SOFT SEDIMENT DEFORMATION IN CONFUSION GULCH

A Thesis

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by

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ABSTRACT

Confusion Gulch is located in Sanpete County, Utah, near the town of Ephraim, on the east face of the Gunnison Plateau. The rocks exposed in this area range in age from Jurassic to Eocene, and are represented by the Twist Gulch, Indianola, North Horn, and Flagstaff formations. The rocks of these formations represent lake, flood plain, and marine deposits. The structures present in Confusion Gulch suggest that the rocks making up the North Horn formation were deformed before they were completely lithified. Soft sediment is indicated by the formation of tight folds in sandstone that is now brittle, cracked pebbles in a conglomerate whose matrix is undisturbed, and split pebbles that have been bonded by sand matrix. Soft sediment deformation is responsible for the formation of the tight "S" fold on the front of the Gunnison Plateau, and for its overturned fold in the center section of Confusion Gulch.

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Introduction

Confusion Gulch is located in central Sanpete County, Utah, in T. 17S., R. 2E. The area is about 100 miles south of Salt Lake City, and about six miles west of the small town of Ephraim. Physiographically, it is in the western part of the Colorado Plateau province, and specifically on the eastern flank of the Gunnison Plateau. The gulch has been formed by the erosion of sedimentary rocks that have been exposed by the Gunnison fault.

The purpose of this report is to establish the occurrence and extent of soft sediment deformation in the area of Confusion Gulch, and to show the role of soft sediment deformation in the development of the structures in Confusion Gulch.

To facilitate the discussion of the stratigraphy and structure of Confusion Gulch, the writer has divided the area into three units. These divisions are the north wall, the center, and the south wall of the gulch. They are distinguished by the basis of their structural and topographic form (plate 1).

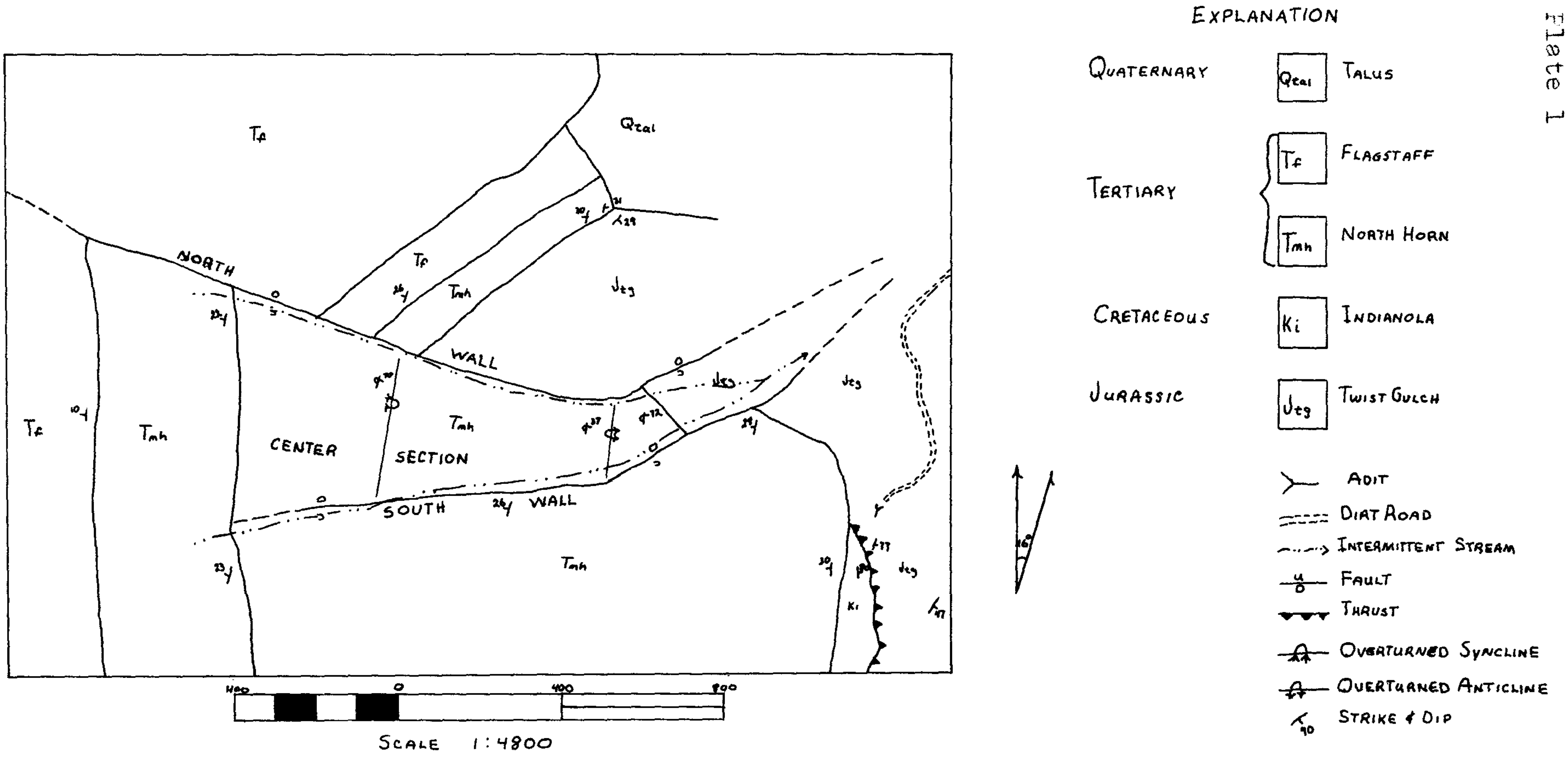
Stratigraphy

The rocks exposed in Confusion Gulch range from Late Jurassic to Eocene. They are entirely sedimentary in origin

Plate 1

GEOLOGIC MAP OF CONFUSION GULCH

SANPETE COUNTY, UTAH



and are composed of both clastics and carbonates. The following stratigraphic units have been recognized: Twist Gulch formation (Upper Jurassic), Indianola formation (Cretaceous), North Horn formation (Cretaceous and Paleocene), and Flagstaff formation (Late Paleocene and Early Eocene).

The oldest rocks exposed in this area belong to the Jurassic Twist Gulch formation. This unit was originally considered to be the upper member of the Arapien formation by E. M. Spieker (1946), but the unit was raised to formational rank by W. K. Gilliland (1951). The formation derives its name from its exposure in Salina Canyon above Twist Gulch, Sevier County, Utah.

In Confusion Gulch the Twist Gulch formation occurs in the lowermost portion of the area and is found in all three subdivisions, but at different topographic elevations. A large percentage of the outcrops are covered by rubble derived from the overlying formations. The section in Confusion Gulch was not measured because there has been repetition of beds caused by thrusting and isoclinal folding (fig. 9), but a representative section was measured on the north wall of Dry Canyon, which is adjacent to Confusion Gulch (plate 2). The total thickness of the Twist Gulch formation at that location is 570 feet. This is not a complete section, however, because the upper part is covered by rubble.

The Twist Gulch formation is composed of alternating beds of red sandstone, siltstone, and shale. The sandstone is fine- to medium-grained, is composed of rounded grains of both quartz and calcite, and is cemented by calcium carbonate. The sandstone shows fair to good sorting and some cross bedding. Parts of the sandstone have been leached of iron content and appear gray or mottled (fig. 7). The structure is massive to thin-bedded with the massive sandstone forming resistant ridges. The individual beds vary from a few inches to about five feet in thickness (fig. 8).

The Twist Gulch formation is overlain in angular unconformity by the North Horn formation in Dry Canyon, and also on the center section and north walls of Confusion Gulch. However, on the south wall of Confusion Gulch, the Twist Gulch formation has been thrust onto the younger rocks of the Indianola formation. It appears to be stratigraphically right side up, but because of isoclinal folding this is difficult to determine.

The next younger formation in the area is the Cretaceous Indianola formation. This formation is named for its exposure in the Indianola district of Sanpete and Utah Counties, Utah. It was originally described by S. L. Schoff (1938), but the name is credited to E. M. Spieker (Schoff, 1938). In the area of Confusion Gulch, the Indianola formation is exposed only on the front of the Gunnison Plateau just south of Confusion Gulch and in a mine adit, which opens on the south wall of the gulch. The total exposed thickness of the formation here is only 58 feet.

The Indianola formation is composed of white to gray alternating beds of sandstone and conglomerate. The conglomerate,

Figure 9. Isoclinal fold in the Twist Gulch formation on the south wall of Confusion Gulch.

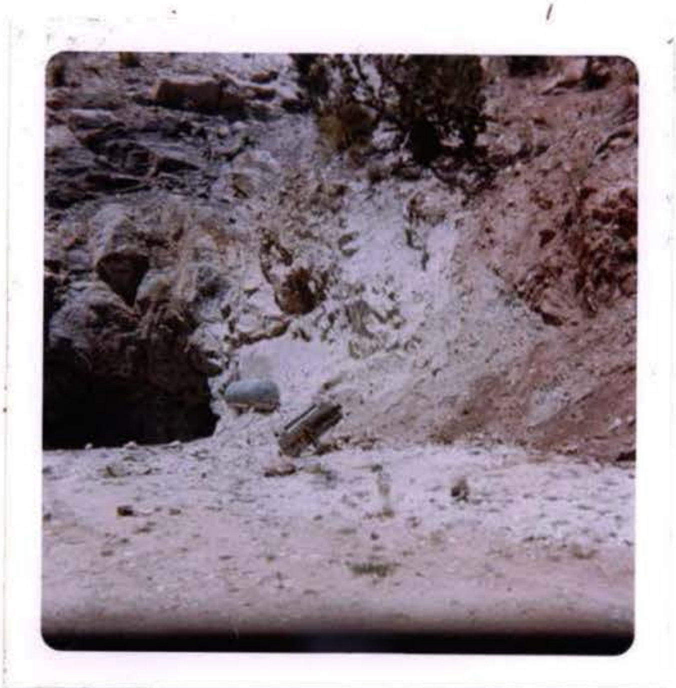


Figure 7. Red and white sandstone of the Twist Gulch formation on Horse Mountain.

which is the predominent lithology, is poorly sorted, and contains material ranging in size from coarse sand to boulders. The matrix is composed of fine to coarse subrounded sand, cemented by calcium carbonate. The pebbles are mostly black limestone and red, white and green quartzite, with some flint and sandstone. Bedding is poorly developed and cross bedding is absent. The conglomerate beds stand out as cockscombs, whereas the sandstone beds weather to form low areas between them.

Because of complicated structures, the base of the Indianola formation is not exposed in this area. The Twist Gulch formation lies above it because of the thrust fault, and therefore the section appears to be up side down. It is also overlain by the North Horn formation, which lies in angular unconformity on it. This unconformity is very well exposed, and the material of the North Horn has filled in the low spots in the erosion surface produced on the Indianola. This interlocking of the two formations seems to be good evidence that there has been no shearing movement between the two formations at this point since the deposition of the North Horn formation.

The next stratigraphic unit above the Indianola formation is the North Horn formation. This unit is considered to be Late Cretaceous and Early Paleocene. Its type area is on North Horn Mountain in the Wasatch Plateau, Utah. Structural and sedimentary features of this formation are the primary subject of this paper, and therefore, they will be considered in greater detail. Its lithology, thickness, and attitude very considerably in each section of Confusion Gulch, and for this reason, each area will be considered separately.

The section making up the south wall of Confusion Gulch is the thickest and best exposed. When this section was measured, it was divided into eleven units that comprise a total thickness of 1,259 feet. At the base the formation is composed of coarse clastics. These grade into finer clastics and eventually into shales and limestones at the top. For this report, three separate units are distinguished.

The lowest unit is about 170 feet thick and is composed of coarse conglomerate with some interbedded sandstone. Within these conglomerates is a thick unit of coarse sandstone with many conglomerate lenses in it. The conglomerate is light rusty brown on fresh surfaces, but is black on the weathered surface due to the decomposition of lichens. The pebbles and cobbles in the conglomerate are composed of red, buff, and white quartzite, black limestone, sandstone, and vein quartz. The matrix consists of a fine- to medium-grained subrounded sand, cemented with calcium carbonate. The conglomerates are massive and show some cross bedding. They are very resistant and form steep, high cliffs.

The sandstone is a light yellowish brown on fresh surfaces and is composed of medium- to coarse-grained subangular to subrounded grains of quartz. For the most part it is massive and shows good cross bedding. The sandstone contains numerous conglomerate lenses, which are similar to the ones just described.

The middle unit is about 1000 feet thick, and is composed mainly of sandstone with some thin beds of conglomerate near the base and some limestone and shale near the top. The sandstone is buff to light brownish-gray and is fine- to medium-grained. It is composed mainly of subangular to subrounded quartz grains. These beds show good to fair sorting and some cross bedding. Beds of oncolites occur toward the upper part of this unit. Oncolites are round or oval bodies composed of calcium carbonate that is deposited in concentric layers around a nucleus such as a pelecypod shell. They are formed by algae and are quite distinctive of the North Horn formation. Oncolites occur scattered throughout the sandstones and limestones, and in some places occur in such high concentrations that they form "oncolite conglomerates". This thick series of sandstones begins to grade into siltstone and shale, in which there are some thin limestone beds. The shales are mostly gray, but some are dark orange or red. They are very friable and contain only a small amount of calcium carbonate. The limestones are arenaceous and light to medium gray on fresh surfaces.

The top unit in the North Horn formation is 96 feet thick and is composed mainly of alternating beds of limestone and shale. The limestones are yellowish-gray and arenaceous. The shales range from gray to red, are calcareous, and contain a few limestone nodules. The contact between the top unit of the North Horn formation and the overlying Flagstaff limestone is gradational.

In the center section of Confusion Gulch, the North Horn lies above red debris of the Twist Gulch formation. This area is structually complicated and parts of it are covered by rubble. For these reasons, a section was not measured here, but a traverse was made by the writer to determine the lithology of the formation in that area. The North Horn formation is divided into three sections by two areas of rubble. These outcrops show that the lithology is similar to that exposed on the south wall of the gulch.

The lowest unit exposed in the center section of Confusion Gulch above the Twist Gulch formation is composed of conglomerate with interbedded sandstone. The sandstone beds have the same composition and texture as the matrix of the conglomerate. There is little or no graded bedding, but there is some cross bedding in the sandstone. These rocks are more highly jointed than the same rocks on the south wall. The average attitude of the joints in the center section is N. 78° W., 83° N.E. No attitudes were taken of the joints on the south wall because they are poorly developed.

The middle and top exposed sections show the gradation from coarse to fine clastics described previously for the North Horn. The lower part of the middle unit is composed of conglomerate that grades upward into sandstone and "oncolite conglomerate" with some gray shale at the top (fig. 2). The top section is exposed above the highest rubble cover, and is composed mainly of limestone and shale. It is possible that the highest rubble beds covers a shale unit. The contact between the top section and the Flagstaff formation is again gradational.

The North Horn formation is also present on the north wall of Confusion Gulch. However, its thickness and lithology are quite different than that which was described for the other sections of the gulch. The total thickness of the formation is about 80 feet instead of 1260 feet. Also, it is not composed of coarse detrital material, but instead is mostly limestone. The rocks that show these radical changes in thickness and lithology are separated by a fault. The contact of the North Horn with the Twist Gulch formation is an angular unconformity. This contact is covered by rubble in many places and is not well exposed. The upper contact is conformable with the Flagstaff limestone.

The base of the North Horn formation on the north wall of Confusion Gulch is composed of red calcareous shale. This shale is thin and is not persistent. Above the shale is a yellowish massive limestone, which forms the rest of the unit. The limestone is very fine-grained and unfossiliferous. It is highly jointed, and weathering along these joints gives the rock a spheroidal appearance. The limestone stands out as a major cliff-forming unit.

The next stratigraphic unit above the North Horn formation is the Flagstaff formation. This unit was first described by E. M. Spieker (1925) and is considered to be Late Paleocene and Early Eocene. The type section for the Flagstaff formation is on the slopes of Flagstaff Peak in Sanpete County, Utah. Its thickness there is 1500 feet, but because there is no cap rock, the actual thickness is not known.

The Flagstaff limestone is the highest stratigraphic unit exposed in Confusion Gulch. Its total thickness, measured in Dry Canyon, is about 600 feet. However, because of erosion, only about half of this thickness remains in Confusion Gulch. The Flagstaff limestone has been divided into two lithologic units. The lower unit is the one exposed in the gulch.

The lower unit of the Flagstaff formation is composed almost entirely of limestone, but there are a few thin shale and sandstone interbeds. The limestone is light gray on fresh surfaces and has a fine-grained to microgranular texture. The basal units are somewhat kerogenous in places. The limestone is compact,contains few fossils, and displays conchoidal fracture. This unit characteristically weathers to form three thick, prominent cliffs separated by gentle slopes. These slopes appear to be composed of shale, but on closer examination, it is found that they too, are composed of limestone. The reason for this is that the slope forming units have a higher clay and silt content than the cliff forming units.

These clastic materials weather more rapidly than the pure limestone, and therefore, form the gentle slopes. Besides clay and silt, nodular structures and calcite grains occur in small amounts.

The upper surface of the lower Flagstaff formation forms the top of the Gunnison Plateau in this area. This surface is moderately level and is covered by debris derived from overlying units that are exposed further to the west in the central part of the plateau.

The total thickness of rocks exposed in Confusion Gulch is almost 2200 feet. These rocks represent sediments that were deposited in a continental and marine environment climatically similar to the present day.

The Twist Gulch formation appears to be formed from sediments that were deposited in a marine environment. The red iron oxide cement of the rock shows that the sediments were either derived from a source area of oxidized rocks or deposited in an oxidizing environment. Because of the uniformity of coloration, it seems that the latter theory is the best explanation.

The site of deposition was at considerable distance from the source area because quartz grains are well sorted and highly rounded, and there are few other minerals present besides quartz.

The Indianola and North Horn formations represent sediments that were deposited mainly on flood plains, in river channels, and in lakes. The lower part of the North Horn was derived from a rugged, nearby source, which in places, possibly formed the shore of the North Horn lake. The source rocks may have been Cambrian limestones and quartzites. The upper part of the North Horn represents sediments derived from a source of lower relief. The lake must have been highly turbid as indicated by the presence of oncolites.

The North Horn lake persisted into Flagstaff time. By this time, the rugged source area had become worn down and clastic sediments were replaced by chemical precipitates. The Flagstaff lake was a large shallow body of water that covered most of the state of Utah as well as parts of neighboring states. In this lake, great thicknesses of relatively pure limestone were deposited.

Soft Sediment Deformation

In Confusion Gulch, the rocks of the North Horn formation exhibit structural features that are not ordinarily associated with brittle deformation. These features provide evidence of the deformational history of this formation, and suggest that these rocks were deformed while they were still in a soft or unconsolidated state. The materials that show this soft sediment deformation best are the conglomerates and sandstones of the lower units of the North Horn formation. The pebbles in the conglomerate have been fractured in an interesting way and the sandstone beds exhibit close folding. The latter will be discussed first.

The North Horn formation, as a whole, has been tightly folded to form a large "S" fold. The strike of the axial plane of this fold is N. 10^{0} E. and its dip is toward the east at a very low angle. This fold is one of the major structural features of the area. However, there is a set of minor folds superimposed on this larger structure, which may be of greater importance. The attitudes of the axial planes of these folds are coincident with those of the larger structure. These folds are best shown by the thin beds of sandstone in the center section of Confusion Gulch (fig. 2). This sandstone is very compact and brittle. The average compressive rupture strength of sandstone is about 740 kilograms per square centimeter (Billings, 1954), which makes it one of the weakest rocks in the crust of the earth. In spite of this, the sandstone beds show wavy folds whose wave lengths are short compared to the thickness of the beds. Under a 10x lens, there appears to be no fractures or joints developed in the sandstone. In other words, a stress has been applied to the sandstone, as well as the whole formation, and instead of yielding like a brittle material, it has deformed as plastic material. Therefore, the sandstone must have been in a semi-consolidated state when the force was applied.

The conglomerates of the North Horn formation also show evidence of soft sediment deformation. As stated before, the conglomerate is composed of pebbles and cobbles in a sandstone matrix. Many of these pebbles have been fractured along preferred directions. There are two basic types of fractured pebbles. The first type have been fractured but show no evidence of movement. These pebbles have been broken, but the matrix has not been disturbed, and the pebbles show no offset (fig. 3). This means that they were deposited in one piece and were broken later, because it is unlikely that broken, fractured pebbles would maintain integrity through transport to the site of deposition. Moreover, conditions had to be met so that the sand composing the matrix would remain undisturbed as the pebbles were fractured.

The second type of fractured pebbles are those exhibiting separation between parts. These pebbles were fractured, the two pieces were separated from each other perpendicular to the fracture surface, and the space between was completely filled with the sand matrix. The sand appears to have flowed around the broken pebbles as slurry, and shows no effects of movement as a brittle material (fig. 4). Again, the pebbles seem to have been broken in place, because the pieces can be put back together to form a complete pebble. From this, it is clear that the conglomerate was deformed while the matrix was still unconsolidated and able to flow.

If it is assumed that the North Horn formation was already lithified when stresses were applied, deformation quite different than that observed would have resulted. First of all, if a brittle material is subjected to a stress, it will deform as an elastic solid up to a point, and if the stress is great enough, the material will eventually rupture. In relation to other rocks, the rupture strength of sandstone is very low. Therefore, instead of a whole series of minor folds, one would expect minor thrust faults and tension cracks to develop. Neither of these were found.

In the case of the conglomerates, if a stress was applied to them that was great enough to fracture pebbles in a hardened matrix, then the matrix itself would be broken, and the fracture would form a joint. There are some joints developed in the North Horn conglomerate, but they are not as common as fractured pebbles. The case of split pebbles filled with sandstone matrix is impossible with a lithified matrix except for the unlikely situation where stress causes the sandstone to become fluid. There is no evidence for such occurrence.

Several requirements must be met for a soft sediment to undergo stress and still keep its integrity. First of all, the material must have been partially consolidated by the removal of much of the interstitial water. Otherwise, the various units would have intermixed and all bedding planes would have been destroyed. The second, and more important requirement is that the material had to be under a high confining pressure. This confining pressure can partially be accounted for by the weight of the overlying units. If it is assumed that these beds were deformed at the same time that the uplift of the Gunnison and Wasatch Plateaus occurred,

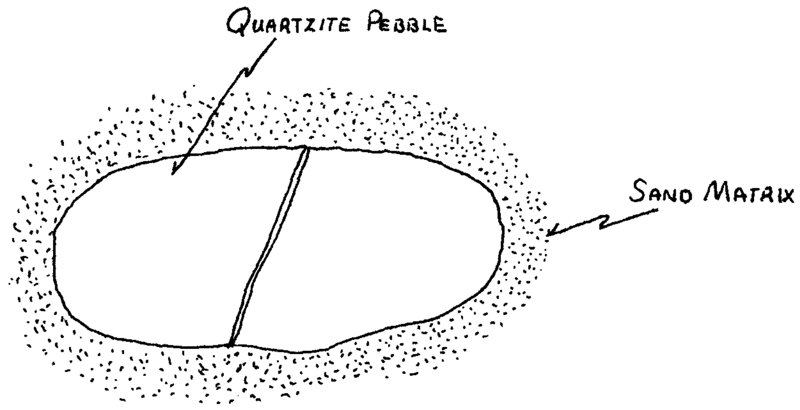


Figure 3. Fractured pebble from the North Horn conglomerate.

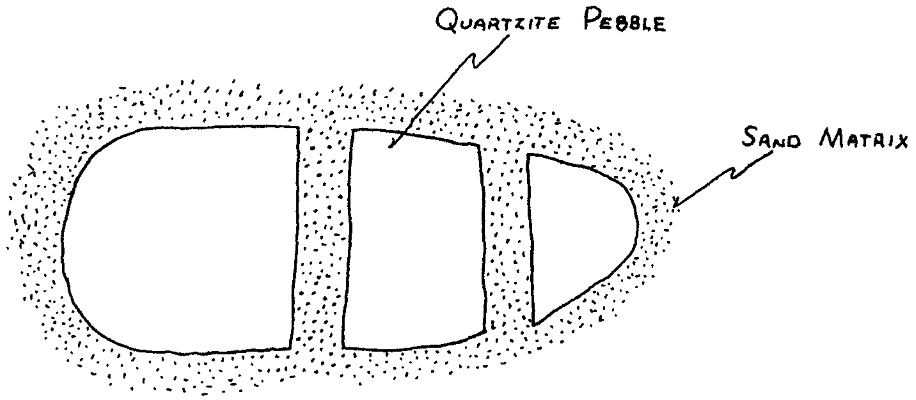


Figure 4. Fractured pebble intruded by sandstone matrix. North Horn conglomerate.

then the total section involved includes the North Horn, Flagstaff, Colton, Green River, and Crazy Hollow formations. All of these formations are exposed in the center of the Gunnison Plateau and at the foot of the Wasatch Monocline. An average stratigraphic thickness of these units is about 3,800 feet or0.7 miles. This thickness of rock alone would exert a tremendous pressure.

Not only does this great thickness of rock exert a pressure due to the force of gravity, but it also exerts a pressure because of its resistance to deformation. In other words, as these rocks are subjected to deformational stresses, their resistance to this deformation increases the confining pressure on the material.

Finally, the force responsible for the deformation also increases the confining pressure on the rocks. This can be compared to the workings of a piston. As the force of the piston compresses the material, the pressure in the chamber is increased. The force that deformed the North Horn formation was directed from the east. This is determined by the attitude of the folds and attitudes of, and the relationship between, the joint sets.

A final point that needs to be considered is the time of final cementation of the North Horn formation. The sediments making up the North Horn were being consolidated and compacted from the moment they were deposited. As a greater and greater thickness of rock was deposited above it, most of the water between the grains must have been forced out.

However, over these millions of years, no cementing agent was available to completely lithify these sediments. Today, the North Horn formation is cemented by calcium carbonate. This calcite may have been present at the time of deposition of the North Horn sediments, but for some reason it was unable to act as a cement until sometime later. It cannot be determined exactly when the cementation took place; however, a range of time can be inferred. Cementation probably occurred toward the end of the deformation or immediately after deformation that inabled the process of cementation to occur. The total time span required to deposit all these units (North Horn formation to Crazy Hollow formation) is from Late Cretaceous to Early Oligocene and represents a minimum of 27 million years (Kulp, 1961). This means that the North Horn formation remained in a semi-consolidated state for at least 27 million years!

Structure

The structures developed in Confusion Gulch are related to the structures of the Gunnison Plateau, and specifically to those developed in the Dry Canyon area. Therefore, the structure and geologic history of this area will be discussed first.

The geologic history of the exposed rocks in the Dry Canyon area began in the Jurassic period. At that time the Twist Gulch formation was deposited, and in Cretaceous time the Indianola formation was deposited above it. Sometime in the Late Cretaceous, these units were uplifted, folded, and partially eroded. Upon their eroded surface, the North Horn formation was deposited in Late Cretaceous or Early Paleocene, forming a striking angular unconformity, which allows us to date this early period of orogeny (fig. 5).

During a relatively long period of calm, the overlying formations were deposited, including the Flagstaff, Colton, Green River, and Crazy Hollow. This depositional period ended in the Late Eocene or Early Oligocene, and a second period of uplift and deformation began. These rocks were folded into broad, flat folds by a force directed from the east that affected all the rocks in the Sanpete Valley area. In the Gunnison Plateau, an asymmetrical anticline and a large, flat syncline were formed. Parts of these two folds form the "S" fold, which is the structure that forms the face of the Gunnison Plateau in the Dry Canyon area (fig. 6). Toward the end of this folding, the Twist Gulch formation was thrusted over the younger Indianola and North Horn formations.

A series of faults developed after the folding, which are possibly related to the folding. In the area of Dry Canyon a graben developed that dropped 580 feet stratigraphically. After this event the Gunnison fault developed, which has an estimated stratigraphic displacement of 10,000 feet. This is a gravity fault and it raised the Gunnison Plateau to its present elevation.

The final events that produced the features seen in the

Dry Canyon area today were produced by erosion and mass movement. Large toreva blocks slid off the steep face of the fault scarp produced by the Gunnison fault. Because of this mass movement and erosion, the front of the plateau has receded about 7,000 feet since it was exposed by the Gunnison fault. Numerous talus slopes have developed below the cliffs formed by the lower unit of the Flagstaff formation. Rock Canyon and Dry Canyon are partly filled with alluvial material that has been disected to form alluvial terraces, which merge into large fans where they enter the Sanpete Valley. This final period of erosion concludes the geologic history of the Dry Canyon area.

Structures of Confusion Gulch

The structuresdeveloped in Confusion Gulch are intimately related to the structures formed in the Dry Canyon area and they are controlled by the deformative properties of soft sediment. The north and south walls of Confusion Gulch exhibit structures similar to the ones just discussed.

The south wall is characterized by a thick sequence of the North Horn formation that represents the lowermost limb of the "S" fold. The north wall of Confusion Gulch represents the southern most limit of the graben block. Here, the North Horn formation is very thin and is composed of carbonate rocks rather than clastics. These two walls are separated by a distance of less than 400 feet, yet the thickness and composition of the North Horn is radically different. A similar situation exists at the northern limit of the graben. One explanation is that at the time of deposition of the North Horn sediments, a horst or elevated area existed at the present site of the graben. This high area remained an elevated surface until the final phase of North Horn deposition. As the horst began to subside a basal conglomerate was deposited on the vertical Twist Gulch formation and this was followed by a thin shale unit upon which the carbonates accumulated. After the overlying units were deposited and the "S" folding was completed, the present day graben formed in the same place that the horst had been.

The center section of Confusion Gulch exhibits structures seen nowhere else in the Dry Canyon area. This section is outside of the graben block and is composed mainly of a thick sequence of rock representing the North Horn formation. However, these rocks are no longer right side up and gently dipping to the west. Instead, they are overturned and dip steeply toward the east.

Beginning with the lowest section of North Horn exposed above the Twist Gulch formation, the maximum dip is 80° S.E. overturned. Continuing up the gulch, the dip changes to 37° S.E. overturned. These rocks are mostly conglomerates that have many fractured pebbles in their matrix. However, there are many closely spaced joints present, which show that this section experienced stress after it was lithified, too.

The middle section of the North Horn formation exposed above the first rubble unit in the center section of Confusion Gulch has a dip ranging from almost vertical to 55° S.E.

overturned. The rocks also show a minor angular unconformity that may represent the position of the shoreline of the old North Horn lake (fig. 2). Rock fall material separates this section from the upper section, whose attitude is the same as that of the North Horn on the south wall. Also, these beds can be traced southward out of Confusion Gulch with no breaks in continuity. This is not the case for the lower sections, where no accurate identification can be made between the rocks of the center section and those of the south wall. In plan view, the dimensions of this section of overturned rock is 400 feet wide and 1,000 feet long.

The most obvious question is what type of structure is developed here and how was it formed? Several hypotheses have been suggested and they will be discussed below.

The first hypothesis deals with mass movement. It is possible thatthe overturned beds represent toreva blocks or some other type of landslide material. There are large amounts of landslide material associated with these rocks and true outcrops are separated by areas of rubble. However, this hypothesis does not seem likely. First of all, the lowermost beds are well preserved and in any type of mass movement, the beds forming the foot of the slide are rarely preserved. Also, the movement appears to be wholly rotational with little down hill movement. The strike of the overturned beds is similar to the strike of the beds on the south wall of Confusion Gulch, but this too is not likely to occur in slide material.

A second hypothesis is that these beds represent an overturned "S" fold. The fold was produced in a manner similar to that on the south wall of Confusion Gulch. However, it was later rotated about 90° toward the west to produce the overturned beds that are present today (fig. 2). This theory seems plausible because if the beds exposed in the center section are connected to one another they form an "S" fold that is similar to one on the south wall of Confusion Gulch. This theory also explains why the bedding is so well preserved, and why there is no change in the strike of these beds from one section of the gulch to another. Since these beds were more deformed they developed a greater number of joints. These joints are oriented in such a waythat they suggest the force that caused the deformation was directed from the east. Abundance of cross bedding and some graded bedding prove that these beds are indeed overturned. Also, many of the oncolites are bowl shaped and most of these were deposited with their concave side down. Therefore, today, the concave sides point toward the bottom of the bed.

If the structure in the center section of Confusion Gulch is truly an overturned "S" fold, how did it form? This section of the gulch is bounded on the north side by the graben fault and on the south by a hinge fault. It seems possible that the formation of the graben, which occurred after the folding, was the cause of this overturning. The graben itself has formed in a peculiar manner.

As the graben formed, its center did not drop vertically or away from its attached end, but instead, it moved down and toward the west. This westward movement is toward the rear of the graben. To make room for the displaced material, a long shallow syncline developed on the graben block parallel to the Gunnison front. This shows that as the graben block subsided it was subjected to a compressive force from the east. It is this shearing motion between the graben block and the adjacent wall that formed the overturned part of the "S" fold.

Conclusion

The formation of this overturned "S" fold in Confusion Gulch is dependent on the fact that the materials being overturned were in a soft state. Brittle material like sandstone would have been ground up and a breccia zone would have replaced the "S" fold. However, soft sediment under high confining pressure could maintain its integrity as it was being sheared.

This report has attempted to show how the presence of soft sediment in the North Horn formation has been responsible for many of the structures developed in Confusion Gulch, as well as those of the Gunnison Plateau itself. On a small scale it has been responsible for the minor folds in the North Horn sandstone and the fractured pebbles in the conglomerate. On a larger scale it has been partially responsible for the large, tight "S" fold that forms the eastern face of the Gunnison Plateau and for the overturned "S" fold in the center section of Confusion Gulch. It is clear that soft sediment deformation is important to the geologic history of the Gunnison Plateau.

Figure 8. Red Twist Gulch formation. Massive sandstone stands out as ridges. North wall of Dry Canyon.

Figure 2. Overturned beds of the North Horn formation in the center section of Confusion Gulch.

Figure 5. Angular unconformity between the Indianola and North Horn formations on the south wall of Confusion Gulch.

Figure 6. "S" fold in the Flagstaff formation on the north wall of Rock Canyon.

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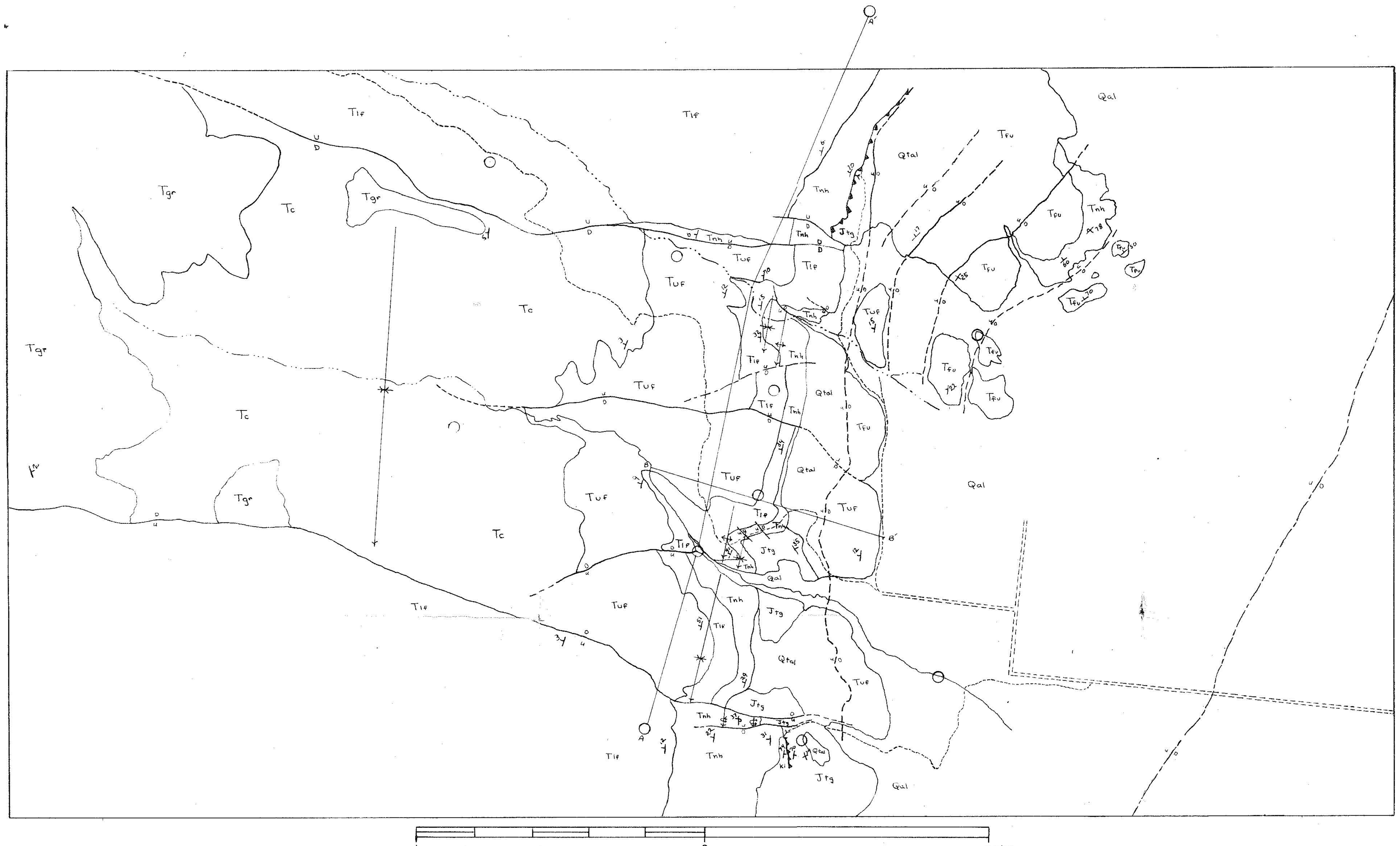
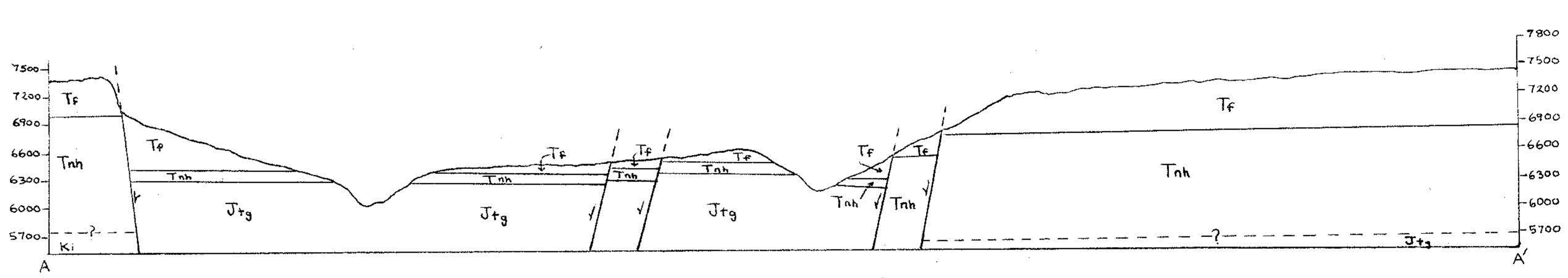
GEOLOGIC MAP OF DRY CANYON, SAN PETE COUNTY, UTAH

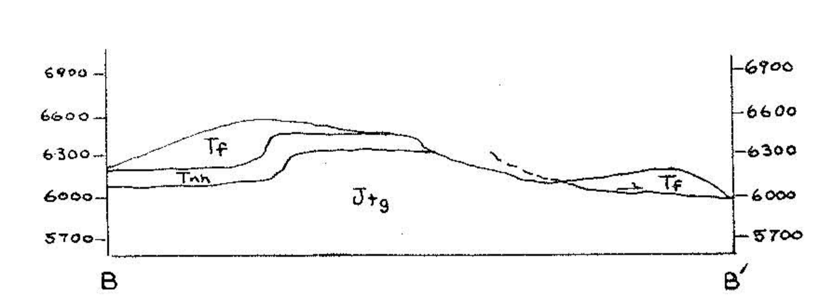
COMPILED BY J. HIATT, R. RICE, R. VAN HORN

AUGUST 9, 1967

SCALE 1:24,000







EXPLANATION

QUARTERNARY
- Qal — ALLUVIUM
- Qtal — TALUS

TERTIARY
- Tgr — GREEN RIVER FORMATION
- Tc — COLTON FORMATION
- Tuf — UPPER FLAGSTAFF FORMATION
- Tlf — LOWER FLAGSTAFF FORMATION
- Tnh — NORTH HORN FORMATION

unconformity

CRETACEOUS
- Ki — INDIANOLA

FAULT

JURASSIC
- Jtg — TWIST GULCH FORMATION

CONTACT

FAULT

FAULT, Location not certain

FAULT taken from air photo

THRUST FAULT

IMPROVED DIRT ROAD

UNIMPROVED DIRT ROAD

STREAM

INTERMITTENT STREAM

ATTITUDE

ANTICLINE, OVERTURNED ANTICLINE

SYNCLINE, OVERTURNED SYNCLINE

ADIT