THE PARUNUWEAP FORMATION IN THE VICINITY OF ZION NATIONAL PARK, UTAH

by

William Michael Dalness

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William Michael Dalness

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ABSTRACT

The Parunuweap Formation has been described in the Virgin, Kanab, and Paria drainage basins of southwestern Utah. It is mainly a coarse fluvial conglomerate which filled existing valleys when they were nearly as deep and as wide as they are today. Subsequent erosion has removed most of the deposits, and isolated patches remain at various elevations above present valley floors.

Fossils or organic material have not been found in the Parunuweap Formation and its age must be inferred from its relationships with late Cenozoic faulting and basalt flows. The Parunuweap was originally assigned to the Pliocene and it has been tentatively correlated with known Pliocene formations. However, most of the geomorphic evidence points to a Late Pleistocene age for the Parunuweap Formation. The deposits along the Hurricane Cliffs post-date a major displacement of the Hurricane fault which occurred in the Middle or Late Pleistocene. Some of the Parunuweap deposits post-date basalt flows of probable Late Pleistocene age.

Two possible causes of deposition are suggested for the Parunuweap deposits throughout the Virgin River drainage basin: (1) uplift along the Hurricane fault tilted the Kolob Terrace and caused ponding and aggradation throughout the Virgin River drainage basin or (2) toward the end of a glacial stage, maximum runoff and contributions

of detritus from melting ice masses in the Kolob overloaded the Virgin River. The Parunuweap fill was removed when: (1) the Virgin River cut through the Hurricane Cliffs near LaVerkin and drained the ponded waters or (2) a return to a semiarid climate initiated erosion. Both factors may have been involved. However, there are very few features in the Parunuweap deposits that suggest ponding and the Late Pleistocene climate in southwestern Utah is a matter of speculation.

In the vicinity of Zion National Park, the Parunuweap Formation is mostly a well-cemented conglomerate composed of cobbles and pebbles in a coarse quartz sand. Many outcrops contain large angular blocks and boulders derived from local landslides and mudslides. The constituents are the same as those found in present stream deposits—the source areas and drainage lines during Parunuweap deposition were essentially the same as they are today.

Prior to Parunuweap deposition, the Virgin River had a steeper gradient and was 100 to 200 feet above its present elevation. A period of vigorous aggradation filled the valleys with perhaps several hundred feet of coarse Parunuweap sediments. Basalt flows poured over some of the Parunuweap deposits in the Virgin River valley, North Creek valley, Long Valley, and south of Toquerville. A second period of aggradation filled the valleys with conglomerate after the streams cut to almost their present elevations. The two periods of aggradation may have been caused by two glacial stages (Illinoian and Wisconsinan?) or intermittent uplift along the Hurricane fault. The streams eventually reexcavated the valleys and cut down to their present grades. Lateral planation of the ancestral Virgin River near Rockville resulted in a terrace cut into the Parunuweap Formation 150 feet above present stream grade. South of Orderville, a pediment surface cut mostly into bedrock was developed at about the same time.

A later period of aggradation (Recent ?) resulted in the deposition of a sand and gravel deposit informally named the Orderville gravel in this report. It overlies the Parunuweap at some localities, and at others fills areas below the Parunuweap outcrops. Like the Parunuweap, its constituents are the same as those found in present stream gravels.

INTRODUCTION

GENERAL STATEMENT

The Parunuweap Formation was first described and named by Gregory (1945, p. 110-115). He stated that the Parunuweap occurs throughout southwestern Utah 10 to 200 feet above present valley floors and consists of two chief classes of sediments—conglomerates and alluvial or lacustrine silts. According to Gregory, these deposits are found in the Virgin, Kanab, and Paria drainage basins and along Coal Creek (near Cedar City), where they are at comparable topographic positions. These deposits were described in more detail by Gregory in his papers on the Paunsaugunt region (Gregory, 1951, p. 54-55), Eastern Iron County (Gregory, 1950b, p. 68-71), and Zion Park region (Gregory, 1950a, p. 170).

Cook (1957, p. 38) has tentatively identified the formation in the vicinity of the Pine Valley Mountains. Thomas and Taylor (1946, p. 33) described deposits in the Cedar City area that were later identified as Parunuweap by Gregory (1950b, p. 68). Eardley (1965, p. 17-32) and Coney (1959, p. 91-98) have studied the Parunuweap in the vicinity of Zion Canyon. Cashion (1961 and 1967) has mapped and described some of the Parunuweap outcrops in Long Valley.

The sediments described by these authors are mostly coarse fluvial conglomerates and mudflow deposits, but alluvial or lacustrine silts have been noted at one locality—along Lawrence Creek near Cedar

City (Gregory, 1945, p. 113 and 1950b, p. 68).

Gregory (1950a, p. 170) stated:

"The position of the remnant outcrops at the top and base and midway up on canyon walls of major streams, as solid filling of short tributary canyons and as patches on low divides between streams, suggests that the consolidated gravel once partly filled some drainage channels and filled others from brim to brim, in places extending beyond. It also shows that when the gravel was deposited the canyons within which it rests--canyons developed within the gorge epicycle--were substantially as deep and as wide as they are today. This deposit... obliterated canyons more than 200 feet deep... Since the conglomerate was laid down, its thicker masses have been largely removed from the canyons..."

PURPOSE AND SCOPE

The purpose of this study is to attempt to solve the problems of distribution, composition, provenance, cause of deposition, and age of the Parunuweap Formation in the vicinity of Zion National Park and to record the geomorphic history of the region during the time of deposition of the formation.

The regional aspects of the formation—age, correlation, and causes of deposition—will be considered first. This is followed by a more detailed description and interpretation of the deposits in the study area.

LOCATION OF STUDY AREA

The study area is in the vicinity of Zion National Park in south-western Utah. Field work was restricted to major stream valleys, their tributary valleys, and interstream divides within a part of the upper Virgin River drainage basin. This area is delineated in figure 1 and includes most of the drainage basin of the East Fork of the Virgin River, a small portion of the North Fork drainage basin, and the main Virgin River valley from Zion National Park to the Toquerville-LaVerkin area.

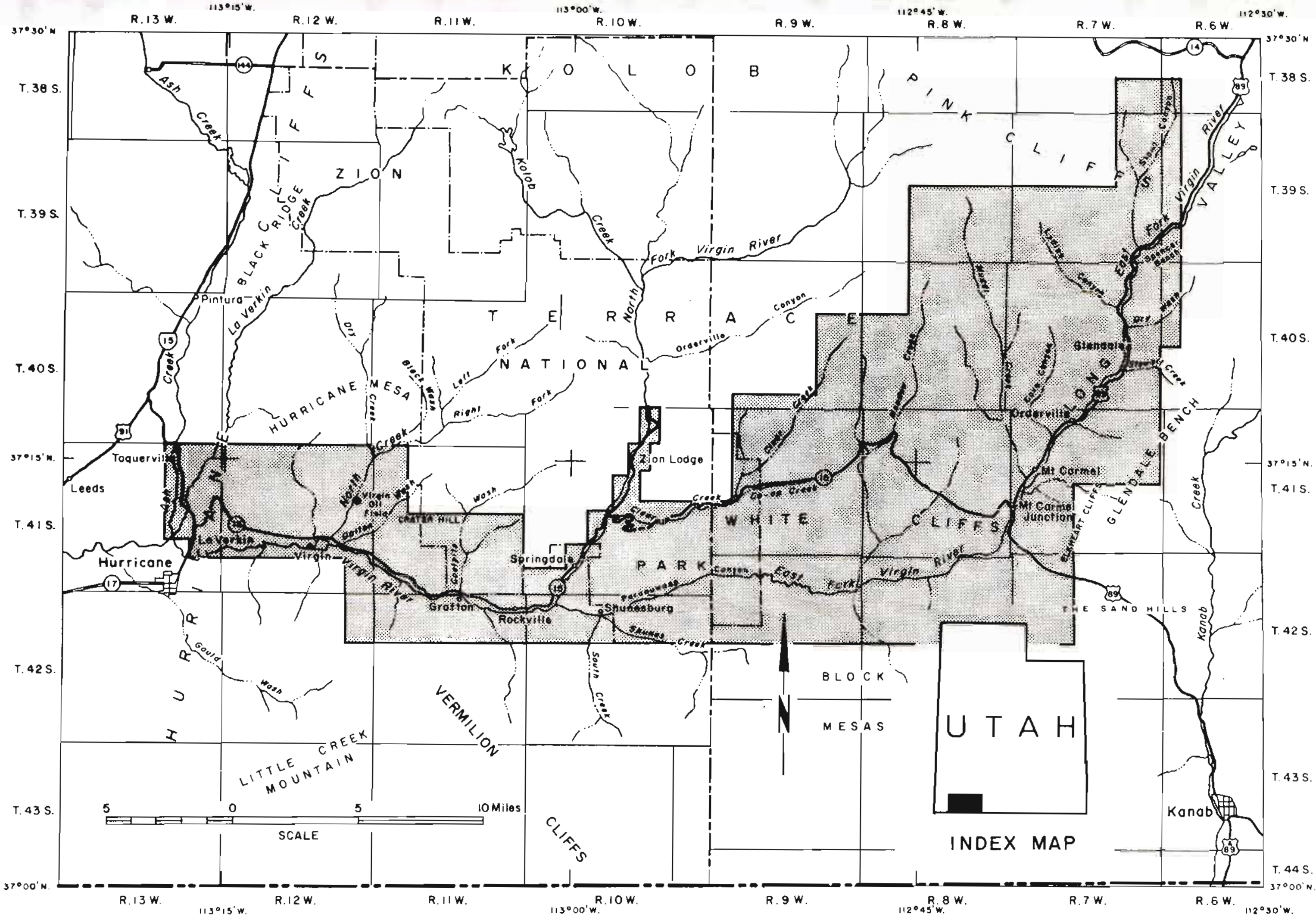


Figure 1.- Map showing location of study area.

PHYSIOGRAPHY OF STUDY AREA

The physiography of this area has been described in detail by Gregory (1950a, p. 4-12). The essential features, which are shown on figure 1, are the following.

The dominant physiographic feature is the Kolob Terrace into which deep canyons have been cut by tributaries of the Virgin River. The Markagunt Plateau, rimmed by the Pink Cliffs, marks the northern boundary of the Kolob. The Hurricane Cliffs, the topographic expression of the Hurricane fault, trend along the western edge of the Terrace. The eastern margin is bounded by the Sevier fault which in the area east of Mt. Carmel forms the Elkheart Cliffs. The southern edge is rimmed by the White Cliffs escarpment.

The Kolob Terrace is drained by the two major tributaries of the Virgin River—the North and East Forks. The Virgin River starts at their confluence and flows westward and eventually southward into the Colorado River.

METHODS OF STUDY

This investigation consisted of both field and laboratory work. The field work was done during the summer of 1968 and consisted of mapping, sampling, and interpreting the geomorphic expression of the Parunuweap Formation.

In the laboratory, pebble count data were interpreted and mechanical analyses were performed on 12 selected samples. Also, heavy minerals were separated from 24 sand samples and the grains were mounted and identified.

TYPE LOCALITY OF THE PARUNUWEAP FORMATION

Gregory (1945, p. 111) called Long Valley the "Parunuweap Valley" and thus from it, derived the formational name. However, in present usage, the name "Parunuweap" refers only to the canyon in the southernmost part of Zion National Park. The name "Parunuweap." leads one to believe that the best exposures are found in the Parunuweap Canyon, which is not the case.

Gregory did not establish a specific type section. His reference to a locality which might be taken as the type is in the explanation of his figure 7 (Gregory, 1945, p. 112), where he states that the outcrop shown in the figure is "2 miles above the Glendale-type locality." There is only one significant outcrop near Glendale and it is shown in figure 2. This exposure serves as well as any other and in this report it is designated as the type.

Figure 2.--Type locality of the Parunuweap Formation; west of Glendale.

AGE AND CORRELATIONS

Because fossils or organic material have not been found in the Parunuweap Formation, its age must be inferred from its relationships with Late Cenozoic faulting and basalt flows.

The Parunuweap was deposited in the same valleys which exist today—valleys developed since the start of the "canyon cycle." Gregory (1950a, p. 167) stated that the "canyon cycle" began in the Late Miocene or Early Pliocene. He concluded that the Parunuweap was deposited in canyons developed in the "gorge epicycle," sometime after the start of the "canyon cycle." Blackwelder (1934, p. 551-566) concluded that uplift in the Late Pliocene or Early Pleistocene initiated this cycle. The recent work of McKee and others (1964) concludes that the "canyon cycle" dates from the time of the diversion of the upper Colorado system into the Hualapai system (which probably included the ancestral Virgin River) in the Early Pliocene. In any case, the Parunuweap was deposited well after the "canyon cycle" had begun, in canyons and valleys almost as deep as they are today.

In his publications on the Zion Park and Paunsaugunt regions, Gregory (1950a, p. 170 and 1951, p. 55) tentatively assigned the Parunuweap to the Early Pleistocene or Late Pliocene. (Although these papers were published in the early 1950's, Gregory completed them prior to his naming the the formation in 1945. In these papers, he referred to the deposits as "consolidated gravels.") Later, when he named the formation, Gregory (1945, p. 114) tentatively assigned it to the Pliocene. Some papers published since 1945 suggest that the Parunuweap Formation is much younger.

Thomas and Taylor (1946, p. 35) assigned their "fanglomerate terrace" (Parunuweap) in the Cedar City area to the Pleistocene. Averitt (1964, p. 905) found evidence that the Parunuweap above Coal Creek near Cedar City was deposited after a major displacement of the Hurricane fault in the Middle or Late Pleistocene. The Parunuweap deposits along LaVerkin Creek near Toquerville post-date the same fault movement. Eardley (1965, p. 29) suggested that the formation in the Rockville-Grafton area was deposited in the Early Wisconsinan Stage of the Pleistocene Epoch. In this same area, some Parunuweap deposits apparently postdate the Crater Hill basalt flow, which Threet (1958, p. 1069) estimates as being "between a few thousand and a few tens of thousands of years" old. I conclude that the Parunuweap Formation was deposited in the Late Pleistocene—perhaps as late as the Wisconsinan Stage.

Gregory (1945, p. 115) tentatively correlated the Parunuweap with the Sevier River Formation of Late Pliocene of Early Pleistocene age. The Sevier River Formation is, in part, a coarse conglomerate which crops out along the Sevier River in central Utah (Callaghan, 1933, p. 100-101). The similar distribution and physical aspects of the two formations seem to justify their correlation. At the time Gregory suggested their correlation, their ages also seemed compatible. If the

Parunuweap is Late Pleistocene age, the correlation would be erroneous. Perhaps the Sevier River Formation is also somewhat younger than previously thought.

Hunt (1956, p. 27) correlated the Parunuweap with the Bidahochi Formation of the Colorado Plateau region in Arizona. Cook (1960, p. 48) included the Parunuweap with the Muddy Creek Formation in his geologic map of Washington County. These formations have been established as Pliocene in age and do not correlate with the Parunuweap Formation.

The "old river deposits" described by Longwell (1936, p. 1440-1443) in the Lake Mead area closely resemble the Parunuweap Formation in both distribution and physical aspects. Longwell mapped these deposits along Boulder Canyon and the Virgin River near St. Thomas, Nevada. The limb bones of a Pleistocene camel were found in these deposits. It is suggested that these deposits are correlated with the Parunuweap Formation of the upper Virgin River.

The problem of correlation has been compounded because the Parunoweap has not been studied in detail and its identity throughout southwestern Utah is very much in question. For instance, terrace gravels in the Pine Valley Mountains, identified as Wisconsinan in age, resemble the Parunuweap Formation south of Toquerville but have not been correlated with it. These gravels, called "Boulder alluvium" by Proctor (1953, p. 39) and "high-level gravel" by Cook (1957, p. 39) are dominated by monzonite boulders similar to those found in the Parunuweap near Toquerville. Cook tentatively identified Parunuweap deposits below the terrace gravels. However, referring to the "high-level gravel", Cook stated: "Thomas and Taylor (1946, p. 33) noted similar material in Cedar City and Parowan valleys, which they mapped as fanglomerate terraces." These are the same "fanglomerate terraces" that Gregory (1950b, p. 68) identified as Parunuweap.

In summary, Gregory originally assigned the Parunuweap Formation to the Pliocene. However, later evidence indicates that its age is Late Pleistocene. Some erroneous correlations with Pliocene formations have been proposed on the assumption that the original assigned age was correct. Because the formation has not been studied in detail everywhere, problems remain in its correlation.

POSSIBLE CAUSES OF DEPOSITION

GENERAL STATEMENT

The Parunuweap Formation was deposited during a time of vigorous aggradation after the Virgin River had cut canyons and valleys almost to their present depths. What caused the river to cease downcutting and then fill the valleys—perhaps brim to brim—with great amounts of coarse sediments? Two hypotheses are suggested: (1) the Virgin River was ponded when uplift along the Hurricane fault tilted the Kolob Terrace, or (2) a climatic change caused an overloaded condition of the rivers for a considerable amount of time. The Parunoweap fill was removed when: (1) the Virgin River cut through the Hurricane cliffs near LaVerkin and drained the ponded waters or (2) normal climatic conditions returned. Both hypotheses have shortcomings and it is difficult to attribute the deposition to only one. Perhaps both faulting and climatic factors were involved.

Eardley (1965, p. 20) suggested that the Parunuweap Formation in the Rockville-Grafton area may have been deposited by a catastrophic flood which resulted from the breaching of a landslide dam in Zion Canyon. Also, the damming of the Virgin River near Grafton by the Crater Hill basalt flow could have caused local aggradation (Threet, 1958, p. 1065-1070). These are local events which did not account for the regional deposition of the Parunuweap.

FAULTING

In the Middle or Late Pleistocene, renewed uplift resulting in a total displacement of 200 to 2000 feet, occurred along the Hurricane fault (Hamblin, 1963, p. 88 and Averitt, 1964, p. 905). Perhaps this uplift caused eastward tilting of the Kolob Terrace which ponded the Virgin River and initiated deposition of the Parunuweap. The fault cuts across the LaVerkin valley near Toquerville. Parunuweap deposits crop out along the valley at approximately the same elevation on both sides of the fault. Therefore, in LaVerkin valley at least, the deposition of the Parunuweap post-dates the fault movement. Perhaps these two events are not far apart in time.

In western Colorado, sediments somewhat similar in make-up to the Parunuweap Formation (but of a different age) have been explained as the result of ponding and aggradation due to regional tilting of the Colorado Plateau (Hunt, 1956, p. 85).

Although ponding may have been a factor in the deposition of the Parunuweap Formation, evidence is lacking. Sediments normally deposited in ponded waters—such as fine grained silts and clays—make up a negligible part of the formation in the area studied. However, Gregory (1945, p. 113 and 1950b, p. 68) has described alluvial or lacustrine silts in deposits along Lawrence Creek near Cedar City. Perhaps most of the fine-grained sediments were removed when the valleys were reexcavated and only the coarse materials from intermittent tributaries and landslides remain. There is no large scale deltaic bedding in the conglomerate which might have developed when the coarse sediments were deposited in the ponded waters.

CLIMATIC

Although regional tilting may have initiated a cycle of aggradation, a great amount of water and material had to be available. One might suspect flash floods similar to those which are common throughout the Virgin River drainage area. However, it would take more than a few periods of exceptional precipitation to deposit coarse sediments which eventually filled some valleys. A nearly constant supply of runoff and detritus must have been available over a long period of time. This runoff not only contributed water and material to the upper Virgin River but also initiated innumerable landslides and mudflows.

It is speculated that the climate in southwestern Utah was pluvial during glacial stages and semiarid during interglacial stages. Gregory (1950b, p. 71-72) has found evidence of Pleistocene ice sheets in the southern part of the Markagunt Plateau. Less extensive ice masses probably covered parts of the Kolob Terrace at the same time. The Parunuweap Formation may have been deposited toward the end of a glacial stage when precipitation was still considerable and runoff from melting ice masses in the Kolob was at a maximum. Material from the melting ice masses may account for the disproportionately high volume of detritus. A return to a semiarid climate initiated erosion which removed most of the Parunuweap deposits.

The relationships of erosion and deposition to climates is a controversial problem. Schumm (1963, p.12) concluded that the maximum amount of erosion occurs in a semiarid climate in a sedimentary terrane at high elevations. If this conclusion is correct, one might expect aggradation during a glacial stage—the wettest time—and erosion during the interglacial stage—the driest time.

THE RELATIONSHIP OF THE PARUNUWEAP FORMATION TO A POSSIBLE FLOOD IN THE ZION CANYON AREA

Grater (1945, p. 116-124) described an ancient landslide in Zion Canyon which dammed the North Fork and formed a lake 75 to 100 feet deep and perhaps 5 miles long. A sudden breaching of this landslide would have resulted in the deposition of great volumes of coarse, heterogeneous debris downstream. Eardley (1965. p. 20) stated that the Parunuweap deposits near Rockville could be the remnants of this flood material. However, the following questions must be answered. Was the slide dam suddenly breached or was it breached slowly? Was there enough water and material available to account for the great volume of Parunuweap deposits near Rockville? Did the breaching of the slide take place at a time which agrees with the inferred time of Parunuweap deposition?

A rapid breaching of the slide was suggested by Grater (1945, p. 121) in the following statement:

> "Probably the initial erosion was rapid, as the waters had a tremendous fall and had only loose debris to move."

I feel that a sudden breaching of the dam is probable but this alone does not prove that it is related to the Parunuweap deposits.

Eardley (1965, p. 11) concluded that the slide which caused the lake occurred after the canyon had eroded to its present elevation or perhaps 20 feet deeper. The lake was no more than 100 feet deep. Therefore, if the lake waters were released in one great torrent, the resulting flood debris downstream would have filled the valley to an elevation of no more than 100 feet above present stream grade. The Parunuweap deposits near Rockville underlie a terrace at an elevation of 150 feet above the river and they probably once extended even higher. Also, the base of most of the Parunuweap deposits is 10 or more feet above present stream grade and therefore, the Parunuweap was deposited when the Virgin River was at a higher elevation. The majority of the Parunuweap deposits are much too high and extensive to have been caused by this event.

Grater (1945, p. 123) stated that the slide is only a few thousand years old. This, of course, would make it too young to account for the Parunuweap deposits. However, Eardley (1965, p. 12) deduced that the slide is much older—perhaps Wisconsinan age. It is possible that the slide and the deposition of the Parunuweap occurred at about the same time; however, the Parunuweap was deposited when the river was at a higher elevation and it predates a possible flood. If the flood did occur, it contributed materials to the lower parts of the valley below the Parunuweap outcrops.

DISTRIBUTION

Isolated patches of the Parunuweap Formation crop out above the East Fork, the main Virgin River, and many of their tributaries. There are no known deposits along the Parunuweap Canyon. The distribution of these deposits is shown in figures 3 and 4. These maps also show the distribution of basalt flows in the area and a third unit, informally named the Orderville gravel in this report.

DESCRIPTION

COMPOSITION AND SOURCE OF MATERIALS

General Statement

Within the area studied, the Parunuweap is essentially a well cemented conglomerate composed of cobbles and pebbles in a matrix of coarse quartz sand. Large angular blocks and boulders are common constituents in some outcrops. At a few localities, the Parunuweap is a coarse sandstone with a few scattered pebbles. The formation consists of fluvial sediments with some material derived from local landslides and mudslides.

The sandy matrix, derived from the many pre-existing sandstones in the region, gives the deposit its color. In Long Valley it is a distinctive yellowish orange. In the Virgin River valley, sands and iron staining from nearby red beds give the formation a reddish brown color.

Long Valley

In the Long Valley area, angular slabs and blocks of local sandstone up to 4 feet in diameter are common (fig. 5). Smaller constituents include red and pink limestone pebbles from the nearby Wasatch Formation and rounded pebbles and cobbles of quartzite and black chert from the basal Wasatch conglomerate.

Basalt pebbles are absent from the deposits north of Stewart Creek; south of this point a small percentage of basalt fragments were found in each exposure examined. The source of these fragments is puzzling. The Spencer Bench basalt flow north of Glendale overlies the Parunuweap. The basalt remnant south of Glendale flowed into the valley after most of the Parunuweap deposits had been removed by erosion. The basalt fragments make up less than 5 percent of each outcrop and are generally less than cobble size. This suggests that they came from a distant source and were carried into the deposit by tributaries south of Stewart Creek. However, they may have been derived from local outcrops of basalt during a period of aggradation after the extrusion of the flows. As will be discussed later, two periods of Parunuweap deposition are evident downstream in the Virgin River valley.

Virgin River Valley

The Parunuweap deposits in the Virgin River valley contain a large percentage of volcanic fragments. Most of these fragments are well rounded pebbles and cobbles of basalt and andesite derived from the Kolob volcanic field (fig. 6). Some are porphyritic with a gray to light gray groundmass. No outcrops of this distinctive rock were found along the Virgin River but it is a common constituent of present stream gravels in the Kolob region.

Large angular blocks of basalt, many up to three feet in diameter, are found in outcrops on the east side of Coalpits Wash and in the exposures along the Virgin River between Grafton and Virgin (fig. 7). Obviously, these large blocks are not far removed from their source. Coney (1959, p. 92-96) concluded that they were derived from the nearby Crater Hill basalt flow. As explained by Coney, the Parunuweap Formation in this area may be differentiated into two periods of aggradation—one prior to and perhaps contemporaneous with the flow and a second later one. The distribution of the deposits containing large basalt fragments seems to substantiate this hypothesis. The Parunuweap deposits overlain by the flow contain only a few small fragments of basalt (fig. 8). Likewise, exposures east of the flow lack large angular blocks of basalt (fig. 9). However, the Parunuweap deposits marginal to the flow—on the east side of Coalpits Wash and along the Virgin River west of Grafton—contain large angular blocks of basalt.

All of the Parunuweap exposures in the Virgin River valley contain pebbles and cobbles of many types of sandstone, limestone, and shale. Many of the larger sandstone and shale fragments can be traced to local outcrops. Rounded pebbles and cobbles of quartzite and black chert were found in all exposures examined. Also, a few deposits contain Wasatch limestone pebbles and small angular chunks of Shinarump Conglomerate. South of Springdale, large blocks of Shinarump are contained in the Parunuweap (fig. 10).

North Creek

The Parunuweap Formation in North Creek consists mainly of subangular blocks and cobbles of basalt. The obvious source of this material is the Kolob volcanic field to the north. Minor constituents are the same as those found in the Virgin River valley deposits--many are locally derived and others came from sources upstream.

Toquerville-LaVerkin area

The Parunuweap deposits in this area have two distinctly different compositions. One deposit contains material derived from the Kolob Terrace and the other contains plutonic rocks derived from intrusive bodies in the headwaters of Ash Creek. The deposit derived from the Kolob crops out along LaVerkin Creek. Its constituents are similar in lithology to those found in the Parunuweap exposures along the Virgin River. The other deposit is overlain by basalt south of Toquerville and consists mainly of well rounded boulders and cobbles of quartz monzonite and other plutonic rocks (fig. 11).

Figure 5. --Parunuweap Formation overlying the Cretaceous Wahweap Sandstone along the west side of Stout Canyon. The blocks in the Parunuweap are of Wahweap Sandstone and the largest is about 3 feet in diameter.

Figure 6. --Typical volcanic pebbles and cobbles in the Parunuweap deposits along the Virgin River valley. Scale is a meter stick.

Figure 7. --Parunuweap Formation resting unconformably on the Triassic Moenkopi Formation in a roadcut 2 miles west of Rockville. The large boulders are basalt. Note the meter stick at the base of the roadcut.

Figure 8. --Parunuweap Formation (Qp) overlain by the Crater Hill basalt flow (Qb) and underlain by the Triassic Moenkopi Fm. (₮ m); west side of Coalpits Wash, one half mile north of the Coalpits Wash bridge. Note meter stick at right center.

Figure 9. --Parunuweap Formation south of Grafton. Scale is a meter stick.

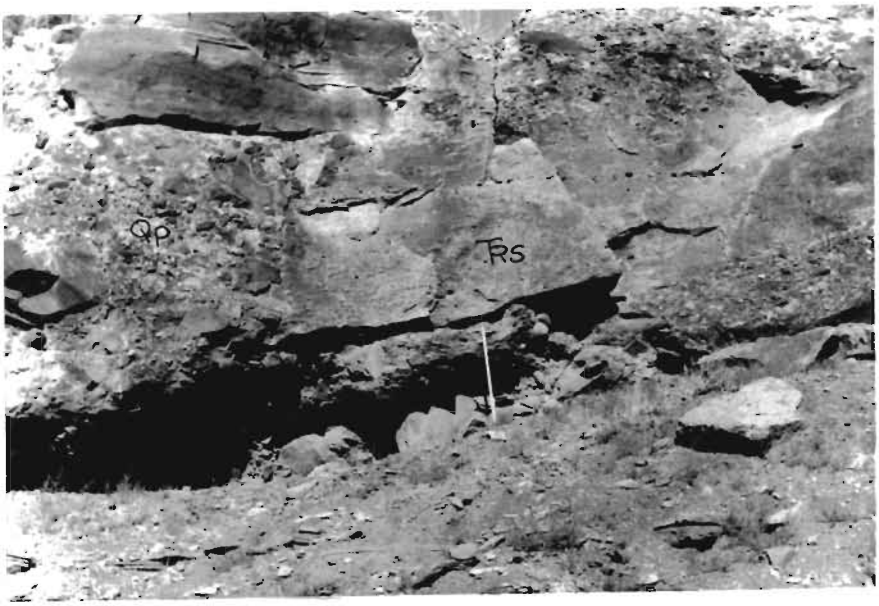


Figure 10. -- Large blocks of Triassic Shinarump Conglomerate (Ꞧs) in the Parunuweap Formation (Qp); one fourth mile south of the Springdale city limits. Scale is a meter stick.

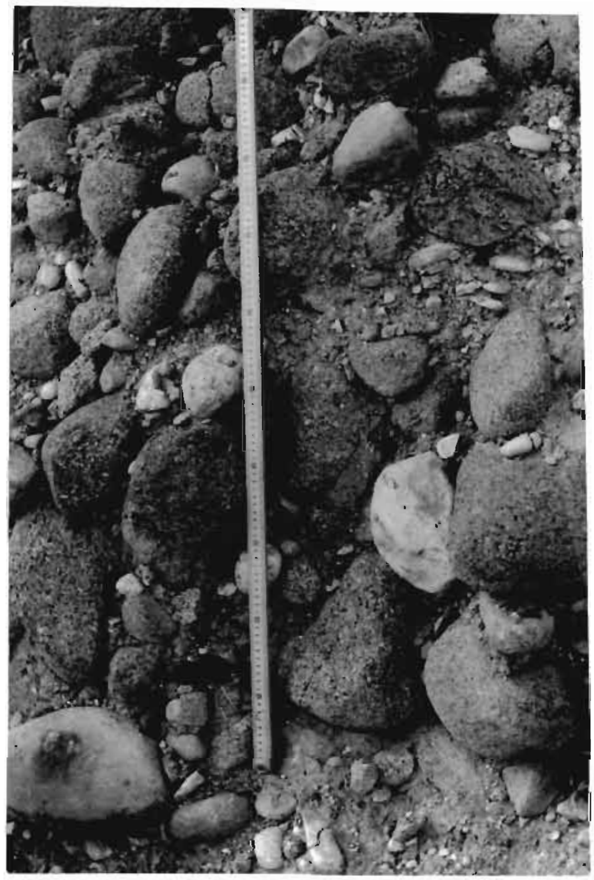


Figure 11. -- Detailed view of the Parunuweap Formation $1\frac{1}{2}$ miles south of Toquerville. The speckled boulders are quartz monzonite; scale is a meter stick.

CEMENTATION

Most of the Parunuweap exposures are so well cemented that they form resistant ledges. The cement is primarily calcium carbonate. Iron oxide is a minor cementing material. Some outcrops are poorly cemented and have been partially decomposed by weathering. There are very few uncemented deposits, probably because the bulk of the uncemented material has been removed by erosion.

SEDIMENTARY STRUCTURES AND TEXTURES

Very few exposures exhibit primary sedimentary structures. At a few localities, crude bedding has developed. Bedding is best developed in the exposure along the south bank of the Virgin River, $1\frac{1}{2}$ miles west of Grafton (fig. 12). Very coarse, graded bedding has developed along a portion of an outcrop one mile west of Rockville (fig. 13). Graded bedding is not common in coarse fluvial sediments and its origin has been explained in several ways. It could be the product of a waning current with a gradual or sudden decline in competency, or the product of sedimentation from a suspension in which all sizes are carried and out of which they settle (Pettijohn, 1956, p. 171). There are no secondary sedimentary structures in the Parunuweap, except for ironstone concretions which are detrital.

Many of the quartzite pebbles and cobbles have circular scars (fig. 14). These scars may be percussion marks caused by blows upon the pebble or cobble surface during transport (Pettijohn, 1957, p. 71). Eardley (1969, personal communication) has suggested that these scars were formed when the pebble and cobble surfaces were in contact in a conglomerate prior to their incorporation into the Parunuweap Formation. In this case they would be called "pressure marks." Some of the deposits in North Creek contain imbricated slabs of basalt; the imbrication indicates that the direction of stream flow during Parunuweap deposition was the same as the present flow of North Creek. These deposits are overlain by basalt which has been shattered and broken by water which once covered the gravels (fig. 15).

ORDERVILLE GRAVEL

Throughout the study area, a sand and gravel deposit—informally named the Orderville gravel in this report— forms alluvial bars and benches and veneers erosion surfaces above present stream grades.

These deposits can be distinguished by their lithologic characteristics and topographic position. Unlike the Parunuweap Formation, the Orderville gravel generally lacks cementing agents. It has a higher degree of sorting and contains a larger percentage of sand than the Parunuweap deposits. The sand is pale yellow and only rarely reddish.

The Orderville gravel was deposited after most of the Parunuweap deposits had been removed by erosion; at places it overlies the lower remnants of the Parunuweap and at others it has filled areas below the

Parunuweap. At some localities, its depositional surface is nearly coincident with the top of the Parunuweap Formation (fig. 16).

The most extensive deposits veneer pediment surfaces in the southern part of Long Valley. The pediment is covered with only scattered gravels at most places. However, south of Orderville, the sand and gravel reaches a maximum thickness of 60 feet (fig. 17). Other deposits, ranging up to 60 feet thick, form alluvial bars and benches throughout the Virgin River drainage. Most of the major deposits are being quarried. The Orderville gravel is probably of Recent age.

GEOMORPHIC EXPRESSION AND DEPOSITIONAL HISTORY

LONG VALLEY

The Parunuweap deposits in Long Valley crop out at various elevations above the main valley. The highest deposits are north of Glendale where their bases are 150-200 feet above the valley floor. Near Mt. Carmel Junction, the Parunuweap deposits are about 100 feet above the main valley floor. Apparently, during Parunuweap deposition, the East Fork flowed at a higher elevation and its gradient was steeper than it is today.

At two localities, faulting has displaced the outcrops from their original positions. Near Glendale, an outcrop 400 feet above the valley floor has been displaced perhaps as much as 200 feet from its original position higher up on the valley wall. This deposit appears to be a

Figure 12. -- Ledge of Parunuweap Formation along the south bank of the Virgin River 1½ miles west of Grafton. Note the stratification in the Parunuweap. The bank near the river is Recent valley fill.

Figure 13. -- Coarse graded bedding in the Parunuweap Formation; south of highway 15, 1 mile west of Rockville. Scale is a meter stick.

Figure 14. -- Circular scars on quartzite pebbles and cobbles from the Parunuweap Fm. 2 miles north of Glendale. Scale is a meter stick.

Figure 15. -- Parunuweap Formation overlain by basalt on the east side of North Creek, $1\frac{1}{2}$ miles north of the Virgin Oil Field. Note the shattered basalt contact and the imbrication in the Parunuweap (direction of stream flow was from left to right).

Figure 16. -- Orderville gravel (Qo), Parunuweap Formation (Qp) and Jurassic Carmel Formation (Jc) near Mt. Carmel Jct. The Orderville gravel is being quarried.

Figure 17. -- View looking east at the Elkheart Cliffs and the pediment surface south of Orderville. The quarry is in the Orderville gravel that veneers the pediment surface.

mudflow which filled a small tributary valley high above the main valley (fig. 18). Near Mt. Carmel Junction, some outcrops in an unnamed canyon have been displaced as much as 100 feet. The outcrops on the upthrown side of the fault are at an elevation of 200 feet above the canyon floor and those on the downthrown side are about 100 feet above the canyon floor.

The outcrops average about 50 feet thick. Along the west side of Stout Canyon, the Parunuweap reaches a maximum thickness of 70 feet (fig. 19). Outcrops 5 to 10 feet thick underlie parts of the pediment surfaces in the southern part of Long Valley.

North of Glendale, two outcrops are overlain by erosional remnants of the Spencer Bench basalt flow (fig. 20). The configuration of the flow conforms to the valley and undoubtedly it once flowed southward through the valley and covered some of the Parunuweap fill. A basalt remnant fills part of Long Valley south of Glendale. Its topographic position below many of the Parunuweap outcrops suggests that it is younger than the Spencer Bench basalt and flowed into the valley after most of the Parunuweap deposits had been removed.

Diagrammatic sections across Long Valley are shown in figures 21 and 22.

The following sequence of events for Long Valley is postulated:

1. Prior to Parunuweap deposition, Long Valley was shallower and steeper than it is now. The East Fork was 200 feet higher near Glendale and 100 feet higher near Mr. Carmel Junction.

2. The valley was filled with perhaps 100 feet of coarse Parunuweap sediments.

3. The Spencer Bench basalt flow filled parts of the valley north of Glendale and covered some of the Parunuweap fill.

4. The East Fork was diverted and flowed marginally along the northwest edge of the basalt flow. It eventually cut through the basalt at a point 3 miles north of Glendale. This probably coincided with the start of the erosion cycle which removed most of the Parunuweap deposits.

5. This erosion cycle--probably interrupted by a period of aggradation--culminated in the development of extensive pediment surfaces cut mainly into bedrock south of Orderville.

6. Basalt from an unknown source flowed into the valley south of Glendale.

7. Minor faulting displaced some of the Parunuweap deposits.

8. Erosion continued to about present stream grade.

9. During a period of aggradation, the Orderville gravel filled parts of the valley and covered the pediment surfaces.

10. The East Fork cut down to its present elevation.

PARUNUWEAP CANYON

There are no known deposits of the Parunuweap Formation along the Parunuweap Canyon. Probably, the deposits were completely removed from the canyon when it was reexcavated and cut to its present depth.

VIRGIN RIVER VALLEY

Here, in contrast to the Long Valley exposures, the Parunuweap deposits are restricted to the lower parts of the valley. The base of the formation ranges from less than 10 feet to about 100 feet above the river. The deposits are 10 to 75 feet thick, although erosion has removed much of their upper part.

The formation crops out along both sides of the Virgin River from Rockville to Virgin. The most extensive deposits are in the Rockville-Grafton area.

Coney (1959, p. 79-91) has described three terrace levels in the Virgin River valley near Zion Park. The upper terrace predates Parunuweap deposition and was developed when the river was 600-900 feet higher than it is now. The middle (or intermediate) terrace level, about 250 feet above the river, coincides with the Parunuweap depositional surface as a few places. However, this terrace is cut into bedrock and predates Parunuweap deposition. The lower terrace, about 150 feet above the river, has been cut into some of the Parunuweap deposits. It is probably equivalent in age to the pediment surfaces near Orderville. The lower terrace is well developed along the south bank of the Virgin River near Rockville (fig. 23).

The Crater Hill basalt flow rests on the intermediate terrace and covers the highest extent of the Parunuweap depositional surface. As explained by Threet (1958, p. 1068-1069), the flow filled the ancient

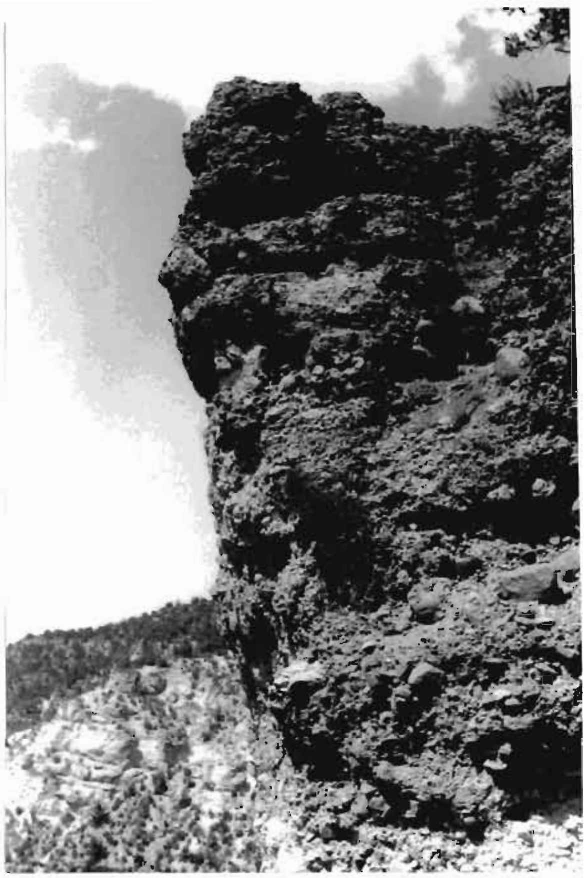
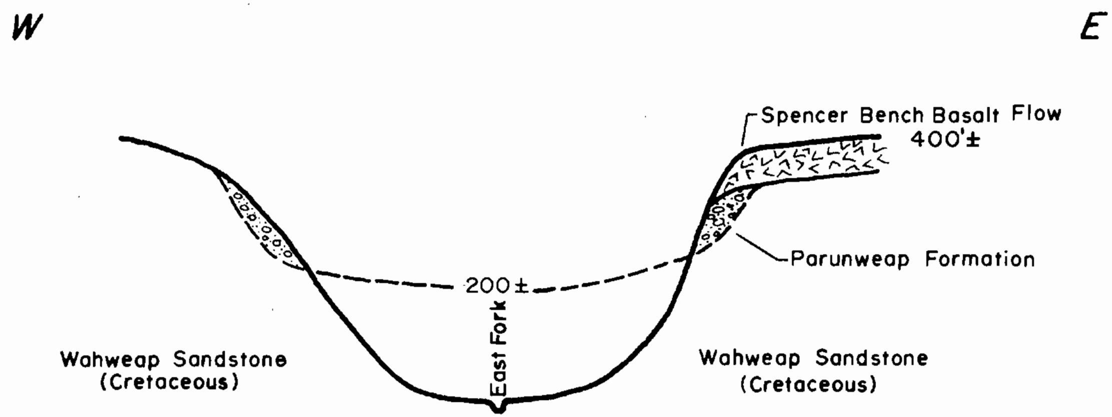


Figure 18. -- Parunuweap Formation 1 mile southwest of Glendale. The largest boulders are about 5 feet in diameter. This is a remnant of a mudflow 400 feet above the valley floor.

Figure 19. -- Parunuweap Formation along the west side of Stout Canyon. The light colored outcrop below the Parunuweap is the Cretaceous Wahweap Sandstone.

Figure 20. -- Parunuweap Formation (Qp) overlain by basalt (Qb) and underlain by Cretaceous Wahweap Sandstone (Kw); east side of highway 89, $2\frac{1}{2}$ miles north of Glendale.



Feet given is above the present stream elevation

Elevations not to scale.

Figure 21.- Diagrammatic section across Long Valley 2 miles north of Glendale. Approximate horizontal scale: 1 inch = 2500'.

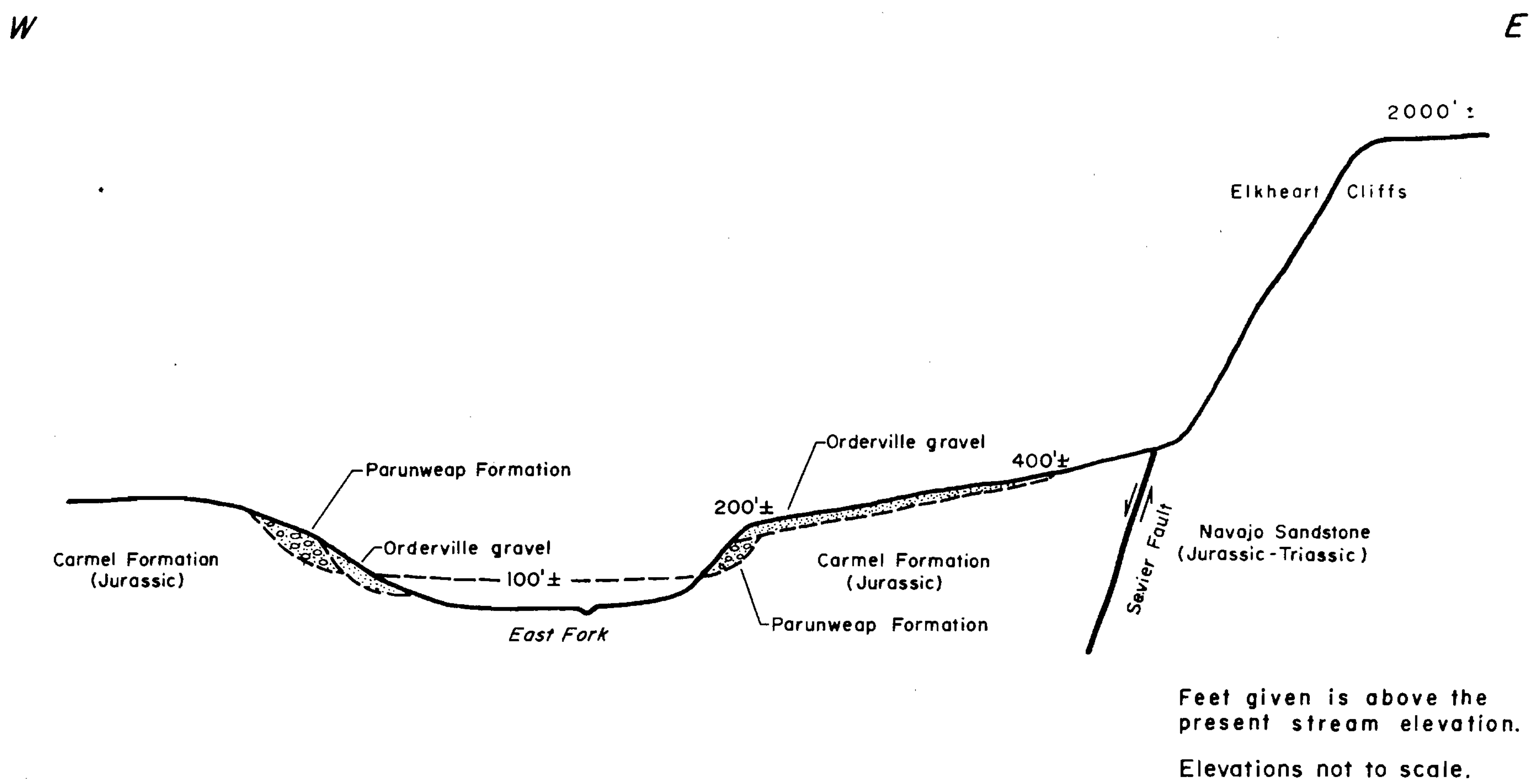


Figure 22.– Diagrammatic section across Long Valley in the Mt. Carmel Junction area. Approximate horizontal scale: 1 inch = 2500'.

Figure 23. -- View looking east toward Rockville. The lower terrace, cut into the Parunuweap Formation, is in the foreground and along the south bank of the Virgin River. The high bench above Rockville is capped by the Shinarump Conglomerate. A few remnants of the intermediate terrace abut against the Shinarump bench. The Eagle Crags form the skyline.

Virgin River valley from Grafton to about the present confluence of Dalton Wash and the Virgin River. Subsequently, the Virgin River was diverted southward and Coalpits and Dalton Washes established new courses along the east and west margins of the flow. After the eruption and a period of erosion, the newly established channels were filled with Parunuweap deposits. Naturally, the Parunuweap deposits underlying the basalt are preflow. The deposits east of Grafton coincident with the intermediate terrace are also preflow. The deposits underlying the lower terrace between Rockville and Virgin and along the east side of Coalpits Wash filled the channels established after the eruption (fig. 24).

Diagrammatic sections across the Virgin River valley and Coalpits Wash are shown in figures 25 and 26.

The following sequence of events is postulated:

1. An erosion cycle proceeded to the development of the intermediate terrace at 250 feet above the present stream grade.

2. The Virgin River then cut down to about 100 feet above its present grade.

3. The valley was filled with about 150 feet of coarse Parunuweap sediments. The depositional surface reached the lower extent of the intermediate terrace.

4. The Crater Hill volcanism occurred and basalt flowed over the intermediate terrace and covered some of the Parunuweap fill.

5. The Virgin River was diverted along its new course.

6. The Virgin River cut to within 10 feet of its present elevation.

7. The newly established Virgin River valley and Coalpits Wash were filled with perhaps 200 feet of Parunuweap deposits.

8. A period of erosion and lateral planation of the Virgin River in the Parunuweap deposits culminated in the lower terrace at about 150 feet above the present stream grade.

9. The Virgin River cut to almost its present grade.

10. The Orderville gravel was deposited below the lower terrace.

11. The Virgin River cut to its present grade.

NORTH CREEK

The North Creek deposits are 10 to 20 feet thick. They crop out below a basalt flow approximately 150 feet above the valley floor (fig. 27) and in isolated patches less than 50 feet above the creek. This 100-foot difference in elevation between deposits no more than a few thousand feet apart suggests that two periods of deposition took place—separated by a period of 100 feet of dissection.

The following sequence of events is postulated; it approximately conforms to the sequence in the Virgin River valley:

1. Prior to Parunuweap deposition, North Creek was about 150 feet higher than its present elevation.

2. Ten to 20 feet of Parunuweap deposits (dominated by angular fragments from the Kolob volcanic field) filled the valley.

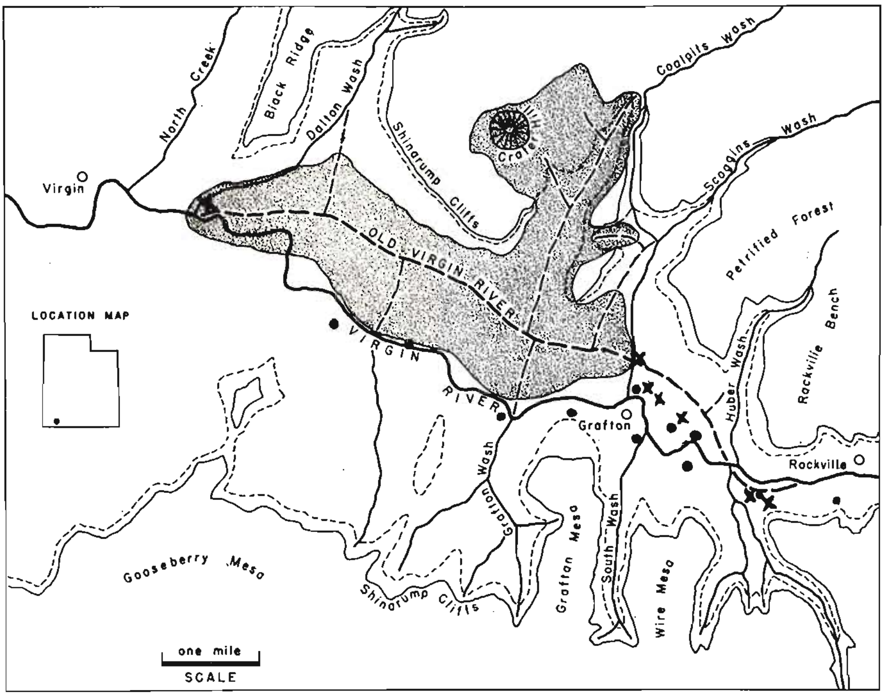
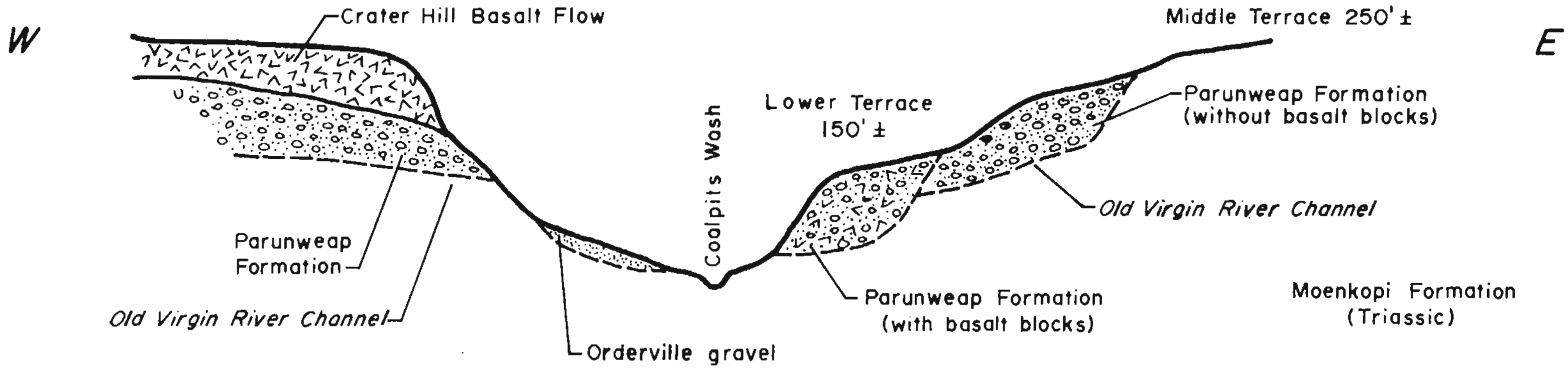


Figure 24.-Map of original extent of Crater Hill lava flow (stippled) showing pre-flow drainage (heavy dashed lines) and probable position of Shinarump cliffs at that time (light dashed lines), in relation to present cliffs and drainage (solid lines). x = Parunuweap deposits associated with the intermediate terrace.
•= Parunuweap deposits overlain by by the lower terrace.
(After Threet, 1958, p. 1067, fig. 2.)



Feet given is above the present stream elevation

Elevations not to scale.

Figure 25.— Diagrammatic section across the lower part of Coalpits Wash. Approximate horizontal scale: 1 inch = 1000'.

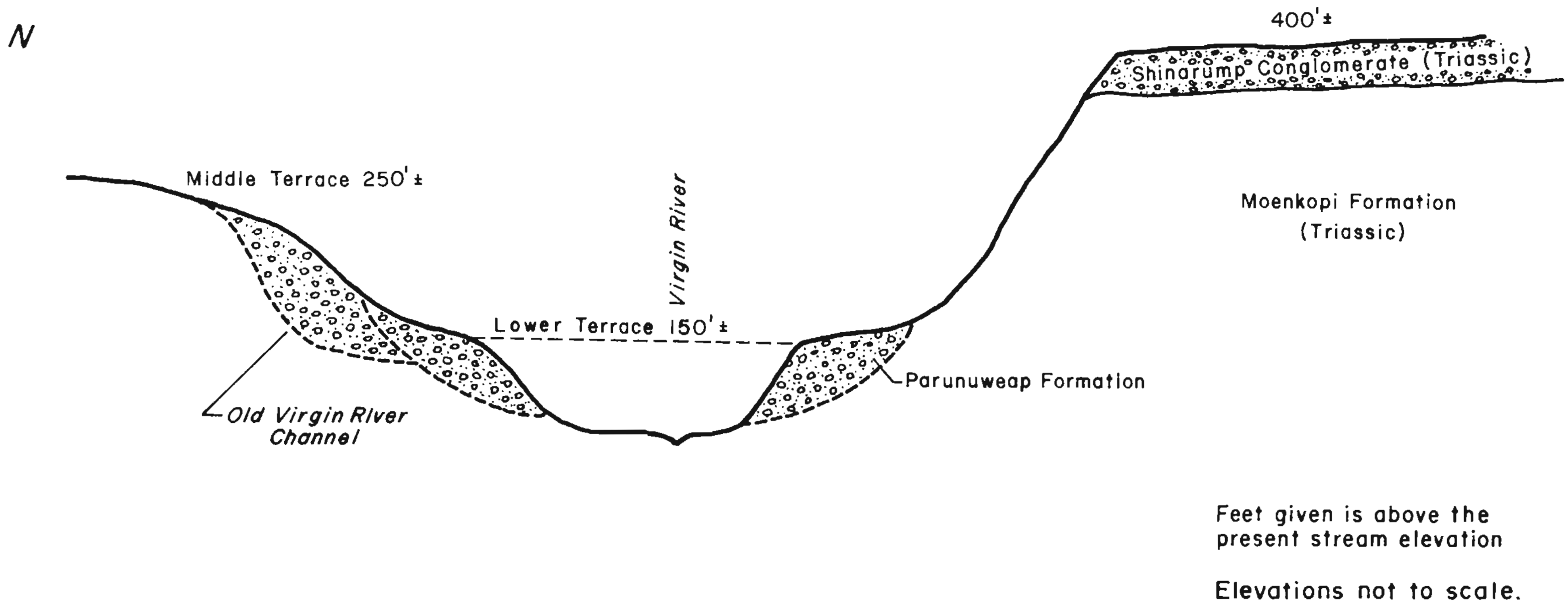


Figure 26.– Diagrammatic section across the Virgin River valley in the Rockville area. Approximate horzontal scale: 1 inch = 1000'.

3. A basalt flow, originating in the Kolob, flowed southward through the valley and covered the deposits. This flow may have been coincident with the Crater Hill flow.

4. North Creek and Black Wash dissected the flow along its margins and eventually cut to within 50 feet of present stream grade (fig. 28).

5. Parts of the valley were filled with up to 10 feet of Parunuweap sediments dominated by basalt fragments.

6. The streams cut to their present grade.

TOQUERVILLE-LaVERKIN AREA

As mentioned in a previous section, Parunuweap deposits from two different source areas crop out in the Toquerville-LaVerkin area. One deposit crops out at stream level along both Ash and LaVerkin Creeks; it is overlain by a basalt flow dated Pliocene (?)-Pleistocene (?) by Hamblin (1963, p. 86)(fig. 29). Outcrops of this deposit are 20 feet thick and their bases extend below stream level. The other deposit—typical of the Parunuweap exposures in the Virgin River valley—crops out 10 to 200 feet above LaVerkin Creek. Middle or Late Pleistocene movement along the Hurricane fault has displaced the basalt flow (Hamblin, 1963, p. 88). Therefore, the Parunuweap Formation underlying the basalt predates the fault movement. Along LaVerkin Creek the Parunuweap crops out at about the same elevation on both sides of the fault and overlies the basalt at a few places. Therefore, it post-dates

Figure 27. -- Parunuweap Formation (Qp) overlain by basalt (Qb) and underlain by the Triassic Moenkopi Formation (Ꞧm); east side of North Creek, $1\frac{1}{2}$ miles north of the Virgin Oil Field.

Figure 28. -- View looking north at the perched lava stream (reversal of topography) between Black Wash on the left and North Creek on the right. A small outcrop of Parunuweap underlies the southeastern margin of the ridge.

Figure 29. -- Parunuweap Formation (Qp) overlain by basalt (Qb) 1 $\frac{1}{2}$ miles south of Toquerville.

both the basalt flow and the fault movement. Because of its older age, the deposit underlying the basalt may have been erroneously identified as Parunuweap. However, this deposit was called Parunuweap by Gregory (1945, p. 114, fig. 12).

Unconsolidated gravels overlie the basalt flow. In figure 3, these deposits are identified as the Orderville gravel; however, they predate the Orderville gravel along the streams originating in the Kolob Terrace. Along LaVerkin Creek (which originates in the Kolob), the Orderville gravel lies topographically below the basalt flow and the Parunuweap ledges.

A diagrammatic section across Ash and LaVerkin Creeks is shown in figure 30.

The following sequence of events is postulated:

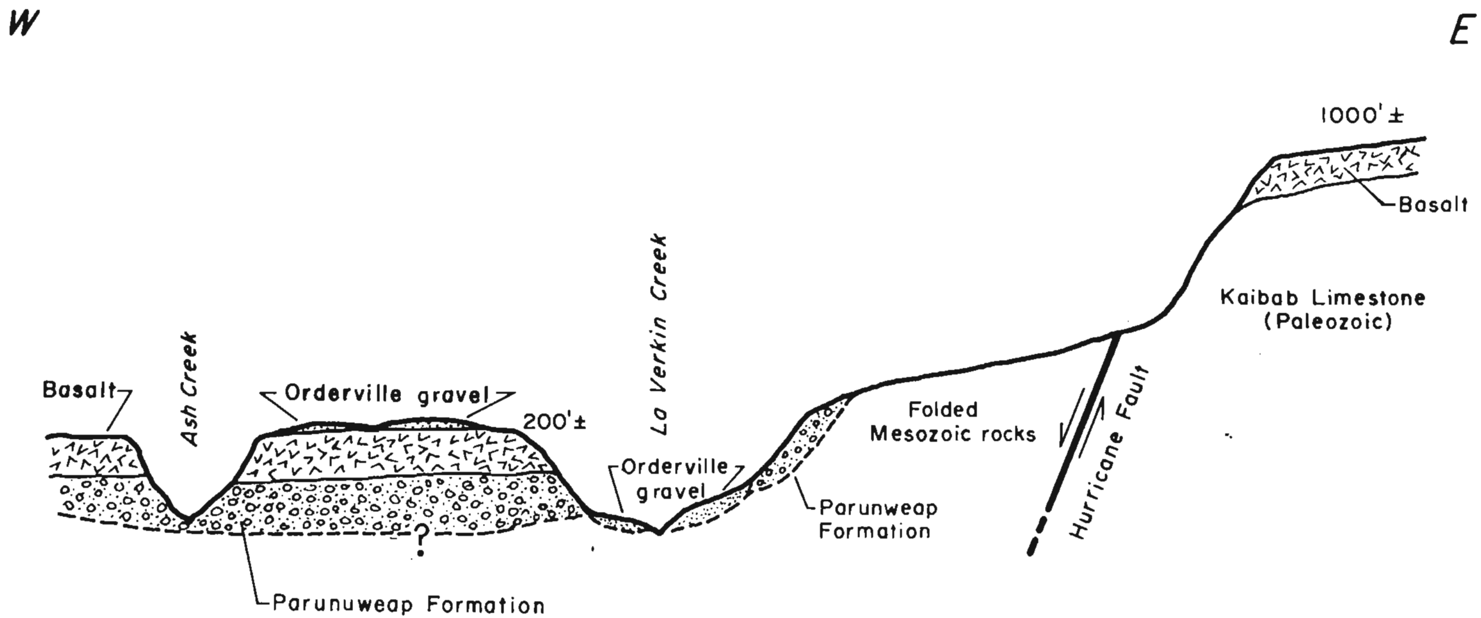
1. A valley approximately corresponding to the present Ash Creek drainage was filled with at least 20 feet of coarse sediments.

2. Basalt filled the valley and covered the gravels.

3. Movement along the Hurricane fault displaced the basalt flow.

4. Ash Creek meandered over the top of the basalt and covered it with sand and gravel deposits; eventually it cut through the basalt flow and formed a canyon 200 feet deep which exposed the gravels underlying the basalt.

5. Meanwhile, LaVerkin Creek cut a canyon through the Hurricane Cliffs and along the eastern margin of the flow.



Feet given is above the present stream elevation

Elevations not to scale.

Figure 30.– Diagrammatic section across Ash and La Verkin Creeks, one mile south of Toquerville. Approximate horizontal scale: 1 inch = 1500'.

6. LaVerkin valley was filled with Parunuweap deposits at various times during its incisement resulting in outcrops 5-20 feet thick and 10 to 200 feet above the present valley floor.

7. A period of erosion removed most of the Parunuweap deposits from LaVerkin valley and exposed the gravels underlying the eastern margin of the basalt flow.

8. A period of aggradation resulted in the deposition of the Orderville gravel along LaVerkin Creek.

9. Both Ash and LaVerkin Creeks cut down to their present grade.

LITHOLOGIC AND TEXTURAL ANALYSES

GENERAL STATEMENT

Sampling localities were selected at approximately equal intervals along the main streams in the study area (fig. 31). Of the 39 sites selected, 32 were in the Parunuweap Formation, 4 were in the Orderville gravel, and 3 were in Recent Virgin River deposits. Three sampling procedures were performed--pebble counts, collection of spot samples for heavy mineral separation, and mechanical analyses. Refer to table 1.

Prior to sampling, it was necessary to determine the correct sedimentation units. A sedimentation unit is "that thickness of sediment which was deposited under essentially constant physical conditions" (Otto, 1938, p. 575). The Parunuweap, Orderville, and Recent Virgin River deposits can be distinguished as separate units by their physical characteristics and topographic positions. Subordinate units could not be delineated within these deposits and each one was considered a separate sedimentation unit.

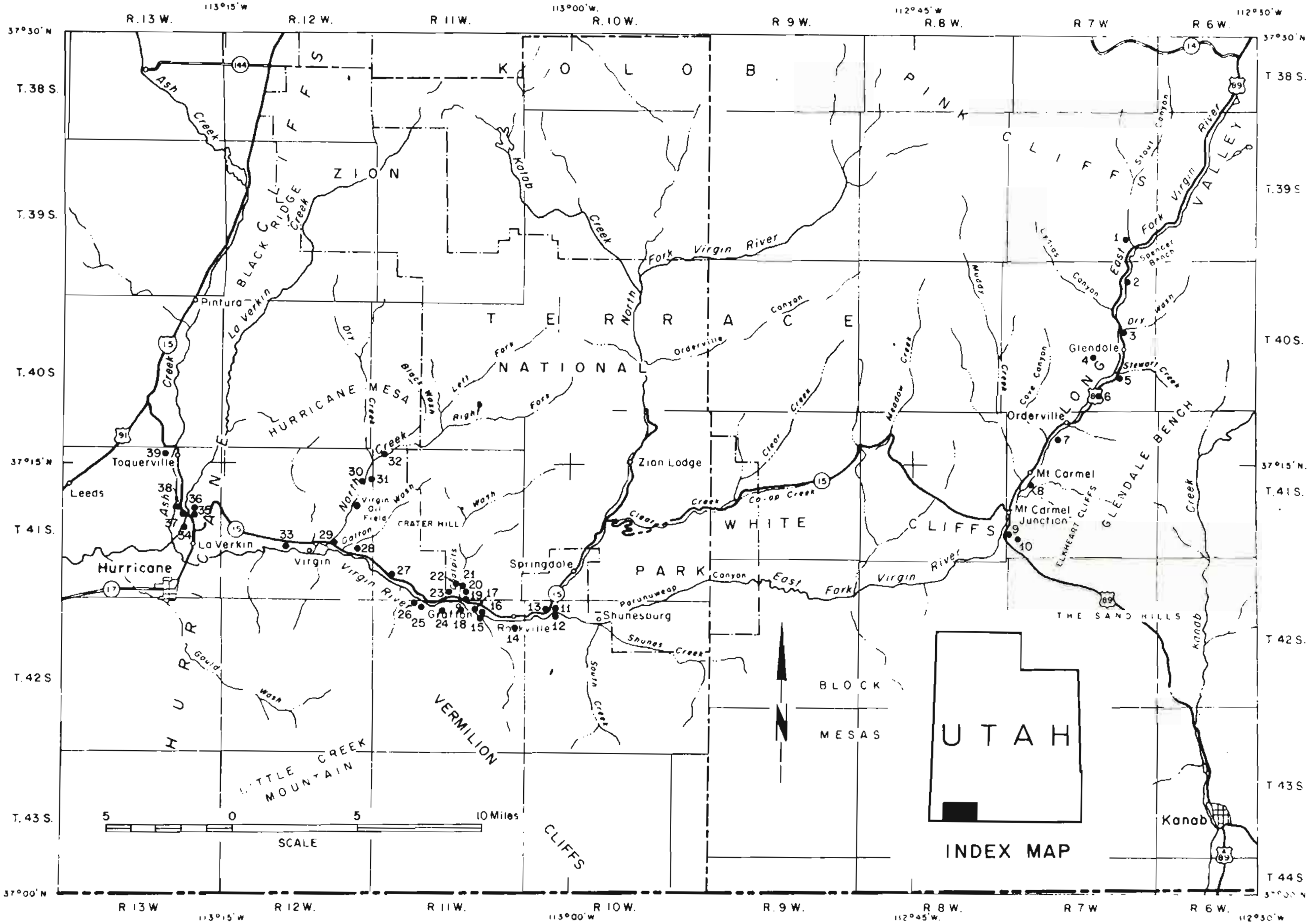


Figure 31.- Map showing location of sampling sites.

TABLE 1

TYPE OF SAMPLING PROCEDURES AT EACH SAMPLING SITE.
(P-Parunuweap; O-Orderville; V-Virgin River deposits)

Sampling Site Number	Deposit	TYPE OF SAMPLING PROCEDURE: Pebble Count	Spot Sample (Heavy Mineral Analysis)	Mechanical Analysis
1	P	X		
2	P	X	X	
3	P	X	X	
4	P	X		
5	O	X	X	X
6	P	X	X	
7	O			X
8	P	X	X	
9	P	X		
10	O		X	X
11	V	X	X	
12	V	X	X	
13	P	X	X	
14	P	X	X	
15	V	X	X	
16	P			X
17	P	X	X	
18	P	X		
19	P		X	
20	P			X
21	P	X	X	
22	P		X	
23	O	X		X
24	P			X
25	P			X
26	P	X	X	
27	P	X		
28	P	X		
29	P	X		
30	P		X	
31	P	X	X	X
32	P		X	
33	P	X	X	X
34	P	X		
35	P			X
36	P	X	X	
37	P	X	X	X
38	O	X	X	
39	P	X	X	

LITHOLOGIC ANALYSIS

Procedures

Pebble counts were performed by identifying a minimum of 200 rock fragments of pebble size or larger within a given area along an outcrop face. Twenty-eight pebble counts were performed--22 on the Parunuweap Formation, 3 on the Orderville gravel, and 3 on Recent Virgin River deposits. The data from the 22 Parunuweap pebble counts are compiled in table 2.

Interpretation of Data

The purpose of the lithologic analysis is to: (1) determine the lithologies of the constituents in the Parunuweap Formation and see if there is a systematic variation in the number and kinds of constituents and (2) compare the lithologies of the constituents in the Parunuweap, Orderville, and Recent deposits.

Red and pink Wasatch limestone pebbles were found in almost all of the Parunuweap deposits examined. The frequency of this constituent at localities along the main drainage is shown graphically in figure 32. It decreases downstream and reaches an asymtote of about 5 percent in the Virgin River valley. The Wasatch Formation crops out only a few miles north of Glendale; this accounts for the large number of Wasatch fragments in the Long Valley deposits. The decrease in the number of pebbles downstream is probably a combination of dilution, selective abrasion, and progressive sorting with a decrease in gradient. As noted previously, there is a distance of approximately 20 miles along the Parunuweap Canyon where there are no outcrops. The steady decrease in the number of limestone pebbles from Long Valley to the Virgin River valley seems to indicate that the deposits were once continuous through the canyon. However, an influx of limestone pebbles from the North Fork probably accounts for a sizeable percentage of these constituents in the Virgin River valley deposits.

The black chert and quartzite clasts show a high degree of roundness and sphericity and a nearly uniform size range throughout the study area. Undoubtedly, they were derived from a pre-existing conglomerate—probably the basal conglomerate of the Wasatch Formation. The frequencies of these constituents at localities along the main drainage is shown in figure 33. Like the limestone pebbles, they decrease in frequency downstream and reach an asymptote of about 5 percent in the Virgin River valley. Because quartzite and chert are highly resistant to abrasion, dilution and progressive sorting are probably the main factors in their decline in percentage downstream. The variations in their frequencies is remarkably similar and strengthens the hypothesis that they were derived from the same formation.

The lithologies of the constituents in the Parunuweap, Orderville, and Recent deposits and their variations along the main drainages are very similar. This leaves little doubt that during Parunuweap and Orderville

TABLE 2

LITHOLOGIC COMPOSITION OF CONSTITUENTS IN THE PARUNUWEAP FORMATION

(Frequency of constituents in percent)

Locality	Basalt and Other Volcanics	Chert, black	Chert, light colored	Ironstone concretions	Plutonic rocks (mostly monzonite)	Quartzite and quartz	Sandstone	Siltstone	Wasatch Limestone	Other limestone	Miscellaneous
1	0	8	0	3	0	8	44	0	36	0	1
2	0	9	4	1	0	12	31	0	42	0	1
3	0	8	4	5	0	6	37	0	39	0	1
4	0	19	3	1	0	40	21	0	13	0	3
6	5	7	2	4	0	8	33	0	33	0	8
8	1	11	5	4	0	8	29	0	16	10	16
9	1	13	4	3	0	12	19	0	19	27	2
13	8	4	0	0	0	2	44	7	12	17	6
14	10	3	0	0	0	4	43	4	8	25	3
17	15	4	4	0	0	3	37	7	7	22	1
18	10	4	3	0	0	5	30	6	14	19	9
21	17	2	0	1	0	10	35	3	9	15	8
26	13	4	0	0	0	3	32	6	2	27	13
27	10	4	3	0	0	7	28	7	5	33	3
28	15	1	2	0	0	3	24	9	5	37	4
29	27	3	0	0	0	2	27	5	10	17	4
31	44	2	3	0	0	3	21	17	0	0	10
33	33	5	2	3	0	10	14	5	2	18	8
34	2	0	0	0	35	5	9	0	4	32	13
36	8	0	0	0	0	2	33	0	1	44	8
37	1	1	3	2	61	12	10	0	3	5	2
39	27	0	0	0	26	4	16	0	0	25	2

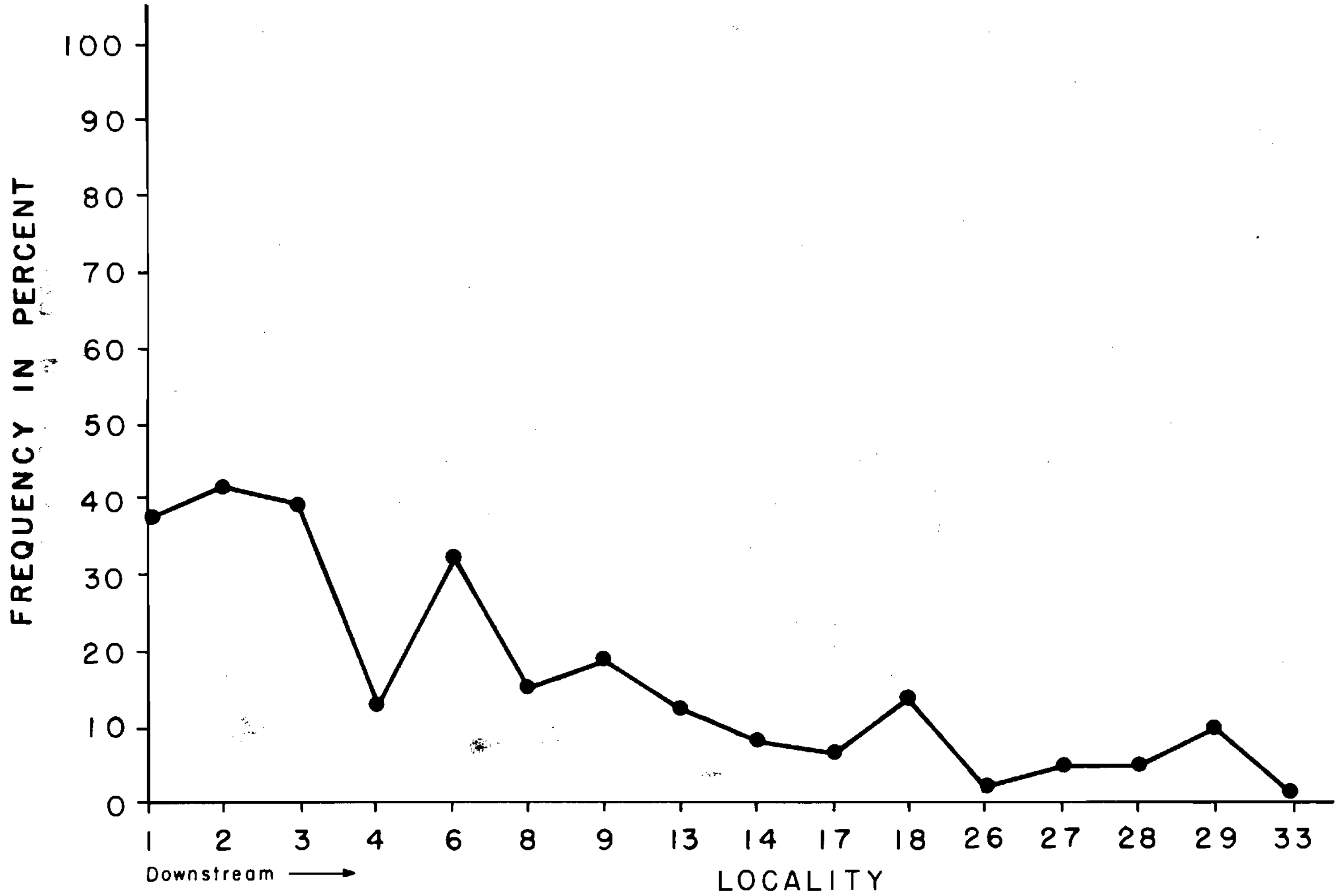


Figure 32.— Variation in percentage of Wasatch limestone pebbles in Parunuweap deposits along the East Fork and the main Virgin River.

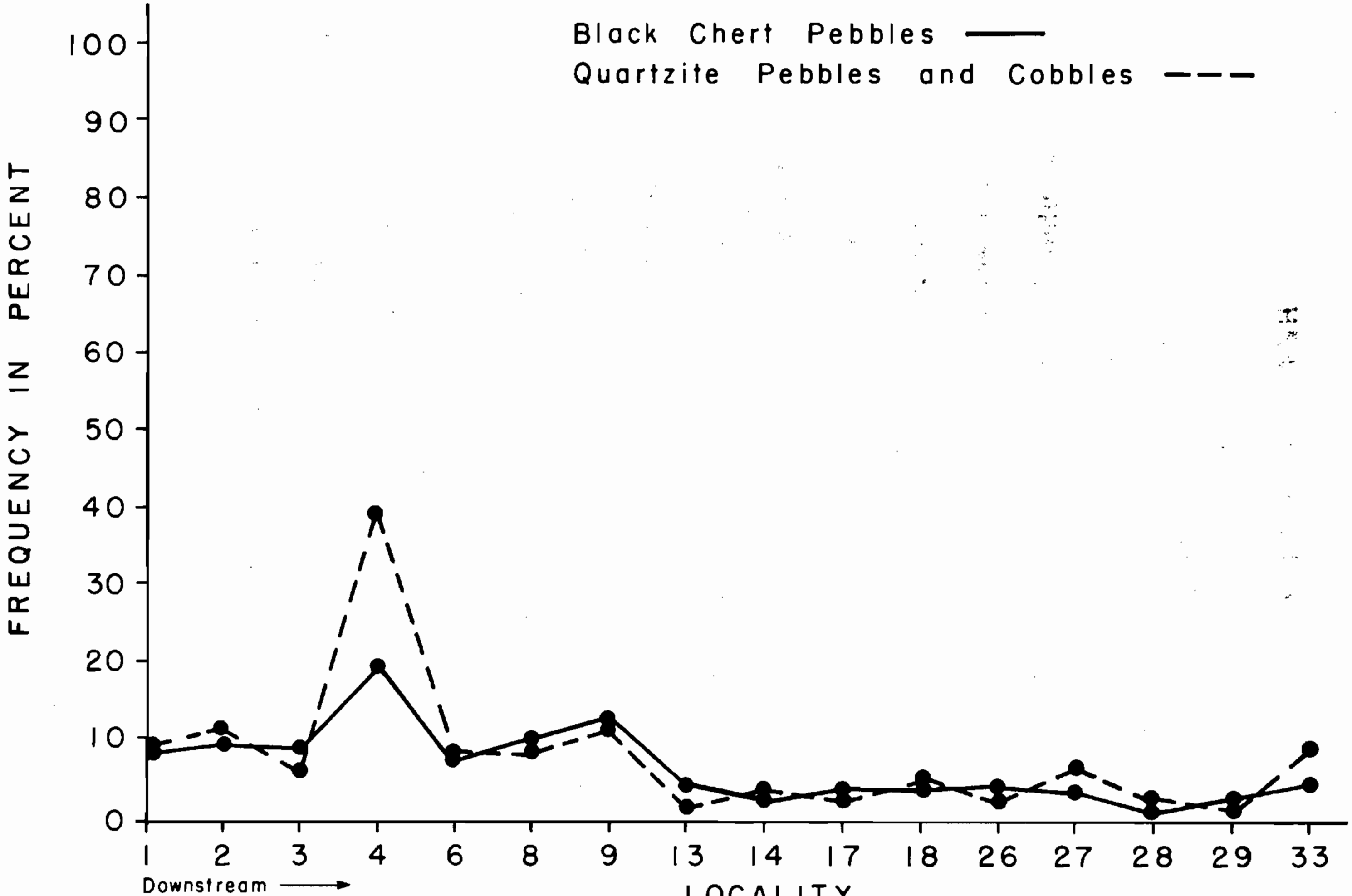


Figure 33. — Variation in percentage of black chert and quartzite in Parunuweap deposits along the East Fork and the main Virgin River.

deposition the drainage lines and source areas were essentially the same as they are today.

HEAVY MINERAL ANALYSIS

Procedures

Spot samples for heavy mineral separation were taken from sandstone or sand lenses wherever possible. Twenty-four samples were collected—18 from the Parunuweap Formation, 3 from the Orderville gravel, and 3 from Recent Virgin River deposits.

The procedures used for heavy mineral separation are based on those used by Nelson (1967, p. 31). Each sample was digested in boiling dilute hydrochloric acid until all soluble material was removed. The acid was poured off and the sample was washed in water and allowed to dry overnight. Each sample was poured through a set of sieves and shaken on a RoTap shaker for 10 minutes. The 0.5 to 0.125 mm fraction was retained for heavy mineral separation. Each retained sand sample was split with a microsplitter until a 2 to 3-gram sample was obtained. The weighed sample was poured into a 2 ml centrifuge tube half filled with Bromoform (specific gravity 2.89). The sample was centrifuged for 5-10 minutes or until the heavy grains ceased to fall to the bottom. The bottom of the tube was immersed in dry ice until the Bromoform was frozen. The light fraction was poured off. After the Bromoform melted, the heavy fraction was poured onto filter paper, washed in acetone and allowed to dry. The heavy minerals were mounted on a glass slide with Lakeside cement. The minerals were identified with the aid of a petrographic microscope.

Interpretation of data

The purpose of the heavy mineral identification is to: (1) compare the heavy mineral suites with those found in possible source rocks, (2) determine if there is any variation in the heavy mineral suites of the Parunuweap deposits throughout the study area, and (3) determine if there is a difference in the heavy mineral suites of the Parunuweap, Orderville, and Recent Virgin River deposits.

Gregory (1950a) identified the heavy minerals in most of the sedimentary rocks in the Zion Park region. These same minerals were identified in all of the heavy mineral residues studied and include (in decreasing abundance) magnetite, zircon, garnet, apatite (?), biotite, tourmaline, and staurolite (?). Gregory did not identify any pyroxenes or amphiboles in the sedimentary column of Zion Park. However, they are common minerals in many of the residues. It is assumed that they were derived from volcanic rocks.

There is a marked increase in the percentage of amphiboles (mostly hornblende) and pyroxenes in the Parunuweap deposits along the Virgin River. This same increase was noted in the sands of the North Fork and the Orderville deposit west of Grafton. Undoubtedly, these minerals were derived from the Kolob volcanic field in the headwaters of the North Fork.

The heavy mineral suites of the Parunuweap and Orderville deposits are generally the same throughout the study area. However, the Parunuweap residues contain a greater percentage of opaque iron minerals (magnetite, ilmenite, hematite, and limonite) either as individual grains or as coatings on grains. This higher percentage of iron minerals (sometimes greater than 65 percent of the residue) in the Parunuweap deposits may account for some of the cementation which the Orderville deposits generally lack.

There is an increase in hornblende and biotite in the deposit overlain by basalt south of Toquerville. These minerals were derived from an intrusive rock terrane in the vicinity of the Pine Valley Mountains.

The heavy mineral analysis shows that during Parunuweap and Orderville deposition, the drainage lines and source areas were essentially the same as they are today.

MECHANICAL ANALYSIS

Procedures

Mechanical analyses were restricted to unconsolidated deposits. Twelve analyses were performed--8 on the Parunuweap Formation and 4 on the Orderville gravel.

Each sample for mechanical analysis was obtained by combining two or more channel samples and splitting them until a 50-pound sample remained. Wentworth's empirical rule (Plumley, 1948, p. 541) requires that a sample be large enough so that it contains several fragments of the largest grade size. However, at sites where the largest fragments were several feet in diameter and weighed hundreds of pounds, it was impossible to include them. Krumbein (1942, p. 1379-1380) found that the mean size of a sample including the largest fragments varied little from the smaller sample.

After splitting and weighing with a hand balance, the sample was poured through a set of sieves with Wentworth scale intervals from 64 mm to 4 mm. Each grade size greater than 4 mm was weighed in the field. The part of the sample passing through the 4 mm sieve was retained for sieving in the laboratory. The retained fraction was poured through a set of five sieves (2 mm to 1/8 mm) and shaken in a RoTap shaker for 10 minutes. Each grade size was weighed. Then, the weight percent of the grade sizes for the entire sample was determined. A value to the nearest whole percent is all that is justified on the basis of the probable error involved.

The size frequency distribution of each sample is shown in figures 34 and 35.

Interpretation of data

The purpose of the mechanical analysis is to: (1) compare the size frequency distribution and statistical parameters of the Parunuweap and Orderville deposits and (2) determine if there is a systematic variation in the statistical parameters of the two deposits.

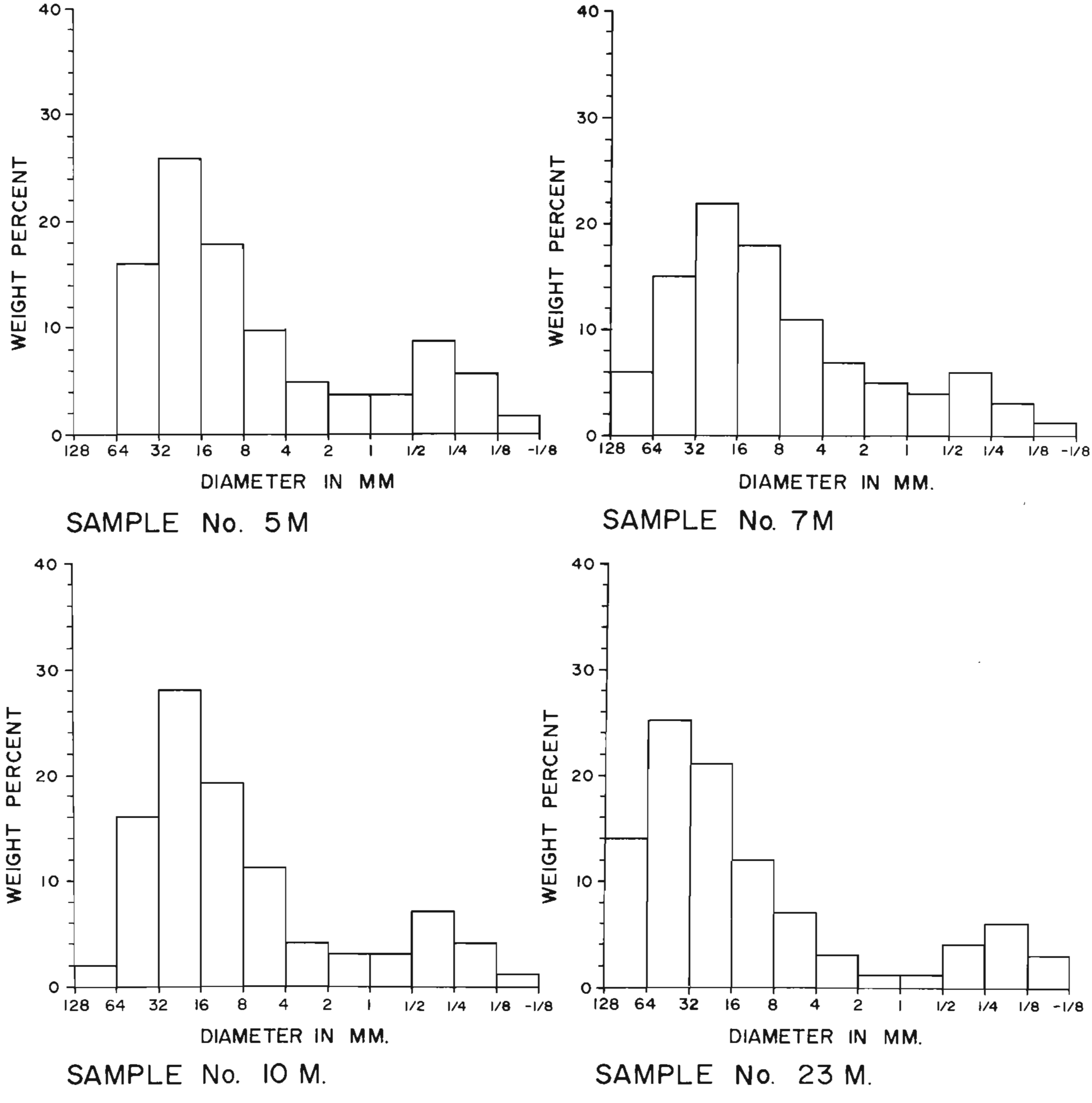


Figure 34.- Size frequency distribution of the Orderville gravel.

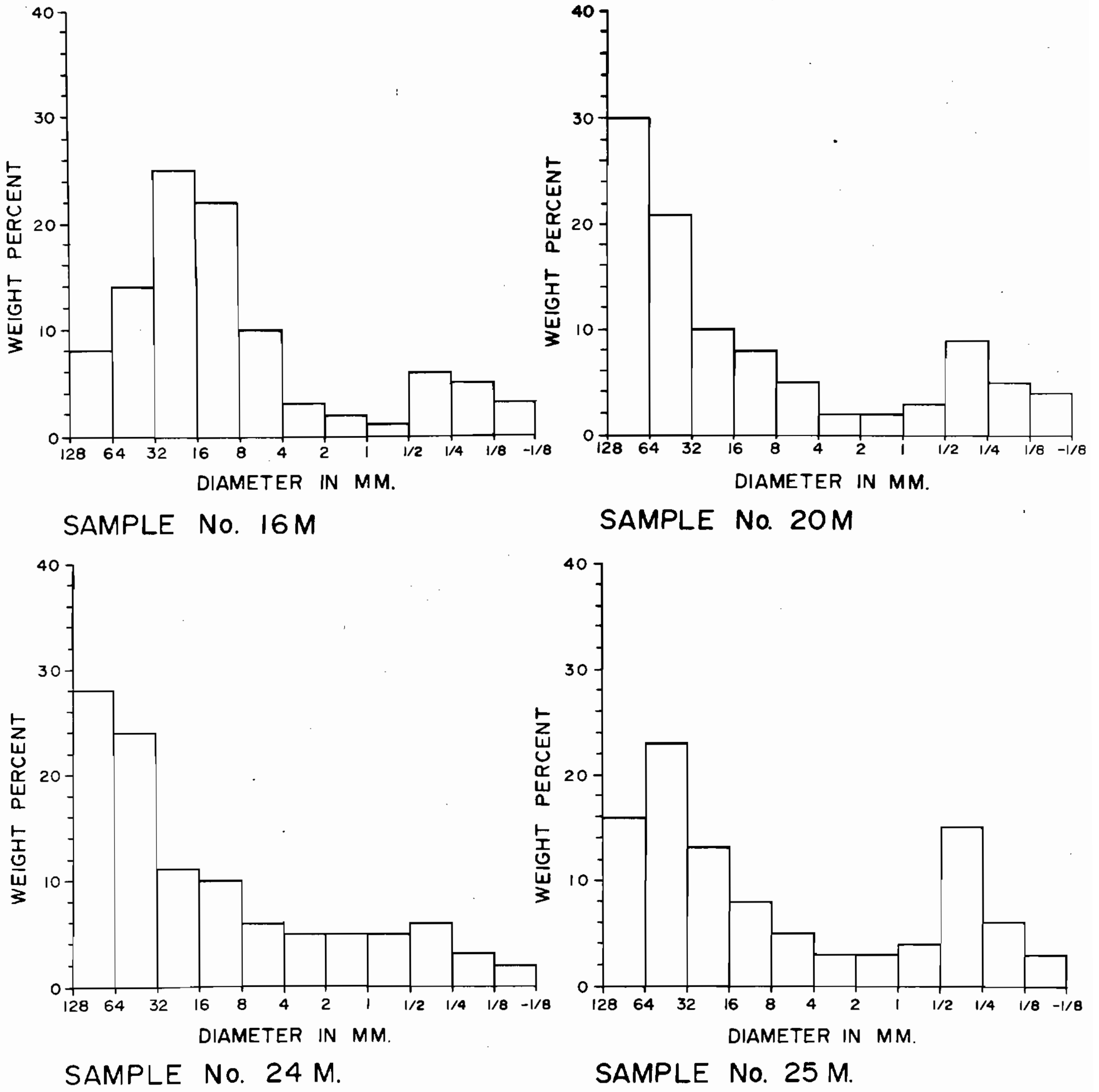


Figure 35.- Size frequency distribution of the Parunuweap Formation.

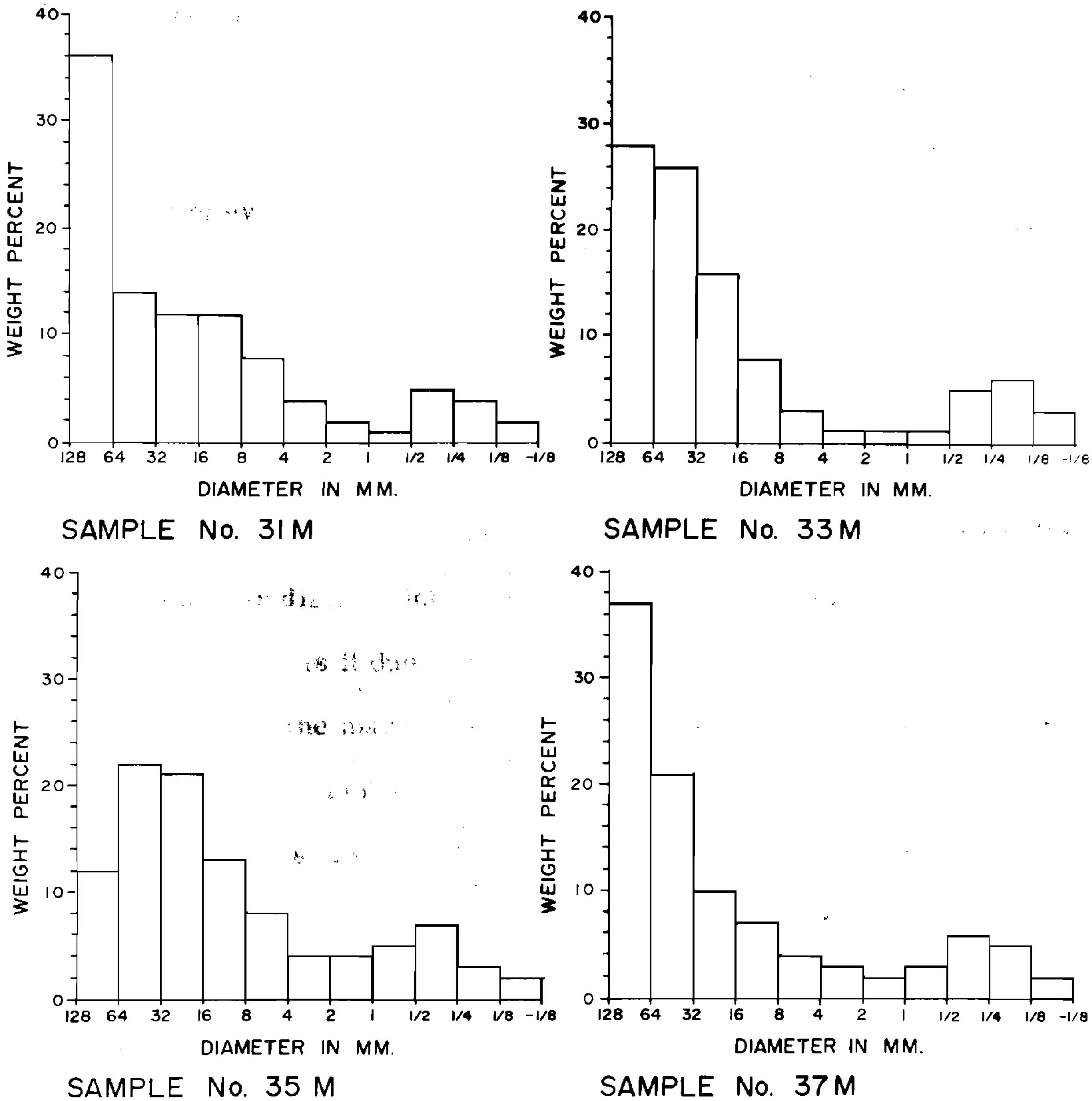


Figure 35.- continued.

All samples are bimodal with a primary mode in the cobble class and a secondary mode in a sand class. The bimodal character of coarse fluvial sediments has been explained as the result of simultaneous deposition of the traction and suspension loads of a stream due to an abrupt velocity change (Krumbein, 1940, p. 648). Fraser (1935, p. 987) and Plumley (1948, p. 543) thought that the simultaneous deposition of cobbles and sand is unlikely and that the finer sizes in gravel is due to later infiltration.

Both the Parunuweap and Orderville samples have a deficiency of material in the 4 mm and 0.5 mm size classes. Also, the secondary mode is in the 0.5 mm to 0.25 mm size class in all but two of the samples. Does this peculiar distribution represent the size grades available from the source rocks or is it due to hydraulic factors? Because the sands were derived from the many sandstones in the Zion Park region, a study of the size distribution of the sandstones could possibly answer this question. Gregory's (1950a) limited petrographic and sedimentological data on the sandstones in this region show that very few have principal modes in the 0.5 to 0.25 mm size class. In fact, most of the sandstones analyzed by Gregory have grain sizes averaging less than 0.25 mm. Because there is an apparent initial deficiency of the 0.5 mm to 0.25 mm size class, a geologic cause for the prominence of this size class in the Parunuweap and Orderville deposits can probably be ruled out. There is certainly an initial deficiency in the 4 mm to 0.5 mm size classes and this may account for their deficiency in the Parunuweap and Orderville samples. However, the 4 mm to 1 mm size classes in the analyzed samples consist mostly of rock fragments and aggregates of smaller grains and an "initial deficiency" hypothesis may not explain the lack of this size material. Perhaps, as suggested by Pettijohn (1957, p. 50), material of this size is structurally weak and unable to survive rigorous stream action.

Cumulative curves were constructed from the histograms using the phi (ϕ) scale. Phi is the negative log to the base two of the size in millimeters and its use greatly simplifies the computation of statistical parameters. Moment measures were used to compute the statistical parameters. They are much more sensitive to "open ends" on the cumulative curve than the quartile measurements are (Krumbein and Pettijohn, 1938, p. 260). Quartile measurements can be used in the study of unimodal sands but give erroneous results when applied to coarse, bimodal sediments.

Two statistical parameters were computed--the phi mean ($M\phi$) and the phi standard deviation ($\sigma\phi$). The phi mean is the center of gravity of the logarithmic frequency curve and when transformed to its diameter equivalent in millimeters becomes the geometric mean of the size distribution. It was computed from percentiles on the cumulative curve using an equation suggested by Folk (1966, p. 81). The phi standard deviation is a measure of sorting--the uniformity of particle size in a sediment. It was also computed from percentiles on the cumulative curve using an equation suggested by Folk (1966, p. 83).

The parameters are listed in table 3 and the average values are listed in table 4. The average mean diameter of the Parunuweap samples is considerably larger than that of the Orderville samples. The average phi standard deviation of both deposits falls in the "very poorly sorted" category of the scale proposed by Folk and Ward (Folk, 1966, p. 84). However, in Friedman's scale (Folk, 1966, p. 84), the Parunuweap samples are "extremely poorly sorted" and the Orderville samples are "very poorly sorted."

A plot of these parameters versus the sample localities shows no systematic variation. If more unconsolidated deposits had been available, a systematic variation might have been detected.

TABLE 3

STATISTICAL PARAMETERS OF SIZE DATA

(O-Orderville; P-Parunuweap)

Sample Number	Deposit	Phi Mean ($M\phi$)	Geometric Mean Diam. in mm.	Phi Standard Deviation ($\sigma\phi$) (higher values indicate a more poorly sorted sediment)
5M	O	-3.2	9.2	2.5
7M	O	-3.5	11.3	2.1
10M	O	-3.5	11.3	2.6
16M	P	-3.6	12.2	2.9
20M	P	-4.2	18.5	3.2
23M	O	-3.9	15.0	3.1
24M	P	-4.4	21.2	2.8
25M	P	-3.4	10.6	3.1
31M	P	-4.5	22.7	2.6
33M	P	-4.4	21.2	3.2
35M	P	-3.9	15.0	2.6
37M	P	-4.6	24.3	2.9

TABLE 4

AVERAGE VALUES OF STATISTICAL PARAMETERS

Parameter	Parunuweap Fm.	Orderville Gravel
Phi mean ($M\phi$)	-4.1	-3.5
Geometric mean diam. in mm.	17.2	11.3
Phi standard deviation ($\sigma\phi$) "sorting"	2.9	2.6

SUMMARY AND CONCLUSIONS

Most of the geomorphic evidence indicates that the Parunuweap Formation is younger than the original assigned date of Pliocene. It is suggested that the age of the Parunuweap is Late Pleistocene.

There are two possible causes of deposition: (1) uplift along the Hurricane fault tilted the Kolob Terrace and caused ponding and aggradation throughout the upper Virgin River drainage basin or (2) near the end of a glacial stage, maximum runoff and contributions of detritus from melting ice masses overloaded the Virgin River. A combination of both factors may have initiated deposition.

Prior to deposition, the Virgin River had a steeper gradient and was 100 to 200 feet above its present elevation. During a period of vigorous aggradation, the valleys were filled with several hundred feet of coarse Parunuweap sediments. Some valleys were filled with basalt flows which covered the Parunuweap deposits. A second period of aggradation, separated by a period of erosion, is evident in most valleys. The two periods of aggradation may have been caused by two glacial stages (Illinoian and Wisconsinan ?) or intermittent uplift along the Hurricane fault. The valleys were reexcavated by streams which eventually cut down to their present elevations leaving isolated patches of the Parunuweap Formation along the valley sides.

A later period of aggradation, probably in Recent time, resulted in an extensive sand and gravel deposit in the lower parts of the valleys.

This deposit is informally named the Orderville gravel in this report.

The constituents in the Parunuweap and Orderville deposits are the same as those found in the present stream gravels. During Parunuweap and Orderville deposition, the drainage lines and source areas were essentially the same as they are today.

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VITA

Name	William Michael Dalness
Birthplace	Sioux Falls, South Dakota
Birthdate	18 December 1942
Elementary School	Willston Elementary Falls Church, Virginia
High School	Brentwood High School Pittsburgh, Pennsylvania
University	Johns Hopkins University Baltimore, Maryland 1960-1961
	University of Cincinnati Cincinnati, Ohio 1961-1964
Degree	B. S., University of Cincinnati Cincinnati, Ohio, 1964
Professional Organizations	American Association of Petroleum Geologists