A Geologic Guide to
TITUS CANYON
Death Valley National Monument

Inyo County

By

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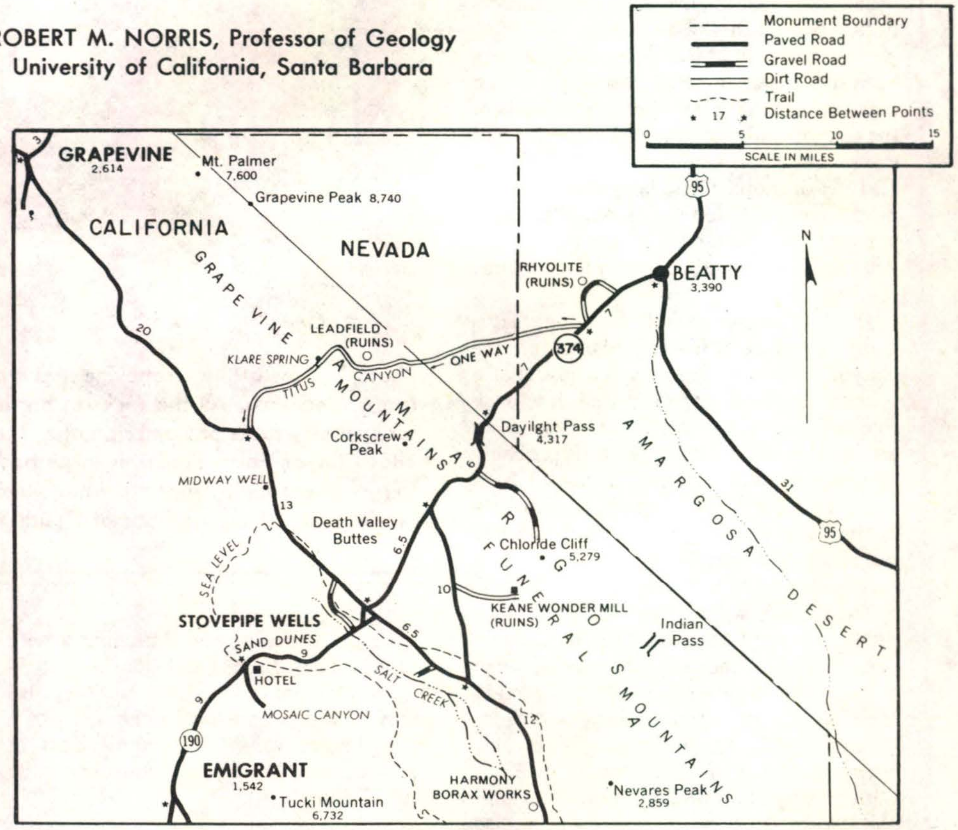

Figure 1. Titus Canyon, Death Valley National Monument, Inyo County, California.

INTRODUCTION

Death Valley National Monument includes hundreds of geologic features of interest to visitors. Titus Canyon is particularly spectacular and well worth the half-day drive needed to see it. Titus Canyon was named for Morris Titus, a mining engineer who perished in the canyon in 1905 while on a prospecting trip. A one-way road through the canyon starts from the Amargosa Desert west of the ghost town of Rhyolite, Nevada. Rhyolite and nearby Bullfrog were bustling gold-mining towns early in the 20th century.

Titus Canyon is a deep, narrow, water-cut gorge that nearly bisects the Grapevine Mountains (Figure 1; Photo 1). Seen from the west, on the Death Valley side, the Grapevine Mountains appear from a distance to be a steep, nearly unbroken wall several thousand feet high. Closer inspection, however, shows that it is cut by numerous deep canyons. At the mouths of these canyons are large, gently sloping cones of coarse gravel alluvial fans.

Alluvial fans formed from gravelly sediment carried out of the mountains by occasional floods. When the flood water leaves the confines of the narrow canyons and spreads out on the valley floor, its velocity decreases and it drops its load of debris. Over a period of many years successive floods shift back and forth across the desert floor, deposit debris and slowly build a characteristic cone-shaped alluvial fan. In Death Valley, alluvial fans at the base of mountain ranges have joined together as they grew.

CLIMATE

The region's climate is arid. The sparse, stunted vegetation and the extensive salt flats emphasize the aridity of the area. Very little rain falls in the valley; however, rainfall in the surrounding mountains often sends floodwaters roaring down narrow canyons. Anyone fortunate enough to observe a flash flood from a safe vantage point will certainly gain insight into the mechanics of how much bed load a desert stream in full flood can carry.

A single, late August flash flood some years ago deposited at least 5 feet (1.5 m) of new gravel on top of one of the fans south of Furnace Creek, completely burying the highway in just a few hours. Summer thunderstorms like this often drop large amounts of water quickly on the barren slopes of desert mountain ranges. The suddenness of the downpour, the lack of vegetation and soil, and the extensive exposures of bare rock ensure that much of the water runs off rather than soaks in. This water quickly picks up and moves loose rock. If the storm is sufficiently intense or prolonged, very large amounts of rain may fall. Canyons in the area rapidly become pathways for boisterous, powerful torrents of muddy water or watery mud. In deep and narrow gorges, such as Titus Canyon, a flash flood can fill the narrower parts of the canyon with wall-to-wall water up to 8 feet (2.4 m) or more with very little warning.

Visitors face little risk from flash floods in Titus Canyon, because most thunderstorms occur in late summer when the canyon is closed to travel. Nevertheless, one should not attempt the trip when heavy rains threaten, even in winter.

EROSION CARVES TITUS CANYON

When one stands at the summit of Red Pass looking down into the large valley that forms the head of Titus Canyon (Photo 1), it may be difficult to believe that all the rock was excavated by what is usually a bone-dry stream. If one million years were allowed to form Titus Canyon and only one flash flood occurred every ten years, there would have been approximately 100,000 flash floods during that time period. Some of these floods would have been small ones, but a few would have been real torrents that filled the narrow parts of the canyon with roaring, turbulent flows of water and mud, some as deep as 30 feet (9.1 m) or more. These large floods would have swept every loose rock out of the canyon and onto the fan below, deepening and widening the entire canyon in the process.

It is not known exactly how long Titus Canyon has been forming. However, the canyon is almost certainly not less that a million years old and may well date back five or six million years. For this reason, an estimate of 100,000 flash floods is probably very conservative. There have also been many climatic changes during the history of the canyon with periods when streams ran most or all year long.

Photo 1. View of the Grapevine Mountains looking toward the northwest from the top of Red Pass. All the rocks in the higher ridges across the valley are marine sedimentary rocks of Cambrian age. The red rocks in the foreground belong to the Titus Canyon Formation. This large bowl-like depression in the Grapevine Mountains was eroded by running water, which carried the rock debris out of the canyon and dumped it on the floor of Death Valley. ***Photos by Robert M. Norris.***

Titus Canyon, together with all other canyons in the Grapevine Mountains, provides abundant and compelling evidence of a long and continuous period of stream erosion with occasional episodes of very intense erosion due to flooding. Evidence, however, shows that the shape of Titus Canyon was sculptured by more than simple stream erosion. Regional uplift also played a significant role in forming Titus Canyon.

One of the more spectacular parts of Titus Canyon is the lowermost section, extending upstream from the canyon mouth for about a mile (1.6 km). The canyon here has nearly vertical walls only about 18 feet (5.7 m) apart at road level (Photo 2). Several hundred feet above the road, the walls begin to spread apart, forming an open V-shape. A cross-section of this part of the canyon resembles a wine glass, with a narrow straight stem at the base and flaring sides above. Valleys of this sort are called wine glass or goblet valleys.

Most stream valleys in the world have flaring sides and a well-developed V-shaped cross section with the point of the 'V' at stream level. This shape is the result of a stream that cuts its channel downward and the stream tributaries erode the sides of the 'V', widening and flattening it with the passage of time. Landslides and rockfalls occur from time to time, and they also serve to widen and flatten the walls of a main stream valley. The upper part of Titus Canyon shows this widening quite well (Photo 1).

A large number of stream valleys in different parts of the world formed under differing climatic conditions but most have the typical V-shape. Some of them will be broad and open Vs and others will be narrow and deep Vs. Recalling that most valleys are products of *downcutting* by the streams that occupy them, and are *widened* by tributary or branch streams and by landslides, it is evident that *widening* processes are sometimes more dominant than the deepening processes. Sometimes the reverse is true. As for Titus Canyon, the narrow lower portion tells us that *deepening* processes have dominated of late; the flaring upper part of the valley suggests that at an earlier time *widening* processes were dominant.

REGIONAL UPLIFT

There are active faults in the Grapevine Mountains. These are large fractures along which the range has been raised with respect to Death Valley. The same effect would be achieved if the floor of Death Valley were depressed with respect to the mountains. It is difficult to tell which, or how much of each type of movement occurred. In regard to the formation of Titus Canyon, however, only the *relative* change in elevation between the mountains and valley floor is significant.

Geologic studies indicate that the Grapevine Mountains have been raised approximately 2.7 miles (4.3 km) relative to the floor of Death Valley since their formation. Herein lies the key to the origin of the wine glass valleys. As the Grapevine Mountains and its canyons were raised with respect to the valley, stream gradients were steepened and more erosional energy was expended in deepening the canyon in an attempt to keep pace with the sinking valley floor. At such times, less energy is expended in the widening processes. The shape of the canyon indicates that the recent history of the Grapevine Mountains has been one of almost continuous uplift; whereas an earlier history shows how a period of slower uplift allowed more time for valley widening to occur.

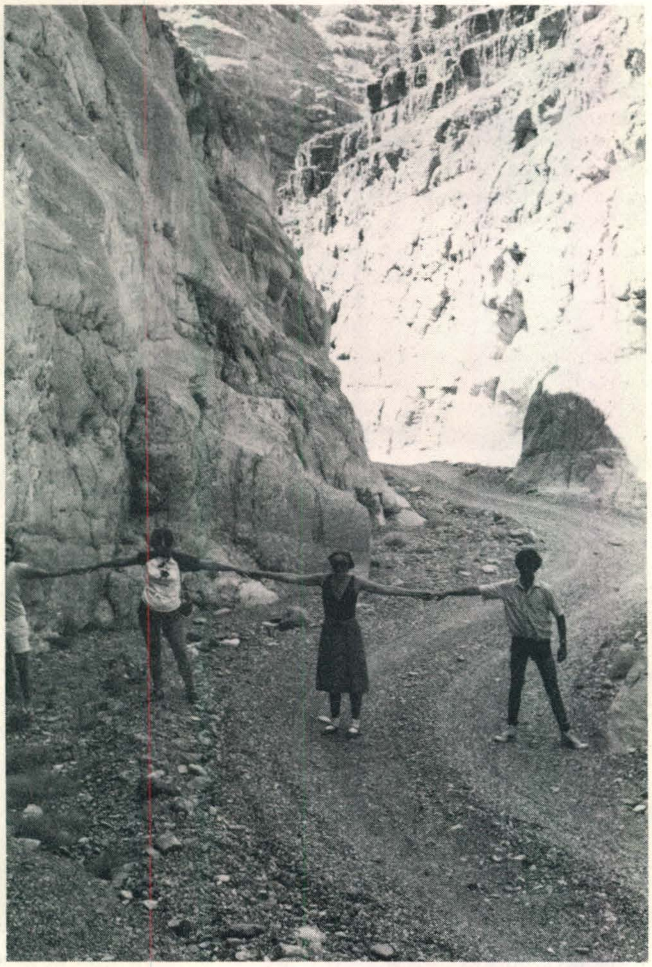

Photo 2. View in lower Titus Canyon showing the narrow stem of the wine-glass valley. Here, the extreme narrowness of the canyon shows that downward cutting by the stream has been more rapid than the various widening processes. This means the mountains, including the canyon, have been uplifted so rapidly that the widening processes have not had time to do much erosional work at the canyon floor.

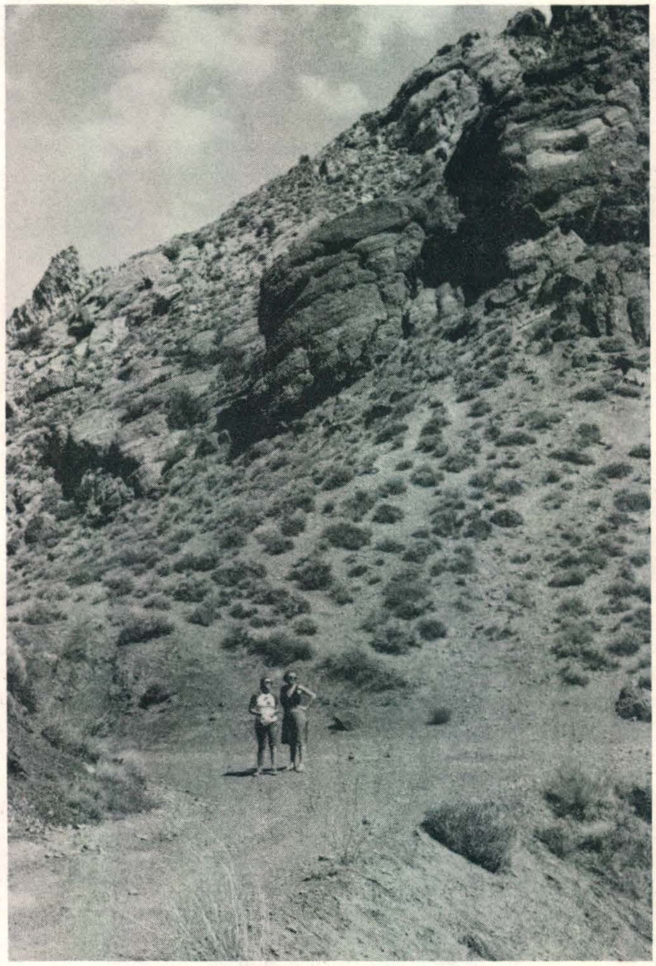

Photo 3. Summit of Red Pass. The rocks in the road and those directly above, including the dark-colored, pebbly beds on the hillside, belong to the Titus Canyon Formation. The fossils held by the people in the photograph were found in similar, dark red mudstones at a nearby locality. The light colored rocks on the ridge are tuff beds younger than the Titus Canyon Formation. NOTE: It is illegal to collect fossils in a National Park!

After coming out of the stem of the wine glass valley at the mouth of Titus Canyon and reaching the highway, stop and take time to look back at the range (front cover). There are several canyons in this region with a wine glass shape, as well as a number of well-developed alluvial fans fed by these canyons.

Uplift Forms Grapevine Mountains

There is still more evidence of rapid uplift of the Grapevine Mountains which is revealed by careful study of alluvial fans at canyon mouths in the range. If the volume of these fans is estimated by assuming the valley floor continues back under them to the mountain front, fan volume works out to be far less than the volume of materials that we can prove was excavated from the valley above. In other words, the volume of rock removed from the Grapevine Mountains to form Titus Canyon is several times *greater* than the volume of the fan at the mouth of Titus Canyon.

What happened to the other material eroded out of the range? The fan seen today is only the *most recent* of several fans, each formed during lulls in the uplift of the range (or valley depression). Older fans have periodically been faulted downward with the valley and have subsequently been buried by younger fans. So, instead of just one fan at the mouth of Titus Canyon, the present fan is simply the topmost one in a great pile of fans.

Now it can be seen how the stem of the wine glass valley and the relatively small, modern alluvial fan at the canyon mouth indicate that the valley has dropped rather rapidly, relative to the mountains, in most recent geologic time.

These events that produced the grand scenery of today occurred in the last few million years—quite recent in geologic time. Scientists now generally agree that Earth has existed for 4,600 million years, so it is not difficult to see why geologists regard events of the last few million years as quite recent. On this basis, the last 1/4,600th of Earth's history is truly quite recent in geologic time.

It is probable that Grapevine Mountains and Death Valley are not older than 6 or 8 million years. Rocks exposed in these mountains record a much earlier history—long before there was a Death Valley or Grapevine Mountains. This rock record, however, is a very incomplete one, with gaps of several hundred million years. Nevertheless, it extends back 1,400 million years to Precambrian time. Rocks of such great age, preserved in the mountains, are former muds and sands deposited in a slowly filling, marine basin. By Cambrian time, which started about 550 million years ago, the sea in the area had become quite shallow and was surrounded by low, relatively featureless land areas.

Cambrian limestones are well represented in Titus Canyon and illustrate that throughout most of Cambrian time the area was covered by a warm shallow sea. At times in the Cambrian Period, distant land areas were a bit higher, and mud, sand, and gravel were carried by streams into the sea. At other times, surrounding areas were eroded almost to sea level and were incapable of producing much sediment. During these quiet periods limy muds of organic and chemical origin accounted for most of the material deposited.

As far as it is known, there was not a single *land* plant or animal in the Cambrian Period. Land areas in those ancient times were barren places because land plants were just beginning to evolve, if indeed they had appeared at all. Life was confined entirely to the sea, where it was quite abundant. Even low lands, quite barren and lacking vegetation would be expected to quickly erode during this time. We know from the rock record that rivers flowed to the sea with enormous amounts of sediment. As a result of this mass-wasting, the Cambrian sedimentary rock preserved in the Grapevine Mountains has a thickness of about 1.5 miles (2.4 km). Originally there may have been a much greater thickness; if so, much of it has since been removed by erosion.

Elsewhere in the Grapevine Mountains, but not in Titus Canyon itself, other marine rock units total about 7,000 feet (2,134 m) in thickness. These units accumulated between the Cambrian and Permian periods—between 450 and 225 million years ago. These rocks were almost certainly once present in the Titus Canyon area also, but they have been entirely removed by erosion. From the Permian Period until the Oligocene Epoch, a span of about 180 million years, there is no rock record of what happened anywhere in the Grapevine Mountains.

Beginning about 35 or 40 million years ago, during the Oligocene Epoch, the pebbly, sandy and muddy beds of the Titus Canyon Formation were unconformably deposited in lakes and streams on top of the upturned and eroded edges of older rocks. The type locality of the Titus Canyon Formation occurs near Leadfield; the thickness of the section is 2,200± feet. Animal fossils preserved in these Oligocene rocks (Titus Canyon Formation) suggest that the area then had a warm, moist climate and was a region of broad valleys containing lakes and a few mountain ranges. Some volcanic activity occurred from time to time. Soft, leafy vegetation was common, but tough grasses were not prominent and did not become abundant until later in geologic time.

Animal fossils do not reveal as much about the climate and landscape as plant fossils. Nevertheless, the environment can be determined even in the absence of plant remains. For example, horse's teeth (herbivorous teeth) are adapted to a diet of tough, wiry grasses, and look quite different from human teeth (omnivorous teeth), which are adapted to a mixed diet of plant and animal material. Teeth of a cat or dog (carnivorous teeth), adapted to a meat diet, are different from the teeth of either horses or man.

Fossils of two large extinct mammals of the titanotheres group were found in the Titus Canyon Formation. Paleontologists classify titanotheres as odd-toed ungulates or perissodacyls. This simply means they were vegetarian animals with an odd-number of toes, like a horse. Titanotheres are distantly related to horses, but looked quite unlike any modern horse. Titanotheres' teeth indicate they lived on a diet of soft, leafy vegetation, rather than on tough, silica-rich grasses. These extinct mammals stood as high as 8 feet (2.4 m) at the shoulder, had a long skull with a sag in the top and a rather peculiar looking pair of horns. The sag in the skull left little room for a brain. The limited intelligence of these animals may have been the reason for their extinction at the end of Oligocene time around 26 million years ago.

Other fossils found with the titanotheres remains include tapirs, browsing horses, running rhinoceroses, and small, squirrel-like rodents. These fossils, first discovered in 1934 by H. Donald Curry, a graduate student studying at the California Institute of Technology, represent the only glimpse of the Oligocene environment in the Great Basin that has so far been found.

The Titus Canyon Formation is exposed on either side of Red Pass (see the road log) (Photo 3). Near the head of the canyon other rock units rest on top of the Titus Canyon Formation. We know these rocks are younger, not because of fossils (none have been found to date), but because they were deposited on *top* of the Titus Canyon Formation. These later rocks include many stream and lake deposits. They also contain lava flows and layers of volcanic ash, which are colorful pink, yellow, deep brown and green. In some places volcanic pipes, which once brought lava to the surface, are exposed as vertical pinnacles cutting across the sedimentary rocks. Although these rocks lack fossils, they appear to be similar to rocks which occur at Furnace Creek, some miles south, that are thought to be Mio-Pliocene age—about 5 to 10 million years old.

The degree to which all these originally, nearly horizontal rocks have been bent, folded, faulted, and uplifted indicates that the processes which formed the present mountains and valleys have been nearly continuous over the past 5 to 10 million years. The episode of mountain-building which produced the present Death Valley landscape seems to have had its beginnings almost 20 million years ago.

FUTURE MOVEMENT

Many of the present landscape features suggest these mountain- and valley-forming processes are still in full swing, although the past 2,000 years have been rather quiet with little sign of active faulting. The most recent fault activity found so far in Death Valley is thought to be about 2,000 years old. This "quiet" period may be misleading, for there are many other signs which show that in recent geologic times mountains have been elevated along faults, almost certainly accompanied by major earthquakes. Death Valley is filled with thousands of feet of very young alluvial deposits derived from the nearby rugged mountains. The straight, steep face of the Grapevine Mountains and other nearby mountains is a consequence of persistent and recent fault activity. Despite the last 2,000 years of geologic quiet, it is virtually certain the future will bring more earthquakes and renewed fault activity. Geologists are not sure when mountain-building forces will be renewed, but most would agree that the future of Death Valley includes more earthquakes and more movement along faults.

Sketches by Elizabeth A. Norris.

Figure 2. Sketch of volcanic plugs on the eastern side of the Grapevine Mountains. These are composed of solidified lava that filled conduits after an eruption. Some of them represent cores of mountains now largely removed by erosion. The plugs are Miocene or Pliocene age, about 5 to 10 million years old.

TITUS CANYON GEOLOGIC FIELD GUIDE

The following road log lists features of geologic interest in Titus Canyon. Some features can be seen easily from the road; others require a stop. Geological stops of special interest are indicated by a star (*).

Car odometers vary in measuring mileage. Correct your mileage from time to time upon reaching an easily identified stop, such as the top of Red Pass. If you do this, there should be little difficulty in following the road log or in identifying the points of interest.

The road log begins at the Death Valley National Monument sign, about 2 miles west of the junction of Titus Canyon Road and Nevada Route 374. If you have a trip meter, set it to 0 at the monument sign.

Leave paved Nevada Route 374 and proceed on the gravel Titus Canyon Road.

ROAD LOG

Mileage

0.0 Boundary sign, Death Valley National Monument. Administered by The National Park Service, Department of the Interior, Death Valley National Monument was established in 1933 to protect the many geological and historical features in this area.

0.9 Desert pavements occur on each side of the road. These are erosionally inactive surfaces formed on alluvial fans between active water courses. They formed quite slowly because wind removed the finer particles gradually from the gravelly fan surfaces. The larger particles left on the surface eventually develop an armor over the underlying material, protecting it from further wind erosion. The final result is a bare, sometimes very smooth, pebble mosaic called desert pavement.

4.4 Entering the foothills of the Grapevine Mountains. Rocks in this area are mainly lava flows (dark brown to black) and sedimentary rocks of volcanic origin, such as ash beds and tuffs (pink, yellow, and brown).

5.5 The prominent, tan colored outcrop to the right is a volcanic plug, probably the feeder pipe for an old volcano.

6.6 The higher peaks which can be seen to the right are composed chiefly of lava flows. As these flows weather and break up, they form loose streaks of coarse, angular rubble extending down the hillsides. This loose material is called *talus* and eventually may form a thick mantle which completely covers the lower slopes.

*7.6 Summit, The dark-colored mountains on the right (Figure 2) are volcanic plugs, so-called because they plug the vents as the molten lava hardens. More resistant than the enclosing rocks, the plugs remain behind to form pinnacle-like features as erosion progresses. The pink and yellow rocks are mainly tuffs. Tuffs are sedimentary rocks composed entirely of volcanic materials and are often deposited in lakes and streams.

8.1 To the left, look down Titanothere Canyon into a portion of Death Valley, where a section of California State Highway 190 can be seen between Stovepipe Wells Village and the Emigrant Ranger Station. The nearest, dark-colored hills straight ahead, comprise the Titus Canyon Formation, which contains fossilized animal remains. The banded or layered mountains slightly to the left are composed of marine, sedimentary rocks of Cambrian age, about 500 million years old.

8.3 Road descends steeply; use low gear. Dark-colored, knobby rocks just above the roadside are part of the Titus Canyon Formation. Green, buff, and pink rocks, just beyond the nearby hills, are younger tuffaceous rocks composed largely of volcanic ash. They are probably Miocene or Pliocene in age, about 5 to 10 million years old.

8.6 Black, pebbly rocks exposed in the road cuts are part of the Titus Canyon Formation.

8.7 Second National Monument gate. More pebbly Titus Canyon Formation in the canyon to the right.

8.9 Red rocks across the gully to the left belong to the Titus Canyon Formation.

9.0 View of Titanothere Canyon on the left.

9.2 More Titus Canyon pebble conglomerate on the right.

9.7 A large fault is exposed in the hillside at the sharp turn in the road. It can be recognized by marked differences in rocks on either side of the gully, which more or less follows the fault. Rocks are crushed and broken along the fault, encouraging more rapid erosion and development of a gully. The red rocks on the right belong to the Titus Canyon Formation and are separated by the fault from the blocky, gray, Cambrian rocks on the left.

10.2 The fault continues up the vegetated canyon above the road on your left. Observe that vegetation in this canyon is appreciably greener than the vegetation on the nearby hillsides. This is a result of the fault which allows groundwater to seep to the surface, adding just enough water to the meager rainfall to support the greener vegetation.

On the left of the road, a water collection box was built many years ago and is called 2-Barrel Spring. It is dry today.

*10.4 Summit of Red Pass (Figure 3). Scenic views. Take care in parking and allow plenty of room for other vehicles to pass. Be sure to close car doors if you leave the vehicle. Looking back toward Nevada, most of the rocks you see are tuffs and lavas (Photo 4). Most rocks at the pass are part of the Titus Canyon Formation. In the distance, across Titus Canyon, are banded, marine, sedimentary rocks largely of Cambrian age (Photo 1).

10.5 The road follows the crushed fault zone along the same fault which you saw on the other side of Red Pass.

Photo 4. View from Red Pass toward the east. Nearly all the rocks in this view are volcanic ash beds, lava flows, and feeder pipes which are Miocene and Pliocene age (about 5 to 10 million years old). These rest on the older, stratigraphically lower Oligocene Titus Canyon Formation, about 25 to 30 million years old, which is exposed in the slopes in the immediate foreground and in the pebbly cliffs on the extreme left of the photo.

10.9 Look at the large mountain straight ahead. The uppermost brown and reddish brown rocks are Miocene and Pliocene tuffs. The Titus Canyon Formation is below and is made up of green, bluish, red, and white rocks. The darker rocks, down in the gully, are on the opposite side of the fault and are Cambrian marine sedimentary rocks.

11.3 On the left, across the gully, is a good exposure of dark gray Cambrian limestone.

11.8 Mine dumps and mine hazard sign. Old mines are subject to cave-in and collapse. In warm weather, they may be refuges for rattlesnakes, so it is wise to stay out of them. Furthermore, in about 99% of old mines, you cannot see any interesting rocks or minerals.

12.1 Just beyond the hairpin bend in the road, overlooking a deep canyon, a fault separates the dark gray, Cambrian limestones on the left from the red Titus Canyon Formation exposed in the roadway. Note the dry waterfall in the limestone at left.

12.3 Although it is very difficult to see, the fault line is crossed here.

12.9 The layered gravels in the stream bank on the left are deposits laid down by streams during receding stages of flash floods. A later flood has cut into older deposits, forming the bank. This shows how floods alternately deposit and erode materials. After seeing these deposits, it becomes easier to understand the importance of water in sculpturing the Grapevine Mountains and all other desert ranges. Although flash floods may affect Titus Canyon only once or twice every eight or ten years, each flood sweeps considerable amounts of loose rock, sand, and gravel off canyon walls and from the stream bottom. It then carries at least part of the load out onto the alluvial fans on the floor of Death Valley. Some debris is always "stored" in the canyon awaiting the next flood to move it along.

13.5 Ghost town of Leadfield (wayside exhibit and restrooms); elevation 5,500 feet; Titus Canyon Formation type locality. The town boomed from 1925 to 1926 as a result of a skillful promotor who controlled a large deposit of nearby very low-grade lead ore. In its short history, the town had a post office, telephone, and newspaper, the *Leadfield Chronicle*.

13.8 Another fault is crossed here in the streambed. Cambrian rocks are on the left.

13.9 "When Rocks Bend" sign. This small syncline shows that brittle rock units can be plastically deformed (bent) when under stress in response to earth forces.

14.0 On the left, these smooth sloping surfaces are "dip slopes". The existing rock surface corresponds exactly to the inclination, or dip, of originally horizontal layers.

14.2 "Entering Titus Canyon" sign. Small caves and hollows seen here are the result of water dissolving away the weaker and more soluble portions of rock.

14.5 Another dip slope on the left. On this one, slabs of overlying layers have slid down the dip slope (bedding plane) to the stream bottom. This is a rockslide, one of many kinds of landslides by which stream valleys are widened.

14.9 The large blocks of limestone in the valley bottom were probably moved by thick, slurry-like mudflows rather than by water. Dense mudflows can transport far larger blocks than even very swiftly moving water.

15.1 Note the polished stream channel at the top of the cliff on the left. This shows abrasion by water laden with sediment, mainly sand and gravel. Clear or muddy water is not abrasive and seldom forms polished surfaces. Large talus piles, seen in the heads of the side canyons, are available sediment supplies for the next flash flood.

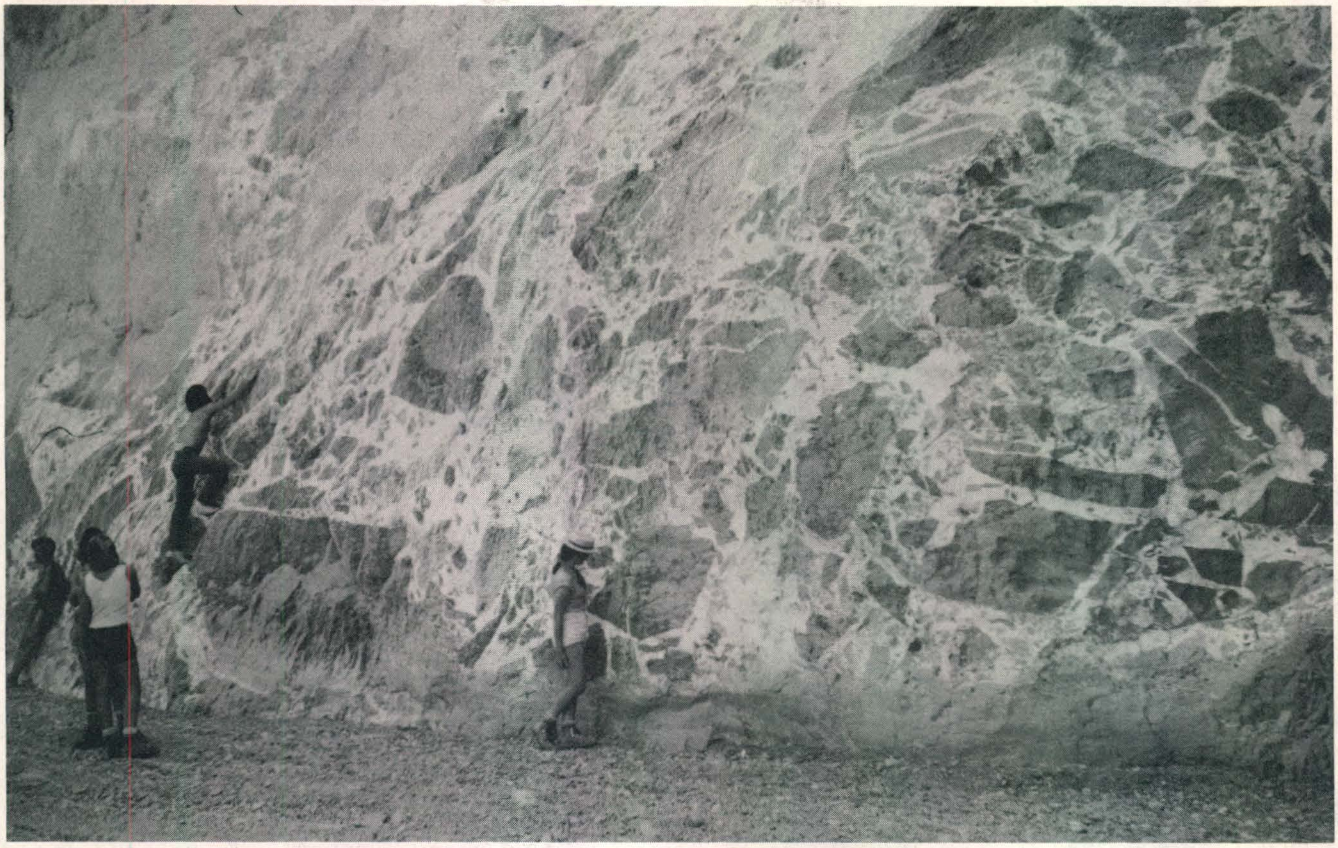

Photo 5. A breccia exposed in the lower part of Titus Canyon. This breccia seems to have been shattered and recemented with little or no transport. Some dark-colored angular blocks can be seen with layers which continue with no offset from one block, across the white cementing material, into the next dark block. If the dark blocks had been transported, this would not be possible. The white cement, like the dark blocks, is composed of the mineral calcite. After the dark blocks were shattered, dissolved calcite was carried in solution by water, calcite crystals were slowly redeposited in the cracks, eventually filling them and cementing the dark blocks together again.

15.5 The hummocky surface of the talus-like deposit on the left indicates that it was moved as a water slurry, something like very wet cement. Such slurries form quickly when heavy rains mix rapidly with copious amounts of loose gravel.

*16.0 Klare Spring. This tiny spring has formed where the large Titus Canyon fault zone crosses the canyon providing a channel for underground water to reach the surface. The spring is small because the rocks contain little water in this dry region. There are some fine Indian petroglyphs on the canyon wall a short distance to the right of Klare Spring.

16.3 The low bank next to the road exposes an old mudflow deposit in cross section. Note that it is a heterogenous mixture of alluvial debris which ranges in size from fine-grained mud to large rocks.

17.2 The low cliffs along the streambed are formed by recent erosion of former stream deposits. If a flood cut a trench into the present streambed, a similar kind of deposit would be exposed. Canyon streams alternately erode and deposit gravels. Deposited gravels are only temporarily stored in the canyon. One day they will be eroded and moved down canyon some distance or they will be swept entirely out of the canyon onto the alluvial fan in Death Valley.

17.4 Note dip slopes on both sides of the canyon.

*17.9 Dip slope on the left has ripple marks on its surface. These ripples formed in a shallow Cambrian sea on soft, horizontal, unconsolidated limy muds, about 500 million years ago. They have been subsequently hardened into rock, uplifted, and tilted.

18.2 On the left, well above the stream, there is a small, synclinal fold through which a tributary stream has cut a channel, almost exactly on the axis of the fold. This is an example of a small synclinal valley formed by stream erosion but controlled by the rock structure (Figure 3).

20.1 An example of a rockfall at the base of the cliff. This pile of loose, angular rocks, showing no sign of stream wear, fell into the canyon from the cliffs above in 1976, after heavy rains. Note the contrast of the sharp, angular fragments in this rubble pile with the more rounded cobbles and boulders in the streambed.

20.2 Now enter the narrowest portion of the canyon; the "stem" of the wine glass valley (Photo 2).

20.3 Small rockfall on the right.

20.7 On the left, note how the light-colored bed near the base of the cliff has been offset by small faults.

21.0 Observe patches of stream gravel caught in crevices up to 15 feet (4.5 m) above the canyon floor. These show that either the canyon has been cut down this much since they were deposited or, more likely, that they were left by a large flood 15 feet (4.5 m) deep, or possibly by some combination of these two causes.

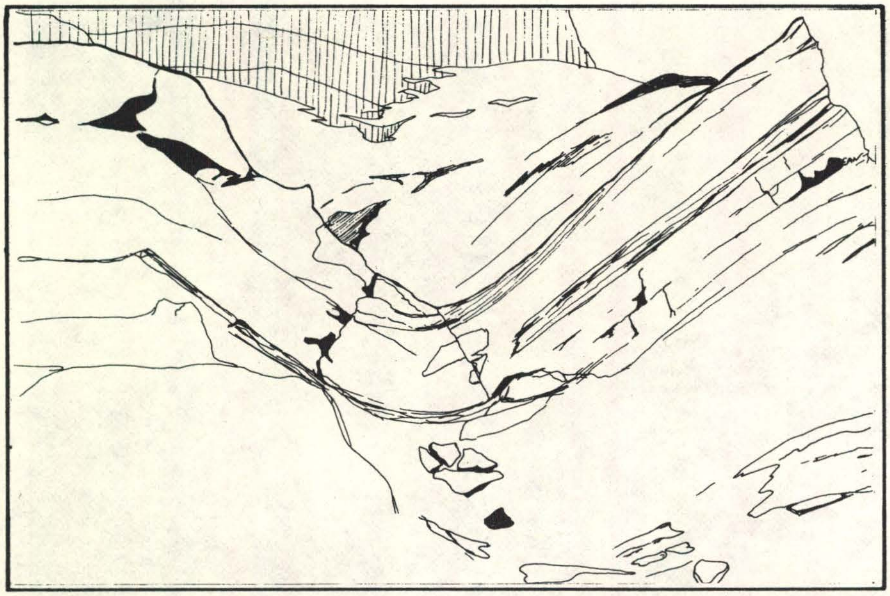

Figure 3. Sketch of the small synclinal fold high on the south wall of Titus Canyon. This fold is interesting because a small stream has established its course in the axis of the fold. Note the dry waterfalls in this steep tributary stream.

*21.1 On the left wall of the canyon is what appears to be a jumble of very angular, dark colored limestones cemented together by white limestone (Photo 5). Look closely at the dark blocks to see that the layers and other structures continue, with little or no deviation, from one dark block to adjacent blocks even though they are separated by the white limestone. This shows that the dark blocks were not moved very much if at all, but were just shattered in place, possibly by motion on a nearby fault. They were then recemented into solid rock by the white limestone carried into the cracks by water. The white material was *dissolved* in the water and deposited slowly until the gray rocks were firmly bound together.

Imagine this place in a flash flood! The water could easily be 10 or 12 feet (3 or 3.6 m) deep and laden with sand, mud, and loose rock. As such materials are swept along by the water, they abrade and polish the canyon walls. Near the streambed, bigger rocks are hurled and banged against the lower canyon walls, undercutting them (Photo 6). When the undercutting proceeds far enough, the cliff above will collapse. This will choke the valley with a pile of sharp-cornered rubble that will gradually be removed by subsequent floods (see rockfall, mile 20.1).

As you continue down canyon, watch for twigs, brush, and even gravel left in crevices and recesses on the canyon walls well above the stream bottom. These deposits give evidence of water depth during past floods.

21.7 Lower gate at canyon mouth. This is the head of the Titus Canyon alluvial fan, the dumping ground for all the debris flushed out of the canyon during floods. The largest blocks on the fan were carried there by dense slurry-type mud flows, but many of the smaller rocks and most of the sand and gravel were moved by ordinary muddy water.

*24.3 Paved road. Turn right to Scotty's Castle and Ubehebe Crater, or left to Stovepipe Wells, Furnace Creek Ranch, and the Visitor Center. Stop for a moment and look back at the Grapevine Mountains. Note the steep front, indicative of active faulting. Try to locate the mouth of Titus Canyon. It is a very inconspicuous feature at the bottom of the stem of the wine glass valley.

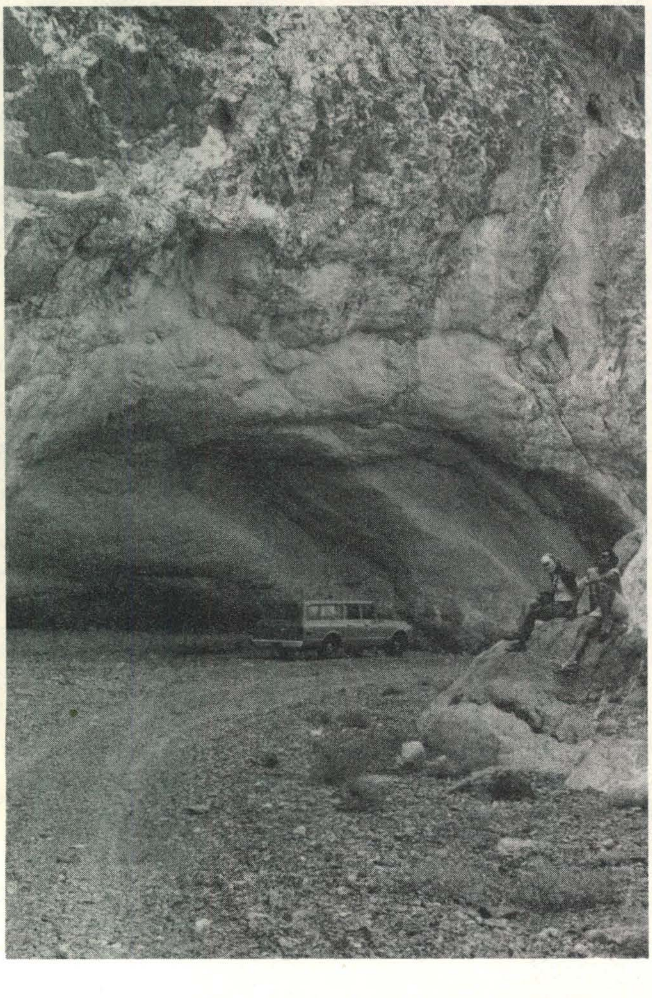

Photo 6. Note how the stream, as it swings against the outside of its channel, has undercut the massive limestone bluff exposed here. Hard boulders, carried by floods, chip away the softer limestone. The limestone is massive, fairly strong, and is able to support a considerable overhang. Eventually, however, as the notch is cut more deeply, a big block of limestone will break off and fall into the narrow channel, temporarily blocking it.

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A GEOLOGIC GUIDE TO TITUS CANYON

Understanding California's Geology - Our Resources - Our Hazards

CALIFORNIA GEOLOGY

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In This Issue

Cover Photo: View from Red Pass in the Titus Canyon area of Death Valley National Monument. The stark and rugged landscape of this region is due largely to its youth and aridity. An article on the spectacular geology of Titus Canyon starts on page 195. *Photo by Robert M. Norris.*

EARTHQUAKE HAZARDS WORKSHOP

A workshop on future directions in evaluating earthquake hazard reduction in southern California will be held at the Davidson Conference Center, University of Southern California, Los Angeles, California, November 12-13, 1985. Co-sponsors of the workshop include the U.S. Geological Survey, Federal Emergency Management Agency, National Science Foundation, Southern California Association of Governments, Southern California Earthquake Preparedness Project, California Department of Conservation/Division of Mines and Geology, California Seismic Safety Commission, and California Office of Emergency Services.

The workshop will be organized to achieve an effective exchange between producers and users of earthquake-hazard information through the use of oral presentations, panels, and sessions designed for participants to respond to the recommendations of work groups. All participants will be asked to focus on two important questions: (1) what additional scientific and technical information is needed for reducing earthquake hazards; and (2) which hazard-reduction strategies are most effective and how can they be improved.

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