itself.

A CREATION-FLOOD PERSPECTIVE

In a creation-flood context one can ask why would the erosion be localized over the Kaibab Plateau and leave the cliffs to the north uneroded. Weather patterns including rainfall are not so precise that they would avoid eroding the “Giant Staircase” to the north and completely clean out the Mesozoic and Cenozoic rocks to the south. If a river did it, why is the denuded area so well cleaned out to a width of over 100 kilometers? This would be a very wide river. It may well be that the best explanation for the “Great Denudation” is the receding waters of the Genesis Flood.

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DRAINAGE PATTERNS

(A discussion)

Streams and rivers often follow unexpected patterns that do not seem to reflect topography. In the Middle Rocky Mountains, major rivers such as the Green River cut through the Uinta Mountains instead of going around their end only a few dozen miles to the east. Any intelligent river would be expected to go around, and not "over" the Uintas. That is not what the Green River has done. It has cut a gorge over 600 m (2000ft) deep through the Uintas. The Colorado River has cut perpendicularly through the Fisher and Moab Valleys and then it cuts a mile down through the Kaibab Upwarp to form the Grand Canyon. This pattern is also well represented in other continents of the Earth. Several models have been used to explain these unusual features. Some pertinent concepts will help you understand proposed models.

A river system that follows a normal downhill pattern along a pre-existing land surface is said to be **consequent** (the consequence of original slope). This pattern can be altered by mountain uplift, erosion around resistant rock units, etc. When altered, this is called **subsequent** (subsequent to the original pattern). Occasionally a river may erode its bed into the path of another and capture it. This is called **stream capture** or **piracy**. When this happens, the downstream portion of the captured river dries up and is said to be **beheaded**.

The case of rivers cutting right through mountain ranges is especially intriguing. Two models have been given serious consideration. The first, called **antecedent**, postulates that the river has stayed more or less in its original position as slow uplift of the region has taken place (compare Diagrams A and B under "Antecedent" in Fig. 21). As long as uplift is slower than the erosional capability of a river, the river can maintain its normal position and grade (slope) across uplifting regions. Its position being antecedent to uplift, the sequence is appropriately referred to as antecedent drainage. The river Arun, which crosses the Himalayas a few dozen km east of Mount Everest through deep and almost impassable gorges, is considered to be antecedent (Sparks 1986, pp. 157-159).

The second model to explain rivers cutting through mountain ranges is called **superposed**, a contraction of "superimposed." In this model the pattern of a river from a higher level is superimposed on the present topography. The mountain ranges are assumed to have already been there but buried in sediments (see Fig. 21, Diagram A, under "Superposed"), and the rivers flow on the surface of the sediments that cover these ranges. The sedimentary layers over and around the mountain ranges are then eroded with time, and the river cuts down through them including the buried ranges (see Diagram B under "Superposed", which is the same as Diagram B under "Antecedent'). With either model one ends up with the same final result. This makes it more difficult to tell which really occurred.

Early geologists studying the Middle Rocky Mountains thought the rivers were antecedent. Later workers, finding remnants of former alluvium (stream deposition) high on mountain sides, have given preference to the superposed model (Bloom 1978, p. 275). In general superposition is given preference over antecedence, the latter being considered a "last resort" (Sparks 1986, p. 156) because of difficulty in authentication. On the other hand, one has some difficulty in envisioning enough of a sedimentary volume to fill up all the space between mountain ranges as suggested for superposition.

The superposed model can be fit into a flood model just as easily as the antecedent one, or even more so. Major sediment removal accompanied the receding "superimposed" flood waters, and rivers entrenched themselves even through mountain ranges as the drainage of the continents continued.

In the context of a creation-flood perspective a third pattern can also be considered, namely that the overlying flood waters could cut through these mountains as they drained a particular region (Fig. 21, receding flood pattern). The rapidly flowing waters of a receding flood could rapidly cut deep gorges through mountain ranges as these waters sought lower elevations. In varied situations, especially when under water, it would be easier for the overlying waters to proceed through an incipient gorge and deepen it than to go all the way around a range. Such a pattern could mitigate the problems of the slow uplift required for the antecedent model and the necessity of sediments to support a high river bed in the superposed model. In the context of a creation-flood model, all three patterns and others could be involved. The receding flood pattern can explain the enigma of the huge side canyons, especially on the north side of the Grand Canyon, that have no source of water to erode them.

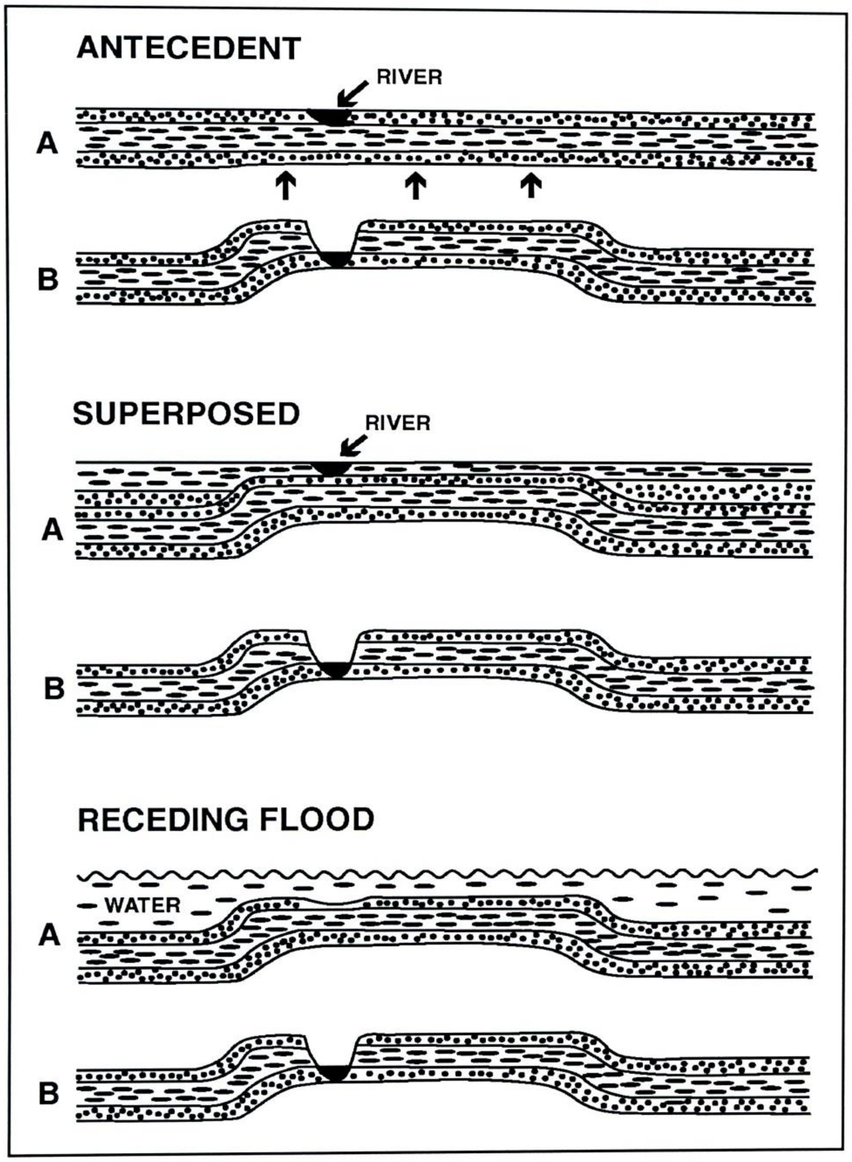

FIGURE 21. Drainage patterns

Under the conditions expected during the receding of the waters of the Genesis Flood, the assumed time imposition that uplift has to be slower than the expected erosional capability of a river is not very restrictive. Rapid erosion could take place as raging waters would drain off the continents. Of interest is the increase in transporting capacity of rivers as their velocity increases. Holmes (1965, p. 512) points out:

> *The transporting capacity of a stream rises very rapidly as the discharge and velocity increase. Experiments show that with debris of mixed shapes and sizes,*

> *the maximum load that can be carried is proportional to something between the third and fourth power of the velocity.*

This means that if the velocity (speed) of the river is increased ten times, it can carry between 1000 and 10,000 times as much sediment.

The abundance of rivers that cut through mountain ranges over the earth strongly suggests a past quite different from the present. The receding waters of the Genesis Flood provide a reasonable and simple explanation for this.

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THE GRAND CANYON

INTRODUCTION

The Grand Canyon of the Colorado River (Figs. 22-24), referred to below as "the Canyon," has been described as one of the world's grandest natural architectural masterpieces. President Theodore Roosevelt, who helped establish the United States National Park System, of which the Canyon is a part, declared that the Canyon is "the one great sight which every American should see." Some have not been that impressed, calling it just a bad case of soil erosion, or commenting that, once you get there, there is nothing to do but turn around and go back. These latter comments belie the fact that over four million people visit the Canyon every year. No one can stand on its edge and not be at least awed by its size. Pictures are but a poor substitute for the experience of actually seeing it.

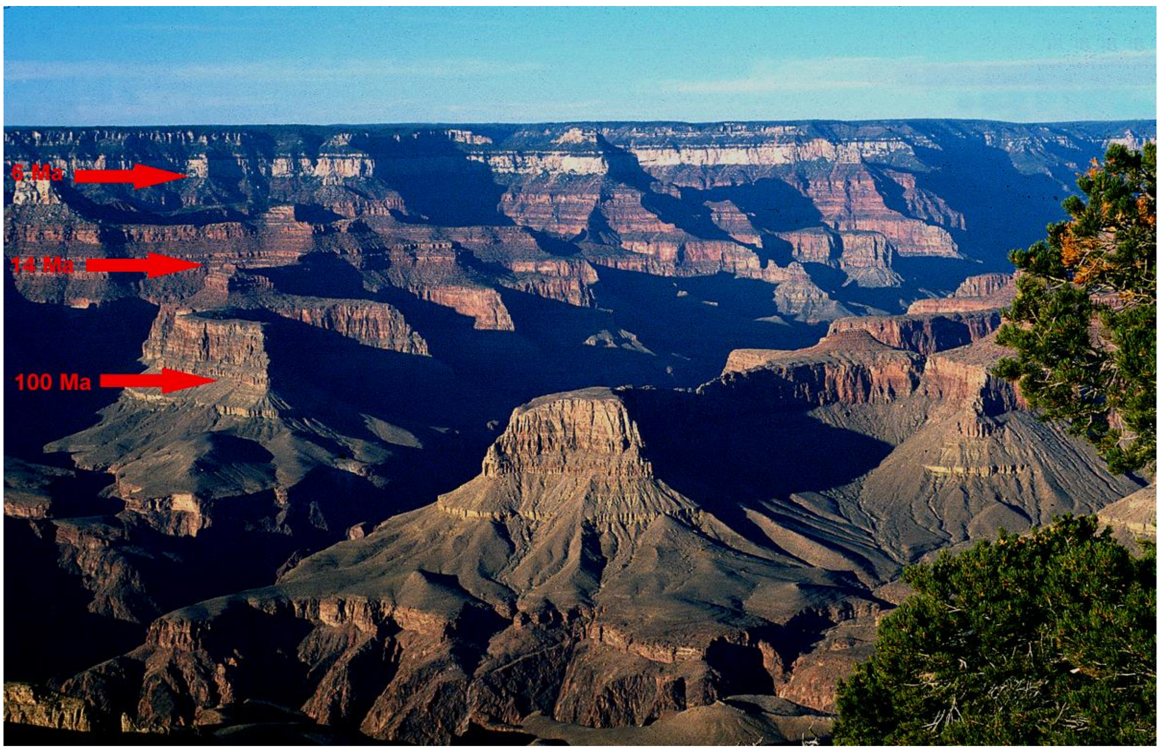

FIGURE 22. View of the Grand Canyon looking north from the South Rim. The three arrows designate where major portions of the geologic column are missing between the layers. From top to bottom they represent assumed gaps of approximately 6, 14, and 100 million years (Ma). The Colorado River, which is not visible here, runs diagonally towards the lower left of the picture in the deep Inner Gorge seen through the middle of the picture.

The Colorado River winds its way for 446 kilometers through the region of the Canyon, dropping about 610 meters in the process. The Canyon is much deeper in the mid region where the river cuts through a broad dome, scores of kilometers wide, called the Kaibab-Coconino Uplift. Here the Canyon reaches a depth of 1.8 kilometers from rim to river, and a maximum width of nearly 30 kilometers. The size is impressive, although some of the transverse gorges of the Himalayas reach nearly three times the depth of the Grand Canyon (Wadia 1975, p 27). However, what is especially important about the Canyon is how well it so openly displays many important geologic features beneath its rim. Rightfully it has been identified as the geologic showcase of the world.

FIGURE 23. View to the north of the Grand Canyon. The arrow points to slanted Precambrian sedimentary layers. The horizontal parallel layers of the upper half of the stack of layers are the Phanerozoic. Note the very extensive erosion to the north of the little river (Colorado River) which is hidden in the small dark gorge in the low foreground.

The size of the Canyon is most arresting, but, once one gets over that, one is duly impressed with the extremely parallel nature of the rock layers, and how small the Colorado River is as it courses its way through this huge canyon (Fig. 24). Two main aspects of this landscape are important to the study of the past: 1) How did the layers get there? And 2) how was the canyon cut? Many mysteries still lie hidden in the rocks of the Canyon, but there is a significant amount of available data that bears on these questions.

THE CREATIONISTIC INTERPRETATION OF THE GRAND CANYON

Most of the widespread layers of rock that we see in the Canyon are composed of various sediments, hence are called sedimentary rocks. They sometimes contain fossils that are occasionally quite abundant. The sediments that produce sedimentary rocks are most often transported by water. However, not all of the layers of sedimentary rock that one sees in the Canyon are interpreted by those scientists who believe in creation as originating during the flood. In the lowest portions of the Canyon, especially towards the eastern end, we find thick layers of sedimentary rocks that have very few or questionable fossils in them. These are part of the lower rock layers we call Precambrian and are seen in Figure 23 as the layers below the arrow. Precambrian layers are usually considered by flood geologists to have been there before the biblical flood. The layers above the Precambrian are designated as Phanerozoic. They contain many more fossils and in the Canyon region are strikingly parallel in arrangement (Figs. 22, 23). Only the lower half of the Phanerozoic is represented in the Grand Canyon. Just beyond the Grand Canyon, especially to the north and east are thick sedimentary layers that lie above the rock layer that forms the rim of the Canyon. These thick layers represent a significant portion of the upper part of the Phanerozoic. Most of the Phanerozoic is considered by flood geologists to have been deposited during the biblical worldwide flood. Creationists believe the Canyon was cut by the receding waters of the flood.

THE STANDARD GEOLOGIC INTERPRETATION FOR THE FORMATION OF THE GRAND CANYON ROCK LAYERS

Most geologists believe that the rock layers of the Grand Canyon, and most other major sedimentary layers of the Earth were formed over many millions of years. For instance, the strikingly horizontal layers of the Phanerozoic of the Canyon are commonly represented as having taken more than 300 million years for their formation. These layers have been extensively studied and the geologic literature covering them is vast. Three useful recent summaries are the publications by Beus and Billingsley (1989), Beus and Morales (1990, p 83-245), and Ford (1994).

FIGURE 24. The Colorado River entrenched in the Inner Gorge of the Grand Canyon.

Various ancient environments are postulated for the deposition of these layers. The lowest (just above the arrow in Fig. 23) is considered to represent a combination of shallow marine and river deposits, although there is evidence of this having occurred in deeper water (Kennedy, Kablanow and Chadwick 1996, McKee and Resser 1945). The Layers above this, up to well past the middle of the Canyon wall, are interpreted as having been deposited mainly in a marine environment with seas repeatedly advancing and retreating over the area, while occasionally rivers deposited sediments in the environment. In this portion of the layers there is an upward trend towards less marine and more terrestrial environments.

One of the most striking rock units of the Canyon is the light-colored Coconino Sandstone found near the top of the Canyon (just above the top arrow in Fig. 22). This has traditionally been interpreted as an ancient desert dune environment, although questions about this have been raised (Brand 1978, Brand and Tang 1991). From the top of the Coconino Sandstone to the rim of the Canyon the layers are thought to have been deposited over millions of years in a marine or near marine type of environment. According to standard geologic interpretation the Canyon itself was cut by slow erosional processes over millions of years.

QUESTIONS ABOUT THE BIBLICAL FLOOD INTERPRETATION OF THE GRAND CANYON

1. **The abundance of sediments.** In the context of the biblical flood, one of the most obvious questions to be asked when viewing the Canyon is how all these thick sedimentary layers could be deposited in a single event such as the Genesis flood which took only about a year. Also, as referred to above, beyond the Canyon region, there are layers of sediment, thicker than the horizontal ones seen in the Canyon itself, that lie above the layers we see in the Canyon. This is a lot of sediment to account for in a one-year flood. However, one needs to keep in mind that: 1) under rapid catastrophic conditions sediments can be deposited at the rate of meters per minutes or even faster; 2) the lowest sedimentary layers seen in the Grand Canyon are not considered to have been deposited during the flood; 3) in terms of thickness of sediments the Canyon region is not at all typical. Here the layers are several times as thick as the average over the earth. Some regions of Earth have virtually no sediments at all. Actually, the average thickness of the sedimentary layers resulting from the flood would form only a very thin veneer (a few hundred meters) on Earth's surface. Proportionately on an ordinary 30-cm globe, the thickness would be less than 1/4 that of an ordinary sheet of paper! It is still a lot of sediment.

2. **Karst surfaces.** Another question which has been posed for those who believe in a recent creation relates to the top of the Redwall Limestone which forms a prominent reddish vertical cliff in the mid-region of the layers of the Canyon (just above the lowest arrow in Fig. 22). In places the top surface of that limestone is irregular. It is interpreted as an ancient "karst" surface that would normally require many years for erosion (see Jennings 1983). The term karst comes from the Karst region of the Adriatic coast where the limestone has been eroded into a characteristic irregular surface. Limestone is quite easily dissolved; that is why we often find cavities (Fig. 25), and even very large caves in it. One of the ancient erosional channels found in the Redwall Limestone is 122 meters deep, and there are many smaller grooves and cavities near the top of the Redwall (Billingsley and McKee 1982, Billingsly and Beus 1985, Beus 1986). How could these irregularities form if the layers of the Grand Canyon had to be all laid down

during a one-year flood, as suggested by the biblical model? Two things need to be kept in mind. 1) During a worldwide flood there would have been plenty of water activity to cut a few channels in the top of the Redwall Limestone which may not even have been very hard then. 2) Also it appears that some of these irregularities developed after the layers that lie over the limestone had already been laid down. Hence they could have formed during the thousands of years since the flood. The evidence for this is that in places we find blocks from the layers above the limestone that have collapsed into the cavities dissolved out of the Redwall Limestone (Fig. 26). If the cavities had formed before the layers above had been laid down, as is assumed for a real karst surface, the cavities would have been first filled in with sediments, but not with hard blocks of rock from the layers above which would not yet have been formed. It appears that at least some cavities formed after the

FIGURE 25. An example of a cavity dissolved in limestone (the Edwards Limestone) in central Texas. Note that the roof of the cavity, which is about a meter across, has not yet collapsed.

layers above the Redwall Limestone had been laid down (Eberz 1995). The traditional karst interpretation for a similar situation to the north of the Canyon region, but at the same location in the geologic column, has been challenged by a traditional geologist (Bridges 1982). He states: "In my opinion, the late Mississippian karst story in the Rocky Mountains is completely fallacious." He is of the opinion that the so-called karst features developed much later. Such a sequence of events would not require that much time be required for laying down of the Canyon layers. The interpretation of ancient karst surfaces is subject to reevaluation.

QUESTIONS ABOUT THE STANDARD, LONG-AGE INTERPRETATION OF THE GRAND CANYON ROCK LAYERS

1. **Widespread sedimentary layers.** The layers of rock exposed by the Canyon seem unusually widespread and horizontal (Fig. 22,23). In some cases this widespread pattern is more than meets the eye. For instance, on the basis of fossils and other characteristics, the Redwall Limestone, which forms the single steep cliff mentioned above, is commonly divided into four units lying one above the other. Many of the other major rock units are subdivided into widespread subunits. Over a century ago, Clarence Dutton, one of the leading pioneers of geology in the United States, studied the Canyon district and commented on this:

> *The strata of each and every age were remarkably uniform over very large areas, and were deposited very nearly horizontally. Nowhere have we found thus far what may be called local deposits, or such as are restricted to a narrow belt or contracted area* (Dutton 1882, p 208-209).

Some local deposits such as those mentioned above found at the top of the Redwall Limestone have been described since Dutton's original survey, but these are small. This would be more consistent with rapid widespread catastrophic flood deposition, than with slow deposition over hundreds of millions of years. During such long periods, changing conditions such as the postulated movements of the continent, including the uplift and subsidence (Dickinson 1981), which would bring about the many advances and retreats of the sea postulated for the area, would seem to favor more local deposition.

2. **Cracks at the top of the Hermit Shale.** The dark-colored formation called the Hermit Shale lies just below the light-colored Coconino Sandstone referred to above. The contact between the two is indicated by the top arrow in Figure 22. Over the Canyon region one finds fine elongated vertical cracks in the Hermit Shale that are filled with sand grains from the Coconino (Fig. 27).

FIGURE 26. A collapsed area (collapsed breccia; dark red rocks in center, around the red pen) at the top of the Redwall Limestone in the Grand Canyon. The light-colored rocks are from the Redwall Limestone, while the darker ones are from the overlying Watahomigi Formation. The presence of blocks of Watahomigi suggests that the Watahomigi was laid down before solution of the limestone and collapse took place.

Some of the cracks are as much as 7 meters deep. One might wonder if the presence of these cracks in the Hermit Shale does not require that the Hermit Shale had first dried out before the Coconino was laid down, thus posing a problem for a flood model. This is not necessarily the case, since cracks can form underwater in soft mud due to the cohesion of clays as the process of dewatering (removing the water) takes place. The presence of the cracks actually seems to pose a problem for the long-geological-ages model, especially since it is assumed that there is a gap of several million years between the Hermit and the Coconino (Fig. 1 in Blakey 1990a, and Figs. 4 and 16 in Blakey 1990b would suggest around 6 million years). How could the cracks in the Hermit remain open for millions of years until the Coconino was laid down? Any rain or strong winds carrying sediments during that time would tend to fill them up. What we have here seems to fit well with rapid action. A possible scenario is that the Hermit was covered with Coconino very soon after it was laid down, then the shrinkage cracks formed due to dewatering of the Hermit, and the still-soft Coconino sediments filled the cracks as they formed.

3. The scarcity of erosion where significant parts of the geologic column are missing.

When looking at the flat-lying Phanerozoic layers of the Grand Canyon, one does not realize that according to the standard geologic interpretation, major parts of the geologic column, representing millions of years, are missing between some of these layers. The way one tells that there is a gap is that the missing parts (layers) of the geologic column, which contain the appropriate fossils, are found in other parts of the world. During those assumed gaps of millions of years when there was no deposition, one would expect a lot of erosion forming gullies, valleys, and canyons (Roth 1988). There is no place on the surface of the Earth where we would not expect either erosion or deposition over these long periods of time. If there is deposition, then there would be no gap in the geologic column. But if there is no deposition, we would expect significant erosion over such long periods of time, and the layers of the Grand Canyon should not appear so parallel. The Canyon itself well illustrates the dramatic effects of erosion. The three arrows in Figure 22 point at significant gaps in the layers estimated from top to bottom at approximately 6, 4, and 100 million years; yet, as can be seen, the underlying layers appear essentially free of erosion. The top arrow points to the gap between the Coconino and Hermit discussed above (see also Fig. 27). In referring to the gap at the middle arrow, a geologist (Beus and Morales 1990, p 158) comments: "Contrary to the implications of McKee's work, the locations of the boundary between the Manakacha and Wescogame formations [where the gap is] can be difficult to determine, both from a distance and from close range." In referring to some localities of the very long lower gap, another geologist (p 111, Beus and Morales 1990) states: "Here, the unconformity [gap], even though representing more than 100 million years, may be difficult to locate." Over these very long assumed periods of time a lot of weathering and erosion of the rock layers would be expected, but this is not what we see.

Average present rates of erosion for the region around the Grand Canyon would erode a layer as thick as the Canyon is deep in less than 12 million years. This means that, according to the standard geologic time scale, the Canyon and the rock layers that form it should have been eroded long ago (Roth 1986). While there is considerable disagreement as to how the Grand Canyon itself was eroded, the geologist Lucchitta (1984) suggests that "most of the canyon cutting occurred in the phenomenally short time of 4 to 5 million years." The discrepancy between the expected erosion over the postulated millions of years, where parts of the geologic column are missing, and what is seen, suggests that those millions of years never took place. What is seen seems to favor the rapid deposition expected during the biblical flood.

4. **The lack of food for animals in the Coconino Sandstone.** In the lower half of the Coconino Sandstone, hundreds of well-defined animal footprint trackways are found. These trackways were probably made by amphibians or reptiles. The surprising thing is that no plants appear to have been present. Aside from the footprints, the only other fossils that have been reported are those of a few worm tubes and invertebrate trackways (Middleton, Elliott and Morales 1990; Spamer 1984). If the Coconino had been deposited over millions of years as is assumed for the standard geologic interpretation, what nourishment was available for the animals who made all these trackways? There is no evidence for the presence of plant food. If simple footprints are well preserved, one would also expect to find the imprints or casts of roots, stems, and leaves of plants, if they were ever present (Roth 1994).

FIGURE 27. Cracks in the dark Hermit Shale of the Grand Canyon (arrows) filled in with sand from the lighter-colored overlying Coconino Sandstone seen in the top of the picture. Note that the white sandstone in the crack to the left has caused some discoloration of the surrounding rock. Only part of a filled crack can be seen towards the right. The cracks are over a meter deep.

Almost all of the trackways in the Coconino indicate that the animals were going uphill. Furthermore, there is good evidence that these trackways were formed underwater, instead of the usual interpretation that they were made on desert dunes (Brand 1978, Brand and Tang 1991). Is it possible that all these uphill trackways were formed by animals seeking to escape the waters of the flood? The bodies of the animals could have been swept away by flood activity. That may be why we don't find them. On the other hand, in the context of the standard interpretation of slow geologic processes, we would expect to find at least the imprint of the roots of the plants on which the animals had to feed, but these appear to be absent.

HOW WAS THE GRAND CANYON CUT?

The simple question of the cutting of the Canyon turns out to be very complex. Although geologists have been intensely studying this matter for over a century, no simple answer or consensus seems in sight. The details of the discussions are beyond the scope of our brief survey, but are well summarized in the professional geologic literature (Brown 2000; Beus and Morales 1990; Babenroth and Strahler 1945; Breed 1969; Elston and Young 1989; Graf et al. 1987; Hunt 1976; Longwell 1946; Lucchitta 1990, 1984, 1972; Perkins 2000; Rice 1983). Recent interpretations suggest much shorter times and catastrophic activities for the carving of the Canyon. These trends are in the direction of a creation interpretation. However, to most geologists the cutting of the Canyon is an unsolved mystery sometimes referred to as the "Canyon conundrum" (Rice 1983).

Among the vexing problems which the Canyon poses is the fact that the Colorado River, which courses through the Canyon, cuts right through a broad dome, instead of going around it. One would not expect that any "intelligent" river would go up over a dome instead of around it.

Another problem is the question of the past location and age of the river. Was it present before the dome formed? Evidence for an ancient Colorado River is notoriously sparse, especially west of the Canyon. Some have suggested that in the past on the east side of the dome the river came from the northeast to the edge of the dome and then went to the southeast towards the Gulf of Mexico without ever traversing through the dome itself. It has also been suggested that the dome was eventually eroded from the west to join the Colorado River from the east, but without much of a source of water to cut a deep gorge through the dome, this seems unlikely. On the west side, it has been suggested that the river may have left the Canyon region, going to the northwest before eventually changing its course and going to the southwest where it is now found. Also puzzling are the huge side canyons found especially on the north side of the Canyon (Fig. 23, far side). These side canyons which end up in the high region of the dome have virtually no streams to erode them.

The Canyon is huge. Some 4000 cubic kilometers of sediment have been eroded to form the Canyon. Yet this is but a fraction of the erosion evident in the region for the layers mentioned earlier that must have been above those exposed in the Canyon (Dumitru, Duddy, and Green 1994). The erosion of these layers forms a broad valley, more than 200 kilometers wide, that lies above the Canyon. Probably 15 to 30 times as much sediment was removed to form the broad valley above the Canyon as was involved in the carving of the Canyon itself. Dutton (1882 p 61-77) called the erosion of this broad valley "the great denudation." According to standard geologic interpretations this great denudation would be considered to be a slow process of broadening of the valley over time as the valley walls retreated laterally as they were slowly eroded. But this does not seem to be the case. The sides of the broad valley do not have active talus (debris) at the base of the cliffs as would be expected for a slow process. The sides of the broad valley are clean as though the valley had been catastrophically washed out. Clean edges are more like what you would expect from the runoff of the waters of the flood than from a slow gradual weathering process. Besides, if the valley was the result of a slow weathering process, one has to explain why all the weathering and washout took place in the broad valley while the sides of the valley are left uneroded.

How did the Canyon get cut? We don't know for sure. We do know that the standard slow model poses a number of questions. It is also of interest that the lore of local Indian tribes reflects more rapid action. One writer, in referring to this comments that: "The Navajo, the Hualapai and the Havasupai still believe that the river is the runoff from a great flood that once covered the earth" (Wallace 1973, p 99). Some scientists who believe in the biblical account of beginnings also suggest that the carving of the Canyon and the surrounding region is the result of the runoff of the waters of the worldwide biblical flood. One model (Austin 1994, p 92-107) proposes that at the end of the flood a lot of water was ponded to the east of the Grand Canyon region. A natural dam on the west side of the ponded water was breached and a great volume of water flowed to the west cutting the Canyon. A second model proposes that the Canyon was cut under water, that is below the surface of the flood waters, as these were retreating to the west. This model may explain the origin of the many side canyons to the Canyon. Although we don't see it, underwater erosion in the ocean is a common thing. We have many underwater canyons cut along the edge of our continental shelves. A submarine canyon, the Monterey Canyon, which lies off the coast of California, is as deep and as wide as the Grand Canyon. We may not know how the Grand Canyon was carved, but the action of the receding waters of the biblical flood present some interesting possibilities.

CONCLUSIONS

The Grand Canyon has much to say about the past history of life on Earth. This fascinating display of rocks has been interpreted in a variety of ways. Most scientists propose that one to many millions of years were involved in its formation. However, a number of questions about this interpretation can be raised when specific details are considered. The biblical model implying rapid formation of the rock layers and of the cutting of the Canyon provides some resolution to some of the questions posed by the standard model. While the Grand Canyon still hides many mysteries, and we still have much to learn about it, it also provides strong evidence that supports the truthfulness of the biblical account of beginnings.

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CONTENT

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THE GEOLOGIC COLUMN

	ERA	SYSTEM OR PERIOD	SERIES OR EPOCH	STANDARD TIME SCALE*
Phanerozoic	Cenozoic	Quaternary	Holocene (Recent)	0.01
			Pleistocene	2.5
		Tertiary — Neogene	Pliocene	7
			Miocene	26
		Tertiary — Paleogene	Oligocene	38
			Eocene	54
			Paleocene	65
	Mesozoic	Cretaceous	Upper, Lower	136
		Jurassic	Upper, Middle, Lower	190
		Triassic	Upper, Middle, Lower	225
	Paleozoic	Permian		280
		Carboniferous		
		Pennsylvanian	Upper, Middle, Lower	325
		Mississippian	Upper, Lower	345
		Devonian	Upper, Middle, Lower	395
		Silurian	Upper, Middle, Lower	430
		Ordovician	Upper, Middle, Lower	500
		Cambrian	Upper, Middle, Lower	550
	Precambrian		Upper, Middle, Lower	4600

*Represents millions of years; not endorsed by the author.

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INTRODUCTION TO INTRODUCTORY PETROLOGY

"THE FIVE MINUTE ROCK COURSE"

Petrology is the study of rocks. Rocks are aggregates of minerals of varying size, composition, physical characteristics and origin. This latter factor is especially important in present classification schemes.

The minerals which form rocks are composed of atoms that are organized into highly defined substances with more or less constant physical and chemical properties. Examples of minerals include diamond, rock salt, graphite, quartz, etc.

A rock, on the other hand, is not so well defined; it can consist of a single or many minerals mixed in various proportions, sizes, etc. The important features of a rock can tell us much about its past history, and this is particularly important as one considers the past history of Earth.

There are three major groups of rocks — igneous, sedimentary, and metamorphic. Their major features will be described below.

IGNEOUS ROCKS

These rocks are formed by the congealing of hot molten material called magma. The hardening of a molten volcanic flow would be an example. Hardening can take place either below or above Earth's surface. Some identifying characteristics of igneous rocks are:

Usually not in layers, at least, not fine layers
Hard and massive
Interlocking mineral crystals

EXAMPLES

Basalt — fine crystals, dark in color from the more rapid cooling of magma.
Granite — consisting of coarse, light and dark interlocking crystals, not in layers, often from slow cooling of magma, but can also be of metamorphic origin.

Ophiolite — group of medium to dark igneous rocks including basalt, derived in part by metamorphism and associated with the development of a geosyncline.

Volcanic breccia — hardened coarse, angular particulate products of volcanoes.

SEDIMENTARY ROCKS

These rocks are formed by the cementing together of fragments aggregated together by various transport mechanisms such as moving water, wind, flowing ice, etc. An example would be the cementing together by minerals of sand particles on a beach to form beachrock or sandstone. Some identifying characteristics of sedimentary rocks include:

Layering
Particulates often rounded by transport Sorted
according to size by transport

EXAMPLES

Anhydrite — hard whitish rock composed of anhydrous calcium sulfate.
Claystone — massive, indurated clay particles.

Conglomerate — cemented round to subround pebbles in a finer matrix.

Dolomite — carbonaceous sedimentary rock, often greyish-tan in color, with a dominance of the mineral dolomite which is a calcium-magnesium carbonate.

Evaporite — composed primarily of minerals such as rock salt, gypsum, anhydrite, thought to have originated by the evaporation of saline solutions.

Gypsum— soft whitish rock composed of hydrous calcium sulfate.

Limestone — usually massive calcium carbonate, often white to grayish, produced by precipitation of lime from seawater either inorganically or by living organisms.

Marl — usually composed of fine impure calcium carbonate with some clay. An ill-defined term.

Sandstone— cemented sand.

Sedimentary breccia — composed of coarse angular clasts and originating from a sedimentary process.

Shale — cementing of fine particles, finely laminar.

METAMORPHIC ROCKS

These rocks originate from igneous, sedimentary, or other metamorphic rocks. They are altered physically or chemically or both, producing a new kind of rock. These changes occur essentially in the solid state and can be either minor or of such a nature as to completely change the characteristics of the original rock. An example would be the changing of a shale into a slate by shearing pressure. Characteristics of metamorphic rocks are:

Generally laminated

Original structures out of shape, hard to identify

Contains mineral assemblages characteristic of metamorphic changes

EXAMPLES

Gneiss — foliated rocks with alternating mineral bands, usually formed from coarser grained rocks, layer greater than 1 mm in thickness.

Granite— coarsely crystalline rock, consisting of light and dark (usually) minerals, sometimes derived by the metamorphism of sedimentary rocks, also of igneous origin.

Marble — from limestone, usually not in layers, altered and bent carbonate crystals.

Mylonite — compact, fine-grained rock produced by extreme mechanical granulation and shearing during metamorphism.

Phyllite — compact, fine grained, usually intermediate between a slate and a schist. Does not cleave as perfectly as a slate.

Schist — strongly foliated crystalline rock, easily split, originating from fine-grained rocks, layers 1 mm or less in thickness.

Serpentine— rock with a black to green, greasy luster, soapy feel, derived from metamorphism, magnesium-rich rocks.

Slate — compact, fine grained, very fine layers, can be split into slabs and plates, usually from shale.

STRATIGRAPHIC SECTION: COLORADO PLATEAU

This is a selected list from the most important formations. Depositional environments given are those implied in the standard literature.

CENOZOIC

QUATERNARY

Various alluvial (recent stream, flood, and lake deposits) and eolian (wind-blown) deposits.

TERTIARY

Sevier River Formation (probably Pliocene)

Grey, partly consolidated, coarse conglomerate with volcanic debris. Thickness to 250 m. Fluvial (river) deposit.

Brianhead Formation (Eocene to Miocene? Probably Eocene)

Grey, consolidated ash flow. Thickness to 300 m, usually thinner. Fossils? Volcanic origin.

Wasatch Formation (also called Claron in S)

Pink, white limestone and calcareous sandstone, soft, conglomeratic at base. Invertebrate and plant (angiosperms) fossils. Thickness up to 1100 m; usually 150 m. Considered to be a freshwater deposit; fluvial (river), paludal (swamp), and lacustrine (lake) environments described.

San Jose Formation (Eocene)

Buff, grey, etc., mudrock with interbedded sandstones. Cuba member is prominent at base. Thickness up to 630 m. Was called Wasath in north before formation worked out. Has yielded one of the most diverse Eocene vertebrate fauna. Deposited by rivers (fluvial), includes flood plain and sheet sandstone deposit. Paleocurrent data indicates high-energy streams from the north.

Naciamento Formation (Paleocene)

Grey to variegated (multicolored) black and white mudstones and sandstones. Thickness up to 525 m. The formation is famous for its Paleocene vertebrate fossils, especially early mammals. E.D. Cope reported about these. Fluvial (river) and lacustrine (lake) paleoenvironment

MESOZOIC

CRETACEOUS

Ojo Alamo Sandstone (Cretaceous from vertebrate evidence, but Tertiary from few plant fragments). Thickness up to 35 m. Vertebrate and plant fossils. Continental (land) paleoenvironment.

Kirtland Shale and Fruitland Formation

Grey to variegated (multicolored) sandstones, shale and coal. Upper Kirtland with more shale. Both with thicknesses up to 500 m. Many vertebrates, fish to mammals, including dinosaurs, crocodiles, turtles, invertebrates and plants. Important coal source. Fluvial (river) deltaic, paludal (swamp), coastal paleoenvironment.

Pictured Cliffs Sandstone (Upper Cretaceous)

"Salt and pepper" sandstone. Thickness up to 60 m. Deposited in a regressive marine offlap of a littoral (intertidal) marine environment. Named for the thousands of "fantastic figures" engraved on the massive sandstone exposed along the San Juan River.

Lewis Shale (Upper Cretaceous)

Dark-grey to drab-grey sandy shale with clay and sandstone and calcareous concretions, and thin white-to-grey sandstone layers. Thickness up to 600 m. Marine fossils include bivalves and ammonites. Marine paleoenvironment. Extends from New Mexico to Montana

MESAVERDE GROUP

Forms a variety of outcrops in different localities. In general it consists of buff, bedded sandstone layers with interbedded shale members, many of which are carbonaceous. Coal seams common, dinosaur tracks, upright trees; marine fossil layers also common. Intertongues with Mancos Shale. Thickness up to 1500 m.

In the Mesaverde region, the group includes the following three formations:

Cliff House Sandstone (Upper Cretaceous)

Thin-bedded to massive buff sandstone with shale partings. Thickness up to 250 m. Deposited in a transgressive (inundating sea) marine paleoenvironment.

Menefee Formation (Upper Cretaceous)

Interbedded grey-buff sandstones, grey shales, and coal seams. Thickness up to 700 m. Fossils include fish, turtles, crocodiles and many plants. Nonmarine, fluvial (river) and coastal paleoenvironment, possibly some marine deposits.

Point Lookout Sandstone (Upper Cretaceous)

Massive, light-grey to yellow sandstone. Thickness up to 100 m. Littoral regressive (receding sea), marine paleoenvironment, sediments supplied by rivers, in part fluvial (river) - deltaic, strand (shore) plane, and barrier beach deposit.

In eastern-central Utah the group includes the following four formations:

Price River Formation (shale; piedmont environment)

Castlegate Sandstone (floodplain environment)

Blackhawk Formation (coal and sandstone; lagoonal environment)

Star Point Sandstone (littoral — intertidal — marine environment)

Mancos Shale

Evenly bedded, light- to medium-dark grey, calcareous, marine shale which weathers yellowish grey. Limestone and sandstone members present. Intertongues with Mesaverde Group above and Dakota Group below. Some marine vertebrates and invertebrates and coal at several levels. Thickness 15-1500 m. Depositional environment: coastal marine, swamp, barrier bar, delta.

Kaiparowits Formation

Grey-blue, arkosic sandstone and shale, forms slopes and badland topography. Fossils include various reptiles, non-marine invertebrates, and plants. Thickness 180-360 m. Considered to be mainly a fluvial (river) deposit.

Wahweap Sandstone

Yellowish-grey sandstone and mudstone layers. Fossils very rare, include reptiles, invertebrates, and leaves. Thickness up to 360 m; usually 180-200 m. Depositional environment: fluvial (river).

Straight Cliffs Sandstone

Yellowish-grey, massive sandstone layers and mudstone. Land fossils (terrestrial vertebrates) rare in top part, marine and brackish water fossils in lower part. Thickness to 300 m. Depositional environments: fluvial (river) and coastal marine.

Tropic Formation

Grey shale with many buff-yellow sandstone beds, especially in lower part. Fossils include coal derived from plants as well as freshwater and marine invertebrates. Thickness to 380 m. Depositional environment considered to be marine.

Dakota Formation (Dakota Sandstone)

Yellow to white, brown to buff sandstone and darker carbonaceous shale and coal, partly conglomeratic. Fossils include coal, petrified trees, marine and freshwater invertebrates. Thickness to 30 m. Depositional environment: marginal marine, fluvial (river).

Cedar Mountain Formation

Grey to dark-grey shale with coarse Buckhorns basal conglomerate. Fluvial (river) and flood- plain paleoenvironment.

JURASSIC

Morrison Formation

Variegated mudstones, siltstone and yellowish grey-brown sandstones. Fossil dinosaurs, plants and freshwater invertebrates, fish, crocodiles, and primitive mammals present. Usually around 100 m thick, may reach 450 m. Depositional environment: fluvial (river), lacustrine (lake), floodplains, deltas.

Cow Springs Sandstone

Fine-grained quartz (mostly) sandstone, greenish carbonate cement. White to light-green, grey or buff in color, difficult to distinguish from Entrada. Fossils (none?). Thickness up to 200 m. Depositional environment: eolian (wind).

Summerville Formation

Crinkled, banded, or massive silty sandstone with some shaley members. Usually tan, grey, orange-red or buff in color. Fossils (none?). Thickness up to 100 m. Depositional environment: tidal flat, possibly some eolian (wind) deposits(?).

SAN RAFAEL GROUP (INCLUDES FIRST 4 FORMATIONS BELOW)

Todilto Formation

Cliff-forming grey limestone, shale, mudstone, and gypsum. Thickness up to 75 m. A few invertebrate fossils and fish. Commercial source of gypsum. Correlated with Curtis in Utah and Pony Express in Colorado. Was considered to be of marine origin, but now thought to represent evaporation in a salina (salt flat) with limited access to the sea.

Curtis Formation

Grey to white, roughly bedded limestone and thick gypsum. Marine fossils. Thickness usually 15 -75 m, up to 220 m. Depositional environment: marine, evaporite.

Entrada Sandstone

Light-red with white bands and reddish-orange, fine-bedded sandstone shale and gypsum. Fossils? Thickness usually 30-60 m, up to 180 m. Depositional environment: mainly fluvial (river) and eolian (wind).

Carmel Formation

Grey to buff limestone in beds alternating with softer, red, shaley layers, etc., some gypsum. More marine to the W. Marine fossils, vertebrates and algae. Thickness usually 30-60 m, up to 180 m. Depositional environment: generally considered to be marine, especially in W.

GLEN CANYON GROUP (INCLUDES FIRST 4 FORMATIONS BELOW)

Navajo Sandstone

Red, pink, orange, buff, grey, white, intensely cross-bedded sandstone. Occasionally with a thin layer of cherty limestone. Virtually no fossils except for a few tracks of dinosaurs, terrestrial reptiles, and plant remains. Thickness usually 30m, up to 670 m. Lower part has been considered Triassic. Depositional environment: mainly eolian (wind) and lacustrine (lake).

TRIASSIC

Kayenta Formation

Red-maroon, cross-bedded sandstone beds, with grey limestone and brown shale layers between. Fossils very rare, some freshwater invertebrates, wood, and vertebrate tracks. Trend is towards considering it Jurassic. Thickness usually less than 60 m, up to 365 m. Depositional environment: fluvial (river) and eolian (wind).

Moenave Sandstone

White to reddish-brown, cross-bedded sandstone and mudstone usually a massive cliff. Fossils include fish and crocodiles, very rare, vertebrate (dinosaur and other reptile) tracks. Thickness to 120 m. Depositional environment: eolian (wind) and fluvial (river).

Wingate Sandstone

Reddish, cliff-forming sandstone. Fossils very rare, some reptile tracks and remains reported. Thickness up to 200 m. Depositional environment: eolian (wind).

Chinle Group

Variegated mudstones, siltstones, sandstones, conglomerates and limestones. Several members including a prominent basal conglomerate called the Shinarump, which has a thickness of 20-40 m. Fossils include petrified wood (locally abundant as in Petrified Forest National Park), other plant remains, reptiles, etc. Thickness usually from 300-600 m. Depositional environment: fluvial (river) and lacustrine (lake). Was considered a formation, but the trend is to divide it into several formations.

Moenkopi Formation

Chocolate-brown to grey, gypsiferous sandstone and shale with gypsiferous and marine limestone members. Fossils include marine invertebrates and some tracks of land animals in other layers. Thickness up to 600 m. Depositional environment: marine, fluvial (river), tidal flat.

PALEOZOIC

PERMIAN

Kaibab Limestone

Grey-white, buff, dense-bedded limestone and dolomite, also with some sand and gypsum. Abundant variety of marine fossils including: fish, trilobites, sponges, brachiopods, rugose coral, gastropods, and scaphopods. Thickness 100 m at central part of Grand Canyon, up to 600 m elsewhere. Depositional environment considered to be an open and restricted ancient seaway.

Toroweap Limestone

Buff, reddish-grey limestone and sandstone with some gypsum layers, marine fossils as for Kaibab. Thickness 85 m at central part of Grand Canyon. Depositional environment assumed to be tidal flat, eolian (wind), marine, evaporite.

Coconino Sandstone

Buff, grey, cross-stratified sandstone. Fossils include locally abundant, mostly uphill, trackways of vertebrates and invertebrates. Thickness 100 m at central part of Grand Canyon, up to 300 m elsewhere. Depositional environment assumed to be a desert. Some data challenge this.

Hermit Formation

Deep-red, thin-bedded, shaly siltstone. Cracks to 5 m deep at top. Scarce fossils include some plants, trackways and insects. Thickness 70 m at central part of Grand Canyon, up to 300 m elsewhere. Correlates with Supai Fm. to the SW. Depositional environment: stream, dunes, coastal plain.

SUPAI GROUP (INCLUDES FIRST 4 FORMATIONS BELOW)

Esplanade Sandstone

Cross-stratified, reddish-brown sandstone units with thickness of 2-15 m, with mudstone or limestones between. Thickness 60-250 m. Some marine fossils, vertebrate tracks, and plant fragments. Assumed to have been deposited in a complex shoreline environment, including a fluvial (river) environment.

PENNSYLVANIAN

Wescogame Formation

Alternating quartz sandstone and intercalated red mudstone and some limestone that increases to the W. Has a lower cliff unit and an upper slope unit. Contact with the Manakacha below (hiatus — most of Middle Pennsylvanian absent) difficult to determine. Thickness about 30- 200 m. Marine fossils mostly in limestones include fusulinids, pelecypods, and gastropods; also vertebrate trackways but no skeletal remains; some plant fragments. Depositional environment not well-defined, but assumed to have been by the sea but largely non-marine.

Manakacha Formation

Quartz sandstone and intercalated, red mudstone with great increase in carbonate content to the NW. Thickness 45-100 m; thickest in Grand Canyon region. Sparse fossils include plant fragments, brachiopods, bryozoans, pelecypods, gastropods, trilobites, and coral. The formation is assumed to have been deposited in a tidally influenced marine environment.

Watahomigi Formation

Consists mainly of red mudstone and siltstone and grey limestone and dolomite. Thickness in Grand Canyon from 30 m in E to 100 m in W. Fossils more abundant than in Manakacha include: brachiopods, gastropods, pelecypods, echinoderms, trilobites, sharks, forams, conodonts, corals, and plant fragments. The formation is assumed to have probably been deposited in a marine and adjacent-to-marine environment.

MISSISSIPPIAN

Surprise Canyon Formation

Appears as isolated lens-shaped exposures. It sometimes consists of a lower, dark-grey to red- brown clastic, terrigenous cherty deposit, and an upper, grey to brown-red marine carbonate. Best represented in the W part of the Grand Canyon. Thickness usually a few dozen meters, but up to 120 m. Fossils include: plants, coral, brachiopods, echinoderms, bivalves, cephalo- pods, trilobites, sharks teeth, and foraminifers. The formation is assumed to have been deposited in an ancient estuarine-stream valley system with a marine shoreline to the W.

Redwall Limestone

Grey to yellow limestone usually stained red from overlying layers. A large variety of marine fossils present including fish. Thickness 150 m in central part of Grand Canyon; slightly thicker elsewhere. Formation divided into 4 members in the Grand Canyon region. Depositional environment: shallow epeiric sea.

DEVONIAN

Temple Butte Limestone

Purplish limestone and dolomite. No clearly identifiable invertebrate fossils found (McKee 1976, p 53), possibly crinoids, corals, stromatoporoids and conodonts. Some fish discoveries made. Thickness 0-300 m. In central part of Grand Canyon, limited to small channels in Bright Angel Shale. Thickens W-ward. Depositional environment: tidal channels, subtidal and open marine.

CAMBRIAN

Muav Limestone

Grey limestone units with layers of mudstone, etc., between. Marine fossils not common, and include some brachiopods and trilobites. Thickness 30 m at central part of Grand Canyon, up to 250 m elsewhere. Depositional environment: shallow marine, intertidal and subtidal.

Bright Angel Shale

Greenish, shaley mudstone and fine-grained sandstone. Fossil brachiopods locally common, trilobites present. Thickness about 170 m at central part of Grand Canyon. Depositional environment: shallow marine, offshore.

Tapeats Sandstone

Brown-grey, coarse to medium cross-bedded sandstone forming a cliff. Fossils include trilobite trails and numerous "problematical worm borings" (McKee 1976, p 47). Thickness 70 m at central part of Grand Canyon, up to 180 m elsewhere. Depositional environment: shallow subtidal.

PRECAMBRIAN

In the Grand Canyon area, various layers of sedimentary deposits totaling 3600 m lie unconformably below the Cambrian. Fossils very rare, many questionable. Below these layers are igneous and metamorphic rocks.

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GLOSSARY OF SOME GEOLOGICAL TERMS

(Consult the "Introduction to Introductory Petrology" and the "Geologic Column" for rock and stratigraphic terms)

ALLOCHTHONOUS — originating from elsewhere, transported.

ANTECEDENT — pertaining to a stream that maintains its original course.

ANTICLINE — a fold which is convex upward.

AUTOCHTHONOUS — indicates no transport, in situ.

BACK REEF — the area between a reef and the mainland.

BALL AND PILLOW —a primary sedimentary structure characterized by hemisphere and kidneyshaped masses usually attributed to foundering.

BENTHONIC — said of an organism living on the ocean bottom, fixed or free.

BOUMA SEQUENCE — the characteristic sequence of complex sedimentary structures deposited by a turbidity current.

CARBONATE — a mineral formed in part using carbonate ions. Limestone is a common example, consisting of calcium carbonate.

CARBONATE COMPENSATION DEPTH — the depth in the ocean where the solution of carbonate exceeds the rate of deposition. Presently this is usually several thousand meters below sea level.

CATASTROPHISM — theory in which phenomena outside our present experience of nature have greatly modified Earth's crust by violent, sudden, but short-lived, events more or less worldwide.

CIRQUE — a steep-walled semicircular recess situated high on a mountain and produced by glacial erosion. It is commonly at the head of a glacial valley.

CLAST — the individual constituent of a sedimentary rock. It can be from clay size to boulder size.

CLASTIC — pertaining to rocks formed of clasts.

COLUMNAR JOINTING — forms parallel prismatic columns as a result of the cooling of magma.

CONCRETION — a hard compact mass of mineral matter in a sedimentary rock.

CONVOLUTE — wavy, disorganized, crumpled sedimentary layers, often occurring between parallel layers.

CORALLINE — pertaining to corals and related features of coral, such as reefs, etc.

CORDILLERA — an assemblage of mountain ranges with a general parallel arrangement.

CYCLOTHEM — a term applied to the repeat unit of a cyclic sedimentary sequence.

DEBRIS FLOW — a moving mass of a mixture of rock and mud with a dominance of the clasts being larger than sand size.

DENUDATION — erosion on a broad scale that results in uncovering the bedrock or a designated rock formation through erosion of overlying material.

DETRITUS — transported fragmental material derived from the breakdown of rocks.

DIAPIR — a dome or anticlinal fold, the overlying rocks of which have been ruptured by the squeezing out of the plastic core material. Diapirs in sedimentary strata usually contain cores of salt or shale; igneous intrusions may also show diapiric structure.

DISCONFORMITY — an unconformity where the bedding planes above and below the gap in deposition are essentially parallel.

ECOLOGICAL ZONATION THEORY — the theory that the sequence of fossils found in the geologic column is due to the ecological distribution of the organisms before the Genesis flood. The preflood ecological zones were destroyed in sequence by the gradually rising waters of the flood. The preflood ecology is assumed to have been different from present ecology.

EOLIAN — pertaining to the action or effect of wind.

EPEIRIC SEA — a sea within a continent or on the continental shelf.

EPIDERMIS FOLDING — folding of the epidermis (sedimentary layers or superficial cover layers) in contrast to a more stable basement which is not so involved in the folding.

EUSTATIC — changes in sea level that are worldwide, not local.

EVAPORITE — a nonclastic sedimentary rock composed primarily of minerals produced from a saline solution that became concentrated by evaporation of the solvent. Examples include gypsum, anhydrite, rock salt, chemically precipitated limestone, primary dolomite, and various rare nitrates and borates.

FACIES — the characteristic textures of a particular rock unit. May refer to rock type, fossil content, etc.

FAULT — a fracture plane in a geologic unit in which there is some observable displacement.

FLUVIAL — pertaining to, or produced by, a river or stream.

FLYSCH — a sedimentary deposit of thin units of marls, sandstones, conglomerate, graded deposits, often alternating in nature. May include turbidites.

FOLD — a bend in an originally planar rock structure.

FOLIATION — the planar structural features of a rock that result from the flattening of the constituent grains in the metamorphic process.

FORELAND — the stable area next to an orogenic belt towards which the belt was thrust. See Hinterland.

FORE REEF — the seaward side of a reef.

FORMATION — a group of rock strata or a body of igneous or metamorphic rock that has certain unique characteristics common to the unit and differing from adjacent units, usually of mappable size.

FOSSILS — any trace, imprint, natural cast or remains of a living organism preserved in sediments.

GEOLOGIC COLUMN — a composite diagram showing in one column a sequence of rocks corresponding to a chronological scale made according to the evolution of the fossils found in these rocks.

GEOSYNCLINE — an extensive elongated downwarped region of Earth’s surface in which sediments and volcanic rocks have accumulated to great thicknesses.

GRABEN — an elongated trough bounded on both sides by high-angle normal faults dipping to the inside.

GRADED BED — a sedimentary layer which has the coarsest material at the base and becoming finer as one proceeds towards the top.

HIATUS — gap, missing layers in a sedimentary structure.

HINTERLAND — the area on the side of an orogenic belt away from the direction of the thrust. See Foreland.

HORST — an elongated block bounded on both sides by normal faults dipping to the outside.

INDEX FOSSIL — fossil used to date and to identify the strata in which it is found; a good index fossil is a species having a broad geographic range, a restricted stratigraphic range, a distinctive morphology and a relatively common occurrence.

ISOCLINE — a fold whose limbs are parallel.

JOINT — a fracture in a rock without displacement. It is often planar.

KARST — a type of topography formed on limestone due to dissolution forming sinkholes and caves.

KLIPPE — a transported block of rock that is isolated from its source either by sliding or by erosion of the thrust sheet from which it originated.

LACCOLITH — an intrusion of igneous rock with a convex upward roof and a flat floor.

LACUSTRINE — belonging to, or produced by, lakes.

LAMINA — very thin sedimentary layer, commonly in the mm range or thinner.

LITHOLOGY — physical character of a rock: color, mineralogic composition, grain size, etc.

LITTORAL — pertaining to the region between low water and high water, i.e., intertidal.

LOAD CAST — the bulbous projection of an overlying layer into the one below due to unequal loading.

MAGMA — molten fluid within Earth's interior formed from the melting of rock.

MATRIX — the finer-grained material filling the space between larger particles or fossils, etc.

MOLASSE — an extensive mixed sedimentary deposit resulting from the early erosion of a mountain range such as north of the Alps.

MONOCLINE — a local steepening of more horizontal sedimentary deposits.

MORAINE — accumulation of larger aggregates of unsorted glacial drift by the action of a glacier.

NAPPE — an extensive body of rock that has moved by recumbent folding or overthrusting.

NORMAL FAULT — fault in which the depressed block is above the fault surface, and the hanging wall has been depressed relatively to the footwall.

OOLITH (OOLITHIC) — a small (0.25 to 2 mm diameter) sphere whose center is usually a debris and whose shell is formed by concentric thin layers, usually of calcium carbonate.

ORGANIC REEF — a wave-resistant ridge or mound built by sedentary organisms showing relief above the surroundings.

OROGENY — the process of mountain formation.

OVERTHRUST — a near-horizontal thrust fault of wide extent usually many km2.

PALEOGEOGRAPHIC DOMAIN — the location of a particular geologic area at a particular time in the past.

PALUDAL — pertaining to a marsh.

PALYNOMORPHS — a resistant, microscopic, organic body such as pollen, spores, acritarchs, etc.

PARACONFORMITY — an unconformity in which there is no erosional surface and the beds below and above are parallel, a non-sequence.

PARAUTOCHTHONOUS — not transported very far, intermediate between autochthonous and allochthonous.

PELAGIC — pertaining to the open sea but not the sea floor.

PENEPLAIN — a widespread featureless (flat) land surface presumably produced by long, continuous subaerial erosion.

PETROLOGY — the study of rocks.

PLATE TECTONICS — theory in which Earth's surface (lithosphere) is formed of rigid plates floating on the aesthenosphere. The different plates interact with one another at their boundaries, causing seismic and tectonic activity.

PROGRADATION — the outward or basinward migration of a shoreline and accompanying basinward sedimentation.

PSEUDO-OOLITHIC ROCK — rock composed of small spherical pseudo-ooliths (ooliths without the defining internal structure). Sometimes with ill-defined outlines.

RECUMBENT FOLD — an overturned fold as in a nappe or other geologic unit.

REEF — a projecting outcrop of rocks.

REGRESSION — retreat of the sea from land areas.

RELIEF — unevenness of Earth's surface.

RETROGRADATION — the landward migration of a shoreline and its accompanying landward sedimentation.

REVERSE FAULT — fault in which the raised block is above the fault surface.

RIFT — a long, narrow continental trough bounded by normal faults; a graben.

RIPPLE MARKS — finely detritic sedimentary structures formed of sub-parallel elongated ripples, 1 to 5 cm high; produced by wind, water currents or wave action.

ROCHE MOUTONNEE — smoothed off, mounded rock usually a few meters in size, produced by the action of glaciers.

SACCHAROIDAL — a rock texture term used for rocks having a sugary appearance.

SALINA — an area in which deposits of salt are found or formed.

SEDIMENTARY — formed by precipitation from solution, or as a result of transport by water.

SEDIMENTATION — processes leading to the formation of sediments: separation of rock particles, transport, deposition and finally consolidation of the particles in a new rock.

SEDIMENTS — any particles (of any size), laid down after some transportation by water, wind or ice.

SHEET — a large, widespread tabular mass of rock.

STRAND PLAIN — a prograded shore built seaward by waves and currents.

STRATA — plural of stratum, a stratigraphic unit. A stratum (or bed, layer) is a layer of sediments limited by two surfaces approximately parallel featuring sharp variations (visually obvious) in the structure of the sediments.

STRATIGRAPHY — science of the strata of Earth's crust, dealing especially with the characteristics, sequence of layers, and the time factors of this sequence.

SUBSIDENCE — gradual or sudden sinking of a large portion of Earth's crust.

SUPERPOSED — pertaining to a stream that maintained its course as it was established on a new lower surface.

SYNCLINE — a fold which is concave upward.

TALUS — rock fragments at the base of a steep slope or an extensive slope of such fragments.

TECTONIC — related to structural or orogenic features of Earth's crust.

TERRIGENOUS — originating from land surfaces in contrast to a marine origin.

THRUST FAULT — a fault whose surface is more horizontal than vertical and in which the direction of movement of the two parts is compressional.

TILL — heterogeneous mixture of clay-boulder clasts resulting from the action of glaciers.

TRANSGRESSION — extension of the sea over land.

TURBIDITE — a sedimentary rock deposited by a turbidity current.

TURBIDITY CURRENT — a downhill, underwater density current consisting of a suspension of sediments. The current has a greater density than water, flows with a characteristic pattern, leaving a characteristic deposit.

UNCONFORMITY — an interruption in deposition in a sedimentary sequence. A gap in the stratigraphic record.

UNIFORMITARIANISM — theory stating that geologic processes operating today acted the same way and at the same speed in the past. This theory does not exclude some local catastrophes.

VARIEGATED — showing irregular variations in color.

VARVE — layer of sediment usually consisting of a coarse and fine portion, and thought to have been deposited during one year.

VERGENCE — the direction of inclination or overturning of a fold.

WILDFLYSCH — a kind of flysch characterized by large, usually unsorted blocks and contorted beds.

WRENCH FAULT — a lateral fault with a more or less vertical fault surface.

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