PETROLOGY, SEDIMENTOLOGY AND STRATIGRAPHIC IMPLICATIONS OF THE ROCK CANYON CONGLOMERATE, SOUTHWESTERN UTAH

by

R. LaRell Nielson

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ACKNOWLEDGEMENTS

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PETROLOGY, PETROGRAPHY, AND STRATIGRAPHIC IMPLICATIONS OF THE ROCK CANYON CONGLOMERATE SOUTHWESTERN, UTAH

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ABSTRACT

Deposition of the Rock Canyon Conglomerate in southwestern Utah and northwestern Arizona resulted from infilling of topography that was cut during the late Permian and early Triassic Periods. Three lithofacies are recognized in the Rock Canyon Conglomerate: 1) a chert pebble conglomerate characterized by lens shaped deposits of cross-bedded lithic conglomerate and quartz wacke deposited as point bars in fluvial channels and alluvial fans; 2) a chert pebble breccia characterized by circular deposits of cross-bedded siliceous and calcareous breccia deposited in doline features; 3) thin breccia and conglomerate deposits, exhibiting irregular lamination and pisoliths produced by pedogenic processes. Analysis of the conglomerate and breccia clasts indicates that they were derived from the underlying Kaibab Formation and not from older stratigraphic units. Clast and cross-bedding orientation studies of the chert pebble conglomerate suggest that the Triassic fluvial channels in southwestern Utah flowed toward the northeast. Paleovalleys, up to 100 m deep, were cut into the Harrisburg Member of the Kaibab Formation. Maximum thickness of the conglomerates is 30 m in the paleochannels. The conglomerate is not present on the positive areas between the channels. The Rock Canyon Conglomerate was deposited in fluvial channels, alluvial fans and fan deltas that were cut as the result of regional tilting and erosion of southwestern Utah, southeastern Nevada and northwestern Arizona during the late Permian and/or early Triassic Periods. Uplift and tilting in southwestern Utah were not sufficient to allow dissection through the Kaibab Formation. Fluvial deposits of the Rock Canyon Conglomerate interfinger with the Timpoweap and Lower Red members of the Moenkopi Formation. This indicates that the Rock Canyon Conglomerate continued to be derived from the positive areas between the channels after the transgression of the Triassic Moenkopi Sea.

INTRODUCTION

Irregular lens shaped deposits of conglomerate are present along the Permian-Triassic boundary in southwestern Utah (fig. 1). These conglomerate deposits were first noted and named the Rock Canyon Conglomerate by Reeside and Bassler

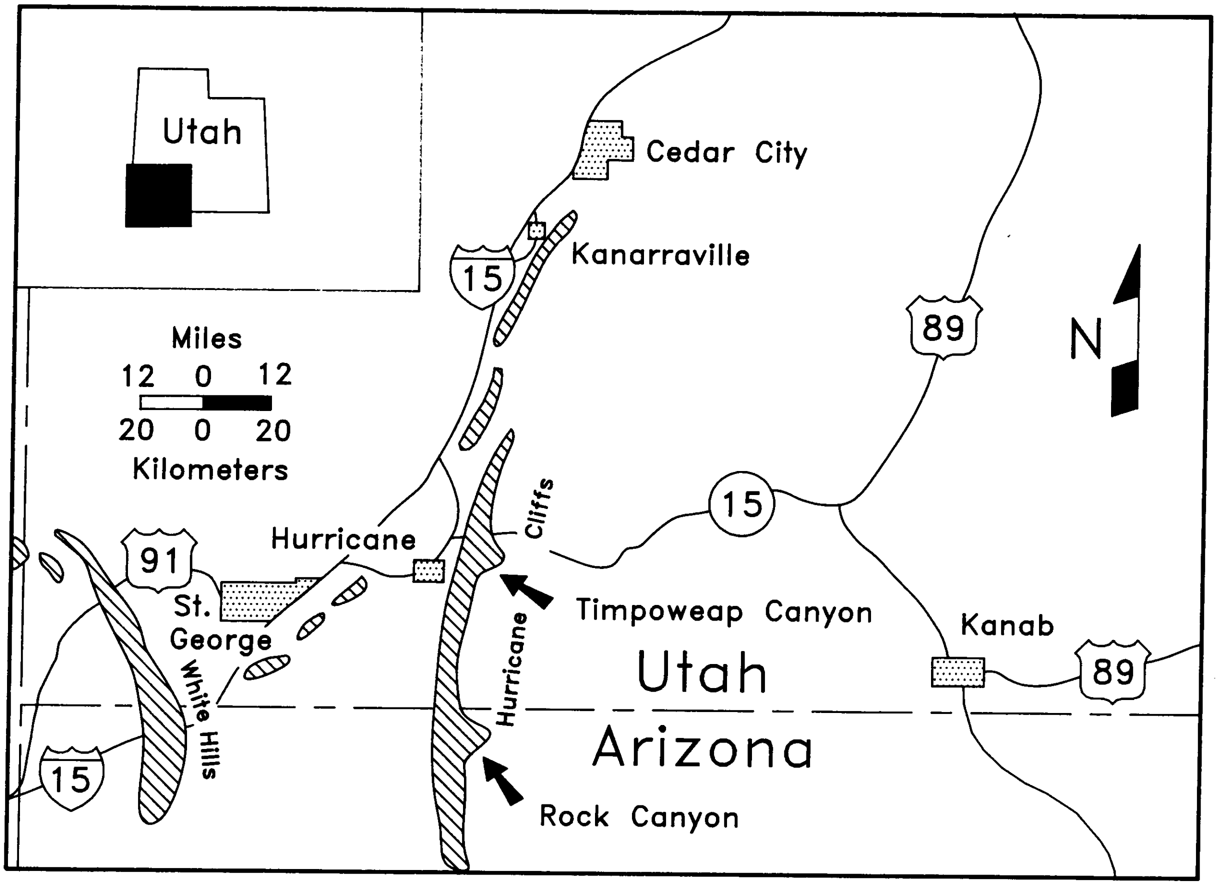

Figure 1. Index map of the study area showing the locations where the Rock Canyon Conglomerate crops out.

(1921, p. 60). Reeside and Bassler (1921) placed the Rock Canyon Conglomerate as the lowest unit in the Moenkopi Formation and divided the Moenkopi into six members which are: the Rock Canyon Conglomerate, Lower Red Member, Virgin Limestone Member, Middle Red Member, Shnabkaib Member and Upper Red Member. Gregory (1950 p. 54), after examining the Rock Canyon Conglomerate at its type section in Rock Canyon, felt that the Rock Canyon Conglomerate was of Permian age and suggested that the name be abandoned and replaced by Timpoweap Member of the Moenkopi Formation. He proposed that exposures in Timpoweap Canyon be used as the type area. Mckee (1954 p. 12-13) considered the conglomerate to be the first phase of Triassic deposition. Study of the type area of the Timpoweap Member by Nielson and Johnson (1979) resulted in the definition of four reference sections for the Timpoweap Member in Timpoweap Canyon. Reference sections R-1,2,3 show a marine limestone, siltstone, limestone sequence for the Timpoweap Member as described by Gregory (1950). However, reference section R-4 shows the same conglomerate sequence found in Rock Canyon by Reeside and Bassler (1921). Nielson and Johnson (1979) placed the conglomerate in the Timpoweap Member. During his study of the oil-impregnated sands of the Timpoweap Member, Blakey (1979) noted that the Timpoweap Member was not present west of the Hurricane Cliffs in southwestern Utah. Nielson (1981) noted the presence of the Rock Canyon Conglomerate west of the Hurricane Cliffs but found no Timpoweap Member in that area. In the White Hills west of St. George, Utah, the Lower Red Member of the Moenkopi Formation is locally absent and the Virgin Limestone Member is in contact with the Kaibab Formation.

The objectives of this study are: 1) study the lithologies, distribution, stratigraphic relationships and depositional environments of the Rock Canyon Conglomerate in southwestern Utah and northwestern Arizona; 2) determine the stratigraphic relationship of the Rock Canyon Conglomerate to the Harrisburg Member of the Kaibab Formation below the Permian-Triassic boundary and Timpoweap, Lower Red and Virgin Limestone members of the Moenkopi Formation above; 3) study the patterns of sedimentation along the Permian-Triassic boundary; and 4) relate the sedimentary history of these units to the tectonic activity during late Permian and early Triassic Periods.

STRATIGRAPHY

Kaibab Formation

The Kaibab Formation in southwestern Utah can be divided into two members. The lower member is the Fossil Mountain Member that is a diagenetically altered fossiliferous packstone with disseminated, ribbon and nodular chert. In southwestern Utah and northern Arizona, it weathers to form a cliff. Above the Fossil Mountain Member is the Harrisburg Member of the Kaibab Formation. It can be divided into seven stratigraphic units: unit one is a thick bedded limestone (fossiliferous wackestone) that weathers to form a cliff above the Fossil Mountain Member. Unit two consists of gypsum west of the Hurricane Cliffs and dissolution breccia, chert bearing dolostone and siltstone east of the Hurricane Cliffs. Unit three is a stratigraphic marker that contains thin to thick bedded dolomitized limestone (fossiliferous mudstone) that grades upward into chert and weathers to form a cliff. Folds present in unit three, were produced by dissolution of the gypsum in unit two before deposition of unit four. The irregular topography present on unit three is filled by sediments of unit four. Unit four is a slope forming unit that in many places contains limestone lenses surrounded by siltstone or sandstone. Unit five, is a massive diagenetically altered limestone (fossiliferous mudstone) that has been partly removed by late Permian and early Triassic erosion so that

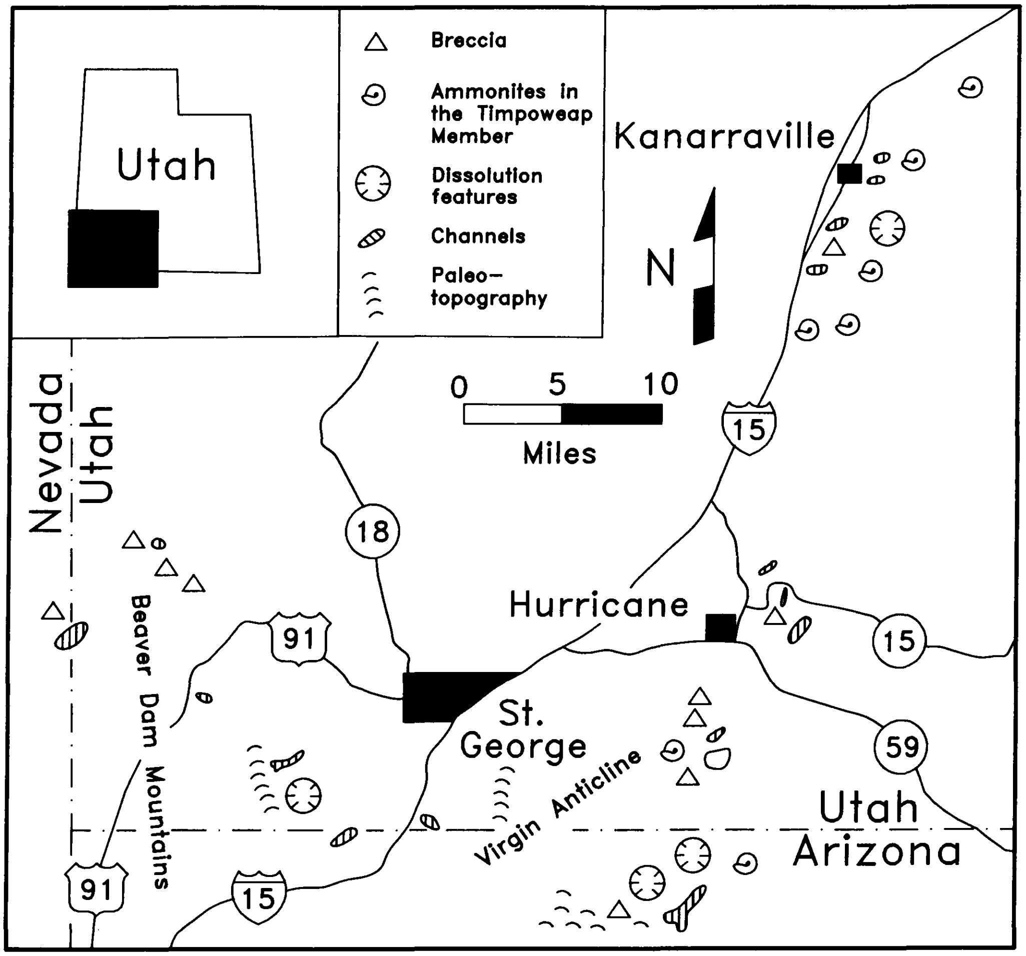

Figure 2. Map showing locations of the different facies of the Rock Canyon Conglomerate in southwestern Utah, southeastern Nevada and northwestern Arizona.

it is not present at every location. Unit six is a siltstone that is variable in thickness. The highest unit is unit seven that is found only on the Permian paleogeographic highs in southwestern Utah. It is a fossiliferous mudstone that contains brachiopods, crinoids, gastropods, bivalves and bryozoans. It weathers to form a massive cliff and is a key marker bed in the Harrisburg Member. Near Rock Canyon, Arizona units five and six have been impregnated at certain locations with oil ("tar sand").

Permian-Triassic Erosion Surface in Southwestern Utah

The Permian-Triassic boundary is marked by what locally appears to be a disconformity, but when studied regionally, is an angular unconformity along which topographic highs and erosional lows (valleys) were produced by erosion during the late Permian and Triassic. Up to 100 meters of late Permian and early Triassic dissection has been observed in the eastern Beaver Dam Mountains along West Mountain Valley Wash. In West Mountain Valley Wash, Permian erosion down-cuts to the Fossil Mountain Member of the Kaibab Formation removing the Harrisburg Member of the Kaibab Formation. Erosion at most locations reaches to unit three of the Harrisburg Member of the Kaibab Formation.

Rock Canyon Conglomerate

The Rock Canyon Conglomerate contains three lithologies (fig. 2). The first lithology is a cross-bedded conglomerate, sandstone and siltstone that exhibits an over-all lens shaped geometry and weathers to form a cliff. Within the conglomerate are smaller lenses that contain planar and trough cross-bedding. The conglomerate at some locations grades upward into laminated breccia and is described as facies three (fig. 3 and 4). The conglomerate has a northeast orientation as determined by cross-bedding, clast orientation and channel geometry data (fig. 5 and 6). Channel complexes vary in width from one kilometer across to 30 meters. The most extensive channel complex is present at the east end of Rock Canyon between the Honeymoon Trail and the cliff cut in the Fossil Mountain Member of the Kaibab Formation west of its junction with Cottonwood Wash (fig. 7). This was the location designated by Reeside and Bassler (1921) as the type section of the Rock Canyon Conglomerate. Additional deposits of conglomerate are located east of where Camp Creek crosses the Hurricane Cliffs near Kanarraville, north of the entrance to the Kolob Canyon Section of Zion National Park along Taylor Creek, in central Timpoweap Canyon east of the diversion dam and south of the Three Brothers. The thickest conglomerate deposits are found along the Hurricane Cliffs. An eastward fining trend from conglomerate to sandstone was noted in Timpoweap Canyon and along Taylor Creek (fig. 8).

Lens shaped deposits, which exhibit a dendritic pattern, are seen in West Mountain Valley Wash and along the south side of the Virgin Gorge west of the Black Rock exit of Interstate 15. Other minor channels were noted on the northeast side of Scarecrow Peak and north of Pakoon Flat south of the Motoqua road.

Lithology two of the Rock Canyon Conglomerate consists of circular deposits of lithic breccia (fig. 9 and 10). These deposits have cross-bedding that dip toward a central point and are observed in West Mountain Valley wash and along Spring Creek southwest of Kanarraville, west of the Fossil Mountain cliff in Rock Canyon, and Curly Hollow Wash west of St. George (fig 11). The third lithology consists of irregular thin beds of breccia that show laminations (fig. 12). Cement is often a white vuggy laminated calcite. Pisoliths and ooliths are common and in some locations this facies

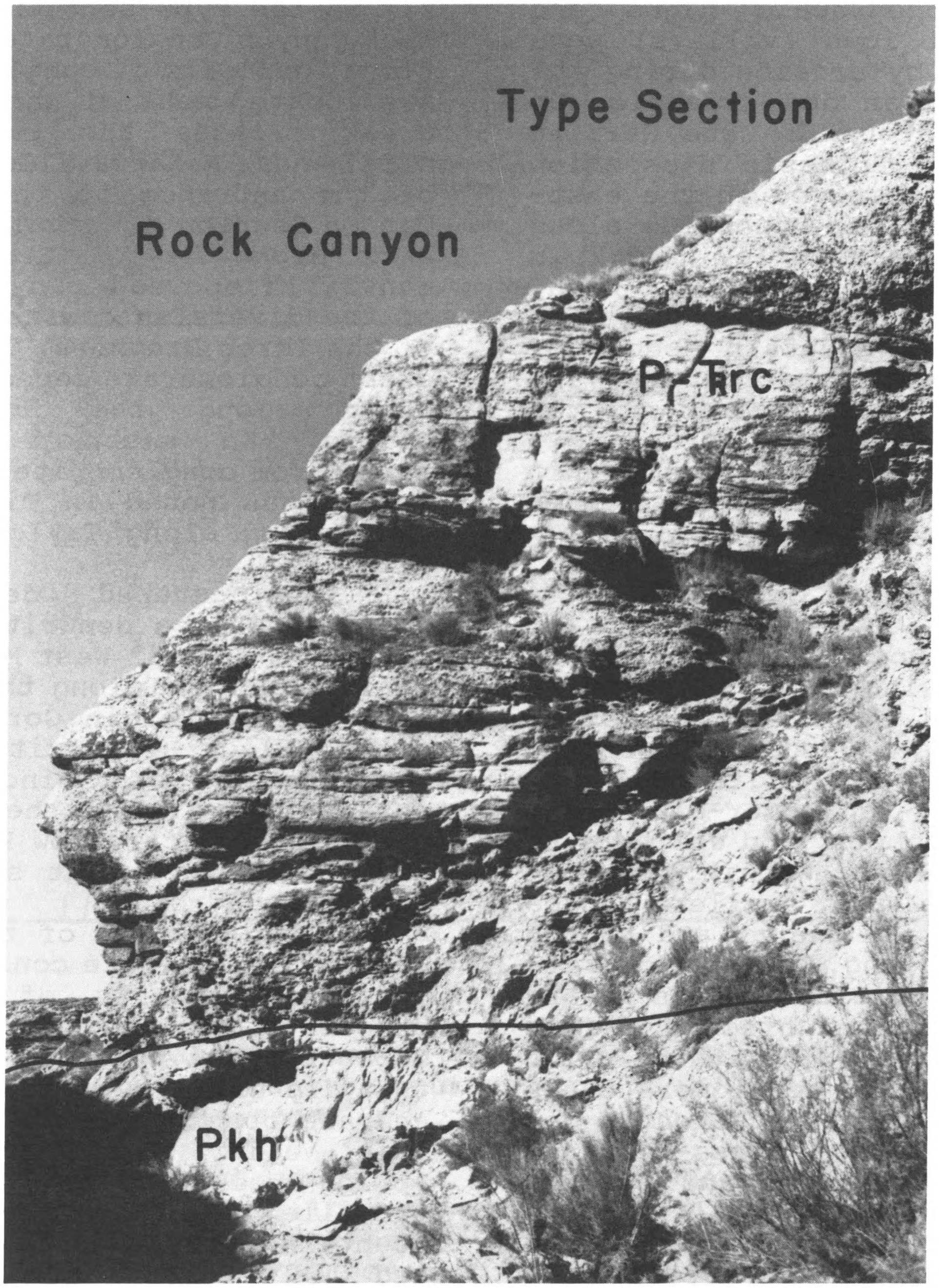

Figure 3. Type section of the Rock Canyon Conglomerate south of Hurricane, Utah. Note the lens shaped geometry and cross-bedding of the conglomerate. Pkh, Harrisburg Member Kaibab Formation; P-$T_R$rc, Rock Canyon Conglomerate.

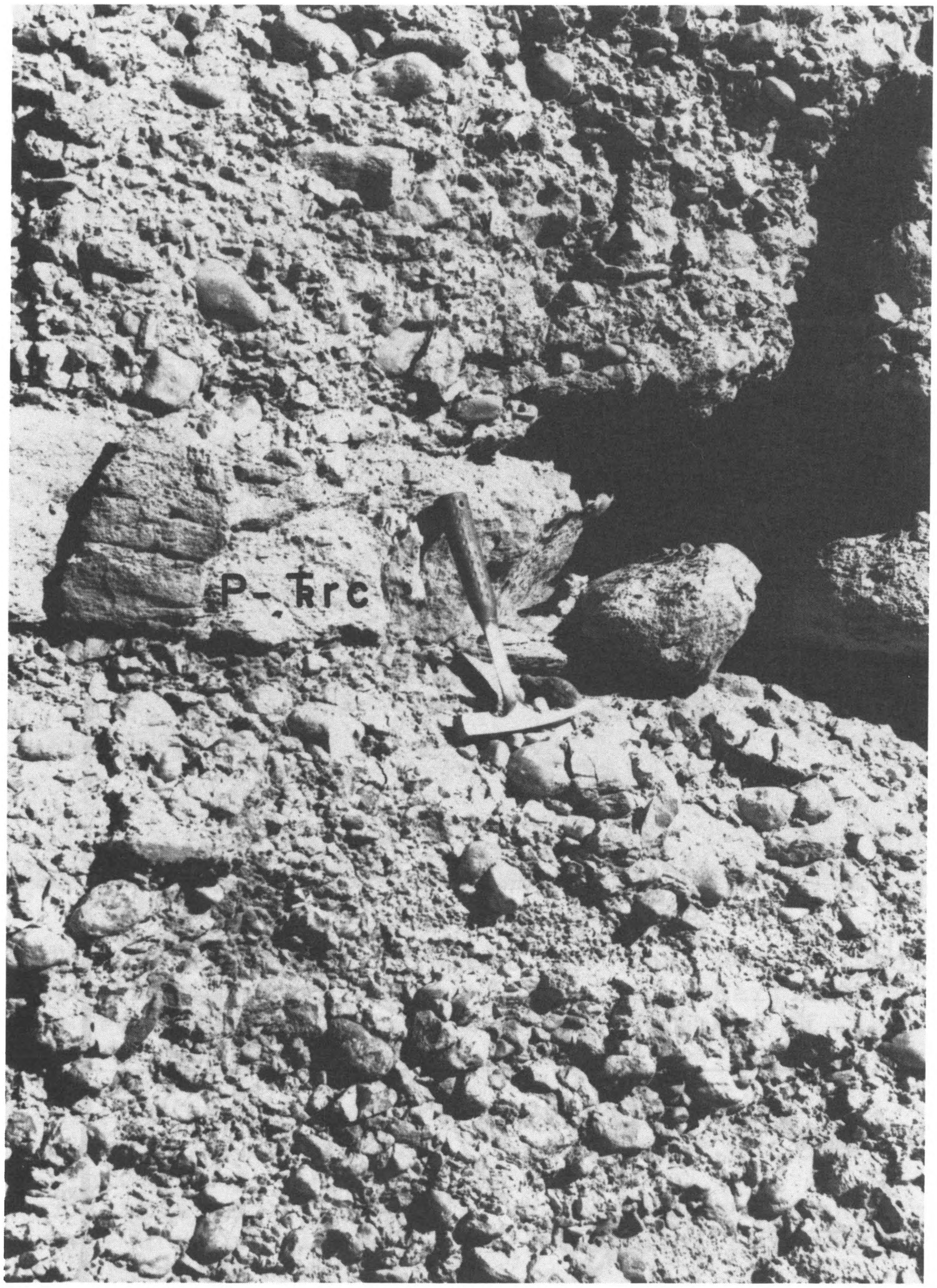

Figure 4. Chert pebble conglomerate of the fluvial alluvial fan and fan delta facies. P-$T_R$rc, Rock Canyon Conglomerate.

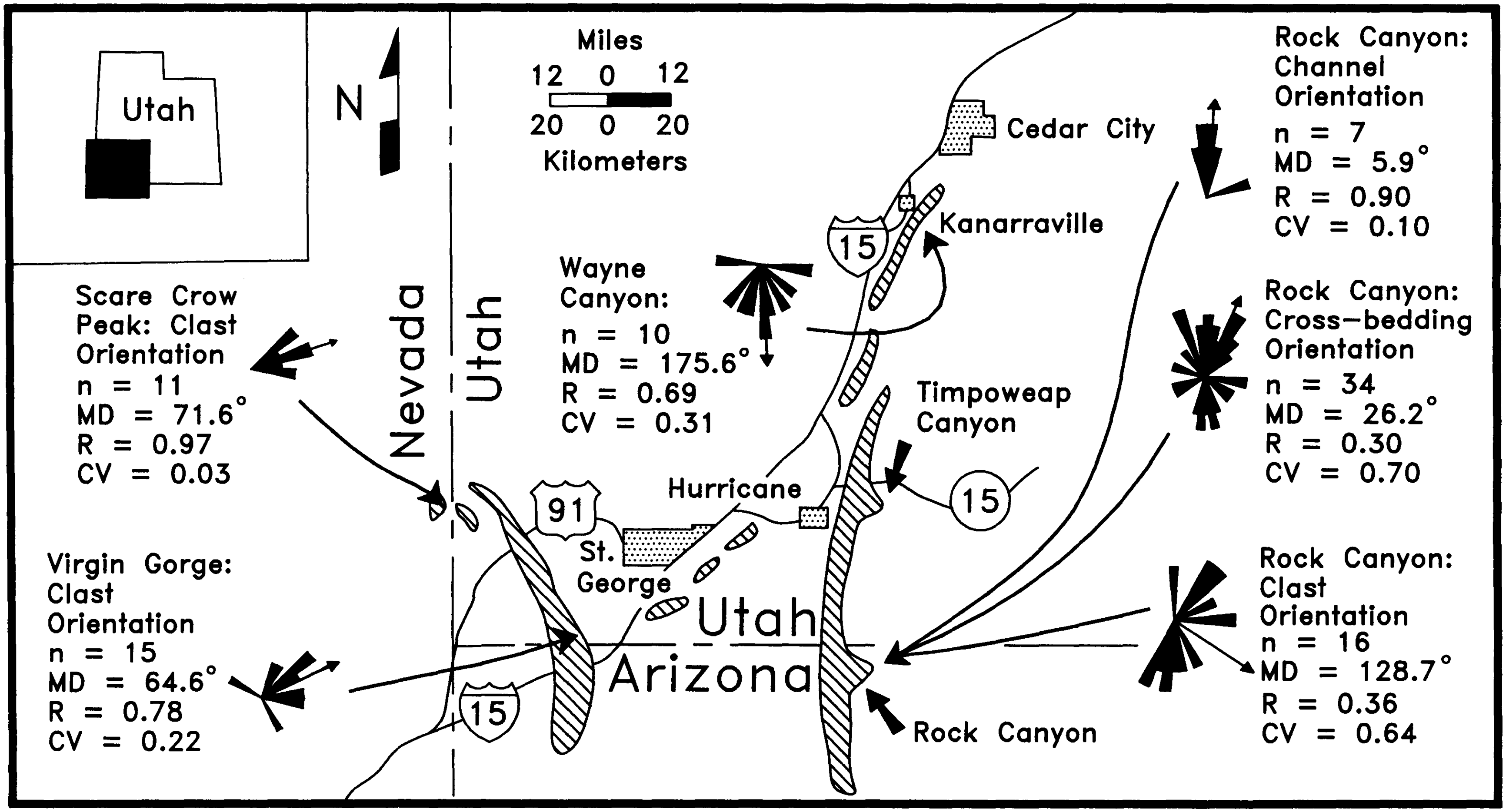

Figure 5. Cross-bedding, clast orientation and channel orientation measurements from the Rock Canyon Conglomerate indicate the development of northeast-southwest drainage pattern.

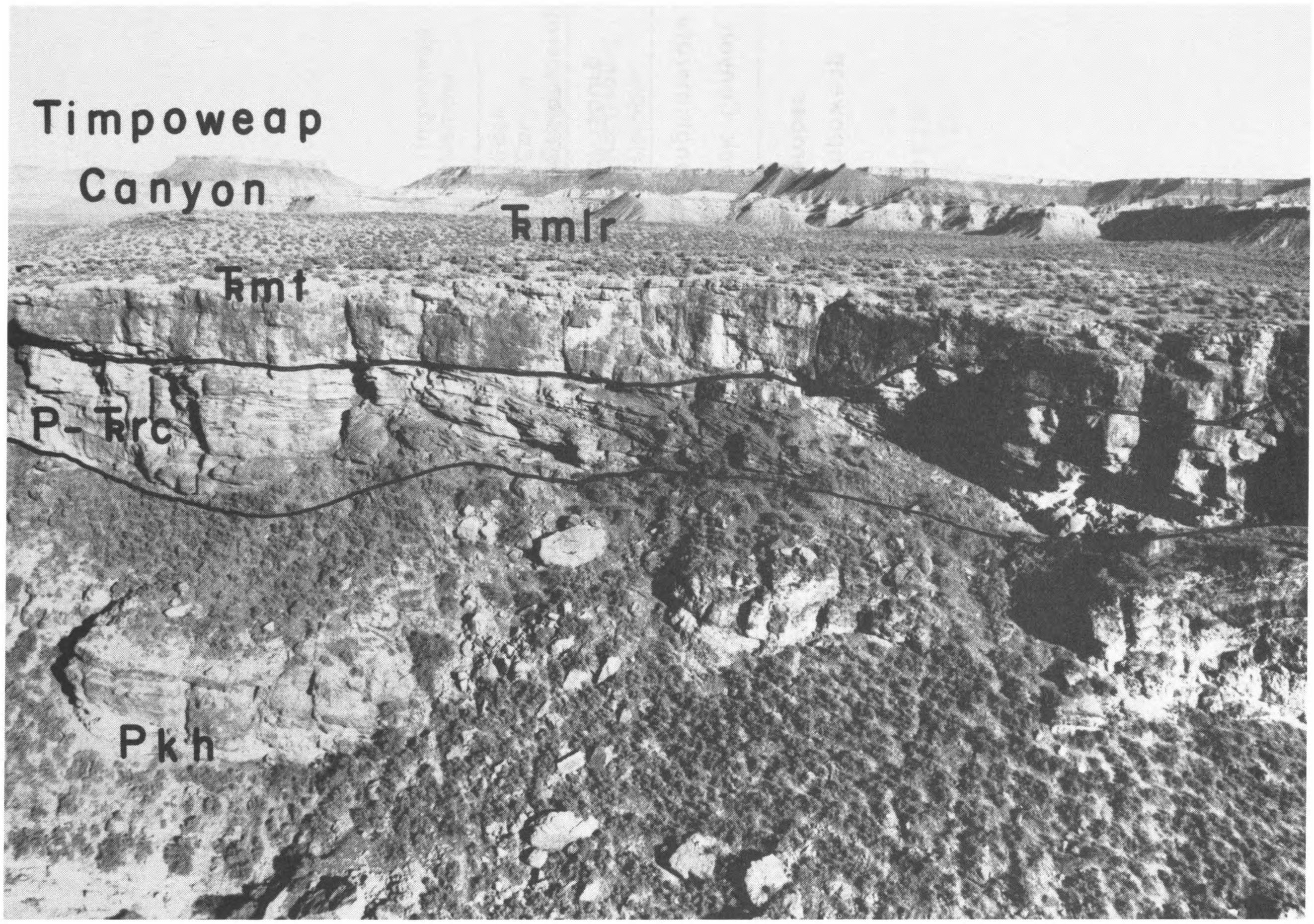

Figure 6. Cross-bedding present in the P-$T_R$rc, Rock Canyon Conglomerate in Timpoweap Canyon, Utah. Pkh, Harrisburg Member of the Kaibab Formation; $T_R$mt, Timpoweap Member of the Moenkopi Formation.

contains sand. Distribution of this facies is irregular and is in close proximity to the Triassic positive areas. It grades upward into the limestone of the Timpoweap Member of the Moenkopi Formation. Examples of this facies are seen south of Molley's Nipple, at the south end of the Three Brothers, along Murrie Creek north of Kanarraville, Utah and along the north side of Pakoon Flat in the Beaver Dam Mountains west of St. George, Utah.

Rock Canyon Conglomerate-Moenkopi Formation Contact

The contact between the Rock Canyon Conglomerate and the Moenkopi Formation in southwestern Utah is controlled by the location of the Permian-Triassic positive areas(fig. 13 and 14). East of the Hurricane

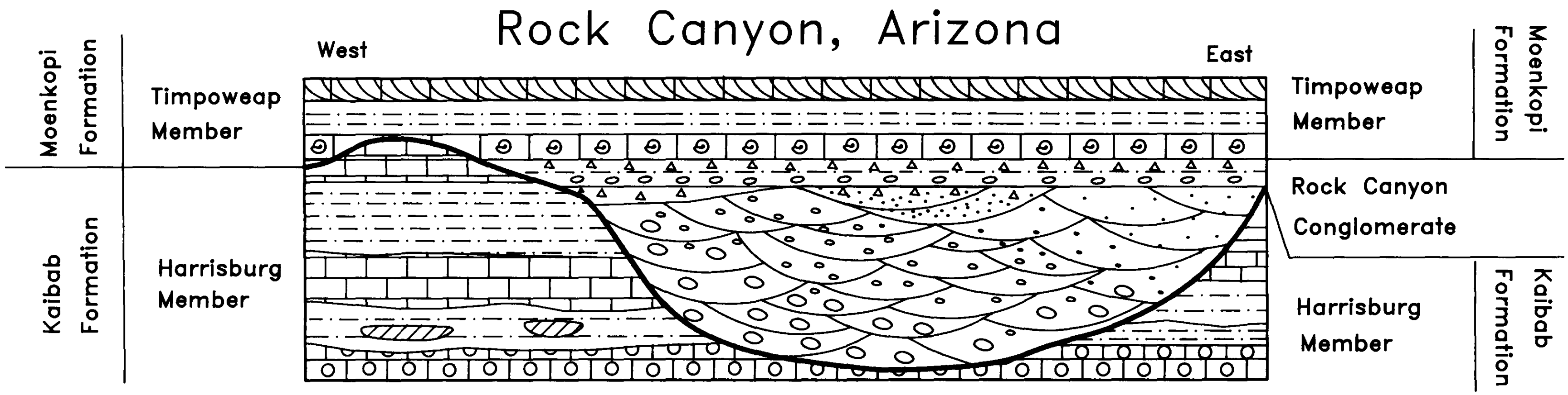

Figure 7. Fluvial facies of the Rock Canyon Conglomerate is illustrated by this generalized diagram of Rock Canyon.

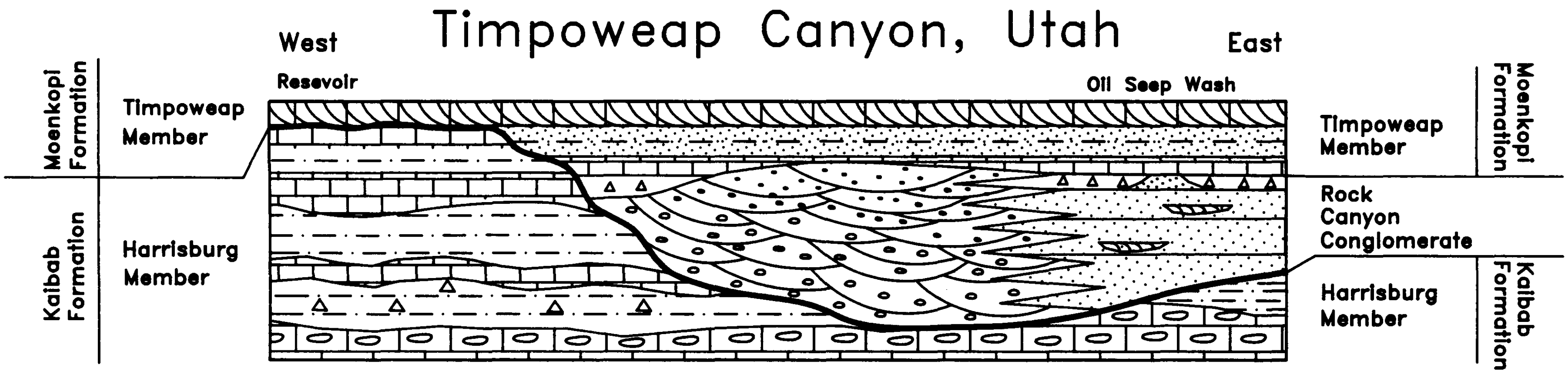

Figure 8. Generalized cross section of the central part of Timpoweap Canyon showing the facies change from coarse clastic sediments to sand sized clasts. This illustrates alluvial fan to fan delta deposition in the Rock Canyon Conglomerate.

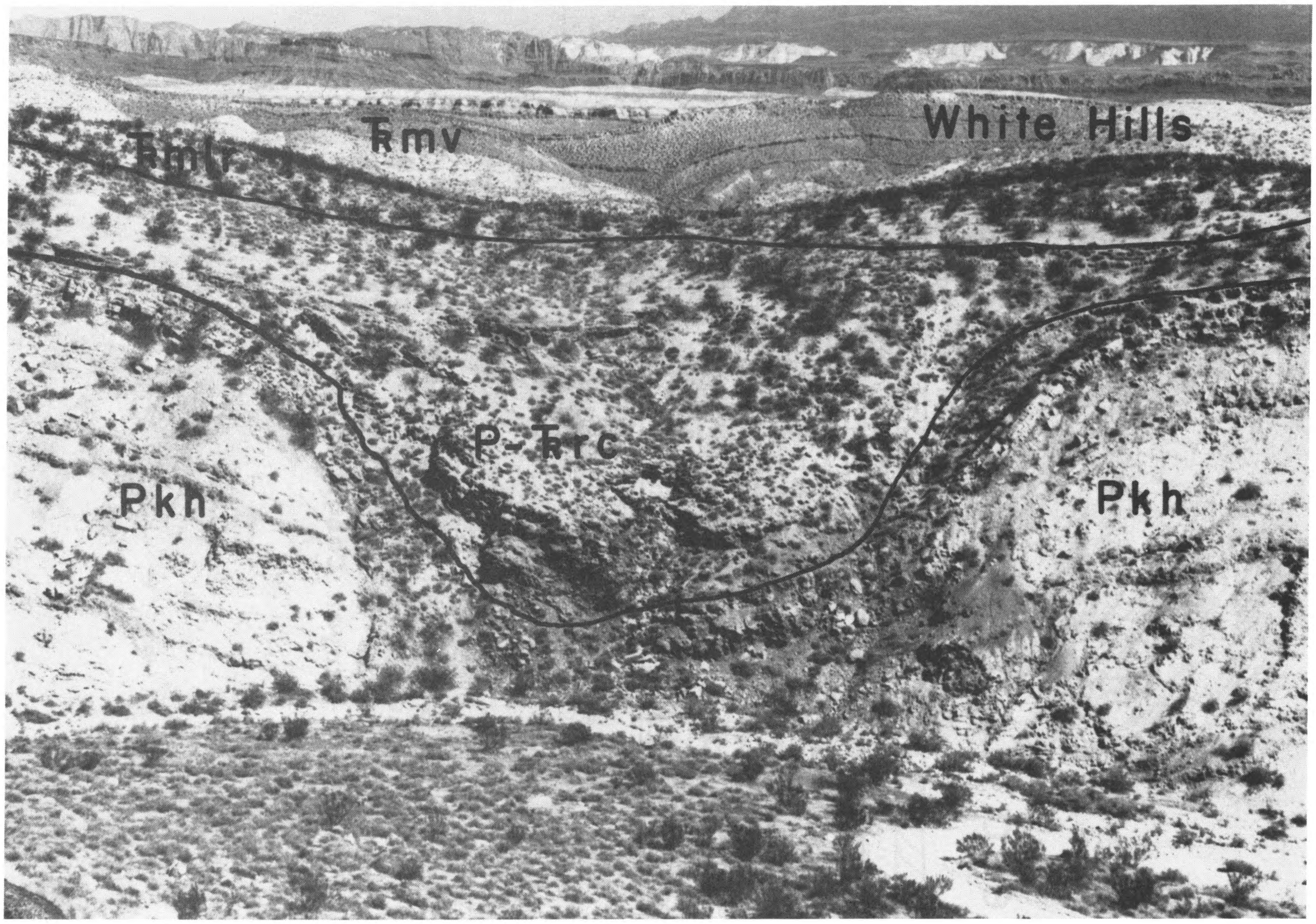

Figure 9. Permian-Triassic dissolution feature that has been filled with angular and subangular cross-bedded breccia seen along the northeast side of West Mountain Valley Wash west of St. George, Utah. Pkh, Harrisburg Member of the Kaibab Formation; P-$T_R$rc Rock Canyon Conglomerate; $T_R$mlr, Lower Red Member of the Moenkopi Formation; $T_R$mv, Virgin Limestone Member of the Moenkopi Formation.

Cliffs, the contact between the Rock Canyon Conglomerate and the Timpoweap Member of the Moenkopi Formation is gradational. The upper conglomerate facies grades into the laminated pisolith facies which grades into the limestone facies of the Timpoweap Member. The Timpoweap Member is only present east of the Hurricane Cliffs and north of Rock Canyon. In the area between the Hurricane Cliffs and the Utah-Nevada state line, the Harrisburg Member of the Kaibab Formation is in contact with the Lower Red Member of the Moenkopi Formation. No exposures of the Timpoweap Member were found in this area. The conglomerate and breccia of the Rock Canyon Conglo-

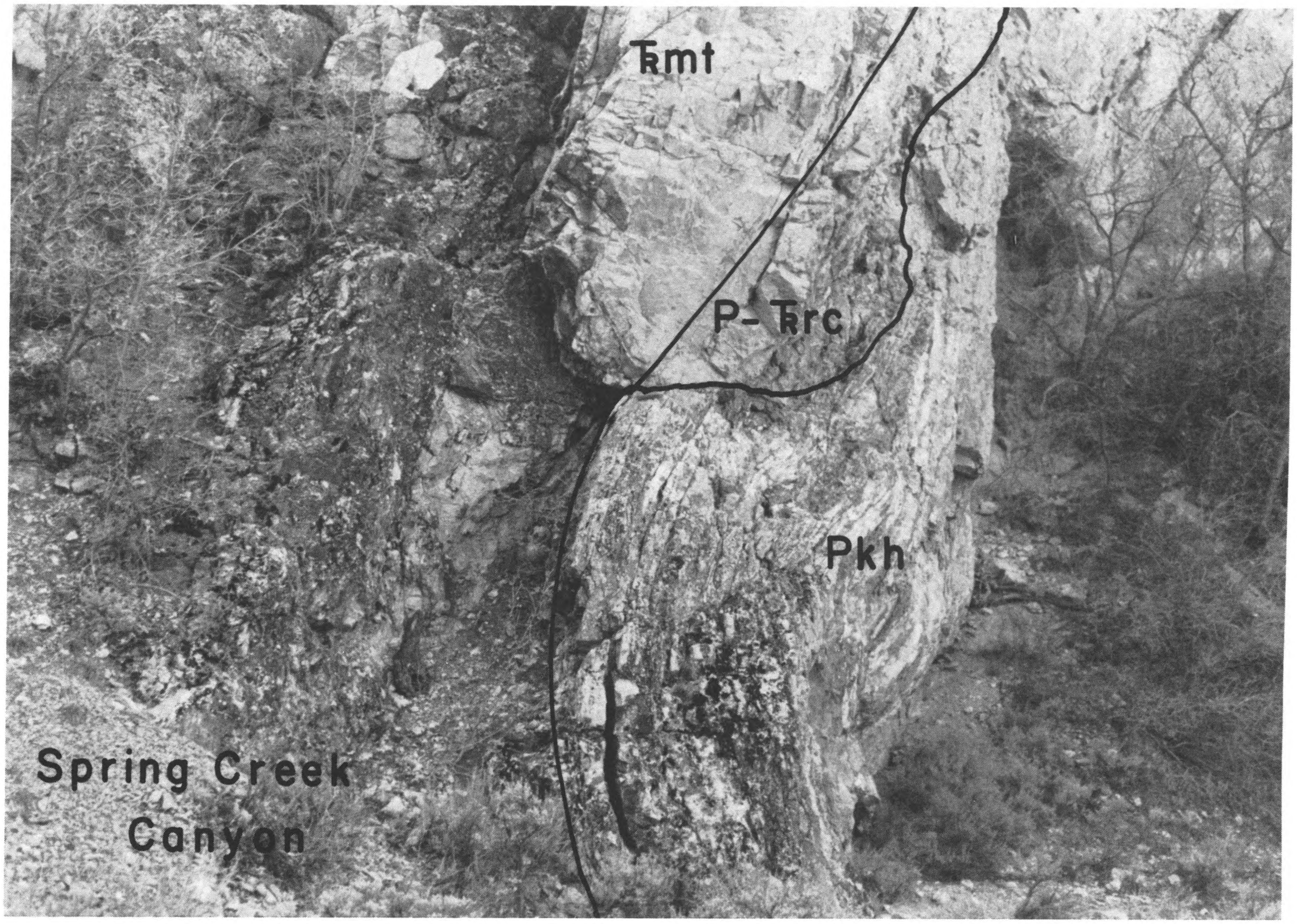

Figure 10. Sinkhole filled with breccia that has been reworked by Triassic seas in Spring Creek Canyon south of Kanarraville, Utah. Pkh, Harrisburg Member of the Kaibab Formation; P-$T_R$rc, Rock Canyon Conglomerate; $T_R$mt, Timpoweap Member of the Moenkopi Formation. Stratigraphic units seen in the photo were tilted during the Cretaceous by the Larmide Orogeny.

merate are present as lenses and circular deposits of conglomerate and breccia. Deposition of the Timpoweap Member did not occur in the southwestern corner of Utah indicating that it remained as a positive area during Timpoweap deposition. In the White Hills west of Bloomington, gypsum of the Harrisburg Member is in contact with the Virgin Limestone Member of the Moenkopi Formation suggesting that Permian-Triassic positive areas were still present during deposition of the lower part of the Virgin Limestone Member. However, no conglomerate or breccia was found along the contact (fig. 15).

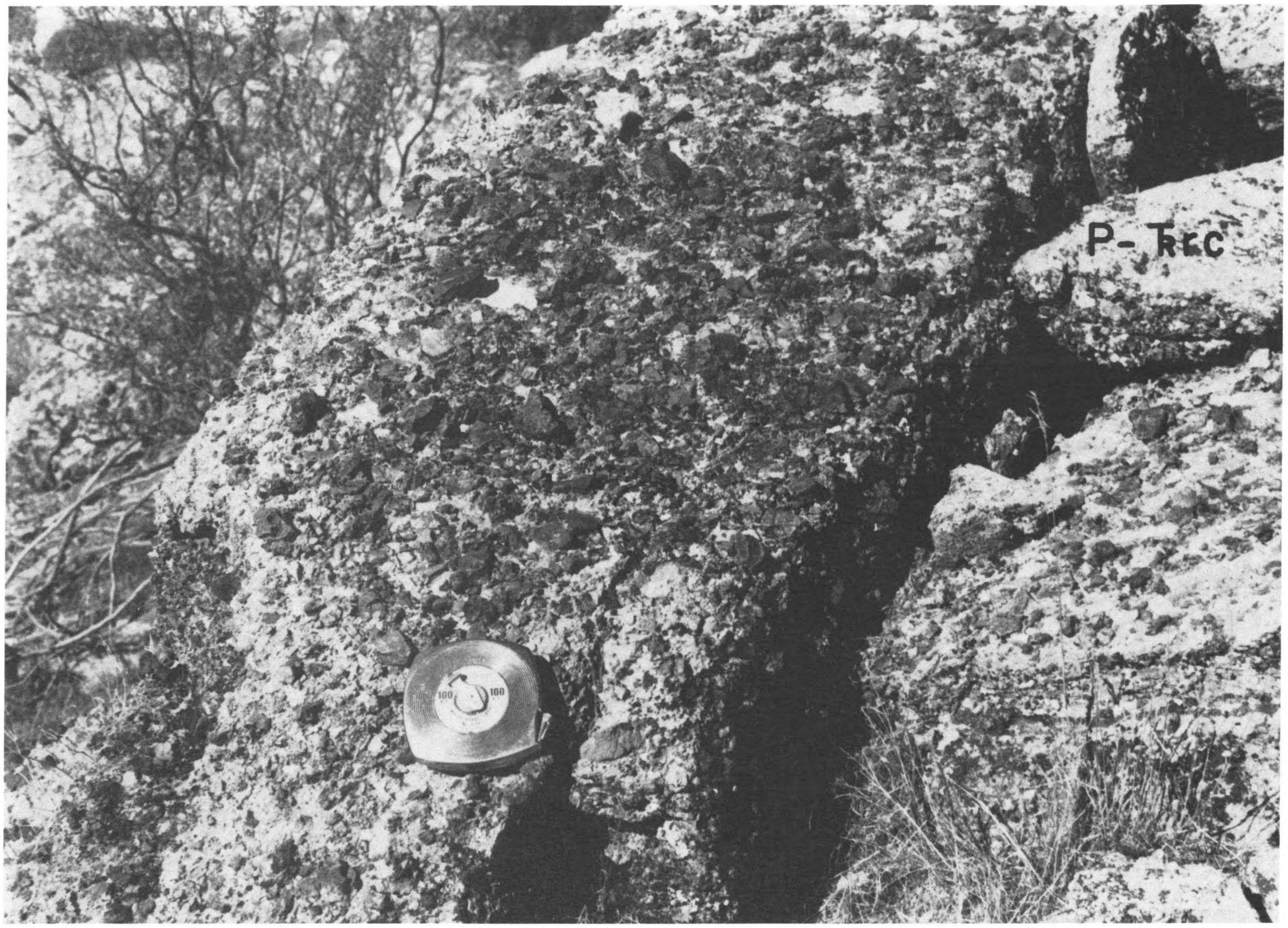

Figure 11. Angular cross-bedded chert clasts that filled in the dissolution features in west Mountain Valley Wash west of St. George, Utah. P-$T_R$rc, Rock Canyon Conglomerate.

Moenkopi Formation

In southwestern Utah and northwestern Arizona, the Moenkopi Formation contains six members. They are: Timpoweap, Lower Red, Virgin Limestone, Middle Red, Shnabkaib, and Upper Red. This study is only concerned with the Timpoweap, Lower Red and Virgin Limestone Members that are in contact or associated with the Rock Canyon conglomerate.

Timpoweap Member of the Moenkopi Formation

The Timpoweap Member of the Moenkopi Formation contains three different lithologies in southwestern Utah. The lower stratigraphic unit is the massive to thick bedded limestone (oolitic-pisolitic fossiliferous mudstone) which weathers to form a cliff. Ammonites have been collected from the limestone at the east end

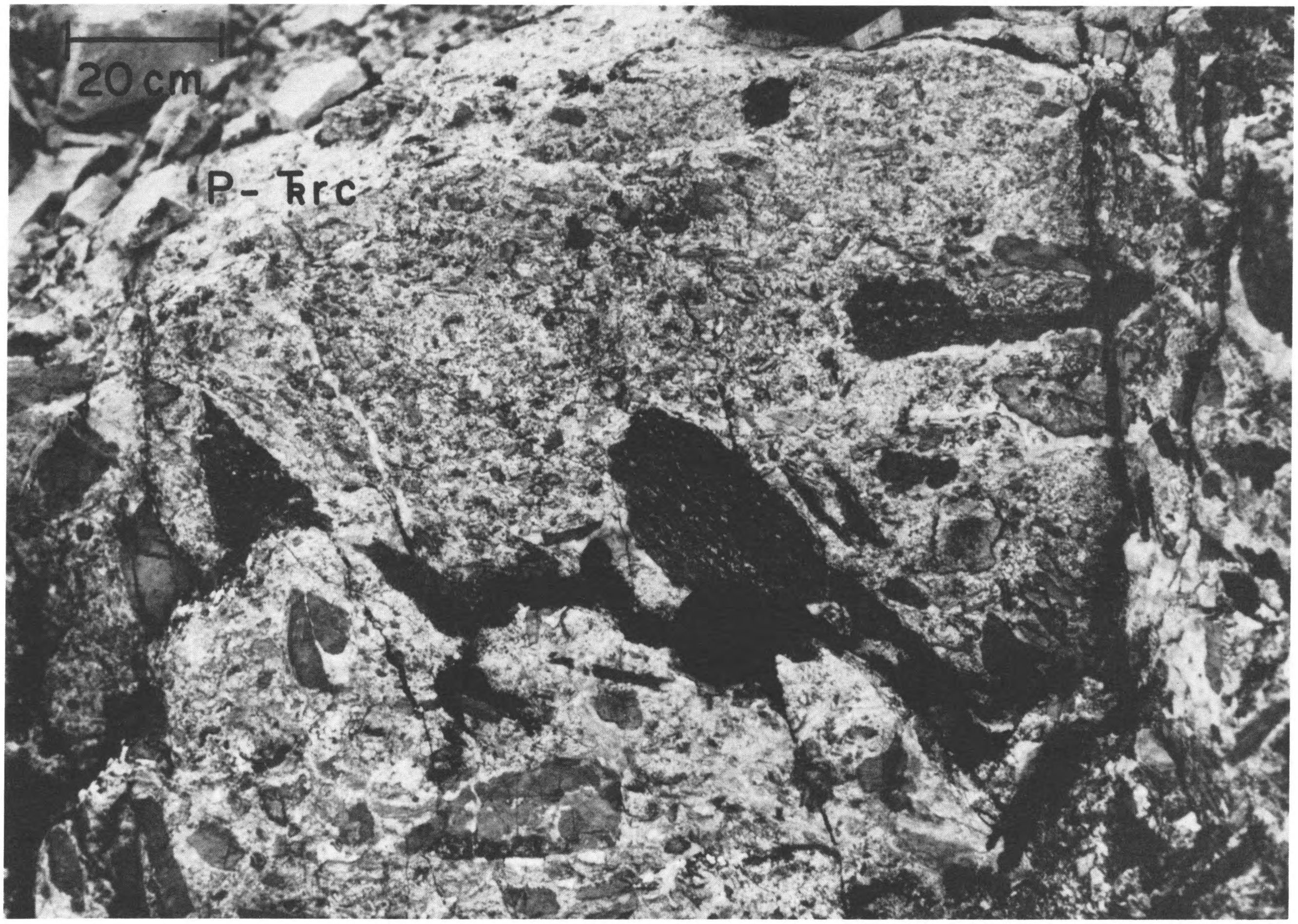

Figure 12. Regolith deposits exhibiting laminations and soil structure south of Molley's Nipple near Hurricane, Utah. P-$T_R$rc, Rock Canyon Conglomerate.

of Rock Canyon, at Camp Creek near the Kolob Canyon Section of Zion National Park, in Spring Creek Canyon southeast of Kanarraville and at the south end of the Three Brothers south of Hurricane. Unit two is composed of thin cross-laminated siltstone and sandstone that weather to form a slope. Unit three contains lenses of cross--bedded sandy limestone to sandstone that weather to form a cliff and appear to be confined to the Hurricane Cliffs south of Black Ridge and North of the Divide.

Lower Red Member of the Moenkopi Formation

The Lower Red Member of the Moenkopi Formation contains laminated to cross-laminated siltstone and fine grained sandstone. It weathers to form a slope to stair-step topography.

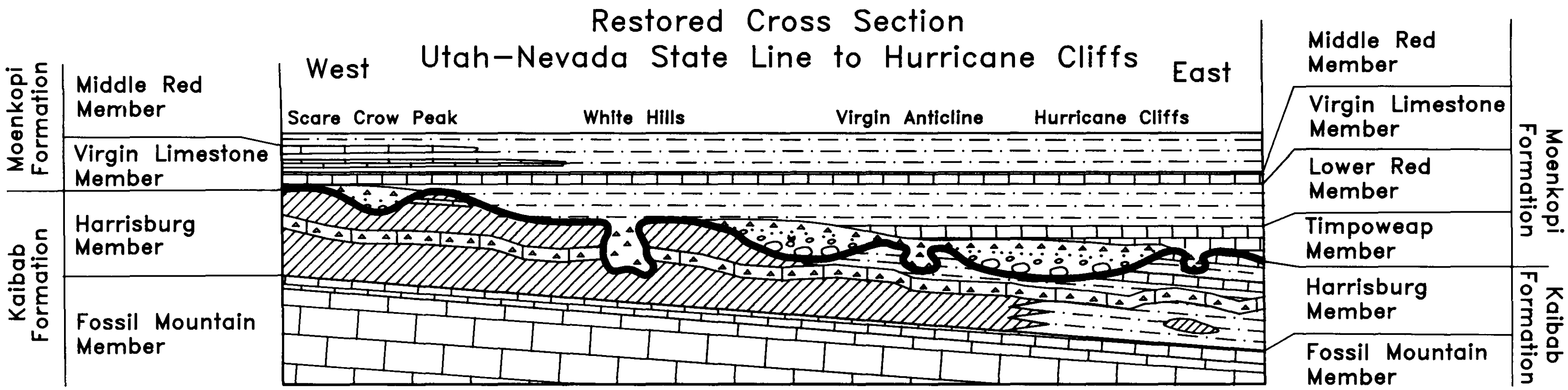

Figure 13. Restored cross section from the Utah-Nevada State Line to east of the Hurricane Cliffs near Virgin Utah illustrating the Permian-Triassic paleotopographic high exposed in the White Hill west of St. George Utah.

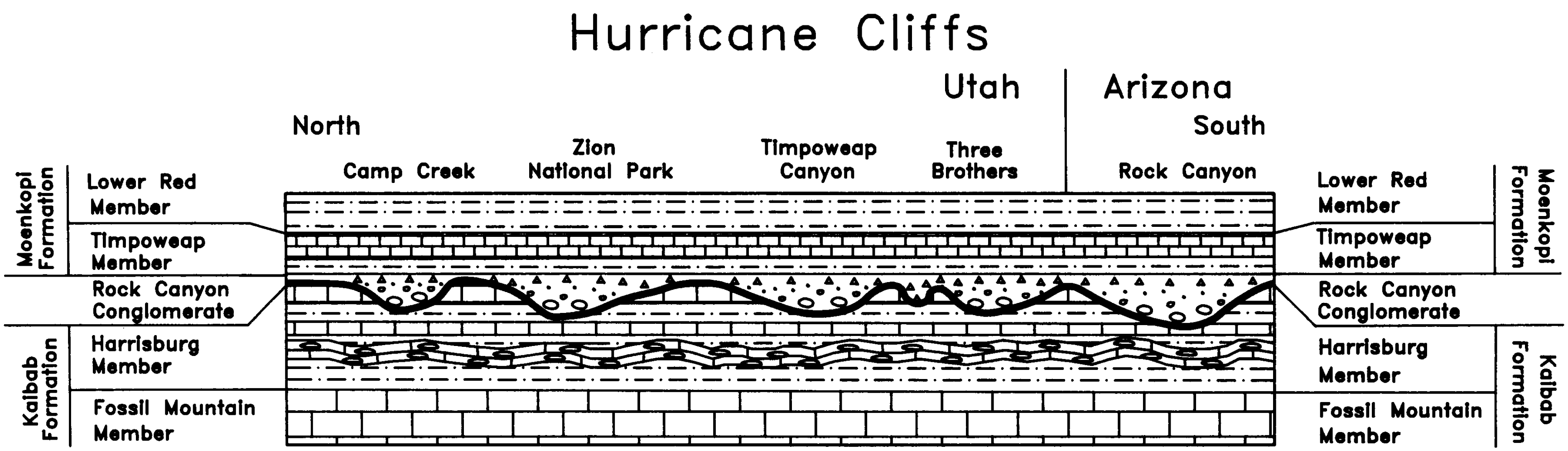

Figure 14. The fluvial, alluvial fan and fan delta deposits crossing the Hurricane Cliffs are illustrated by this restored cross section.

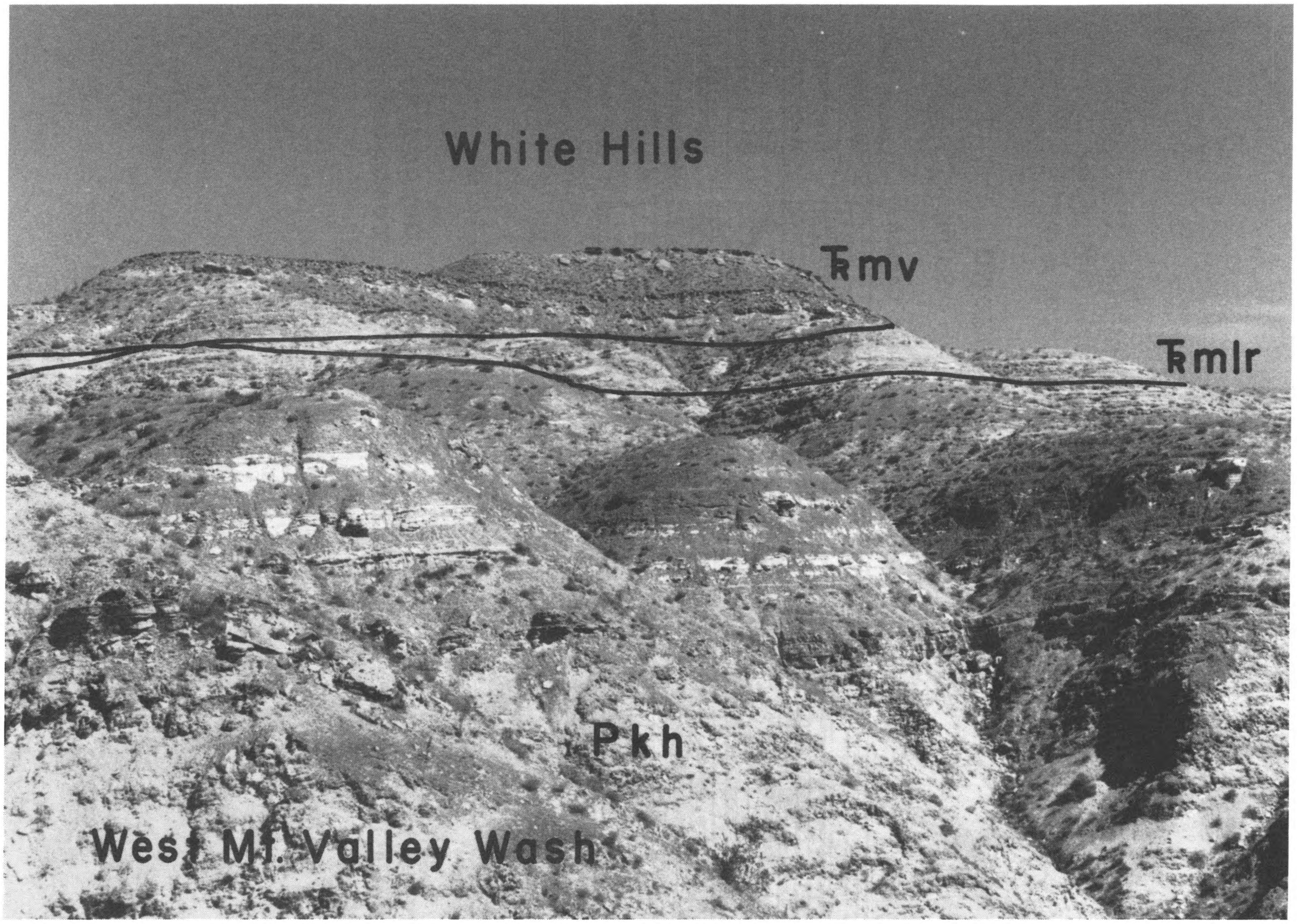

Figure 15. In West Mountain Valley Wash exposures of the Harrisburg Member of the Kaibab Formation (Pkh) are in contact with the Virgin Limestone Member ($T_R$mv) of the Moenkopi Formation representing the location of the last paleotopographic high to be covered by the Moenkopi Sea. Pkh, Harrisburg Member of the Kaibab Formation; $T_R$mlr, Lower Red Member of the Moenkopi Formation; $T_R$mv, Virgin Limestone Member of the Moenkopi Formation (after Collinson and Hasenmueller, 1978).

Virgin Limestone Member of the Moenkopi Formation

From its type section near Virgin, Utah, the Virgin Limestone Member of the Moenkopi Formation thickens from a single limestone bed to a sequence of alternating limestone (oolith, fossiliferous wackestone) and sandy siltstone (Poborski, 1953, 1954). The Virgin Limestone Member is not observed to be in contact with the Rock Canyon Conglomerate but is in contact with the Harrisburg Member of the Kaibab Formation where topographic highs occur.

PETROLOGY

Rock Canyon Conglomerate

The Rock Canyon Conglomerate can be divided into three different petrographic groups. Group one is a lithic conglomerate that grades into sandstone and siltstone. The conglomerate contains clasts of chert (60%), limestone (20%), dolostone (10%), sandstone (5%), and gypsum (5%). Cement is predominantly calcite with minor amounts of silica and hematite. The presence of rounded clasts indicates that the clasts were transported far enough to round the angular corners of chert. The chert clasts were derived from the Harrisburg Member and possibly the Fossil Mountain Member of the Kaibab Formation and do not indicate that other units were exposed in southwestern Utah during deposition of the Rock Canyon Conglomerate. Gypsum clasts are rounded indicating a shorter transportation distance. Sandstone lenses in group one are: lithic wackes that contain quartz (60%), dolomite (30%) and limestone (-10%). Petrography of the siltstones indicates that they had a similar composition to the sandstones present in group one. Limestone and dolostone clasts were produced from the erosion of the Harrisburg Member of the Kaibab Formation. The circular deposits of lithic breccia represent the second group of coarse clastic rocks. They contain 90% chert clasts with minor amounts of limestone clasts. Sand sized clasts are present in the matrix and the cement is principally silica with some calcite. All clasts are of pebble size indicating that sorting occurred. Group three is represented by laminated vadose pisolith breccia to calcareous lithic arenite. Along the Hurricane Cliffs, group three often grades into the Timpoweap Member.

Timpoweap Member of the Moenkopi

The Timpoweap Member of the Moenkopi Formation contains three lithologies. Lithology one consists of sandy silty fossiliferous mudstone that has been altered to microsparite. Fossils are poorly preserved gastropods and bivalves. Ammonites are present at Tyler Creek, Three Brothers and the east end of Rock Canyon. Sand sized clasts are quartz, detrital limestone and detrital dolostone. Some ooliths, pellets, and intraclasts show alteration to microsparite. Planar and trough cross-laminations are also present. Facies two consists of cross-laminated lens-shaped sandy siltstone to silty lithicarenite. Group three is sandy fossiliferous mudstone to calcareous lithic arenite that contains well developed cross-laminations. The sandstone contain quarts (65%), limestone (20%) and dolomite (15%) clasts.

DEPOSITIONAL ENVIRONMENT OF THE ROCK CANYON CONGLOMERATE

Each lithology present in the Rock Canyon Conglomerate was deposited in a different depositional environment. The chert pebble conglomerate was deposited as a sequence of fluvial channels and alluvial fans or fan deltas that devel-

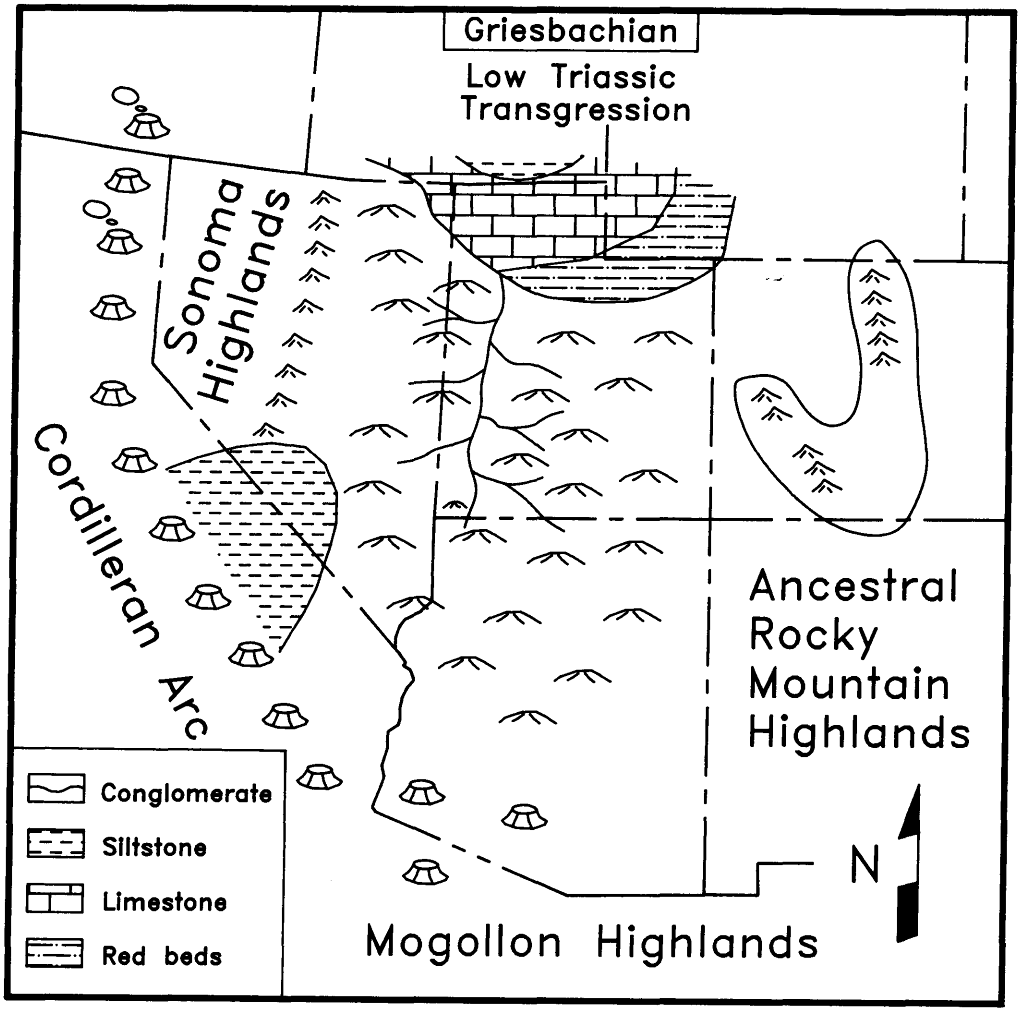

Figure 16. Paleogeographic map of Utah, Nevada and Arizona showing the development of northern drainage after the regression of the Permian Kaibab sea and tilting and faulting of the late Permian and Early Triassic (Griesbachian) Periods (after Collinson and Hasenmueller 1978).

oped from positive areas. Larson (1966), Marly (1983) and Shorb (1983) have interpreted the conglomerate sequence in southeastern Nevada as being deposited in fluvial paleochannels associated with a Triassic transgressive sequence. Channel geometry, cross-bedding and clast orientation data suggests that the positive areas were west of the present location of the Hurricane Cliffs in southwestern Utah and southwest of Rock Canyon in northwestern Arizona. Late Permian and early Triassic drainage flowed to the northeast (fig. 16). The clasts are composed mostly of chert and limestone from the

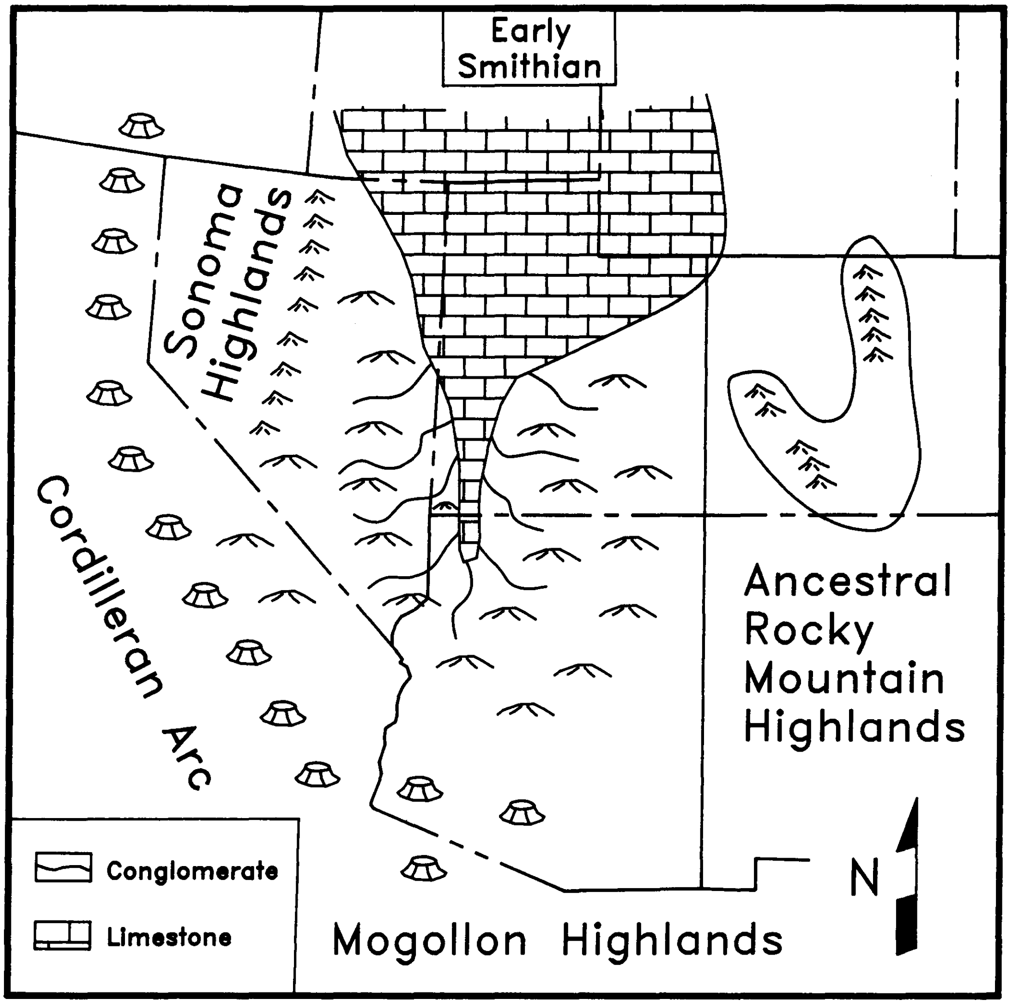

Figure 17. The transgression of the early Triassic sea (early Smithian) into southern Utah and northern Arizona that resulted in the deposition of the Timpoweap Member of the Moenkopi Formation.

Kaibab Formation indicating that deformation in the area was not sufficient to allow down-cutting through the Kaibab Formation. The presence of gypsum clasts in the conglomerate and gypsum units in the Kaibab Formation, that were exposed on the positive elements, would indicate an arid climate during uplift and erosion of southwestern Utah and northwestern Arizona during the late Permian and early Triassic. The chert pebble conglomerate facies of the Rock Canyon Conglomerate grades laterally to the northeast into a cross-bedded sandstone and siltstone facies. This suggests deposition as alluvial fans or fan deltas into estuaries cut by late Permian and early Triassic stream dissection and flooded

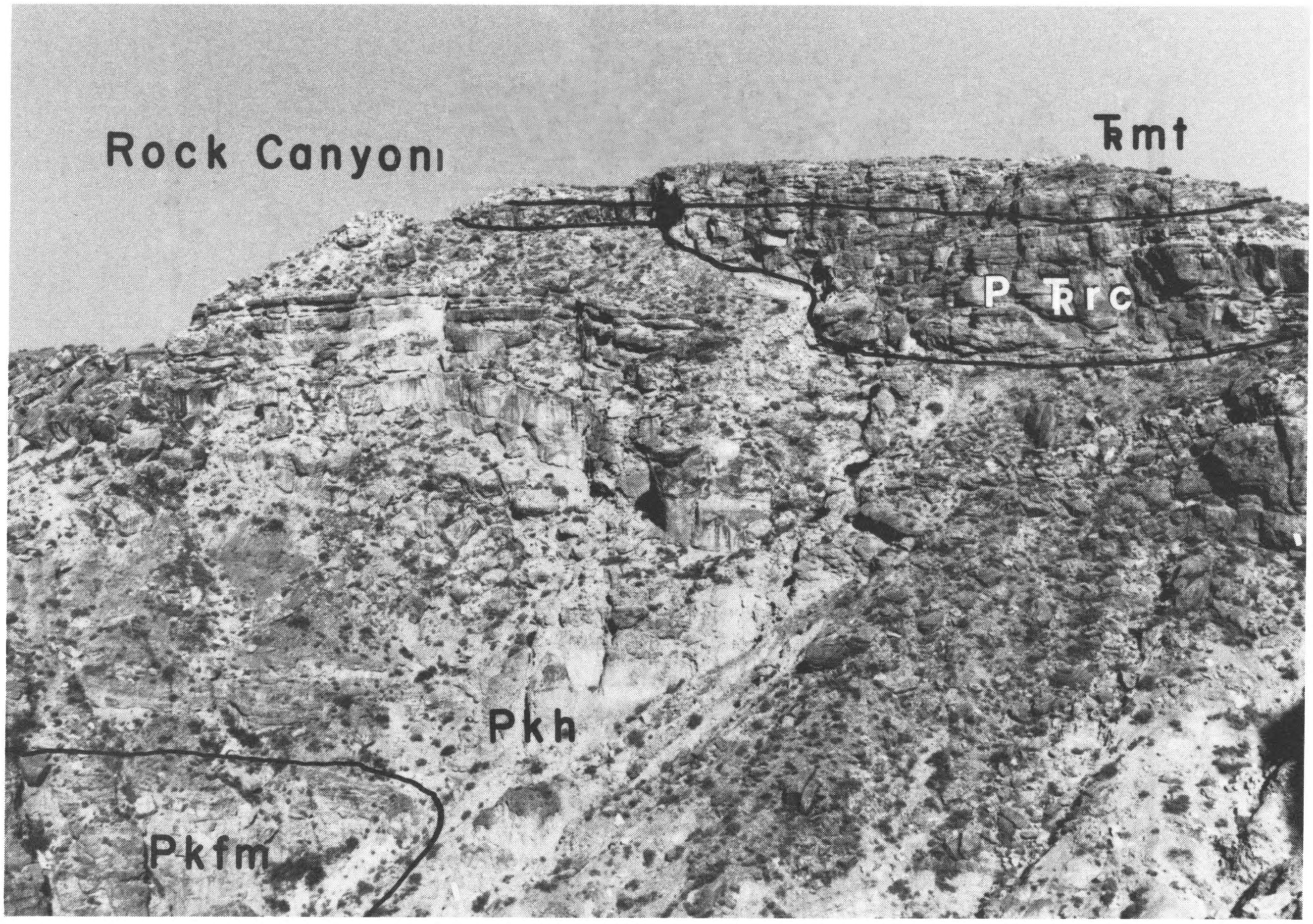

Figure 18. In Rock Canyon, Arizona, the Rock Canyon Conglomerate can be seen filling a channel. The Timpoweap Member of the Moenkopi Formation thins to the west indicating that the Moenkopi sea entered the Permian-Triassic canyons from the northeast to produce estuaries depositing beach and shallow marine sediments on top of the fluvial deposits of the Rock Canyon Conglomerate. Pkfm, Fossil Mountain Member of the Kaibab Formation; Pkh, Harrisburg Member of the Kaibab Formation; P-$T_R$rc, Rock Canyon Conglomerate; $T_R$mt, Timpoweap Member of the Moenkopi Formation.

by the Triassic transgression from the north (fig 17). Topography was produced by faults which tilted southwestern Utah. These faults were sub parallel to the present Hurricane Fault. The high concentration of Permian-Triassic alluvial fan and fan delta complexes along the Hurricane Cliffs supports this interpretation. Facies transitions from cross-bedded coarse clastic rocks to cross-bedded fine-grained clastic rocks are seen in both Timpoweap Canyon east of the diversion dam near

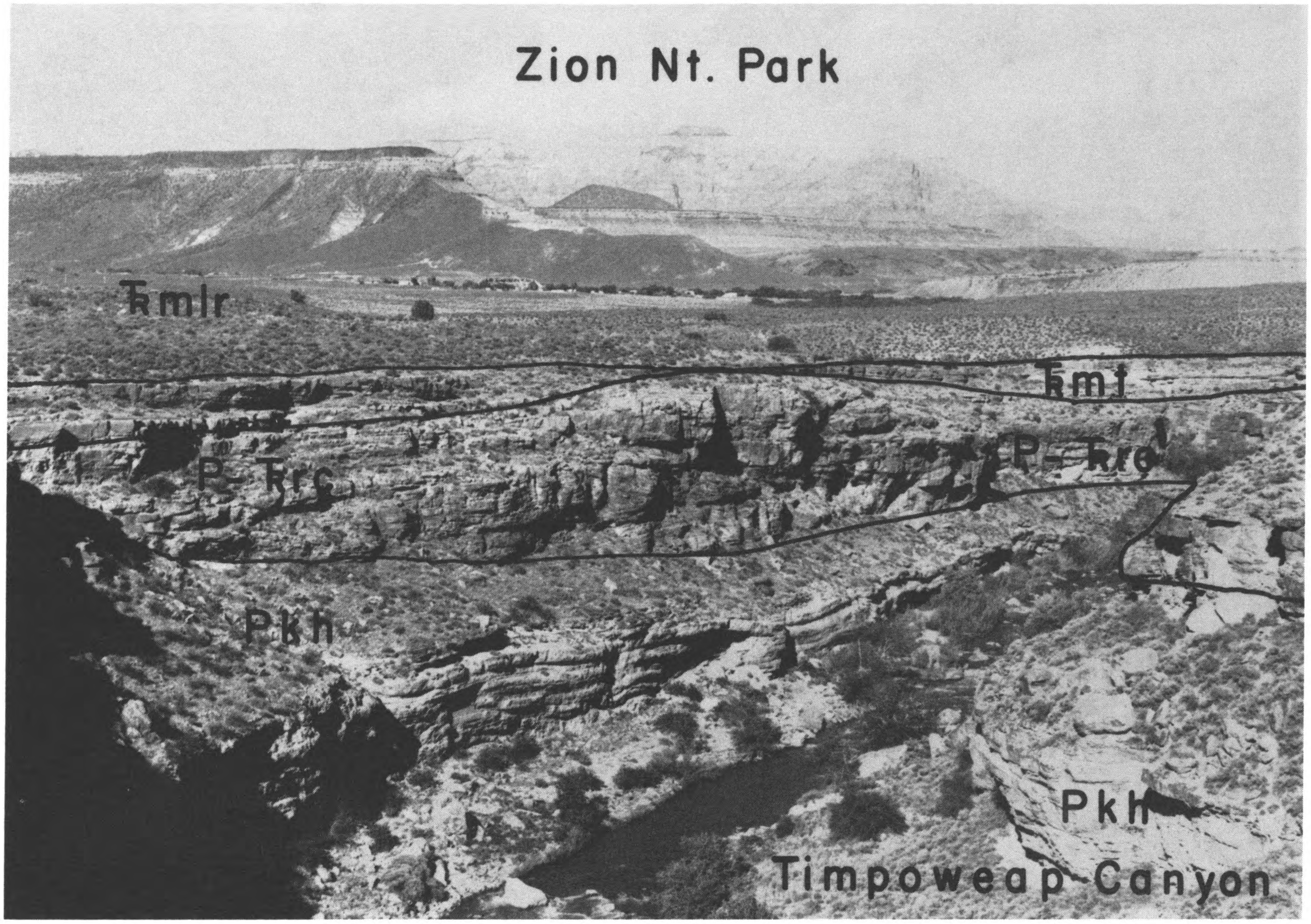

Figure 19. The Rock Canyon Conglomerate in Timpoweap Canyon with the Timpoweap Member of the Moenkopi Formation thinning over the upper part of the Permian-Triassic alluvial fan. Conglomerate lenses grade laterally into sandstone and siltstone eastward. The conglomerate represents the upper alluvial fan facies and the siltstone and sandstone represent the fan delta facies. Pkh, Harrisburg Member of the Kaibab Formation; P-$T_R$rc, Rock Canyon Conglomerate; $T_R$mt, Timpoweap Member of the Moenkopi Formation.

Oil Seep Wash and along Camp Creek in the Kolob Section of Zion National Park. These facies transitions suggest deposition as fan deltas (fig. 18, 19, and 20). At the type locality of the Rock Canyon Conglomerate in Rock Canyon, deposition of the conglomerate occurred as point bars. The lens shaped geometry of the conglomerate deposits, upward fining of the clasts and paleocurrent data support this interpretation. Point bars were developed in stream channels

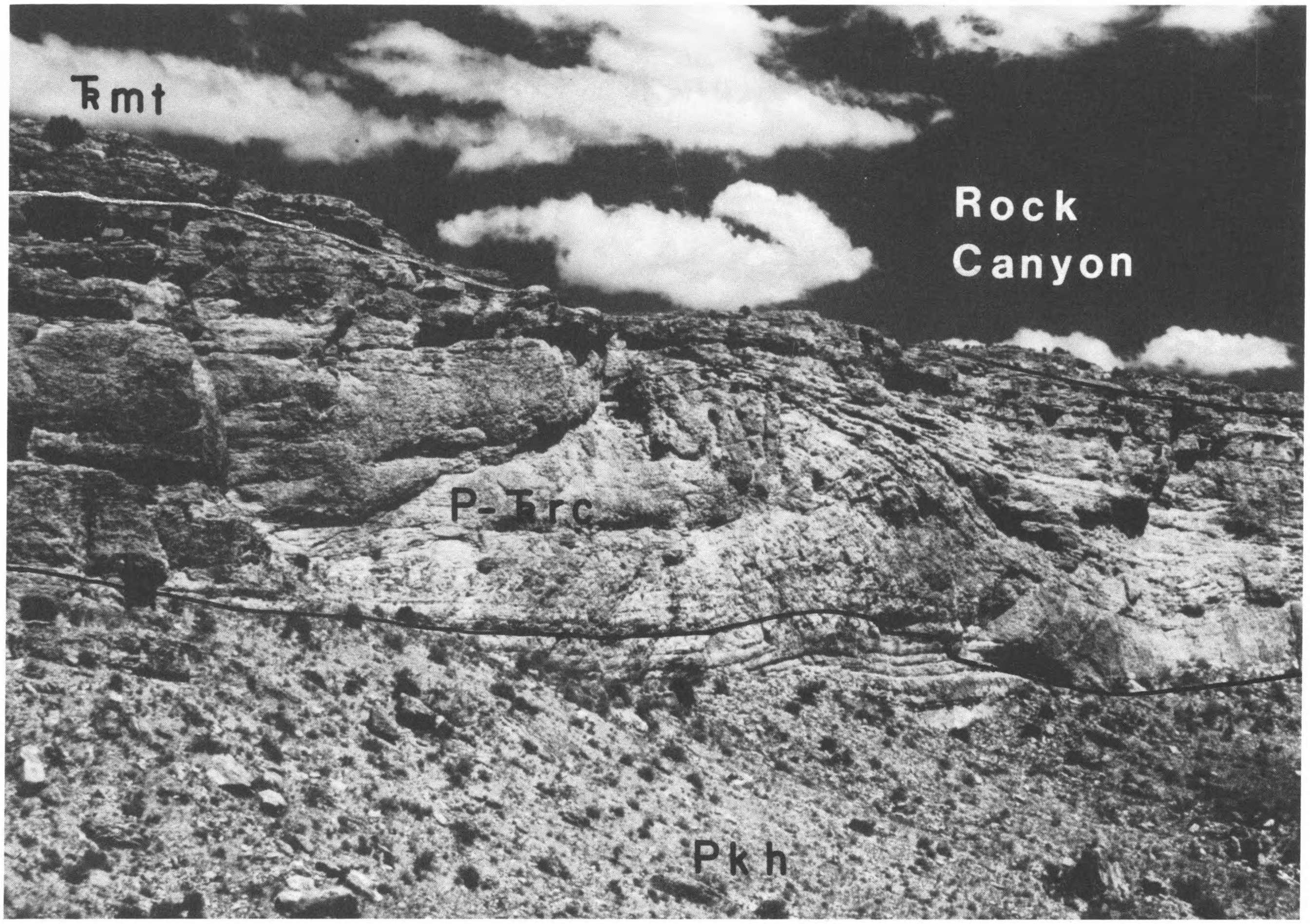

Figure 20. Lens shaped deposits in the Rock Canyon Conglomerate (P-$T_R$rc) representing the alluvial fan facies of the Rock Canyon Conglomerate. Pkh, Harrisburg Member of the Moenkopi Formation; Tmt, Timpoweap Member of the Moeknopi Formation; $T_R$mlr, Lower Red Member of the Moenkopi Formation.

that exhibit a dendritic drainage pattern from the positive area southwest of Rock Canyon. The conglomerate facies is capped by the angular chert facies at many locations indicating that a soil developed on top of the fluvial deposits. This would suggest a period of time elapsed between the deposition of the Rock Canyon Conglomerate and the transgression of Triassic seas that deposited the Timpoweap Member.

Facies two consists of circular deposits of cross-laminated breccia and sandstone that is interpreted as having been deposited in sink holes produced by dissolution of the limestone and gypsum units of the Kaibab Formation during the late Permian and early

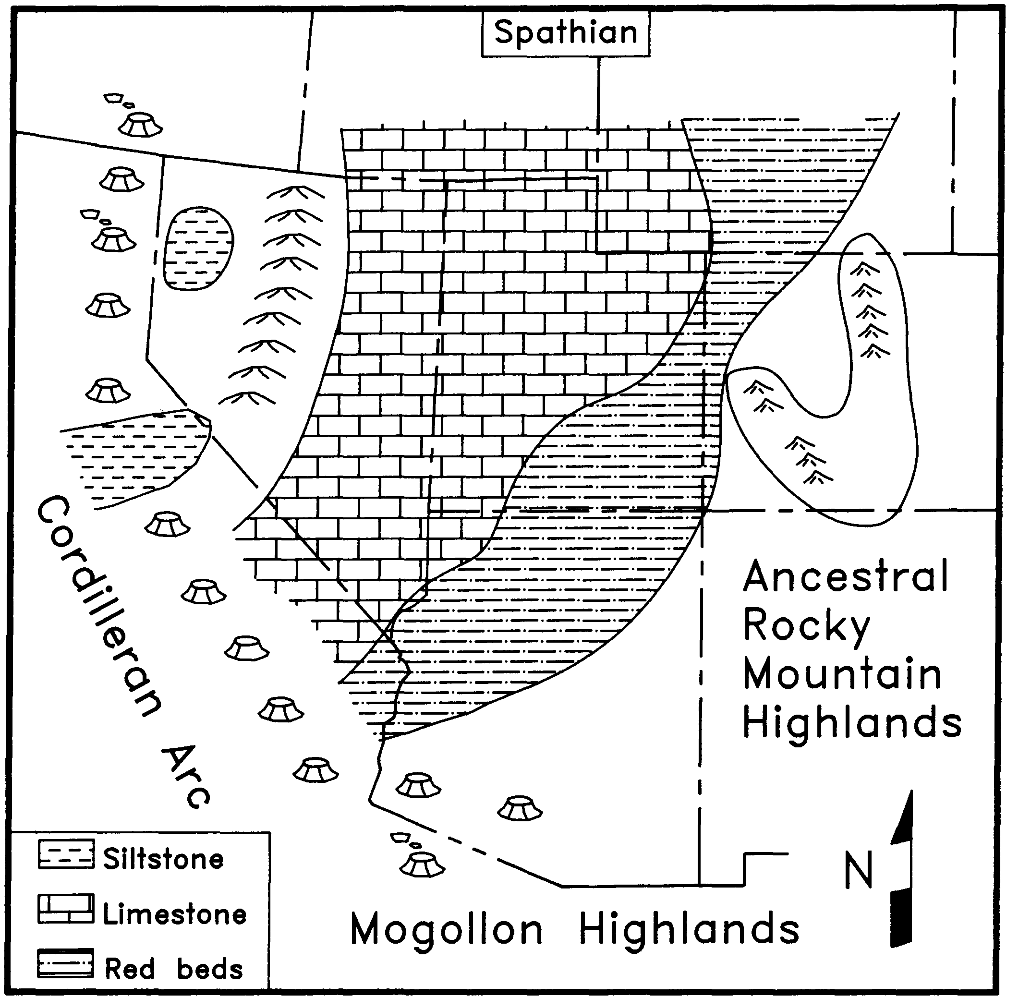

Figure 21. Paleogeographic and facies map showing deposition of the Virgin Limestone Member during the early Triassic (Spathian). After Collinson and Hasenmueller, 1978.

Triassic. Final filling of the dissolution features occurred during the transgression of the Moenkopi Sea from the north. The circular nature of the deposits, the lack of rounded clasts, cross-bedding patterns that point to a central area and breccia zones near the bottom of the deposits support deposition in sinkholes. Dissolution features are seen principally in the White Hills west of St. George and south of Kanarraville.

The laminated angular chert, vadose pisoliths and coated grain facies, that represent facies three, were deposited as a regolith around the paleo-hills. The evidence supporting deposition as regolith is the irregular distribution of the deposits around the positive areas, laminations similar to those found in modern caliche deposits and vadose pisolites and ooliths similar to those present in modern arid soils. Gradation of the three facies of the Rock Canyon Conglomerate into the Timpoweap Member of the Moenkopi Formation suggests that the Triassic, Moenkopi Sea transgressed across the fan deltas, alluvial fan, fluvial channels, karst topography and lithified regolith deposits.

DEPOSITIONAL ENVIRONMENT OF THE LOWER MOENKOPI FORMATION

The Timpoweap Member thins from ten to zero meters and changes facies from fossiliferous marine limestone to shore face sandstone and oolite bar deposits from east to west in the canyons that cross the Hurricane Cliffs. The fossiliferous oolitic sandy limestone to sandstone of the Timpoweap Member of the Moenkopi Formation were deposited in a shallow marine environment and grade westward into beach deposits. The thickness of the Timpoweap Member is controlled by the Permian paleogeography (fig 17). Ammonite and gastropod bearing limestones are found where the Triassic sea entered the paleovalleys. The Timpoweap Member is thin and unfossiliferous or absent over the paleogeographic positive areas. This suggests that the southwest corner of Utah was a positive area during early Triassic. These positive areas decreased in size during the deposition of the Lower Red Member which was deposited in tidal flat conditions as indicated by mud cracks, ripple marks, rain drop impressions, and salt casts. Along the northeast flank of the Beaver Dam Mountains deposits of the Rock Canyon Conglomerate grade into the Lower Red Member. This indicates that deposition of the Rock Canyon Conglomerate occurred after the deposition of the Timpoweap Member.

Deposition of the Virgin Limestone Member of the Moenkopi Formation occurred under shallow marine conditions as indicated by the presence of crinoids, bivalves and gastropods. Along the northeast side of the Beaver Dam Mountains oolites were present in the Virgin Limestone (fig. 21). In the White Hills, west of St. George, the Virgin Limestone Member is in disconformable contact with the Harrisburg Member of the Kaibab Formation indicating that the last Permian-Triassic paleogeographic highs were located west of St. George in southwestern Utah.

STRATIGRAPHIC PROBLEMS WITH CONGLOMERATE AND BRECCIA DEPOSITS IN THE WHITE HILLS AND BLOOMINGTON DOME

In the White Hills west of Bloomington, Utah, there are three elongate, lens shaped deposits of lithic conglomerate that contain cross-laminations and were deposited in dendritic drainage patterns (fig. 22). In these conglomerate deposits clast size decreases upward and they have an orientation to the northeast. The conglomerate deposits are sub-parallel to the current drainage patterns present in the White Hills. They have the same orientation

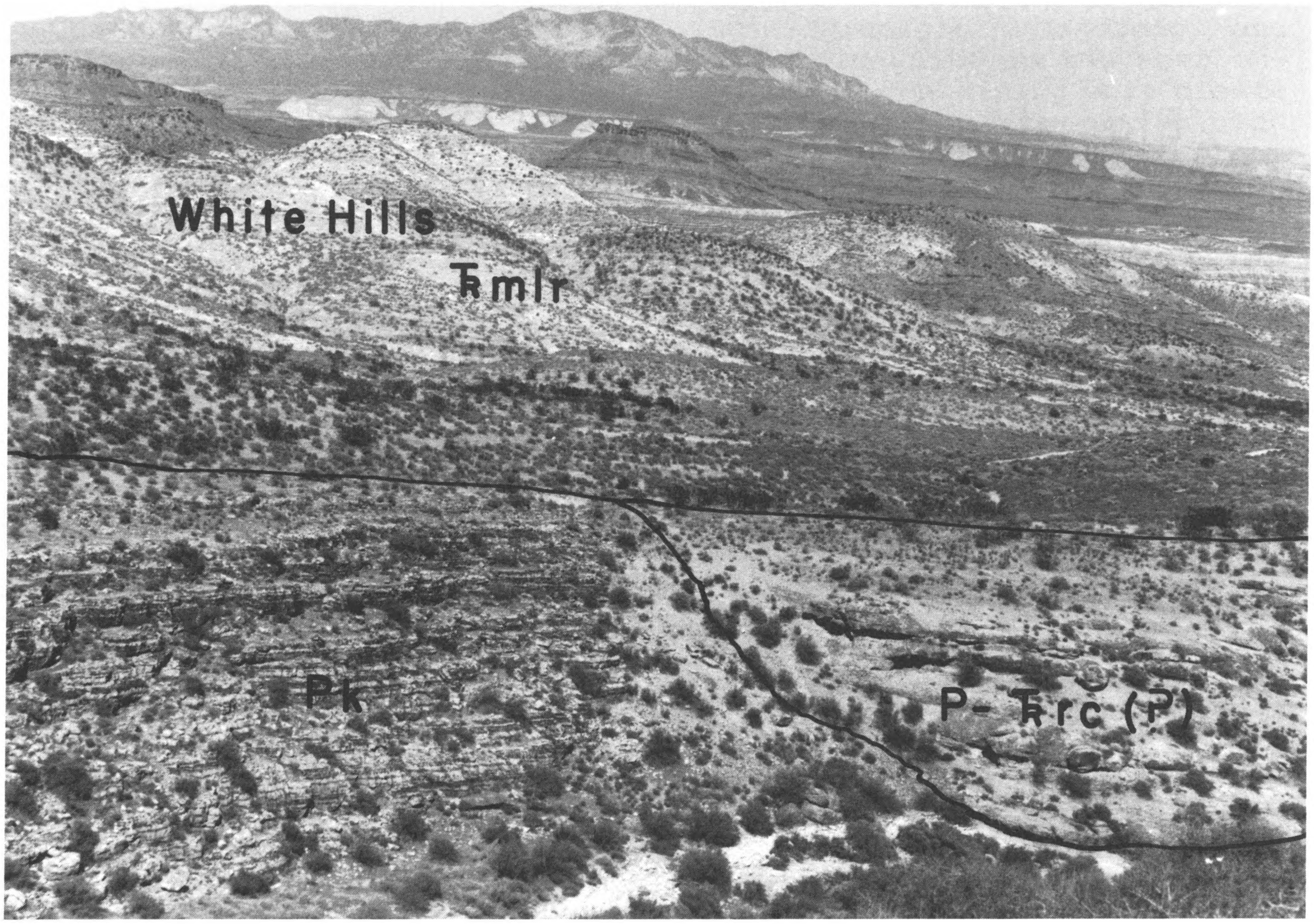

Figure 22. Conglomerate filled paleo-channel present in West Mountain Valley Wash which could be either of Triassic (P-$T_R$rcc ?) or of Tertiary-Quaternary age. These channels do not have Lower Red Member ($T_R$mlr) of the Moenkopi Formation in contact with their upper surface making it difficult to determine their relative age.

as the Rock Canyon Conglomerate deposits along the Hurricane Cliffs.

On the southwest side of the Bloomington Dome there is a thick deposit of angular to subrounded conglomerate which is present in the valley between the ridges of the Harrisburg Member of the Kaibab Formation and the Virgin Limestone Member of the Moenkopi Formation (fig. 23). The coarse clastic rocks contain chert clasts from the Harrisburg Member of the Kaibab Formation, but lack clasts from the Virgin Limestone Member of the Moenk-

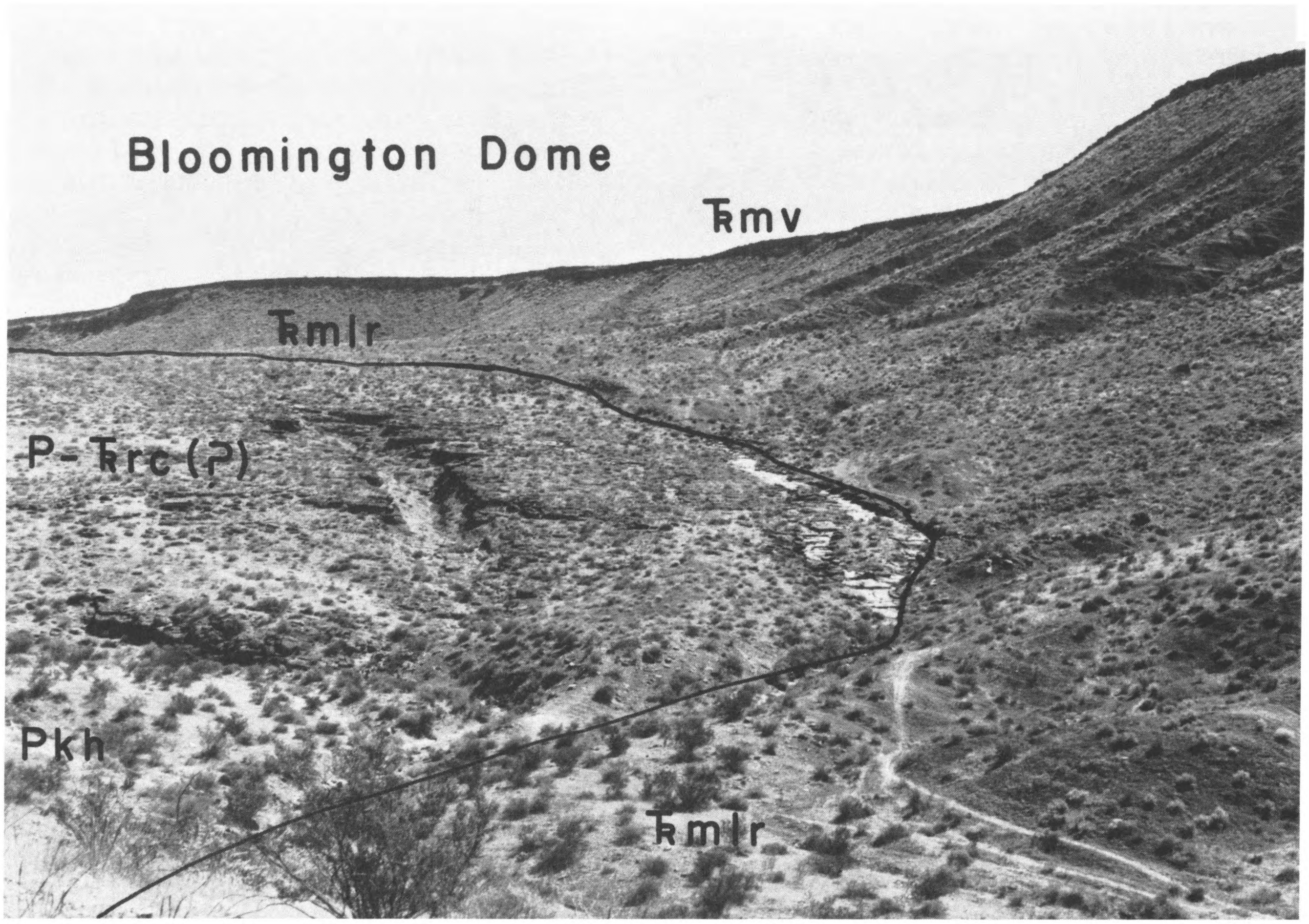

Figure 23. Conglomerate filled paleo-channel present in the Bloomington Anticline south of St. George, Utah which could be either of Triassic (P-$T_R$rcc) or of Tertiary-Quaternary age. This channel does not contain clasts from either the Lower Red ($T_R$mlr) or the Virgin Limestone ($T_R$mv) members of the Moenkopi Formation. The lack of Lower Red Member($T_R$mlr) or the Virgin Limestone Member($T_R$mv) in contact with their upper surface making it difficult to determine the relative age of the conglomerate.

opi Formation. The dip of the upper surface is sub-parallel with the dip of the Lower Red and Virgin Limestone members. South of the fold axis of the Laramide aged Bloomington Anticline there is a change in dip of the Kaibab Formation which does not affect the coarse clastic rocks. A possible Permian aged fault is present in the wash between the two ridges. The deposit is elongated to the northwest. It is sub-parallel to the current drainage developing in the poorly lithified Lower Red Member of the Moenkopi Formation.

Cross-bedding and clast orientation suggest deposition was from the southeast to the northwest. This follows the orientation of the current drainage patterns rather than the Permian drainage pattern. The upper contact with the Lower Red Member of the Moenkopi Formation is poorly exposed suggesting that the Lower Red Member of the Moenkopi Formation rests on top of the conglomerate.

Interpreting the environment of deposition of these conglomerate and breccia deposits which formed as channel deposits, regolith, and karst deposits and filled depressions is not a problem. The problem arises in determining the age and stratigraphic significance of the deposits. In the White Hills both the karst depressions and the channel deposits contain only clasts derived from the Kaibab Formation which would suggest that they were deposited during the late Permian and early Triassic and are related to the Permian and Triassic erosional cycle. A second interpretation based on the similarity of the orientation of the channels and clasts to current drainage patterns would suggest that they were deposited during the late Tertiary and Quaternary by the same process that produced the Prunoweap channels described by Dalness (1969) and Nielson (1977) west of Zion National Park. Jensen (1986), in his study of the Permian and Triassic boundary did not mention the conglomerate channels, but did describe the paleokarst features suggesting that he may have considered them as being Tertiary or Quaternary in age. If they were Tertiary or Quaternary aged channels, they should contain clasts from other Paleozoic, Mesozoic and Cenozoic units in the area instead of containing only clasts from the Kaibab Formation. The lack of an upper contact presents a problem in establishing the appropriate age relationships. Based on clast composition, paleocurrent orientations and style of conglomerate deposition, I feel that these conglomerate and breccia deposits are related to the Triassic erosional cycle. However, there still remains the possibility that they could be related to the current erosional cycle.

DISCUSSION

Study of the literature points to a problem in differentiating the Rock Canyon Conglomerate (which is still considered by some authors to be the basal member of the Moenkopi Formation) from the Timpoweap Member of the Moenkopi Formation. Reeside and Bassler (1921) described a conglomerate above the Kaibab Formation and below the Moenkopi Formation. Gregory (1950) noted that conglomerate was present between the Kaibab and Moenkopi formations, but he felt that it was not deposited in association with the lower Moenkopi Formation. He suggested that it was part of the Kaibab Formation. Study of the Kaibab Formation by Nielson (1981) and Jenson (1986) have shown dissolution breccia near the middle of the Harrisburg Member of the Kaibab Formation which is related to minor regressive and transgressive cycles in the late Permian Kaibab seas. The conglomerate and breccia deposits described by Reeside and Bassler (1921) are associated with erosion following the deposition of the Kaibab Formation and before and during the transgression of Moenkopi seas. The presence of parallel laminations and pisoliths in the upper part of the Rock Canyon Conglomerate suggest the development of a caliche over which the Moenkopi seas transgressed. This transgression reworked the upper half meter of the Rock Canyon Conglomerate.

After studying the conglomerate present along the Permian-Triassic boundary, I feel there is a significant difference in stratigraphy, petrography, depositional environment and tectonic origin between the Rock Canyon Conglomerate representing deposition of coarse clastic sediments in point bars, fan deltas, alluvial fans, filled sink holes and regolith and the marine, estuarine and tidal flat deposition of the Moenkopi Formation. If the conglomerate is included in the Timpoweap Member of the Moenkopi Formation and considered as a basal conglomerate, this does not lead to an understanding of the regional faulting, tilting and deformation that occurred during the late Permian and early Triassic Periods. It is for this reason that I feel that the Rock Canyon Conglomerate should be considered as a separate formation representing the period of deformation associated with the Sonoma Orogeny of Nevada. Similar conglomerates have been noted in northern Utah and Nevada by Collinson, Kendel and Marcantel (1976), and Clark, Peterson, Stokes, Wardlaw, and Wilcox, (1977) and on the Colorado Plateau by Ochs and Chan (1989), Nielson (1986, 1989) and Kamola (1989) which when carefully studied could lead to a better understanding of Permian deformation.

TECTONIC SIGNIFICANCE OF THE ROCK CANYON CONGLOMERATE

Deposition of the Rock Canyon Conglomerate in clastic wedges that thicken to the east indicates that uplifts occurred along faults that are sub-parallel to the present Hurricane Fault system. The presence of a positive area west of St. George and south of Rock Canyon also supports a northwest-southeast trending fault system. This uplift could be associated with the reversal of the Wasatch-Las Vegas hinge which occurred between the late Permian and Jurassic (Stokes 1976, 1986). Uplift may also be associated with the stress generated by the Sonoma Orogeny and the associated Permian-Triassic subduction zone in western Nevada during late Permian and early Triassic [Dickinson (1981) and Blakey and Gubitosa (1983)].

In southern Utah, following the retreat of the Kaibab Sea during the Word Epoch, as indicated by the fossils in the upper Kaibab Formation, regional tilting of southwestern Utah occurred. This tilting produced sufficient uplift to allow 100 m or more of down-cutting. The youngest remaining unit of the Harrisburg Member of the Kaibab Formation is a marine limestone deposited during a Permian transgressive cycle. Erosion has removed the last regressive cycle if not additional transgressive and regressive cycles. Locally thick gypsum deposits west of St. George, Utah, west of Rock Canyon, Arizona and North of Kanarraville, Utah which are surrounded by fossiliferous limestone, could indicate that uplift began during the Word Epoch. This allowed the deposition of gypsum in a sebkha and/or shallow marine environments. Study of the Park City Group in northern Utah (Wardlaw and Collinson, 1978) indicates that Permian seas remained much later in northern Utah than in southwestern Utah. Two models could be used to explain the distribution of facies and the lack of younger Permian rocks in southwestern Utah. One is that the additional sedimentary sequences seen in the Park City Group of northern Utah may have been deposited in southern Utah and then removed by erosion that produced the Rock Canyon Conglomerate. Second, regional tilting may have occurred in southern Utah earlier than northern Utah so that sediments were never deposited. The second model would be supported by the gypsum deposits in the Harrisburg Member of the Kaibab Formation and the lack of younger Permian clasts in the Rock Canyon Conglomerate. Late Permian regressions to the west and north along with eastward tilting in southwestern Utah is necessary in order to produce the positive areas that were dissected. Down-cutting and the development of eastward trending drainage systems then occurred. The concentration of thick coarse clastic deposits in alignment with the Hurricane Cliffs would suggest that Permian and Triassic faults were sub-parallel to the present Hurricane Fault. The lack of recognizable Permian-Triassic fault traces, with the exception of the Bloomington Dome, creates a problem. Study of the Permian stratigraphic units supports tilting rather than faulting. Throw on the faults would not have been great.

CONCLUSIONS

1. Stratigraphic analysis indicates that the Rock Canyon Conglomerate was deposited during the late Permian and early Triassic as the result of faulting and eastward tilting that produced a dendritic drainage system and doline features that were partly filled with conglomerate in southwestern Utah.

2. The Rock Canyon Conglomerate contains three different lithologies: one is a rounded cobble and pebble conglomerate that often grades laterally to the northeast into sandstones and siltstones; two is a chert pebble breccia deposited in circular lenses; and three is an irregular laminated pisolithic sandy breccia to conglomerate.

3. Deposition of the Rock Canyon Conglomerate occurred as fluvial, alluvial fan and fan delta deposits, as infilling of sinkholes and as colluvial wedges of regolith around positive areas. Arid soil forming processes at many locations produced caliche that lithified the upper part of the units. The upper part of the Rock Canyon Conglomerate was reworked by the transgression of the Triassic sea from the north

that deposited the Timpoweap, Lower Red and Virgin Limestone members of the Moenkopi Formation over the later Permian and early Triassic topography.

4. Permian-Triassic positive areas, where the Beaver Dam Mountains are currently located, continued to produce clastic wedges (Rock Canyon Conglomerate) until the deposition of the Virgin Limestone Member of the Moenkopi Formation covered the positive areas. The Triassic Moenkopi Sea transgressed from the Hurricane Cliffs on the east, to the White Hills on the west, depositing the Timpoweap and Lower Red members of the Moenkopi Formation on top of the clastic wedges of the Rock Canyon Conglomerate.

5. Permian faults, that are subparallel to the Hurricane Fault system, may have been responsible for the regional uplift that allowed the development of the late Permian and Triassic topography.

6. The Rock Canyon Conglomerate is a sequence of fluvial, alluvial fan, fan delta, sinkhole and regolith deposits that resulted from Permian faulting, regional tilting and subsequent infilling of the Permian-Triassic topography.

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PETROLOGY, SEDIMENTOLOGY AND STRATIGRAPHIC IMPLICATIONS OF THE ROCK CANYON CONGLOMERATE, SOUTHWESTERN, UTAH

APPENDIX

Measured Sections of the

Rock Canyon Conglomerate

Southwestern, Utah

East End of Rock Canyon Measured Section
Section No. RCC1

Section Location: Rock Canyon Quadrangle, Mohave County, Arizona, 7 1/2 Minute Topographic Series, NE 1/4, NW 1/4 Section 9, T. 41 S., R. 9 W. Section was measured 1/2 mile west of the Honeymoon Trail Road where Rock Canyon narrows. Section was measured on the north side of the canyon starting at stream level.

Section was measured by R. LaRell Nielson on January 3, 1990.

Unit	Lithology	Thickness Meters (Feet)	Distance Above Base Meters (Feet)
	Moenkopi Formation (Triassic): Timpoweap Member:		
1.	Limestone, dolomitic, conglomeratic, sandy; grayish orange 10YR7/4, weathers pale yellowish brown 10YR6/2; thin- bedded, contains laminations; clasts are subangular to subrounded chert; weathers to form a cliff; fossiliferous, fossils are: poorly preserved, non silicified, bivalves, gastropods, ammonoids; upper contact modern erosional surface; lower contact gradational..........	2.7 (9)	30.2 (99)
	Total incomplete thickness of the Moenkopi Formation......................	2.7 (9)	
	Total incomplete thickness of the Timpoweap Member............................	2.7 (9)	

Rock Canyon Conglomerate (Permian-Triassic):

2. Sandstone, lithic arenite, conglomeratic; moderate yellowish brown 10YR5/4, weathers grayish orange 10YR7/4; thick-bedded; contains cross-laminations and laminations;clasts are chert; lacks fossils; weathers to form a slope; lower contact conformable.....	3.4 (11)	26.8 (88)
1. Conglomerate, lithic, cobble, pebble, boulder; very pale orange, 10YR8/2, weathers grayish orange 10YR7/4; calcareous; thick to very thick-bedded, cross-laminated; contains sandstone lenses; subrounded chert, limestone, and sandstone clasts, probably derived from the Kaibab Formation; weathers to form a cliff; lower contact is a disconformity.....................	20.7 (68)	6.1 (20)
Total thickness of the Rock Canyon Conglomerate.............................	24.1 (79)	

Kaibab Formation (Permian):
Harrisburg Member:

3. Limestone, mudstone; very pale orange 10YR8/2, weathers grayish orange 10YR7/4; thin-bedded, laminated; contains rounded chert nodules; fossiliferous, fossils are bachiopods and bivalves collected from the south wall of the canyon; weathers to form a cliff; lower contact gradational........	1.8 (6)	4.3 (14)

2. Limestone, mudstone, sandy, silty; very pale orange 10YR8/2, weathers grayish orange 10YR7/4; bedding, massive; lacks sedimentary structures; allochems are intraclasts and pellets; weathers to form a cliff; lower contact gradational........................	2.1 (7)	2.1 (7)
1. Siltstone, calcareous; very pale orange 10YR8/2, weathers moderate reddish orange 10R6/6; contains lens of sandstone (quartz arenite); thin-bedded; folded sandstone beds suggest dissolution; chert nodules are present; lacks fossils; weathers to form a slope; lower contact not measured to....................	2.1 (7)	00 (0)
Total incomplete thickness of the Kaibab Formation...............................	4.3 (14)	
Total incomplete thickness of the Harrisburg Member	4.3 (14)	

Scare Crow Peak Wash Measured Section
Section No. RCC2

Section Location: Scare Crow Peak Quadrangle, Utah and Nevada, 7 1/2 Minute Topographic Series, SW 1/4, SE 1/4, Section 6, T. 41 S., R. 19 W., Section was measured starting in the narrow part of the canyon to the northeast of Scare Crow Peak continuing north east to the covered slope southwest of the road.

Section was measured by R. LaRell Nielson on January 4, 1990.

Unit	Lithology	Thickness Meters (Feet)	Distance Above Base Meters (Feet)
	Rock Canyon Conglomerate (Permian-Triassic):		
4.	Breccia, lithic; light brown 5YR6-/4, weathers grayish orange pink 5YR7/2; thin-bedded, contains laminations and cross-laminations; clasts are: limonite, chert, sandstone and dolostone; weathers to form a stair step slope; lacks fossils; upper contact is covered, the Virgin Limestone Member of the Moenkopi Formation can be seen at the road level three meters to the north; covered unit is probably the Lower Red Member of the Moenkopi Formation; lower contact gradational................................	4.6 (15)	39.3 (129)
3.	Sandstone, quartz arenite; light brown 5YR6/4, weathers grayish orange pink 5YR7/2; thin-bedded, contains cross laminations; angular clasts, clast size increase upward; contains silica and calcite cement; weathers to form a cliff; lacks fossils; lower contact conformable.	3.0 (10)	36.3 (119)

2. Siltstone; grayish orange 10YR7/4, weathers dark yellowish orange 10YR6/6; very thin-bedded, laminated; hematite stained; weathers to form a slope; lacks fossils; lower contact conformable................	1.2 (4)	35.1 (115)
1. Breccia, lithic; light olive gray 5Y6/1, weathers yellowish gray 5Y8/1; thin-bedded; clastic dikes present; clasts are angular to subangular chert and hematite stained sandstone; weathers to form a cliff; lacks fossils; lower contact is an erosional surface that is marked by lens shaped breccia deposits.........................	10.4 (34)	24.7 (81)
Total incomplete thickness of the Rock Canyon Conglomerate.....................	19.2 (63)	
Kaibab Formation (Permian): Harrisburg Member:		
5. Limestone (dolomitic), mudstone; light olive gray 5Y6/1, weathers yellowish gray 5Y8/1; thin-bedded, contains laminations; chert nodules are common; weathers to form a cliff; silicified brachiopods are present west of the section; lower contact gradational................	5.2 (17)	19.5 (64)
4. Limestone (dolomitic), mudstone, sandy, silty; light olive gray 5Y6/1, weathers yellowish gray 5Y8/1; thin-bedded, contains laminations; weathers to form a stair step slope; fossiliferous, fossils are: algal laminations and heads; lower contact gradational.........	3.7 (12)	15.8 (52)

3.	Limestone (dolomitic), mudstone; light olive gray 5Y5/2, weathers yellowish gray 5Y7/2; thin-bedded, laminated; chert nodules and chert stringers; fossils are: brachiopods and crinoids; weathers to form a cliff; lower contact gradational..	1.2 (4)	14.6 (48)
2.	Limestone, sandy, cherty, brecciated, and vuggy, mudstone; grayish pink 5R8/2, weathers grayish orange pink 10R8/2; thin-bedded, bedding has been contoured and broken; laminations are present; contains chert nodules; weathers to form a slope; lacks fossils; lower contact gradational...............	7 (23)	7.6 (25)
1.	Limestone (dolomitic), mudstone; light olive gray 5Y6/1, weathers yellowish gray 5Y8/1; thin to thick bedded; elongate chert nodules that form bands; chert nodules contain silicified fossils; weathers to form a cliff; fossils are: crinoids and brachiopoda; lower contact conformable........................	4.6 (15)	3.0 (10)

Total thickness of the Harrisburg Member of the Kaibab Formation................. 21.7 (71)

Kaibab Formation (Permian):
Fossil Mountain Member:

1.	Limestone, mudstone; medium light gray N6, weathers light gray N7; thick-bedded; contains chert nodules; weathers to a form cliff; fossils are: bryozoans, brachiopods, crinoids, and rugose coral; lower contact not measured to.....	3.0 (10)	00 (0)

Total incomplete thickness of the Fossil Mountain Member........................	3.0 (10)
Total incomplete thickness of the Kaibab Formation..............................	24.7 (81)

Jackson (VABM) Measured Section
Section No. RCC3

Section Location: Shivwits Quadrangle, Washington County, Utah 7 1/2 Minute Topographic Series, SW 1/4, NE 1/4, Section 3, T. 41 S, R. 18 W. Section was measured on the north side of Jackson Peak (VABM). Section is overturned and was measured in a northeast direction through a conglomerate/breccia deposit.

Section was measured by R. LaRell Nielson on January 4, 1990.

Unit	Lithology	Thickness Meters (Feet)	Distance Above Base Meters (Feet)
	Moenkopi Formation (Triassic): Lower Red Member:		
2.	Siltstone, sandy, gypsiferous; moderate brown 5YR4/4, weathers very pale orange 10YR8/2; very thin bedded; parasitic folds are present; weathers to form a slope; lacks fossils; lower contact covered; upper contact not measured to................................	6.1 (20)	32 (75)
1.	Covered slope.....................	8.2 (21)	15 (49)
	Total incomplete thickness of the Moenkopi Formation.........................	6.0 (20)	
	Total incomplete thickness of the Lower Red Member.............................	6.0 (20)	

Rock Canyon Conglomerate (Permian-Triassic):

1. Breccia, lithic, sandy, to sandstone, lithicarenite, conglomeratic; light brown 5YR5/6, weathers moderate brown 5YR4/4, thin-bedded; contains laminations and cross-laminations; clasts are angular to subangular chert and limestone clasts; weathers to form a stair step topography; lacks fossils; lower contact disconformable.....................	12 (39)	2.7 (9)
Total Thickness of the Rock Canyon Conglomerate.............................	12 (39)	

Kaibab Formation (Permian):
Harrisburg Member:

1. Limestone, mudstone; yellowish gray 5Y7/2, weathers light olive gray 5Y5/2; massive bedding; contains laminations; disseminated chert; weathers to form a cliff; fossiliferous, fossils are broken and disarticulated crinoids; lower contact not measured to............	2.7 (9)	00 (0)
Total incomplete thickness of the Kaibab Formation..................................	2.7 (9)	
Total incomplete thickness of the Harrisburg Member..........................	2.7 (9)	

Wayne Canyon Measured Section
Section No. RCC4

Section Location: Kolob Arch Quadrangle, Utah, 7 1/2 Minute Topographic Series, SE 1/4, SE 1/4, Section 9, T. 38 S., R.12 W. Section was measured between Wayne Canyon and Camp Creek. Section is located approximately 100 meters north of the entrance to Wayne Canyon.

Section was measured by R. LaRell Nielson on January 9, 1990.

Unit	Lithology	Thickness Meters (Feet)	Distance Above Base Meters (Feet)
	Moenkopi Formation (Triassic): Lower Red Member:		
1.	Siltstone, sandy; yellowish gray 5Y8/1, weathers grayish orange 10YR7/4; very thin-bedded, laminated, ripple marks are common; weathers to form a slope; fossiliferous, fossils are bivalves; upper contact not measured to; lower contact conformable..........	3.0 (10)	68.2 (224)
	Total incomplete thickness of the Lower Red Member........................	3.0 (10)	
	Moenkopi Formation (Triassic): Timpoweap Member:		
2.	Limestone (dolomitic sandy), mudstone, dolomitic; light brown 5YR5/6, weathers grayish orange 10YR7/4; thin-bedded, laminated; pisolites/oncolites common; weathers to a form stair step topography; fossiliferous, fossils are: ammonoids and gastropods; lower contact gradational................	5.2 (17)	63 (207)

1. Limestone, mudstone, dolomitic and conglomeratic, lithic, sandy; light brown 5YR5/6, weathers grayish orange 10YR7/4; thin-bedded; lenses of limestone; angular chert clasts common; weathers to form a cliff; fossiliferous, fossils are: ammonoids, gastropods, bivalves; lower contact gradational................	22.2 (73)	40.8 (134)
Total incomplete thickness of the Moenkopi Formation......................	30.4 (100)	
Total thickness of the Timpoweap Member.	27.4 (90)	
Rock Canyon Conglomerate (Permian-Triassic):		
3. Conglomerate, lithic; pale yellowish orange 10YR8/6, weathers grayish orange 10YR7/4; very thick-bedded, laminated; chert and limestone clasts present; weathers to form a cliff; lacks fossils; lower contact conformable...............	.3 (1)	40.5 (133)
2. Sandstone (with conglomerate lenses), lithic arenite to quartz arenite; pale yellowish orange 10YR8/6, weathers to grayish orange 10YR7/4; thin-bedded; contains trough cross-bedding, cross-laminations and laminations; clast are angular to subangular; weathers to a form slope; lacks fossils; lower contact gradational................	2.1 (7)	38.4 (126)

1.	Conglomerate to breccia (pebble), lithic conglomerate to breccia; dark yellowish orange 10YR6/6, weathers grayish orange 10YR7/4; thick bedded, cross-laminated; weathers to form a cliff; lacks fossils; lower contact is disconformable....................	22.2 (73)	16.1 (53)
	Total thickness of the Rock Canyon Conglomerate..............................	24.6 (81)	
	Kaibab Formation (Permian): Harrisburg Member:		
3.	Limestone to dolostone, mudstone; yellowish gray 5Y7/2, weathers light olive gray 5Y6/1; thin-bedded, laminated; rounded chert nodules; becomes more dolomitic upward; weathers to form a cliff; lacks fossils; lower contact gradational............................	4.2 (17)	11.9 (39)
2.	Limestone, mudstone, to dolostone with sandstone and siltstone lenses; very pale orange 10YR8/2, weathers grayish orange 10YR7/4; thin to very thinly-bedded; siltstone and sandstone lenses; chert stringers; weathers to form a slope; lacks fossils; lower contact gradational............................	6.0 (20)	5.7 (19)
1.	Limestone, dolomitic, mudstone; yellowish gray 5Y7/2, weathers light olive gray 5Y6/1; thin bedded; rounded chert nodules; weathers to form a cliff; lacks fossils; lower contact gradational.........	2.7 (9)	3.0 (10)
	Total thickness of the Harrisburg Member of the Kaibab Formation................	12.8 (46)	

Kaibab Formation (Permian):
Fossil Mountain Member:

1.	Limestone, mudstone; yellowish gray 5Y7/2, weathers light olive gray 5Y6/1; thin-bedded, horizontal bedded chert; weathers to form a cliff; fossiliferous, fossils are broken and disarticulated crinoids and brachiopods; lower contact not measured to........................	3.0 (10)	0 (0)

Total incomplete thickness of the Fossil Mountain Member of the Kaibab Formation. 3.0 (10)

Total incomplete thickness of the Kaibab Formation.............................. 11.8 (39)

Camp Creek Measured Section
Section No. RCC5

Section Location: Kanarraville Quadrangle, Iron County, Utah, 7 1/2 Minute Topographic Series, SW 1/4, NE 1/4 Section 10, T. 38 S., R. 12. W. Section starts at the base of the second water fall and follows the canyon to approximately 15 meters east of the upper water fall.

Section was measured by R. LaRell Nielson on January 9, 1990.

Unit	Lithology	Thickness Meters (Feet)	Distance Above Base Meters (Feet)
	Moenkopi Formation (Triassic): Lower Red Member:		
1.	Siltstone, sandy; grayish orange 10YR7/4, weathers dark yellowish orange 10YR6/6; very thin bedded, laminations, ripple marks; weathers to form a cliff; fossiliferous, fossils are bivalves; upper contact not measured to; lower contact conformable......................	3.0 (10)	24.9 (82)
	Total incomplete thickness of Lower Red Member of the Moenkopi Formation........	3.0 (10)	
	Moenkopi Formation (Triassic): Timpoweap Member:		
2.	Limestone, dolomitic, mudstone; yellowish gray 5Y8/1, weathers light olive gray 5Y6/1; thin-bedded, laminated; weathers to form a stair step topography; fossiliferous, fossils are: ammonoids, gastropods, and bivalves, fossils are oriented in the upper part of the unit; lower contact gradational......................	1.5 (5)	23.4 (77)

1. Limestone (dolomitic), mudstone; pale yellowish brown 10YR6/2, weathers grayish orange pink 5YR7/2; thin-bedded, laminated; weathers to form a cliff; lacks fossils; lower contact conformable................	10.6 (35)	12.8 (42)
Total thickness of the Timpoweap Member of the Moenkopi Formation...............	12.1 (40)	
Total incomplete thickness of the Moenkopi Formation..........................	15.1 (50)	
Rock Canyon Conglomerate (Permian-Triassic):		
2. Sandstone (with conglomerate lenses), lithic arenite; light brown 5YR5/6, weathers grayish orange 10YR7/4; thin-bedded, cross-laminated; ripple marks present; clasts are: rounded and subrounded chert; weathers to form a slope; lacks fossils; lower contact gradational...............................	7.3 (24)	5.4 (18)
1. Conglomerate to sandstone, lithic conglomerate to lithic wacke; light brown 5YR5/6, weathers grayish orange 10YR7/4; thin-bedded, laminated; chert and limestone clasts; weathers to form a cliff; fossiliferous, fossils are poorly preserved bivalves and gastropods; lower contact disconformable.......	2.4 (8)	3.0 (10)
Total thickness of the Rock Canyon Conglomerate.............................	9.7 (32)	

Kaibab Formation (Permian):
Harrisburg Member:

1.	Sandstone to siltstone, quartz arenite to sandy siltstone; yellowish gray 5Y7/2, weathers light brown 5YR5/6; thin to very thin-bedded; contains laminations and cross-laminations; weathers to form a slope; lacks fossils; lower contact not measured to.............	3.0 (10)	0 (0)
	Total incomplete thickness of the Harrisburg Member........................	3.0 (10)	
	Total incomplete thickness of the Kaibab Formation..............................	3.0 (10)	

Rock Canyon-Clay Hole Wash Measured Section
Section No. RCC6

Section Location: Rock Canyon Quadrangle, Mohave County, Arizona 7 1/2 Minute Topographic Series, NE 1/4, NW 1/4, Section 9, T. 41 S., R. 9 W. Section was measured on the southwest side of the junction of Rock Canyon and Clay Hole Wash. Section was measured starting at river level.

Section was measured by R. LaRell Nielson on January 10, 1989.

Unit	Lithology	Thickness Meters (Feet)	Distance Above Base Meters (Feet)
	Moenkopi Formation (Triassic): Timpoweap Member:		
1.	Limestone, dolomitic, conglomeratic, mudstone; light brown 5YR5/6, weathers dark yellowish brown 10YR4/2; thin-bedded, laminated; chert clasts; fossiliferous, fossils are: algal fragments and ammonoids; weathers to form a cliff; lower contact gradational; upper contact modern erosional surface..................	2.5 (8)	19.2 (63)
	Total incomplete thickness of Timpoweap Member of the Moenkopi Formation........	2.5 (8)	
	Total incomplete thickness of Moenkopi Formation..............................	2.5 (8)	
	Rock Canyon Conglomerate (Permian-Triassic):		
2.	Siltstone to sandstone, sandy siltstone and lithic arenite; pale yellowish orange 10YR8/6, weathers dark yellowish orange 10YR6/6; thin to very thin-bedded, cross laminated; weathers to form a slope; lacks fossils; lower contact gradational.	1 (3)	17 (55)

1. Conglomerate, lithic; pale yellowish orange 10YR8/6, weathers dark yellowish orange 10YR6/6; thick to thin bedded, laminated, cross-laminated; clasts are: boulder, cobble and pebble sized, that fine upward; clasts appear to come from Kaibab Formation; weathers to form a cliff; lacks fossils; lower contact conformable........................	6 (19)	16 (52)
Total thickness of the Rock Canyon Conglomerate............................	7 (22)	
Kaibab Formation (Permian): Harrisburg Member:		
2. Sandstone, quartz arenite; grayish orange 10YR7/4, weathers very pale orange 10YR8/2; thick-bedded, laminated and cross-laminated; ripple marks and load structures are present; contains conglomerate lenses; weathers to form a cliff; fossiliferous, fossils are vertical burrows; lower contact conformable.	4.5 (15)	10 (33)
1. Limestone (sandy), mudstone; light gray N7, weathers light olive gray 5Y6/1; thick bedding, laminated; becomes sandy upward; disseminated chert; weathers to form cliff; lacks fossils; lower contact conformable...........................	5.5 (18)	0 (0)
Total incomplete thickness of Harrisburg Member of the Kaibab Formation..........	10 (33)	
Total incomplete thickness of Kaibab Formation..............................	10 (33)	

Cottonwood Wash-Rock Canyon Measured Section
Section No. RCC7

Section Location: Rock Canyon Quadrangle, Mohave County, Arizona, 7 1/2 Minute Topographic Series, NE 1/4, SE 1/4, Section 9, T. 41 S., R. 9 W. Section was measured at the junction between Cottonwood Wash and Rock Canyon on the southwest side of Rock Canyon, Arizona.

Section was measured by R. LaRell Nielson on January 9, 1990.

Unit	Lithology	Thickness Meters (Feet)	Distance Above Base Meters (Feet)
	Moenkopi Formation (Triassic): Timpoweap Member:		
1.	Limestone, conglomeratic, mudstone; grayish orange 10YR7/4, weathers grayish orange pink 5YR-7/2; thin to very thin-bedded, laminated; chert clasts decrease in size upward; pisolites are present near the top of the unit; weathers to form a cliff; fossiliferous, fossils are bivalves and gastropods; preservation is poor due to diagenesis; lower contact gradational............................	4 (14)	28 (92)
	Total incomplete thickness of Timpoweap Member Moenkopi Formation..............	4 (14)	
	Total incomplete thickness of Moenkopi Formation...............................	4 (14)	

Rock Canyon Conglomerate (Permian-Triassic):

1. Conglomerate, lithic; light olive gray 5Y6/1, weathers pale yellowish brown 10YR6/2; thick bedded, trough and planar cross-stratification present; lenses of laminated and cross-laminated pebble, cobble and boulder clasts; weathers to form a cliff; lacks fossils; lower contact disconformable....................	19.5 (64)	24 (78)
Total thickness of the Rock Canyon Conglomerate..............................	19.5 (64)	

Kaibab Formation (Permian):
Harrisburg Member:

2. Siltstone to sandstone, sandy siltstone to quartz arenite; very pale orange 10YR8/2, weathers light brown 5YR6/4; thin to very thin-bedded; lamination and lenses of sand present; clasts are quartz; weathers to form a slope; lacks fossils, lower contact gradational................................	4 (14)	1.5 (5)
1. Limestone, dolomitic and sandy, amount of sand varies, mudstone; yellowish gray 5Y7/2; weathers pale yellowish orange 10YR8/6; thin-bedded; rounded chert nodules present; weathers to form a cliff; fossiliferous, fossils are: brachiopods and bivalves, crinoids; lower contact conformable..........	3 (9)	0 (0)
Total incomplete thickness of Harrisburg Member of the Kaibab Formation..........	7 (23)	
Total incomplete thickness of Kaibab Formation.............................	7 (23)	

Cottonwood Wash Measured Section
Section No. RCC8

Section Location: Rock Canyon Quadrangle, Mohave County, Arizona, 7 1/2 Minute Topographic Series, NE 1/4, SE 1/4, Section 9, T. 41 S., R. 9. W. Section was measured 400 yards south of the junction of Rock Canyon and Cottonwood Wash along the southwest side of Cottonwood Wash starting at stream level.

Section was measured by R. LaRell Nielson on January 9, 1990.

Unit	Lithology	Thickness Meters (Feet)	Distance Above Base Meters (Feet)
	Moenkopi Formation (Triassic): Timpoweap Member:		
2.	Limestone, sandy, wackestone, pisolitic; grayish orange pink 5YR7/2, weathers light brown 5YR-6/4; thin-bedded, laminations present; pisolites present; weathers to form a cliff; fossiliferous, fossils are gastropods; lower contact conformable..................	3 (9)	36 (119)
1.	Limestone, mudstone; sand content decrease upward; light brown 5YR-6/4, weathers moderate brown 5YR-4/4; thin-bedded, laminated; concretions present; weathers to form a cliff; fossiliferous, fossils are poorly preserved gastropods; lower contact gradational	12 (39)	33.5 (110)
	Total incomplete thickness of the Timpoweap Member...........................	14.5 (48)	
	Total incomplete thickness of the Moenkopi Formation.........................	14.5 (48)	

Rock Canyon Conglomerate (Permian-Triassic):

2.	Siltstone, sandy siltstone; very pale orange 10YR8/2, weathers grayish orange 10YR7/4; thin to very thin-bedded, cross-laminated; weathers to form a slope; lacks fossils; lower contact conformable	4 (13)	21.5 (71)
1.	Conglomerate, lithic; yellowish gray 5Y8/1, weathers light olive gray 5Y6/1; massive bedding, cross-bedding and cross-laminations; limestone and chert clasts, weathers to form a cliff; lower contact disconformable............	9.5 (31)	18 (58)

Total complete thickness of the Rock Canyon Conglomerate.................... 13.5 (44)

Kaibab Formation (Permian):
Harrisburg Member:

1.	Limestone, sandy and silty in places, mudstone to packstone with beds of crinoids; white N9, weathers yellowish gray 5Y8/1; thin-bedded, laminated, cross- laminated; lenses of sandstone; weathers to form a stair step topography; fossiliferous, fossils are crinoids and brachiopods; lower contact not measured to......................	8 (27)	0 (0)

Total incomplete thickness of the Harrisburg Member Kaibab Formation......... 8 (27)

Total incomplete thickness of the Kaibab Formation............................. 8 (27)

South Cottonwood Wash Measured Section
Section No. RCC9

Section Location: Rock Canyon Quadrangle, Mohave County,Arizona, 7 1.2 Minute Topographic Series, NE 1/4, SE 1/4, Section 9, T. 41 S., R. 9 W. Section was 800 meters south of the junction of Rock Canyon and Cottonwood Wash, in Cottonwood Wash starting at stream level on the north side of the wash.

Section was measured by R. LaRell Nielson on January 9, 1990.

Units	Lithology	Thickness Meters (Feet)	Distance Above Base Meters (Feet)
	Moenkopi Formation (Triassic): Timpoweap Member:		
1.	Limestone, mudstone to wackestone; light olive gray 5Y6/1, weathers olive gray 5Y4/1; thin-bedded, laminated and cross-laminated; weathers to form a cliff; fossiliferous, fossils are: poorly preserved bivalves and gastropods; lower contact conformable..........	2 (6)	32 (99)
	Total incomplete thickness of the Timpoweap Member Moenkopi Formation..........	2 (6)	
	Total incomplete thickness of the Moenkopi Formation.........................	2 (6)	

Rock Canyon Conglomerate (Permian-Triassic):

3. Conglomerate, lithic; yellowish gray 5Y8/1, weathers light olive gray 5Y6/1; massive bedding; cross-laminations present; boulder to pebble sized clasts at bottom, cobble to pebble at top; inter-fingers laterally with the Timpoweap Member; weathers to form a cliff; lacks fossils, lower contact conformable......................	10 (33)	28 (93)
2. Siltstone, sandy; pale yellowish orange 10YR8/6, weathers grayish orange 10YR7/4; very thin-bedded; laminations and cross-laminations present; weathers to form a cliff; lacks fossils; lower contact conformable.........................	4 (13)	18 (60)
1. Conglomerate, lithic; yellowish gray 5Y8/1, weathers light olive gray 5Y6/1; bedding massive; contains chert and limestone clasts; cross-bedding and cross- laminations present; weathers to form a cliff; lacks fossils; lower contact is a disconformable...............	9 (31)	14 (47)
Total thickness of the Rock Canyon Conglomerate.............................	23 (77)	

Kaibab Formation (Permian):
Harrisburg Member:

1. Limestone, sandy, mudstone to packstone; yellowish gray 5Y7/2, weathers pale yellowish orange 10YR8/6; thin-bedded, contains laminations; rounded chert nodules; sandstone lenses present; weathers to form cliff; fossiliferous, fossils are: brachiopods present; lower contact not measured to......	5 (16)	5 (16)

Total incomplete thickness of the Harrisburg Member Kaibab Formation.........	5 (16)
Total Incomplete thickness of the Kaibab Formation...............................	5 (16)

South of The Three Brothers Measured Section
Section No. RCC10

Section Location: The Divide Quadrangle, 7 1/2 Minute Topographic Series, SW 1/4, NE 1/4, Section 34, T. 42 S., R. 13, W. Section was measured one fourth mile south of The Three Brothers and west of Gould Reservoir.

Section was measured by R. LaRell Nielson on August 13, 1990.

Unit	**Lithology**	**Thickness Meters (Feet)**	**Distance Above Base Meters (Feet)**
	Moenkopi Formation (Triassic): Timpoweap Member:		
2.	Limestone to sandstone, mudstone, sandy to calcareous lithic arenite; light olive gray 5Y6/1, weathers yellowish gray 5Y7/2; thin-bedded; contains cross-laminations and herringbone cross-bedding, simple and planer cross-bedding; contains chert and rock fragment clasts; weathers to form a cliff; lacks fossils; upper erosional surface, lower contact gradational..........	4.5 (15)	45 (149)
1.	Limestone, mudstone, fossiliferous; light olive gray 5Y6/1, weathers yellowish gray 5Y7/2; thin-bedded, contains laminations; fossiliferous, fossils are poorly preserved bivalves and gastropods; weathers to form a cliff; lower contact gradational...............	3 (11)	41 (134)
	Total incomplete thickness of the Timpoweap Member of the Moenkopi Formation...	8 (26)	
	Total incomplete thickness of the Moenkopi Formation..........................	8 (26)	

Rock Canyon Conglomerate (Permian-Triassic):

2.	Limestone, mudstone; grayish orange 10YR7/4, weathers moderate yellowish brown 10YR5/4; bedding, massive, contains laminations and secondary sparry calcite; weathers to form a cliff; lacks fossils; lower contact gradational..........	2 (6)	37.5 (123)
1.	Conglomerate, chert, cobble to boulder; dark yellowish orange 10YR6/6, weathers grayish orange 10YR7/4, bedding massive, weak cross-laminations, subrounded to rounded chert and limestone clasts; weathers to form cliff; lacks fossils; lower contact disconformable	20 (65)	36 (65)

Total complete thickness of the Rock Canyon Conglomerate.................... 22 (71)

Kaibab Formation (Permian):
Harrisburg Member:

6.	Siltstone, sandy, silty; light brown 5YR5/6, weathers dark yellowish orange 10YR6/6; thin-bedded, contains laminations; weathers to form a slope; lack fossils; lower contact conformable................	5 (17)	16 (52)
5.	Sandstone, quartz arenite; grayish orange pink 5YR7/2, weathers the same color; laminations present; unit pinches out latterly; fine grained; symmetrical ripple marks present; weathers to form a cliff; lacks fossils; lower contact conformable.........................	2 (8)	11 (35)

4.	Gypsiferous siltstone to gypsum; yellowish gray 5Y7/2, weathers white N9; thin-bedded, laminated and cross-laminated; weathers to form slope; lacks fossils; lower contact conformable................	2 (7)	8 (27)
3.	Limestone, mudstone, fossiliferous; olive gray 5Y4/1, weathers light olive gray 5Y6/1; massive bedding; unit pinches out laterally; laminations present; weathers to form a cliff; fossiliferous, fossils are: disarticulated bivalves and gastropods; lower contact conformable.	1 (2)	6 (18)
2.	Limestone to siltstone,mudstone togypsiferous siltstone; yellowish gray-5Y7/2, yellowish gray 5Y7/2, irregular and wavy bedding; chert nodules; sandy; weathers to form a slope; fossiliferous, fossils are poorly preserved bivalves and gastropods; lower contact gradational..................	1 (4)	5.5 (18)
1.	Limestone, cherty, mudstone; yellowish gray 5Y7/2, weathers to a moderate yellowish brown 10YR5/4; massive bedding; chert stringers chert has replaced up to 60% of the rock; weathers to form a slope at bottom and cliff at the top; lacks fossils; lower contact gradational.	1 (4)	3 (10)
Total thickness of the Harrisburg Member of the Kaibab Formation.................		12.8 (42)	

Kaibab Formation (Permian)
Fossil Mountain Member:

1.	Limestone, fossiliferous wackestone; yellowish gray 5Y7/2, weathers light gray N7; thick bedded to massive; contains chert stringers and nodules; weathers to form cliff, fossiliferous, fossils are brachiopods, bryozoans, and crinoids, lower contact not measured to..........................	3 (10)	0 (0)

Total incomplete thickness of the Harrisburg Member of the Kaibab Formation..	15.9 (52)
Total incomplete thickness of the Kaibab Formation	3 (10)