UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
AFFILIATED WITH
THE COLLEGE OF MINES AND MINERAL INDUSTRIES
UNIVERSITY OF UTAH
SALT LAKE CITY, UTAH

GEOLOGIC ATLAS OF UTAH

WASHINGTON COUNTY

By

By EARL FERGUSON COOK

Bulletin 70 September, 1960

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UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

The Utah Geological and Mineralogical Survey was authorized by act of the Utah State Legislature in 1931; however, no funds were made available for its establishment until 1941 when the State Government was reorganized and the Utah Geological and Mineralogical Survey was placed within the new State Department of Publicity and Industrial Development where the Survey functioned until July 1, 1949. Effective as of that date, the Survey was transferred by law to the College of Mines and Mineral Industries, University of Utah.

The *Utah Code Annotated 1943, Vol. 2, Title 34,* as amended by *chapter 46 Laws of Utah 1949,* provides that the Utah Geological and Mineralogical Survey "shall have for its objects":

1. "The collection and distribution of reliable information regarding the mineral resources of the State.

2. "The survey of the geological formations of the State with special reference to their economic contents, values and uses, such as: the ores of the various metals, coal, oil-shale, hydro-carbons, oil, gas, industrial clays, cement materials, mineral waters and other surface and underground water supplies, mineral fertilizers, asphalt, bitumen, structural materials, road-making materials, their kind and availability; and the promotion of the marketing of the mineral products of the State.

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4. "The consideration of such other scientific and economic problems as, in the judgment of the Board of Regents, should come within the field of the Survey.

5. "Cooperation with Utah state bureaus dealing with related subjects, with the United States Geological Survey and with the United States Bureau of Mines, in their respective functions including field investigations, and the preparation, publication, and distribution of reports and bulletins embodying the results of the work of the Survey.

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The Utah Geological and Mineralogical Survey has published maps, circulars, and bulletins as well as articles in popular and scientific magazines. For a partial list of these, see the closing pages of this publication. For other information concerning the geological and mineralogical resources of Utah address:

ARTHUR L. CRAWFORD, *Director*

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

College of Mines and Mineral Industries

University of Utah

Salt Lake City 12, Utah

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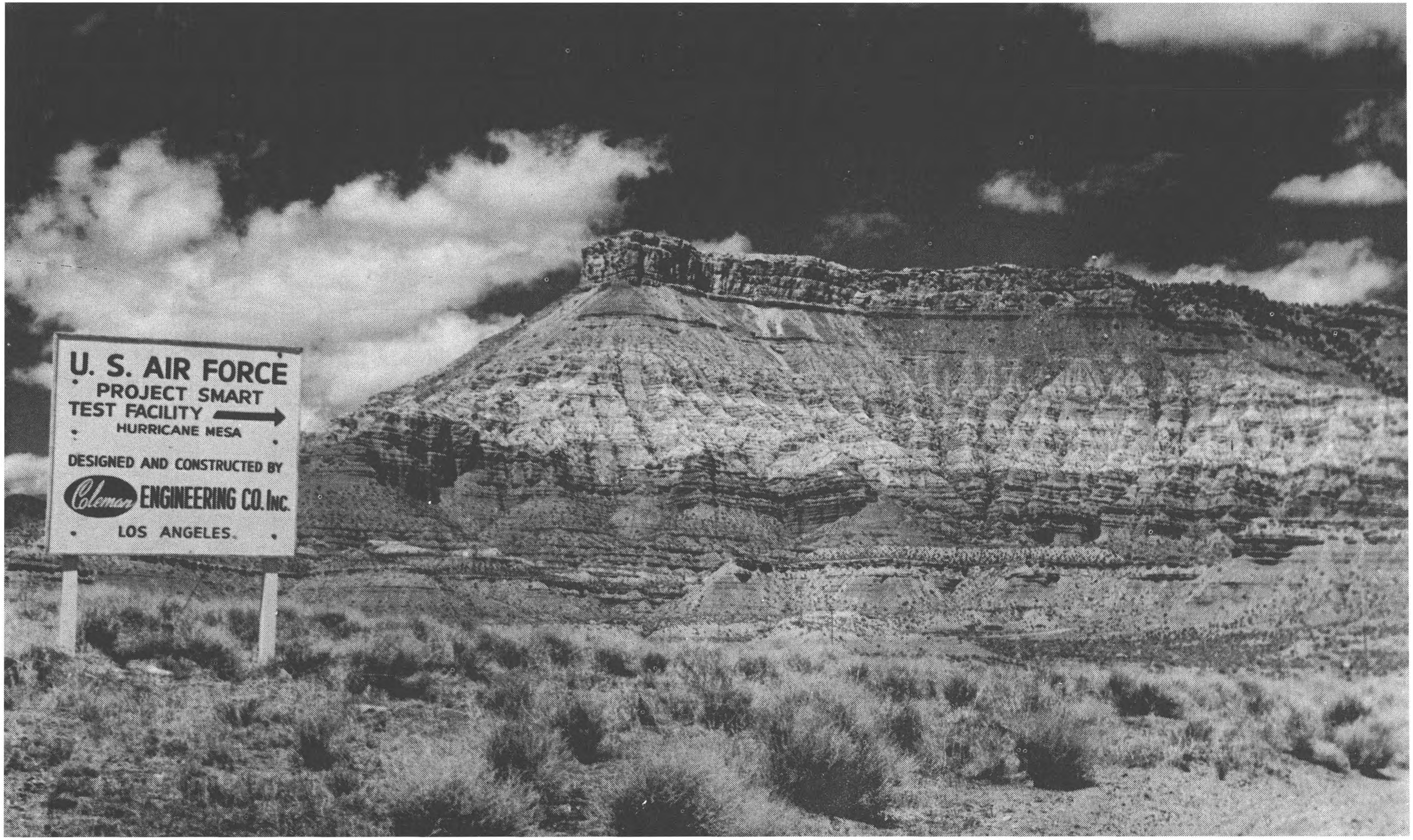

Plate 1. Hurricane Mesa from the ground. (See further explanation with Plate 2 and Colored Scene 4).
--Phot[illegible]ph by Arthur E. Bruhn

F O R E W O R D

When the atlas series to which this bulletin belongs was first conceived, Arthur F. Bruhn was thought of as the author. Though his formal training in geology had been subordinate to his major in biology, his interest in taking and showing geologic photographs at Dixie College had kindled an enthusiasm for which his students will ever be grateful. The demand for his geologic lectures brought him before the public and no doubt influenced his selection as president of Dixie College. His new duties, however, made it increasingly difficult for him to pursue his beloved "minor" and for him to develop the story he wanted so much to tell. Hence, with his cooperation, a search was made for some other suitable authority to author "Washington County."

About this time another educator of unusual clarity of diction and with a keen perception for scientific reading of the "story of the rocks" made himself appreciated as an interpreter of the geology of Utah's Dixie. Dr. Earl Ferguson Cook published his classic on the "Geology of the Pine Valley Mountains, Utah," which at once stamped the author as an authority in his field. Since the Pine Valley area occupies a central position in Washington County and since Doctor Cook had gone beyond his area to solve its problems, immediate arrangements were made with him to participate in the GEOLOGIC ATLAS OF UTAH--WASHINGTON COUNTY. Almost simultaneously with this arrangement, Doctor Cook was appointed Dean of the College of Mines at the University of Idaho and was also made Idaho's State Geologist. These heavy responsibilities threatened that he, too, would be prevented from giving the time necessary to work out and publish the geology of Washington County.

However, with his remarkable ability to "plan his work" and to "work his plans" Doctor Cook has persisted with the Washington County manuscript, until, during the summer of 1959, funds were made available through the Utah State Land Board for him to complete the field work and do the checking he felt was necessary before the bulletin could be published. The Utah Geological and Mineralogical Survey is fortunate to have this publication by so able an author and to have had the enthusiastic cooperation of President Bruhn in its planning and execution. Thanks are given for the valuable help of President Bruhn and for the use of his many excellent photographs. The generosity of others who have allowed the summation of local studies or have contributed photographs is also appreciated. Special mention should be made of the helpful guidance of Dr. Walter P. Cottam and Dr. Angus M. Woodbury, two members of the University of Utah staff who grew up in Washington County, and particularly are we grateful for the use of the lovely painting of the Beaver Dam Mountains at sunset with the giant Joshua in blossom at the southern gateway (or exit) to Washington County, via U. S. Highway 91. This painting was prepared especially at our request by Lynn Fausett, Utah's celebrated landscape artist.

Among the early students of geology who taught at Dixie College was Vasco M. Tanner. Those of us who had an opportunity to share his enthusiasm, to read with him the works of Dutton, Dellenbaugh and Powell, to climb with him the ancient Indian shrine of Shnabkaib, to measure with him up the face of its inner escarpment the entire Moenkopi section from the Kaibab base to the Shinarump cap, formed a resolution that someday this fascinating story of earth history laid bare for all to see would be called to the attention of more people, who would share with us this beautiful simplicity where Nature has opened her book to make easy her lessons for the uninitiated.

Though a guest scientist from outside Utah, Doctor Cook has entered into the project with enthusiasm. His diagrams and photographs admirably supplement the written text. The color scenes have been chosen not only with the purpose of vivifying nature's evidence for the professional geologist, but also with the hope that these scenes will fire the imagination of the amateur geologist and the informed tourist so that these amateurs will want to linger and "read the rest of the story." It will be evident that the underlying geologic formations have influenced the development of the landscape. Within the limitations of our format these scenes have been presented sequentially beginning with the entrance to Washington County from the north via Interstate Highway 15;[1] thence following down the Hurricane escarpment to Hurricane City; thence east to Zion Park; west to Leeds; north to Pine Valley Mountains; west to Pine Park near the Enterprise reservoir; south to the Magotsu; east to Diamond (Damron) Valley;[2] south through Dixie State Park at Snows Canyon and back to Interstate Highway 15, east of Washington; west to St. George; and finally, passing out of Washington County with the setting sun reflected against the Beaver Dam Mountains in Fausett's painting.

The structural cross-section A - A' through the north-central part of Washington County across Pine Valley Mountains and Bull Valley will be crossed by the tourist about twelve miles south of Kanarraville if he enters the county from the Union Pacific Railroad's "Zion Park Gateway" at Cedar City. Section B - B' "slices" the Plateau province near the eastern border of the county, east of the great Hurricane fault. These sections will enable the student entering the county from the northeast to readily orient himself with reference to the geology extending both west and south.

As in all of the bulletins of this Geologic Atlas of Utah series, it is suggested that the reader begin by opening the book to the "Center Spread" made easy by the position of the saddle-stitch staples. Here, in color, is indicated the position of the county in the state, the relation of the various colored maps to the area portrayed by each other map, as well as to the areas covered in publications of previous authors. We think such a preview will streamline efforts by the reader to better utilize the printed index and cross-references.

Unfortunately, the limitations of the format used in Utah Geological & Mineralogical Survey bulletins necessitate segmenting the structural cross-sections to conform to the color map plates. However, for the serious student of geology desiring to study the details with the entire county spread out before him, a separate one-sheet areal geologic map on which the structure sections are in full length at a 1/2 inch-to-the-mile scale in six colors has been prepared and is available at a price of $1 each at the Utah Geological & Mineralogical Survey.

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[1] At the northern boundary of Washington County and throughout most of the distance to Leeds the new Interstate Highway 15 and the old U. S. Highway 91 follow the same route. From Leeds to St. George projected "15" will be north of "91." From St. George south into Arizona, the new "15" will take a new route to the south, cross the Virgin River above Bloomington, and emerge from the Beaver Narrows (see Plate 7) east and a little south of the area shown in colored scene 19.

[2] This valley has come to be known as "Diamond" through a corruption of "Damron"--the name of the original pioneer whose name also is recorded in some of the records as "Dameron," an archaic spelling of this family name.

Arthur L. Crawford, Director
UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

by

E. F. Cook[1]

A B S T R A C T

Washington County, in the southwest corner of Utah, is more or less coincident with the area known as Utah's Dixie, a region of colorful rocks, spectacular scenery, and great contrasts.

Washington County is divided into two topographically dissimilar parts by the Hurricane Cliffs. East of the Hurricane escarpment rise the colorful mesas and plateaus of the Zion Park region. To the west is a basin and range topography, reflecting more complex geologic structure.

Every period of the Paleozoic and Mesozoic eras with the exception of the Silurian is represented in a sedimentary sequence over 19,000 feet thick underlain by Precambrian rocks in the Beaver Dam Mountains and capped by the pink cliffs of the Tertiary Claron (Wasatch) formation in the Pine Valley Mountains. A complex succession of volcanic rocks including flows, breccias, and ignimbrites, aggregating several thousand feet in thickness, overlies the sedimentary sequence. Several laccolithic intrusive bodies in the northwest part of the county are intimately related to volcanism and deformation in that area.

Within Washington County takes place a complete transition in geologic structure from the flat-lying formations cut by a few widely spaced faults of the Colorado Plateau on the east to the tilted fault blocks of previously folded and thrust-faulted rocks that define the Basin-Range province. As G. K. Gilbert wrote in 1875, "...the whole phenomena belong to one great system of mountain formation, of which the ranges exemplify advanced, and the plateau faults, the initial stages.....it is impossible to over - estimate the advantages of this field for the study of what may be called the embryology of mountain building."

I N T R O D U C T I O N

Washington County, in the southwest corner of Utah, has the lowest elevations and the warmest temperatures in the State. It is an area of great contrasts--in elevation, rainfall, vegetation, animal life, and geologic features. It contains spectacular scenery and self-reliant people. Its rocks and its inhabitants are products of history, and the history, both human and geologic, has been more than a little unusual.

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EXPLORATION

The first white men to visit the Washington County area were eight members of a party headed by Father Silvestre Velez de Escalante which set out from Santa Fe in 1776 to seek a land route to Monterey in California. The expedition was unsuccessful. In turning back to Santa Fe from a point south of Sevier Lake, the Escalante party came down Ash Creek Valley, along the present route of U. S. Highway 91, skirting the Hurricane Cliffs past the Virgin River (Colored Scene 2) nearly to Mt. Trumbull before heading for the Colorado Crossing of the Fathers and home.

Fifty years passed and then, in 1826, Jedediah Strong Smith, fur trapper and explorer, descended Ash Creek and the Virgin River seeking new beaver country. He took his party through to California where it remained while he and one companion went back across central Nevada to Beaver Lake in northern Utah, whence he returned to his party through southwestern Utah in 1827.

In the next few years trappers from the north and Spaniards out of Santa Fe developed the Old Spanish Trail which came into Washington County near Pinto, led westward to Mountain Meadows, thence south past the site of Gunlock to the Virgin River and California. Captain John C. Fremont, coming up the Trail from California in 1844, found it well defined and well used; he paused in Mountain Meadows (Fremont, 1845, p. 270-271) to rest and to boil water and, by measuring the temperature at which it boiled, to estimate the altitude at that place.

A party of Mormons led by Jefferson Hunt traveled the Old Spanish Trail in 1847, going to the Pacific Coast for supplies for their newly established Mormon home in Salt Lake Valley. A few years later, when wagon trains were moving over this route to California, it became known as the Mormon Trail.

COLONIZATION

A band of 50 Mormon men came south from Salt Lake in the late fall of 1849 to explore southwest Utah for colonization. Following the favorable report of this troup, the Mormon church organized companies of chosen colonists and sent them southward. Parowan and Cedar City in Iron County were founded in 1851. In February 1852 a company led by John D. Lee made the first settlement in what is now Washington County at a place about eight miles south of the present Kanarraville, near the junction of Harmony and Kanarra Creeks. The new settlement, called Harmony, was moved about four miles northwest in 1854. Although the second Harmony, or Fort Harmony, was the county seat of Washington County from 1856 to 1859, its site can scarcely be located today; the town was all but destroyed by floods in 1861-1862 (Cleland and Brooks, 1955, v. 2, p. 4-7) and was gradually transferred to its present site where it became known as New Harmony (Bruhn, 1952, p. 26).

In 1853 Harmony became headquarters for the Southern Indian Mission. In 1854 Jacob Hamblin and other missionaries established Santa Clara. Hamblin, later president of the Southern Indian

Mission, became a great liaison man with the Indians. Hamblin's skill in dealing with Indians was described by Major J. W. Powell who was aided by Hamblin in his explorations of the Grand Canyon region. In 1855, under Hamblin's direction, a sawmill was set up in Pine Valley; he and his wife wintered in Pine Valley in 1855-1856 before moving to the north end of Mountain Meadows where they established a ranch.

A short time later Mountain Meadows was the scene of a tragic event. On September 11, 1857 a group of local white men and Indians attacked a party of emigrants encamped at the Meadows, killing over 120 of them, sparing only 17 children. The events that led up to this affair included the sending to Utah by the U. S. Government of a force to put down "rebellion" in the territory, a force the Mormons viewed as an invading army. An excellent analysis of the tensions and troubles of these times has been given by Juanita Brooks (1950). Twenty years later John D. Lee was executed at Mountain Meadows for his part in the massacre.

Cotton seed was planted by the missionaries of Santa Clara in 1855. A crop was harvested. Some of the cloth made from the cotton was sent to Salt Lake City (Woodbury, 1950, p. 145) where it aroused considerable interest and led to the settlement of Washington in 1857 by a group of cotton farmers. The area then became known as Utah's Dixie.

In 1861 Brigham Young visited Dixie. In the same year, under the threat of a cotton shortage produced by the Civil War, the church leaders decided to foster a cotton mission to Washington County by "calling" settlers for this purpose. The "call" consisted of reading publicly in church the names of those being requested to go.

St. George, founded in December 1861, quickly became Dixie's principal settlement. Brigham Young established his winter home there. The short-lived Mormon experiment in cooperative living known as the United Order was born in St. George in 1874. The first Mormon Temple in Utah was completed at St. George in 1877.

The southern Utah pioneers were "called," in many cases from fertile farms, to go into a barren desert. They showed their religious faith, their courage and spiritual endurance, their physical strength and ingenuity, by battling the inhospitable land for a perilous living.

G E O G R A P H Y

ECONOMIC GEOGRAPHY

After the early years of colonization, during which it was difficult to raise enough food for survival, Washington County began to export products. Lumbering in the Pine Valley Mountains became a small industry; special timbers were hauled to Salt Lake City to be used in construction of the Tabernacle. Wine was made at Toquerville and sold both outside the district and to the non-Mormon miners at Silver Reef. Early attempts to make the Mormon land of Deseret self-sufficient led to the founding of a cotton industry in Dixie. An interesting account of the cotton factory at Washington is given in The Red Hills of November by Larson (1957). The cotton venture failed, not because it was impossible to raise cotton or to manufacture cloth from it (both were done successfully for a number of years), but because, as the necessity for Mormon self-sufficiency disappeared with the bettering of relations with the United States, it became more economical to buy British cotton goods made from southern U. S. cotton than to make cotton cloth in Utah. Molasses was another Dixie export, as were grindstones made from sandstone at Leeds.

A Leeds grindstone figured in the discovery of silver at Silver Reef, according to an apocryphal story (in Utah, a Guide to the State, 1941, p. 300-301). In 1875 some of the prospectors of Pioche, Nevada, suspected an assayer of that town, one "Metalliferous" Murphy, of finding good values in dubious samples. The suspicious miners prepared a sample from a broken Leeds grindstone to test Murphy's reliability. When he reported high silver values in the sample, they ran him out of town (according to another version he was hanged), considering it impossible for silver to occur in sandstone. Nevertheless, some of the prospectors decided to check, and by November of 1875 a stampede was on to Silver Reef where it had been found that the sandstone hogbacks or reefs west of town did indeed contain rich silver ore.

Agriculture is the principal basis of the economy of Washington County, although income from stock-raising and tourist travel is important. The small amount of arable land (in Washington County only 2.5 per cent of the land is under cultivation) is used for peach and apricot orchards, for hay and alfalfa fields, and for family gardens. Agriculture is limited to areas that can be irrigated in midsummer. The erratic nature of the rainfall makes farming hazardous without adequate storage dams; even then, sudden summer floods frequently destroy dams and silt up irrigation ditches.

Cattle raising is a source of considerable revenue and, with the road improvements of recent years and the building of the Union Pacific branch line to Cedar City in 1923 (Washington County has no railroad within its borders), tourist travel has greatly increased and has become an important income source.

Although the natural increase (excess of births over deaths) in the white population of southern Utah is about twice that of the country as a whole, the total population remains rather stable because the land can support no more than the present number of inhabitants (9,836 in 1950). Many of the children are forced to leave the region to earn a living. It might be said that Dixie's principal export in recent years has been young people.

Topography and Drainage

Washington County is divided into two topographically dissimilar parts by the Hurricane Cliffs. East of the Hurricane escarpment rise the colorful mesas (Colored Scene 4) and plateaus of the Zion region, into which steep-walled narrow canyons have been cut by streams of low volume and for, the most part, intermittent flow. These streams are given great erosion competence by abrasive loads of silt and sand which are carried at relatively high velocities down the youthful, ungraded valleys. The plateaus and mesas, cut from horizontal sedimentary rocks, diminish in elevation southward in step fashion as successively older resistant formations cap them.

West of the Hurricane ledge the aspect of the landscape contrasts with the tabular country of the plateaus. The rock formations are folded, faulted, and more varied. St. George lies in a topographic basin, north of which rises the dark mass of the Pine Valley Mountains (Colored Scenes 3, 10, 14); between St. George and the highest peak in these mountains is an elevation difference of more than 7,000 feet. The St. George Basin is contained on the west by the massive, gray Beaver Dam Mountains (Colored Scene 19), beyond which a low intermontane basin extends into Nevada. In the northwest part of Washington County a jumble of low,irregular hills, above which only two or three eminences rise, reflect complex geologic structure.

The drainage artery of Washington County is the Virgin River. From the high plateaus it flows southward through the depths of Zion Canyon, turns west to cut through the Hurricane scarp at LaVerkin, crosses the St. George Basin, and plunges in a spectacular incised chasm through the southern Beaver Dam Mountains. Virgin River water flows to the Pacific Ocean. Only a small portion of Washington County is part of the Great Basin.

Climate

Contrast and variation in natural phenomena in Washington County are revealed statistically nowhere so well as in climatological records. At New Harmony the annual precipitation is 20 inches; at St. George, it is 8 inches. Winter snowpacks of 10 to 12 feet are not uncommon in Pine Valley; 20 miles south, at St. George, snow that remains on the ground is rare. Recorded snowfall ranges from 4.3 inches at Hurricane to 58.3 inches at Pinto (more falls at Pine Valley but records are not available). The average growing season at Leeds is 59 days longer than that at Cedar City, about 40 miles north.

Rainfall records show great annual and monthly variations. Much of the irregularity is due to the local distribution of the rainfall. The annual rainfall at St. George, for example, has been as little as 3.55 inches and as much as 18.71 inches. Monthly precipitation differences are extreme during the winter; Leeds, for example, has had December rainfall ranging from 0.0 to 10.3 inches, and New Harmony's January records show a range from 0.00 to 9.02 inches.

Gregory (1950, p. 31) pointed out that:

> "Some monthly rainfalls are the records of single showers...The usual showers, particularly those of summer at lower altitudes, are short-lived, far apart, and cover no large areas. These infrequent showers are torrential and seem to flood the surface with water. Sheets of water cover the flat land, pour over the canyon rims, and convert dry washes into turbulent, muddy streams. Scores of waterfalls start suddenly, only to disappear within an hour."

During the year there are two wet seasons and two dry seasons. A moist, cool winter and early spring become progressively drier and warmer to a dry, hot June; and the moist, hot weather of July and August becomes drier and colder toward winter. Gregory notes (1950, p. 31) that "the season of least rainfall is unfortunately the growing season for most crops." As a consequence, most dry farms have been abandoned.

Great variations in temperature are as characteristic of Dixie climate as are rainfall fluctuations. A diurnal temperature range of 50 degrees is not uncommon at St. George, where an annual range of 117 degrees has been recorded.

Flora and Fauna

The great ranges is altitude, precipitation, and temperature in Washington County are reflected in the range and variety of its vegetation and natural animal life (Colored Scene 12). Five life zones, from the Lower Sonoran to the Hudsonian, are represented in the county; the flora and fauna characteristic of each of these zones are described by Bruhn in Your Guide to Southern Utah's Land of Color (1952).

NOTES ON THE GEOLOGIC MAP

The geologic map of Washington County in this bulletin was compiled to a base furnished by the Utah Highway Department. Geologic data was taken from existing maps, as shown on the source index map, supplemented by original work.

Data was transferred without modification from the six photogeologic maps (Marshall, 1956a-c; Pillmore, 1956a-c) of the U. S. Geological Survey that cover portions of eastern Washington County. Because these maps show a revised Triassic and Jurassic stratigraphic sequence not in use at the time Gregory (1950) and Cook (1957) mapped, and not used by McCarthy (1959), information taken from the maps of Gregory, Cook, and McCarthy has been revised in accordance with the Triassic and Jurassic divisions used by the photogeologists of the U. S. Geological Survey. The new contacts were carried westward from the Zion region to Beaver Dam Wash by photogeology checked by field traverses.

It was found necessary, for the scale of the map in this bulletin, to reduce the number of volcanic map units shown on the maps of Blank (1959) and Cook (1957) by combining them into units of higher rank. In addition, part of Cook's map was revised in light of new field work: in particular, the Grass Valley and Atchinson formations (Cook, 1957, p. 59-61) were removed from the map because they do not exist. The Grass Valley formation is Quichapa, probably emplaced by sliding. The Atchinson formation is Little Creek breccia of the Quichapa formation.

Gregory's map of the Zion Park region was made before air photos were available. By the use of photogeology it has been possible to more accurately locate some of the contacts shown on his map. Minor modifications of the maps of McCarthy (1959) and Reber (1952b) have been made as a result of air photo study.

Not shown on the source map but very helpful in the completion of this project was the geologic map of the St. George Basin and the Beaver Dam Mountains prepared by C. E. Dobbin (1939). Dobbin's published map is a small map of a large area, and the scale precludes use of his map as source material for the county map. On the other hand, Dobbin's map was a valuable reference and control on the photogeologic work in the southwest part of the county.

Among those who contributed personal knowledge of the previously unmapped portion of Washington County are H. R. Blank, J. H. Mackin, and G. C. Mattson. The descriptions of the volcanic rock units of the Bull Valley district are condensed from Blank's thesis.

In addition to the time spent in compiling existing geologic data to the base and in mapping other areas by photogeology, approximately one month was spent in the field, in unmapped portions of the county, during the summer of 1959. This field work and the completion of the county map were sponsored by the Utah State Land Board, through the supervision of Dr. Wm. Lee Stokes of the University of Utah.

OUTLINE OF GEOLOGIC RELATIONS

A sequence of sedimentary rocks over 19,000 feet thick lies between the Precambrian metamorphic rock outcrops in the Beaver Dam Mountains and the Tertiary igneous rocks of the Pine Valley and Bull Valley Mountains, a few miles northeast and north. Overlying the sedimentary rocks is a succession of volcanic rocks aggregating several thousand feet in thickness. The Pine Valley Mountains are capped by the world's largest known laccolith, its cover stripped off by erosion. Three other Tertiary intrusive bodies have been found in the northwest part of Washington County; one of the most interesting, in the Bull Valley district (Blank, 1959), has both intrusive and extrusive characteristics and marks the place of eruption of some of the voluminous volcanic rocks of the district.

Within Washington County takes place a complete structural transition from the flat-lying formations of the Colorado Plateau on the east to the fault blocks of previously folded and thrust-faulted rocks that define the Basin-Range province. Whereas elsewhere the boundary between these two structural provinces is sharp, in Washington County the change takes place in a transition block that lies between the Hurricane fault and the Gunlock-Shebit fault system. The transition block includes the St. George Basin and the Pine Valley Mountains. In it the sedimentary rocks are moderately folded along northeast axes. The structural transition zone in Washington County was noted and analyzed over 85 years ago by one of the "giants" among American geologists, G. K. Gilbert (1875, p. 59-61):

"Throughout this region there is a graduated mingling of characters, completely bridging over the interval from the plateaus on one side to the ranges on the other...

"...the whole phenomena belong to one great system of mountain formation, of which the ranges exemplify advanced, and the plateau faults, the initial, stages...

"...it is impossible to overestimate the advantages of this field for the study of what may be called the embryology of mountain building. In it can be found differentiated the simplest initiatory phenomena..... and the process can be followed from step to step, until the complicated results of successive dislocations and erosions baffle analysis."

S T R A T I G R A P H Y

PRECAMBRIAN ROCKS (p€)

Gneiss, schist, and granitic rock of Precambrian age crop out in the southwest corner of the Beaver Dam Mountains. Isoclinally folded foliation in the metamorphic rock may represent original bedding; in any case, the folds are truncated by an erosion surface on which lies the Prospect Mountain quartzite. The granitic rock seen during the field work for this project is in the form of irregular to tabular bodies of feldspathic pegmatite. Reber (1952a, p. 43) reports an older, gray granite that occurs in large bodies.

PALEOZOIC FORMATIONS

Prospect Mountain quartzite (€pm)

The basal sandstone of the Cambrian system, called the Prospect Mountain quartzite in Nevada and western Utah, is equivalent to the Tapeats sandstone of the Grand Canyon district. In the Beaver Dam Mountains the formation is about 530 feet thick and consists mainly of red-brown metaquartzite, grading upward into the overlying Pioche shale through a transition zone of some 50 feet. The Prospect Mountain quartzite is probably Lower Cambrian in southwest Utah.

Pioche shale (€p)

Approximately 220 feet thick in the Beaver Dam Mountains, the Lower and Middle Cambrian Pioche shale consists mainly of reddish-brown to green micaceous shale. Some quartzite beds as much as three feet thick are found near the base. The upper contact is conformable and gradational with a Cambrian limestone and dolomite sequence (Reber, 1952b, p. 102-103).

Undifferentiated carbonate rocks (€OD)

Alternating dark- and light-gray limestones and dolomites, totaling nearly 2,200 feet in thickness, crop out in the western part of the Beaver Dam Mountains. The limestones are in the basal part of the succession and grade upward into massive dolomites. Cambrian and Devonian rocks are probably present; Ordovician may be. McNair (1952, p. 46) indicates that Ordovician(?) limestone is overlain unconformably by Devonian Muddy Peak limestone in the Beaver Dam Mountains.

Redwall limestone (Mr)

The base of the Redwall limestone (called Rogers Spring limestone in southeast Nevada) is marked by a disconformity (Reber, 1952b, p. 103) above which lies medium- to light-gray crystalline limestone that grades upward into massive ledge-forming limestone containing Mississippian fossils. Rocks in the lower part of the formation are medium gray, dense, medium grained, and hard. The middle limestone member is given a dark-brown hue by the presence of abundant interbedded dark chert. Beds in the upper part are medium to dark gray and contain a minor amount of chert; some of these beds contain carbonaceous matter and give off a fetid odor when broken. Although McNair (1952, p. 49) states that the Redwall is Lower Mississippian, Reber describes the contact with the overlying Pennsylvanian Callville limestone as gradational and conformable: massive Mississippian limestone with large festoons of corals gradually gives way upward to thin-bedded Pennsylvanian sandstone and limestone. The answer to this seeming contradiction may be, as McNair suggests, that Upper Mississippian limestone, equivalent to the Blue Point limestone on the Muddy Mountains, is present in the Beaver Dams and has been mapped with the Redwall. Supporting this suggestion is the identification of 210 feet of cherty limestone as Blue Point in the St. George No. 1 well of the California Company (Campbell, 1952, p. 88); the Redwall in that well was measured as 559 feet thick. The Redwall in the Beaver Dam Mountains, as measured by Reber, is 1,120 feet thick.

Callville limestone (Cc)

The Callville limestone, of Pennsylvanian age, is extensively exposed in the Beaver Dam Mountains. It is about 1,560 feet thick and consists of limestone, sandstone, and dolomite. In the lower part of the formation, about 530 feet thick, chert in nodules and lenses is common. The middle member of the formation is a bed of tan to white crystalline dolomite about 500 feet thick. The upper part of the formation consists of 530 feet of fine-grained limestone containing abundant sandstone as thin beds within the limestone layers. McNair (1952, p. 46) indicates that the upper part of the Callville as mapped in the Beaver Dams is Permian and equivalent to the Pakoon limestone of the Grand Wash Cliffs. A sequence of thin-bedded limestone and dolomite 830 feet thick in the St. George well of the California Company was assigned to the Pakoon limestone. Under the Pakoon was found 1,620 feet of limestone, siltstone, and shale of the Callville limestone (Campbell, 1952, p. 88).

Supai-Coconino sandstone (Psc)

The undivided Supai-Coconino succession in the Beaver Dam Mountains consists of massive, fine-grained, tan, white, and yellow, cross-bedded sandstone about 1,800 feet thick. The California

FIGURE 1. GEOLOGIC FORMATIONS OF WASHINGTON COUNTY

AGE		UNIT	DESCRIPTION	THICKNESS (FEET)
QUATERNARY	Recent	Silt, sand, gravel	Alluvium, hillwash, pediment gravel, landslide material, dune sand.	0-200
QUATERNARY	Pleistocene	CULBERT BRECCIA	Mudflow breccia remnants northwest of New Harmony.	0-150
QUATERNARY AND TERTIARY (?)	Late Tertiary (?) to Recent	Basalt	Basalt flows, cinder cones; includes both hypersthene-augite and olivine-augite basalt.	0-900
QUATERNARY AND TERTIARY (?)	Late Tertiary or Pleistocene	Dacite	Porphyritic hornblende dacite flows northeast of Central.	500+
TERTIARY	Pliocene and Pliocene (?)	MUDDY CREEK FORMATION	Mainly soft pink to white and gray silt and sandstone, much of it tuffaceous. Some fine gravel and, in Flattop Mountain area, rudely stratified pink to buff volcanic conglomerate. Includes Parunuweap(?) formation of Cook (1957) and Reservoir formation of Blank (1959).	0-1400
TERTIARY	Pliocene and Pliocene (?)	FLATTOP MOUNTAIN SUITE	Flows and shallow intrusive bodies. Gray, tan, and red biotite-hornblende rhyodacite; gray-purple to brown siliceous rhyolite; light-tan to gray biotite rhyolite; light bluish-gray to purplish rhyolite porphyry. Local conspicuous flow layering.	0-1200
TERTIARY		OX VALLEY TUFF	Bluish-purple rhyolite vitric-crystal tuff, lightly to highly welded, with iridescent sanidine.	0-400
TERTIARY	18MY	COVE MOUNTAIN FORMATION	White and pink airfall tuff, sediments, and green-tan-purple rhyolite vitric tuff (Cedar Spring member, 0-300 feet); basalt (Pilot Creek basalt, 0-400 feet); white to gray biotite-hornblende rhyolite vitric-crystal ignimbrites, nonwelded to moderately welded, with abundant lithic fragments (Racer Canyon tuff, 0-1500 feet-equivalent to Kane Point tuff); and sediments and ash (Willow Spring member, 0-50 feet).	0-2200
TERTIARY		PAGE RANCH FORMATION: KANE POINT TUFF	Vitric rhyolite ignimbrite with abundant lithic fragments, nonwelded to moderately welded.	300+
TERTIARY		MAPLE RIDGE PORPHYRY	Purple biotite-augite andesite(?) with coarse plagioclase phenocrysts.	0-300
TERTIARY		PAGE RANCH FORMATION: PINE VALLEY LATITE	Augite-biotite latite porphyry with well-developed platy parting. Basal glass zone 10-150 feet thick.	2000+
TERTIARY		SHOAL CREEK BRECCIA	Dark, variegated hypersthene-augite-hornblende andesite(?). Some basalt and clastic breccia.	0-200
TERTIARY		PAGE RANCH FORMATION: IRONTOWN MEMBER	Rudely bedded tuff-breccia of possible lahar origin.	0-300
TERTIARY	22MY	RENCHER FORMATION	Bull Valley district: Rust-colored biotite-hornblende augite quartz latite crystal tuff locally overlying white to tan tuff-breccia of same composition, and grading into dark red-purple lava. Pine Valley Mountains: Reddish-brown latite(?) breccia at top; volcanic sandstone; dacite porphyry breccia; bedded, welded tuff-breccia; massive white nonwelded biotite tuff grading down into biotitic crystal-vitric welded tuff with quartzite pebbles.	0-1000
TERTIARY	27MY	QUICHAPA FORMATION	Harmony Hills tuff: Dark-pink to red-brown biotite crystal ignimbrite, dacitic or quartz latitic, moderately welded, (0-550 feet). Little Creek breccia: Variegated augite-hypersthene andesite (0-1200 feet). Bauers tuff: Red to bluish-purple vitric ignimbrite, highly welded with prominent foliation (0-200 feet). Leach Canyon tuff: Pink crystal-vitric rhyolite ignimbrite with lithic fragments (0-800 feet).	0-1800±
TERTIARY		ISOM FORMATION	Andesite(?) flows and chocolate and purple highly welded latite vitric ignimbrites.	0-170
TERTIARY	34MY?	CLARON (WASATCH) FORMATION	Upper gray massive lacustrine limestone member includes interbedded pink to green hornblende-biotite quartz latite crystal tuff (Needles Range tuff); medial siltstone member includes some pink limestone and black-limestone pebble conglomerate; lower conglomerate member, which in area northwest of Gunlock comprises entire formation, is a cobble to boulder conglomerate.	0-1500±
UPPER CRETACEOUS		KAIPAROWITS FORMATION	Thin-bedded, lenticular, friable light-gray to buff sandstone, fine to medium-grained; much of it is cross-bedded. Iron concretions are common. At the base, silty red shale and quartzite cobble conglomerate.	0-1200
UPPER CRETACEOUS		STRAIGHT CLIFFS & WAHWEAP		

UPPER CRETACEOUS	TROPIC FORMATION	Alternating silty gray shales and thin, gray, yellow-brown, red, and black sandstones with some coal beds. Becomes more arenaceous westward.	0-1000
	DAKOTA(?) SANDSTONE	Poorly sorted pebble conglomerate with sandstone lenses. Contains quartzite, chert, and black limestone pebbles.	0-108
UPPER JURASSIC	WINSOR FORMATION	Evenly bedded, thinly laminated, fine-grained red and white sandstone.	0-188
	CURTIS FORMATION	Basal gypsum overlain by calcareous sandstone and limestone conglomerate.	0-60
	ENTRADA SANDSTONE	Friable red-chocolate and greenish-white sandstone.	0-250
UPPER AND MIDDLE JURASSIC	CARMEL FORMATION	Platy, argillaceous gray limestone; gray and brown arenaceous limestone; soft red sandstone, gypsiferous shale, and gypsum.	0-675
JURASSIC AND JURASSIC (?)	NAVAJO SANDSTONE	Cross-bedded quartz sandstone, forming massive cliffs. Color predominantly red, although upper part in places, notably in Zion Park, is white.	1800-2200
JURASSIC (?)	KAYENTA FORMATION	Red-brown siltstone and mudstone with a few layers of light-gray siltstone.	640-740
TRIASSIC (?)	MOENAVE FORMATION	Springdale-Silver Reef sandstone, a ledge-forming white to orange-brown sandstone overlying the Dinosaur Canyon sandstone, consisting of gray-buff to red-purple sandstone and chocolate, red, and purple shale.	455-475
UPPER TRIASSIC	CHINLE FORMATION	Variegated sandy and conglomeratic shale and fine calcareous sandstone.	385±
	SHINARUMP CONGLOMERATE	Fine to coarse, gray to purple sandstone, conglomeratic in the lower part. Grades up into the Chinle. Contains silicified wood.	75-185
MIDDLE (?) AND LOWER TRIASSIC	MOENKOPI FORMATION	Chocolate, red, and gray shale and siltstone with gypsum; green, and pink gypsum and gypsiferous shale (Shnabkaib member); red to brown sandy shale and siltstone; gray silty limestone (Virgin limestone member); red to chocolate sandy gypsiferous shale; gray sandy limestone, reddish-brown and gray-green shale, and conglomeratic limestone (Timpoweap member).	1545-2115
LOWER PERMIAN	KAIBAB LIMESTONE	Hard, massive, cherty, fossiliferous, gray limestone in two thick beds separated by a gypsum-anhydrite layer 150 feet thick.	800-1050
	SUPAI-COCONINO SANDSTONE	Massive, fine-grained, tan, white, and yellow cross-bedded sandstone. Has characteristic, uniformly distributed, small yellowish-brown spots of iron oxide.	1785-1850
PENNSYLVANIAN	CALLVILLE LIMESTONE	Fine-grained gray limestone with abundant thin beds of sandstone; a middle member of tan to white crystalline dolomite; basal cherty limestone.	1496-1620
MISSISSIPPIAN	REDWALL LIMESTONE	Upper beds are gray limestone, some of which contains carbonaceous matter. Middle beds are dark-brown, cherty limestone. Lower beds are gray, dense, hard limestone. Formation commonly forms massive cliff.	1120±
DEVONIAN AND ORDOVICIAN (?)	Limestone and dolomite	Alternating dark- and light-gray limestone and dolomite.	2100±
CAMBRIAN	PIOCHE SHALE	Reddish-brown to green micaceous shale.	215
	PROSPECT MOUNTAIN QUARTZITE	Red-brown metaquartzite.	533
ARCHEAN	VISHNU SCHIST(?)	Gneiss, schist, granitic rock	2000+

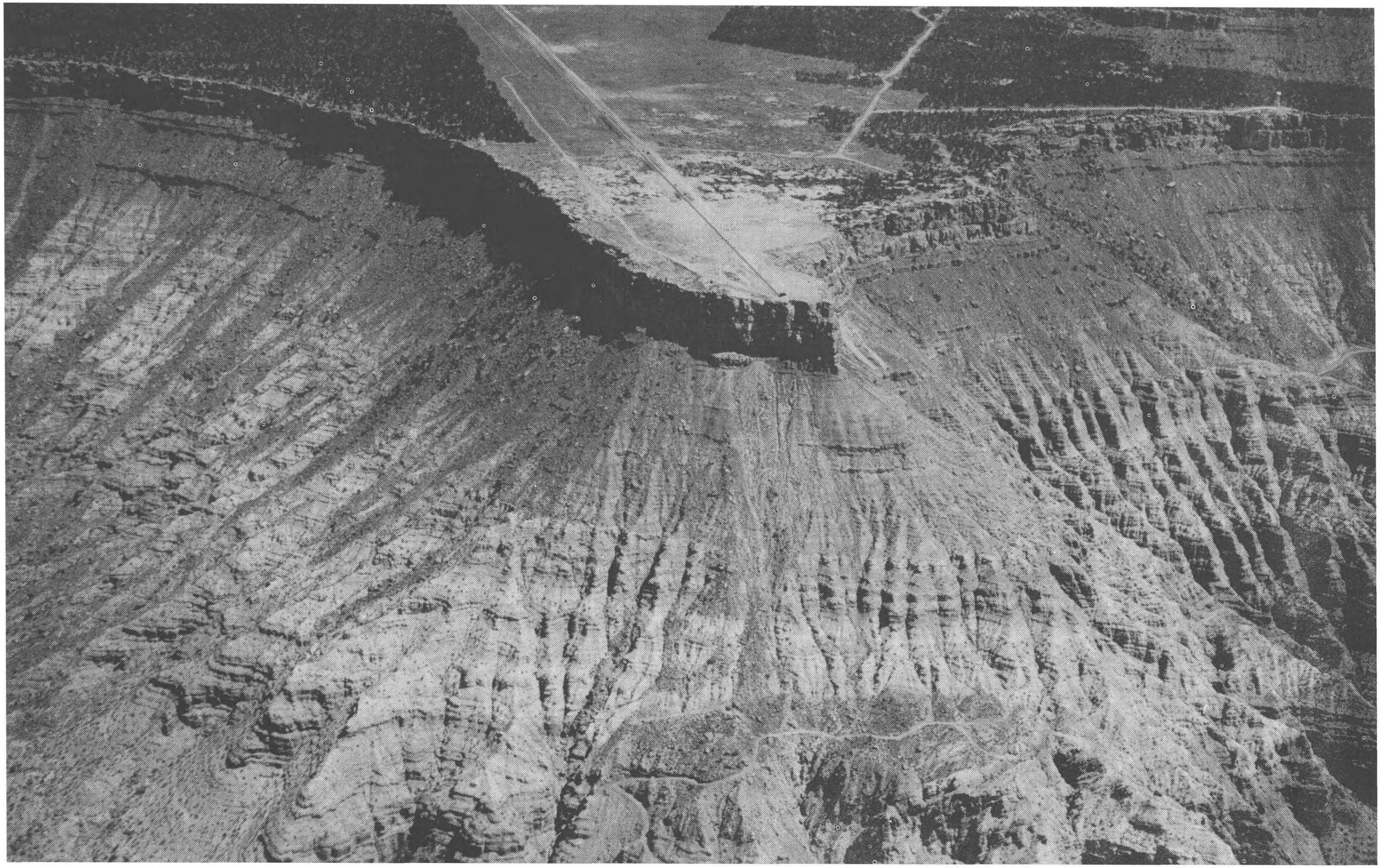


Plate 2. The top of Hurricane Mesa on which is the U. S. Air Force Hurricane Supersonic Research Site, a facility operated by Coleman Engineering to study ground speed, acceleration, deceleration, the mechanism of ejecting pilots and passengers from jet planes, and other supersonic flight problems. The track for these tests is laid on the capping of Shinarump conglomerate which h[illegible] been resistant to erosion [illegible] the ages so as to form this spectacular mesa. Underneath [illegible]

Company well five miles south of St. George passed through 1,850 feet of calcareous sandstone between the Kaibab limestone and the Pakoon limestone. About 500 feet of Coconino sandstone crops out in places in the lower part of the Hurricane fault scarp. Most of the rock contains uniformly distributed, small yellowish-brown spots of iron oxide. If the limestone beneath this sandstone unit in the St. George well was correctly identified as Pakoon, the entire unit is Permian. The Supai-Coconino occupies the stratigraphic position of the Supai-Hermit-Coconino sequence of the Grand Canyon district.

Kaibab limestone (Pk)

Conformably overlying the Supai-Coconino sandstone is 800-1,050 feet of hard, gray, massive, cherty, fossiliferous limestone in two thick beds separated by a gypsum-anhydrite layer 150 feet thick. Together these three units comprise the Kaibab limestone, Permian in age, cropping out extensively in the Beaver Dam Mountains, forming most of the Hurricane scarp in Washington County, and appearing locally along the crest of the Virgin anticline. The most abundant Kaibab fossils are of brachiopods, corals, and crinoids.

The Kaibab as described above and mapped is "the Kaibab of older authors." McKee (1938) redefined the Kaibab, restricting it to the upper massive limestone unit of the formation as described above and an overlying sequence, not everywhere present, of thin-bedded magnesian limestone, red mudstone, and gypsum; the lower part of the "old" Kaibab was given a new formational name, the Toroweap formation.

The two limestone members of the Kaibab are cliff-formers, whereas the intermediate gypsum member is a slope-former. The limestones weather to rough-textured, dark-gray ridges and cliffs, into which transverse valleys are sharply notched.

As McKee (1952, p. 55) points out, withdrawal of the Kaibab sea was followed by a long hiatus of nondeposition and erosion that spans the upper half of the Permian period and the early part of the Lower Triassic. In southwest Utah uplift must have occurred during this time because narrow valleys, incised in the Permian strata and filled with gravel, have been found in several localities.

MESOZOIC FORMATIONS

Moenkopi formation (Ћm)

Disconformably overlying the Kaibab limestone is the Moenkopi formation, one of the most conspicuous sedimentary units of Washington County. Its soft chocolate and red sandy shales form the riser of one of the giant steps of the Plateau province, between the mesas and plateaus capped by the Kaibab below and the Shinarump conglomerate above. West of the Hurricane fault the Moenkopi crops out extensively along the Virgin anticline and along the northeast and north flanks of the Beaver Dam Mountains.

In Washington County the Moenkopi is 1,545 to 2,115 feet thick. The formation can be subdivided into six members: from the base upward, the Timpoweap member; the lower red member; the Virgin limestone member; the Shnabkaib member; and the upper red member.

The Timpoweap member consists of a basal conglomerate, gray-blue limestone, and light-colored sandy shale. The member varies considerably in thickness (Thomas, 1952, p. 57); 450 feet has been measured in some sections, but in the Beaver Dam Mountains it appears only in depressions in the post-Kaibab erosion surface. Wells in the Virgin field obtain oil from limestone at the top of the Timpoweap.

The three red members are similar. All are continental deposits of light-red to chocolate-brown, thin-bedded, shale sandstone and mudstone, with some gypsum and limestone. Each may have a thickness of 400 feet or more.

The Virgin limestone member, by its contrasting lithology and resistance, forms a prominent marker bed in the Moenkopi. It is a blue-gray to gray-tan limestone, 8 to 150 feet thick, resting unconformably on the lower red member. Although the Virgin limestone contains abundant marine fossils, its age was not established until 1954 when Poborski showed its stratigraphic position to be near the top of the Lower Triassic sequence and inferred a Middle Triassic age for post-Virgin Moenkopi strata.

The Shnabkaib member consists of white, pink, and light-red gypsiferous sandy shale and gypsum. It ranges in thickness from about 260 to 715 feet thick in Washington County.

<u>Shinarump</u> <u>conglomerate</u> (Ʀs)

Although the Shinarump is now regarded as a basal member of the Chinle formation (Stewart, 1957), it has been mapped separately because of its importance as a stratigraphic and structural marker.

The resistant Shinarump forms a pronounced gray ridge or ledge above the chocolate and red slopes of the Moenkopi (Plates 1, 2). It is a light-gray to reddish-brown, fine to coarse sandstone, locally grading into lenticular pebble conglomerate near the base. It is rudely bedded and contains silicified wood. The pebbles in the conglomerate are largely quartz, quartzite, and chert with a sand matrix. The thickness of the Shinarump in Washington County ranges from 75 to 185 feet. Its age is determined only by its stratigraphic position: it lies disconformably on the Moenkopi, the upper part of which is Middle Triassic, and it grades upward into the Upper Triassic Chinle formation; consequently, it may be Middle or Upper Triassic or both.

<u>Chinle</u> <u>formation</u> (Ʀc)

The Upper Triassic Chinle formation, as mapped, includes only beds between the top of the Shinarump conglomerate and a disconformity at the base of the Moenave formation, now regarded as the lowermost unit of the Glen Canyon group. In general, the disconformity is indicated by a transition from the fine-grained typical grayish-red to purple shale of the Chinle to the coarser-grained reddish-orange sandstone, siltstone, and mudstone of the overlying

Colored Scene 1. Kolob Buttes in the northwest corner of Zion National Park as viewed from the Harmony Hills to the west. Old U. S. Highway 91 and the Interstate Highway 15 now under construction cross the Great Basin-Colorado River divide in the pass or valley between the Kolob Buttes in the distance and the pygmy-forested Harmony Hills in the foreground. These Buttes have been carved from massive wind-blown deposits of Navajo (Jurassic). One of them (that farthest to the right of the picture, featured again in Colored Scene 11, and known as Timber Top) has thus far never been scaled. Unfortunately, the tourist on U. S. Highway 91 (or Interstate Highway 15) does not see this magnificent landscape. The foothills forming the Hurricane fault scarp east of the highway obscure the Buttes. --Photograph by Arthur F. Bruhn--

Dinosaur Canyon member of the Moenave (Averitt et al., 1955). The Chinle so defined is about 385 feet thick in Washington County.

Moenave formation (TRmo)

Disconformably above the Chinle is the Moenave formation. It includes two members: a lower sequence of sandstone and siltstone, named the Dinosaur Canyon sandstone; and an upper unit, the cliff-forming Springdale sandstone. The Dinosaur Canyon member is about 300 feet thick and not as resistant to erosion as the Springdale sandstone, which is only 175 feet thick. At Springdale, its type locality, the Springdale sandstone forms a prominent ledge low in the cliffs on the north side of town. West of the Hurricane fault the Springdale is known as the Silver Reef sandstone (Colored Scene 7). It was in this white sandstone, near Leeds, that rich silver ore was discovered in 1875.

The age of the Moenave is Triassic(?).

Kayenta formation (Jk)

The Kayenta formation, of Jurassic(?) age, includes the sequence of beds between the top of the Springdale sandstone member of the Moenave to the base of the Navajo sandstone and ranges in thickness from 640 to 740 feet in measured sections in Washington County. It consists mainly of red-brown siltstone and mudstone and a few layers of light-gray siltstone.

The top of the Kayenta must be drawn somewhat arbitrarily. West of Silver Reef, for example, the red-brown siltstone of the Kayenta grades upward into massive, resistant, poorly bedded, fine-grained red sandstone and then into a soft section of red shaly sandstone before reaching the massive, cross-bedded sandstone of the Navajo. These transition beds are about 100 feet thick and have been included in the Navajo in the mapping for this bulletin.

Navajo sandstone (Jn)

The most prominent formation in southern Utah is the Navajo sandstone, which forms the walls of Zion Canyon (Colored Scenes 5, 6); flaming red Kolob Buttes (Colored Scenes 1, 11); and a massive ledge west of Leeds and north of St. George and Santa Clara, into which are cut precipitous canyons. One of the most spectacular of these is Snow Canyon (Colored Scene 16), north of St. George, where the intricate pattern of cross-bedding and joints, and the interwedging of red and white phases of the sandstone seem to be made unusually vivid by the black splashes of basalt and the perfect volcanic cones in the background.

The Navajo overlies the Kayenta formation conformably and gradationally. In Washington County it ranges from 1,800 to 2,200 feet in thickness. In most places it is composed of fine- to medium-rounded quartz grains, cemented by iron oxide and lime. Cross-bedding on a grand scale is the principal structural characteristic of the formation, although strong jointing that controls drainage and helps shape almost vertical canyon walls is almost as universal in the Navajo.

The color is predominantly red, although in places, notably in Zion Canyon, the upper part is white. This color difference led Huntington and Goldthwait (1904, p. 203) to define two formations, the Colob sandstone for the upper white portion and the Kanab sandstone for the lower red part; these are probably the White Cliff sandstone and Vermilion Cliff sandstone of Dutton and earlier authors. However, the boundary between red and white has no definite position and may vary within a short distance from the middle to the top of the formation.

No fossils have been found in the Navajo in southwest Utah. Its tentative age assignment to the Jurassic is based on stratigraphic position.

Carmel formation (Jc)

The Carmel formation appears to overlie the Navajo conformably, but the cross-bedding of the Navajo is sharply truncated by a surface of erosion on which the basal member of the Carmel, composed to a large extent of reworked Navajo, rests. The thickness of the Carmel in Washington County ranges in measured sections from 480 to 675 feet. In its thickest section the formation consists of three units: lowermost is a group of soft-red sandstones, gypsiferous shales, and gypsum--the Temple Cap member--about 225 feet thick; in the middle is 150 feet of gray and brown arenaceous limestone; and uppermost is 250 feet of platy argillaceous gray limestone. The age of the Carmel, established by abundant fossils, is Upper Jurassic.

Entrada formation (Je)

In the plateaus and beneath the Pine Valley Mountains the Carmel is overlain by a narrow band of extremely friable red-chocolate and greenish-white sandstone designated the Entrada formation. From a maximum thickness of 250 feet it wedges out southward and is not found south of the Pine Valley Mountains. West of the Pine Valley Mountains the Entrada becomes finer-grained; in the Bull Valley district it consists of 50 to 130 feet of maroon to olive-green shale (Blank, 1959). The age of the Entrada is established by its position in the plateau region between the fossiliferous Carmel and Curtis formations, both of Upper Jurassic age.

Curtis and Winsor formations

In the northern part of the Zion Park region the Entrada, Curtis, and Winsor formations could not be distinguished by photogeology and were mapped as a unit. The Curtis consists of a basal unit of gypsum and anhydrite and an upper unit of limestone conglomerate, the total thickness being 40 to 60 feet. The Winsor formation, which overlies the Curtis east of the Hurricane fault, is composed mainly of evenly bedded, thinly laminated, fine-grained, white to yellow-white sandstone with red bands and a few lenses of conglomerate. It has a maximum thickness of 188 feet in the Zion Park region. Although unfossiliferous, the Winsor has been considered the youngest of the Jurassic formations.

Colored Scene 2. The Virgin River "Crossing of the Fathers," looking east at the Hurricane Bridge over the Virgin River in the center of the picture with the edge of the town of La Verkin to the left and Hurricane to the right in front of the Hurricane fault scarp. The green field in the lower left is on the alluvial fan of Ash Creek which comes into the Virgin from the north; opposite which is the "ramp" of basalt up which Escalante's party climbed to the lava platform west of the present location of the city of Hurricane. Back of Hurricane can be seen the Short Creek road ascending the Hurricane Cliffs to the east. The high mesa forming the center skyline is capped by Shinarump conglomerate, as is the Hurricane mesa northwest of Virgin City on which were constructed the installations for "Operation Smart" for testing ejections from jet airplanes. --Photograph by Arthur F. Bruhn and Arthur L. Crawford--

Colored Scene 3. Pine Valley Mountains from a point on the Hurricane Ledge southeast of Hurricane. The southwestern edge of Hurricane City is plainly visible. This view overlooks the viewpoint from which Colored Scene 2 was taken. In the middleground can be seen the low range of volcanic hills during the formation of which a stream of lava ran down to the Virgin River forming the ramp up which the Escalante party ascended from the confluence of Ash Creek with the Virgin River and reached the platform now shown in the Hurricane fields below Hurricane. Goulds Wash, the arroyo entrenched in the Hurricane fields, was formed by the drainage from east of the Hurricane escarpment spilling over onto the hanging wall of the Hurricane fault. --Photograph by Walter P. Cottam--

Upper Cretaceous formations (K)

General features

A broad belt of gray Upper Cretaceous rocks, sharply contrasting with the pink rocks above and the white-and-red rocks below, crops out over a large part of southwest Utah. The lower and upper parts of the section form brushy, undistinguished slopes, while the thicker middle part of the sequence produces a subdued, laminated ledge-and-slope topography.

From east to west there is a marked facies change in the Cretaceous rocks. East of the Pine Valley Mountains four units of the Cretaceous may readily be distinguished on the basis of lithology. West of the Pine Valley Mountains, however, the shale units become arenaceous, and the lithologic characteristics of the Upper Cretaceous rocks are so alike that, with the exception of the basal Dakota(?), it is not possible to map separate formations.

The Upper Cretaceous rocks west of Leeds and Pintura have a total thickness of about 4,100 feet. The section east of Diamond Valley and that west of Gunlock are about 3,850 feet thick.

Dakota(?) sandstone (Kd)

The Dakota(?) sandstone is the basal unit of the Upper Cretaceous rocks. It unconformably overlies formations from the Carmel to the Winsor. It is 4 to 108 feet thick in Washington County. It is composed of sandstone and conglomerate and is essentially a basal conglomerate of the Tropic formation into which it grades upward. Although resistant to erosion in the main plateau area, in southwest Utah the Dakota(?) is friable and forms no projecting ledges. Its base is not much of an unconformity angularly but it represents all of the Early Cretaceous. As Gregory (1950, p. 102) remarked:

> "It is difficult to realize that a line on a cliff that separates rocks differing in color and texture but otherwise undistinguished represents a time interval of some millions of years during which most or all of the Lower Cretaceous sediments were deposited elsewhere."

Gregory also points out that the pebbles in the Dakota(?) conglomerate, which include limestone with Carboniferous fossils, could not have come from the rocks below but must have come from some distant source. The pebbles closely resemble those in the Shinarump nearly 3,000 feet below. The Dakota(?) is probably Lower Colorado in age.

Tropic formation

The Dakota(?) grades up into the Tropic formation, which has a maximum thickness of about 1,000 feet. The Tropic is composed of arenaceous, carbonaceous, gypsiferous, and calcareous shale; earthy lignite and coal; and coarse to fine, tan, gray, drab, and black sandstone in beds 2 to 20 feet thick. In cliffs and steep slopes east of the Hurricane fault, the Tropic is conspicuous because of its dark color and scant vegetation. In flatter terrain it weathers into low mounds covered with fine, loose debris.

Coal is part of all sections measured. There are, in any section, 3 to 7 beds each less than four feet thick, interstratified with dense shale and fine sandstone. Within a vertical distance of 200 feet some lenses of sandy limestone contain marine fossils, others brackish-water fossils, and still others fresh-water forms (Gregory, 1950, p. 105). The Tropic is of Lower Colorado age.

Straight Cliffs and Wahweap sandstones (Ksw)

Gradationally overlying the Tropic formation is an 1,800-foot sequence of alternating massive sandstones and soft shales recognizable as the undivided Straight Cliffs and Wahweap sandstones. The sandstone beds range in thickness from a few inches to 80 feet and are lenticular. The two formations consist essentially of piles of overlapping wedges of sandstone and shale. Ironstone concretions are fairly common in the sandstone, which is tan, buff, or yellow gray.

Kaiparowits formation (Kk)

Disconformably above the ledge-forming sandstones of the Straight Cliffs and Wahweap is the Kaiparowits formation. It consists largely of soft sandstone above a basal conglomerate and is up to 1,200 feet thick.

An erosion surface of low relief developed on Wahweap sandstone is everywhere overlain by a conglomerate layer one to 40 feet thick, composed of pebbles of quartzite, quartz, black chert, and sandstone. Above the conglomerate is a thin section of red, sandy shale. The bulk of the formation consists of friable, fine- to medium-grained, buff to white, cross-bedded sandstone in which iron concretions are numerous. The sandstone crumbles readily, in consequence of which the formation forms gentle slopes, by which erosional characteristic it is easily distinguished in the landscape from the more resistant rocks of the Straight Cliffs and Wahweap sandstones.

Gregory (1950, p. 109) notes that the Kaiparowits contains an interesting terrestrial fauna and flora:

> "Several species, not only of fresh-water mussels and land snails, turtles, and dinosaurs, but also of dicotyledons and gymnosperms, are represented in the collection.....Some of the vertebrate fossils are partial skeletons, but most of them are isolated bones, worn by attrition or gnawing. The plants in the beds of fine-grained sandstone and shale have left fairly clear impressions of leaves; in coarser beds they are represented by twigs, bark, and the fragments of tree trunks more carbonized than agatized. Some of the macerated leaves and splinters of lignite were found suitable for campfires."

Richardson (1927, p. 467-8) concluded that the Tropic, Straight Cliffs, and Wahweap are of Colorado age and that the Kaiparowits is of Montana age. Because the Dakota(?) is essentially a basal conglomerate of the Tropic it likewise is probably of Colorado age.

Colored Scene 4. Hurricane Mesa (formerly known as Smith's Mesa) from the southwest. The picture is taken from the top of the Hurricane escarpment east of La Verkin on the Timpoweap member of the Moenkopi formation about 200 feet above the top of the Kaibab limestone. The large tree cactus frames this interesting erosion "peninsula" capped by Shinarump conglomerate on which the Coleman Engineering Company constructed facilities for the U. S. Government described more fully with Plate 2. The reds, whites, and grays revealed on the erosion face of this mesa reproduce with remarkable fidelity the various members of the Moenkopi (Triassic) formation, exposed almost in its entirety.

--Photograph by Coleman Engineering Company--

Colored Scene 5. West Temple of Zion from an alcove under the Shinarump ledge near the Pipe Springs dugway, high on the south wall of the Virgin River south of Rockville. Massive cliffs of Navajo sandstone form the skyline. At the base of the Navajo cliffs are more gentle slopes on the red-brown siltstones of the Kayenta formation, below which the Moenave sandstones form the lower red-brown cliffs. Below the Moenave are the softer, lighter-colored Chinle shales, underlain by the mesa-forming, resistant, buff sandstone and conglomerate of the Shinarump below which are seen the vermilion sandy shales of the Moenkopi.

--Photograph by Arthur F. Bruhn--

Claron (Wasatch) formation (Tc)

Although the Claron (Wasatch) formation is here listed as a Cenozoic formation, the lower part of it may well be of Late Cretaceous age, as Bissell (1952, p. 73) believes. No evidence has been found by which the precise age of the Claron in southwest Utah can be determined. It unconformably overlies formations from the Kaiparowits down to the Navajo sandstone; it is overlain conformably or accordantly by the volcanic Quichapa formation, the lower member of which has a zircon age (based on measurements of the lead-alpha ratio in the mineral zircon) of 28 million years (Mackin, 1960). It could range in age, therefore, from very Late Cretaceous to Oligocene.

The hiatus represented by the basal unconformity is not great in geologic terms, but it includes the major orogenic epoch of the region.

In most places the Claron is a sequence of fresh-water limestones with subordinate calcareous sandstone, limestone pebble conglomerate, and shale above a basal sandstone and quartzite cobble conglomerate. The beds of the Claron show a wide range of composition, texture, and color. The general color of the unweathered limestone is pale red, yellow, gray, and white, but weathering produces a strong pink tone, especially in the lower part of the formation. Some thin lenses of the oxidized iron coloring material were a source of red paint for the Piutes (Gregory, 1950, p. 111). The upper part is commonly gray to white. The thickness of the normal Claron is about 475 feet in the area of the Pine Valley Mountains.

East of the Hurricane fault the Claron has been known as the Wasatch formation. Spieker (1946, 1949), however, has shown that the Wasatch in central Utah actually consists of several formations. It seems more proper, therefore, to use a local name (the type locality for the Claron is at Mt. Claron in the Iron Springs district) for the Wasatch in southwest Utah. The "Wasatch" in the high plateaus forms the Pink Cliffs, the intricate erosion of which has formed landscapes of surpassing beauty in Cedar Breaks and Bryce Canyon.

Westward there is an abrupt increase both in the percentage of clastic material in the Claron and in its thickness. Near Gunlock, only six miles west of a dominantly calcareous Claron section, no limestone remains, and the Claron consists of pebble, cobble, and boulder conglomerate with sandstone lenses. The Gunlock section is 959 feet thick. The Claron continues to increase in thickness westward, until, in the region of Square Top Mountain, 7 to 10 miles west of Gunlock, it ends against a thrust sheet from which, in that locality, it has obviously been derived. The thrust sheet is composed of Callville limestone and Supai-Coconino sandstone. Near the eroded edges of the sheet the lower part of the abutting Claron is composed of sandstone clasts from the Supai-Coconino; the upper part is composed of limestone clasts from the Callville. The upward transition in the Claron from sandstone conglomerate to limestone conglomerate represents the time when erosive agents had succeeded in removing the Supai-Coconino from

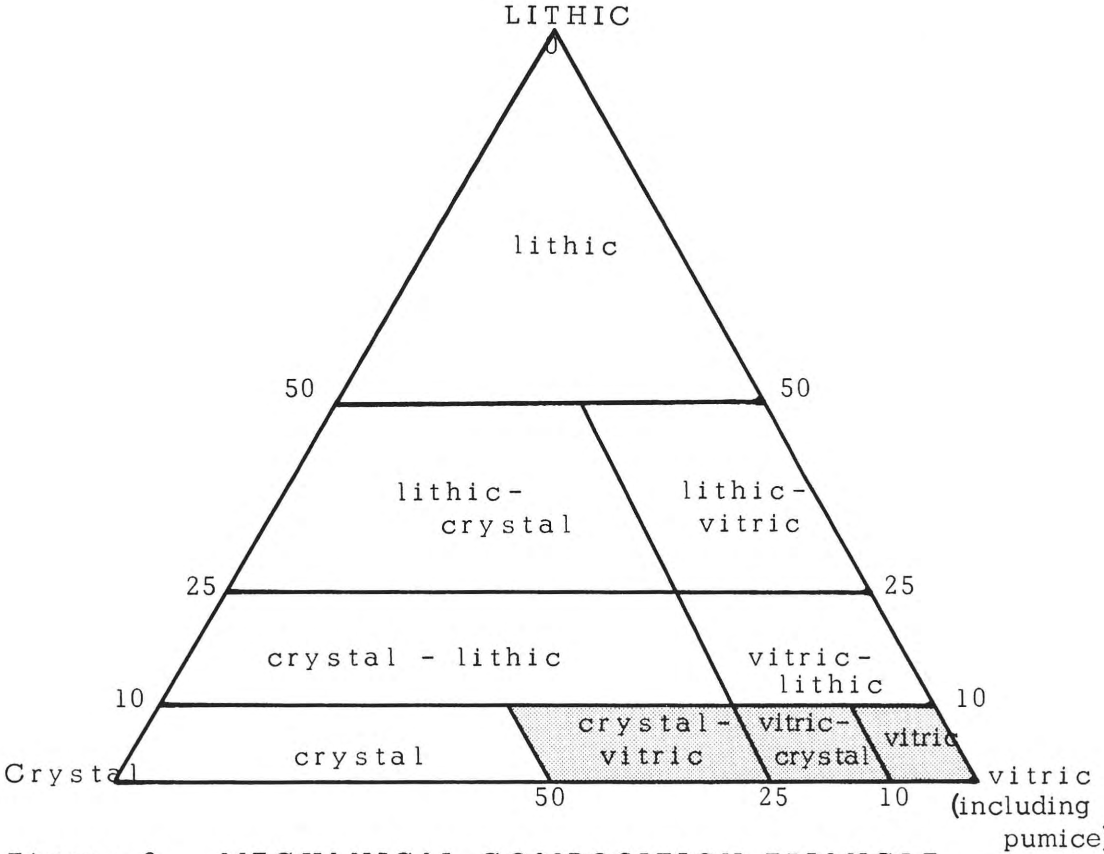
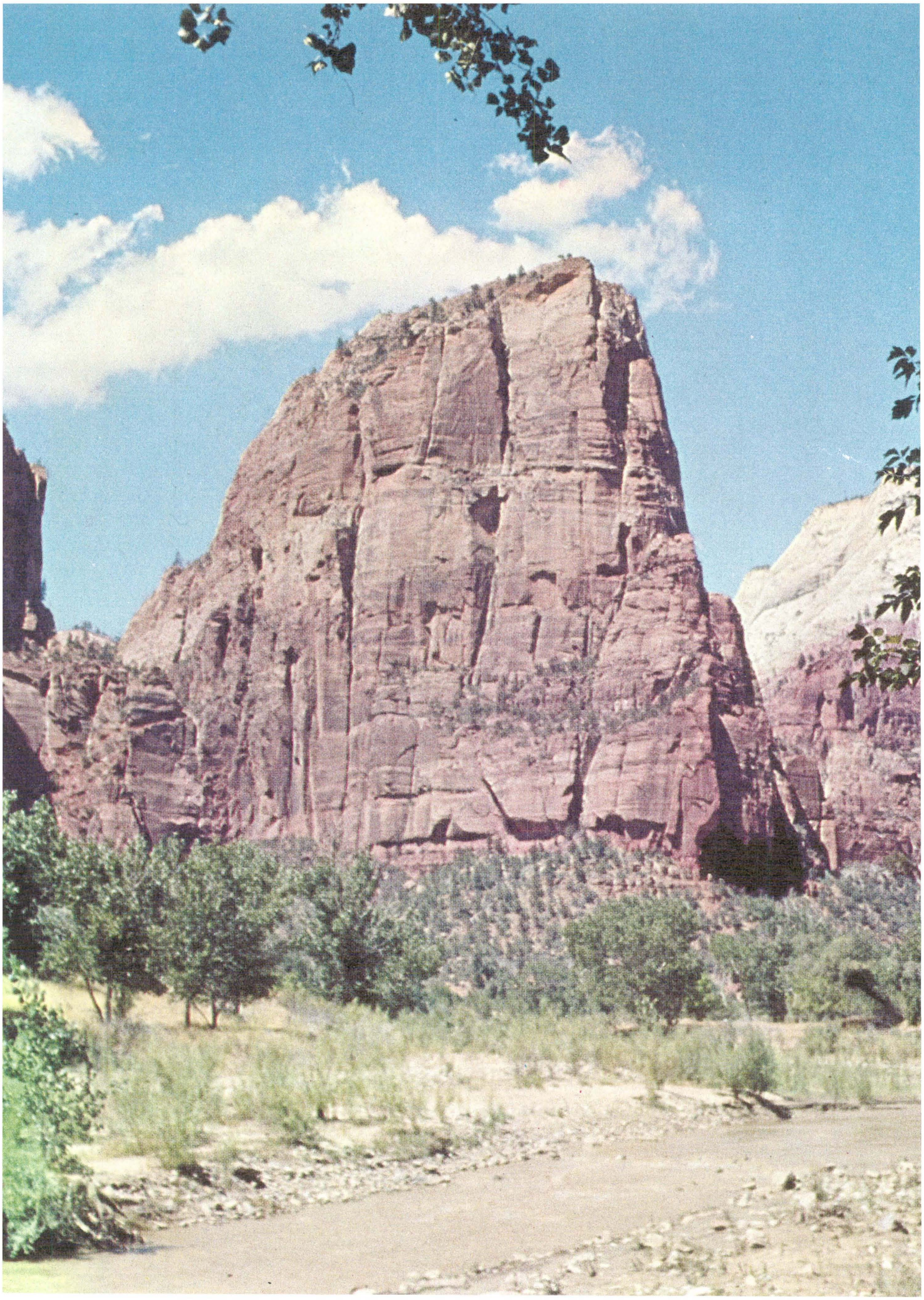


Figure 2. MECHANICAL COMPOSITION TRIANGLE FOR IGNIMBRITE ROCK TYPES
(Rocks of most ignimbrites fall within shaded area)



Colored Scene 6. Angel's Landing in Zion National Park--an erosion-carved monolith of massive Navajo sandstone with some Kayenta at the base.
--Photograph by Arthur F. Bruhn--

Colored Scene 7. The famous Silver Reef sandstone (in the middleground) repeated by faulting on the northwest flank of the Virgin anticline. The viewpoint is from the Shinarump hogback south of the town of Leeds with the Vermilion Cliffs and Pine Valley Mountains in the background. --Photograph by Arthur F. Bruhn and Arthur L. Crawford-the nearby portion of the thrust sheet and were just starting to eat into the Callville. The Claron along the northeastern margin of the thrust sheet has not been measured but is well over 1,000 feet thick. Westward, still along the margin of the thrust sheet, it thins and disappears within a few miles. An interesting feature of the basal Claron sandstone conglomerate is its distribution. Outside of the region northwest of Gunlock the conglomerate is, in most sections, not over 55 feet thick--except in a narrow zone trending northeast from the Gunlock area in which the thickness of the basal conglomerate is 400 to 500 feet (Page Ranch vicinity; Parowan Canyon; Paragonah Canyon). This linear zone may represent a shallow syncline on the southeast side of a Laramide anticline that probably extended from the Iron Springs district to the Bull Valley district.

In some localities the Kaiparowits formation appears to grade upward into the Claron by increase in coarseness and thickness; in other places an erosion surface, channeled and iron-stained, can be clearly seen at the base of the Claron. Where the unconformity is angular, the basal Claron cuts sharply across a surface of low relief developed on truncated formations down to the Navajo sandstone.

Interbedded in the upper Claron is a thin hornblende-biotite quartz latite crystal tuff 55 feet thick identified by Blank (1959, p. 27) as part of the Needles Range formation of Mackin (1960, p. 99-100). The Needles Range formation is at least in part the equivalent of a volcanic formation that in central Nevada overlies another volcanic unit having a potassium-argon age of 34 million years. The lower unit of the Quichapa formation has a zircon age of 28 million years. These age determinations, if the regional stratigraphic relations have been correctly worked out, indicate that the uppermost Claron (the "white Wasatch" or "Claron facies of the Wasatch") in Washington County is of Oligocene age.

Isom formation (Tvi)

Above the Claron formation in the northwest part of Washington County are several thousand feet of volcanic rocks. The most prominent and extensive rock units in the volcanic succession are ignimbrites (Cook, 1957, p. 49-51)[1] consisting of welded and nonwelded

1/Ignimbrites are blanket-like deposits of fragmental volcanic material. What distinguishes them from ordinary airfall or water-laid tuffs is their lack of sorting and the fact that the fragments may be welded together to produce a hard, lava-like rock. In fact many ignimbrites have been called lava flows because of their hardness and resistance. The word ignimbrite means "fiery-cloud rock" and refers to the main hypothesis of origin for such rocks, that they are somehow abruptly deposited from hot subaerial density or turbidity currents (glowing clouds or nuées ardentes) which, erupting from vents or fissures as rapidly vesiculating or foaming magma, carry in turbulent suspension intratelluric crystals, magma droplets, and rock fragments torn from the walls of the vent or picked up from the surface over which the current rolls. Upon deposition the broken magma bubbles, now in the form of plastic glass shards, may, because of the heat still retained and the weight of overlying material, become firmly welded together into a hard rock whose pyroclastic origin is difficult to recognize.

tuff and tuff-breccia of dacitic to rhyolitic composition. Basalt, andesite, and latite flows as well as volcanic mudflow deposits are locally conspicuous but as rock units do not have the extent of the ignimbrites.

In some sections the Claron is overlain with apparent conformity by a sequence of volcanic rocks, made up of ignimbrites and lava flows, which Mackin (1960, p. 98-99) has designated the Isom formation. The Isom wedges out southward; in the Pine Valley Mountains, for example, the Claron is directly overlain by the Quichapa formation.

The Isom formation crops out in the Bull Valley district (Blank, 1959, p. 38-42) where it has a maximum thickness of 150 feet and is made up of andesite(?) flows overlain by two thin, highly welded, latitic, vitric ignimbrites with sparse phenocrysts. According to Blank, the top of the Isom is probably an erosion surface.

Quichapa formation (Tvq)

Leach Canyon tuff

The Quichapa formation (Mackin, 1960, p. 89-97) is represented in Washington County by three ignimbrites and a breccia unit. Each of the ignimbrites has characteristics that make it easily distinguished from the others in the field. The Quichapa formation has a maximum thickness of about 1,600 feet.

The lowermost member of the formation is the Leach Canyon tuff, 100 to 800 feet thick, composed of crystal-vitric (according to a modification of the Wentworth and Williams classification of pyroclastic rocks, shown diagrammatically in Figure 2), rhyolitic, lightly to moderately welded tuff that contains prominent angular red lithic fragments. Although the lithic fragments make up only 5 to 10 per cent of the tuff, they are a striking feature of the smooth surfaces along which the rock breaks. The moderately welded tuff of the Leach Canyon ignimbrite is pale red-violet to pink; it contains feldspar (mostly sanidine) and biotite phenocrysts 1 to 2 millimeters in diameter. In most sections there is 5 to 20 feet of black glass near the base of the ignimbrite.

Bauers tuff

Overlying the Leach Canyon tuff is the Bauers tuff, an ignimbrite composed of strongly welded vitric quartz-latitic or rhyolytic tuff. The Bauers ignimbrite is about 180 feet thick in most measured sections. Above a basal black glass zone 10 to 20 feet thick is a strongly foliated pale-red section that in turn grades up into a very hard pale-purple zone near the top of the ignimbrite. The foliation in the medial portion is expressed in thin white discoids up to six inches in diameter and one inch thick (most of the discoids are much thinner but not much smaller in diameter). Crystals of sanidine and plagioclase, in roughly equal proportion, and sparse biotite are set in the lithoidal to glassy groundmass.

Colored Scene 8. Water is Washington County's most important mineral resource. In the picture above water from Leeds Creek is being diverted for irrigation near the old mining camp of Silver Reef. --Photograph by Earl F. Cook--

MAP EXPLANATION

QUATERNARY

- Qs — Silt, sand, gravel
- Qc — Culbert breccia
- QTb — Basalt
- QTs — Silt, sand, gravel
- QTd — Dacite

TERTIARY

- Tmc — "Muddy Creek" formation
- Tvf — Flattop Mountain suite
- Tvo — Ox Valley tuff
- Tvcm — Cove Mountain formation
- Tvmr — Maple Ridge porphyry
- Tvsc — Shoal Creek porphyry
- Page Ranch formation:
  - Tvpr2 — Kane Point tuff
  - Tvp — Pine Valley latite
  - Tvpr I — Irontown member
- Tvr — Rencher formation
- Tvq — Quichapa formation
- Tvqx — Chaotic Quichapa
- Tvi — Isom formation
- Tv — Undifferentiated Tertiary volcanics
- Tc — Claron (Wasatch) formation
- Ti — Tertiary intrusive rocks, mainly quartz monzonite

UPPER CRETACEOUS

- Kk — Kaiparowits formation
- Ksw — Straight Cliffs and Wahweap sandstones
- Kdt — Dakota (?) sandstone and Tropic formation
- Kd — Dakota (?) sandstone
- K — Cretaceous rocks undifferentiated

JURASSIC

(UPPER)

- Jecw — Entrada sandstone, Curtis and Winsor formations
- Je — Entrada sandstone
- Jc — Carmel formation
- Jn — Navajo sandstone
- Jk — Kayenta formation

Map explanation continued on map 6.

Little Creek breccia

Resting on the Bauers tuff in sections west of the Pine Valley Mountains is a great mass of andesitic flows and breccia named the Little Creek breccia by Blank (1959, p. 45-48). The massive flow rock is dark red to dark purple and black; in addition to these colors the brecciated rock also shows gray, olive green, and brown. Phenocrysts of pyroxene and plagioclase are set in a glassy to aphanitic matrix. The brecciation appears to have been brought about neither by tectonic movements nor by partial consolidation during flowage. More likely, in view of lateral and vertical gradations from breccia into unbroken flow rock, the shattering is the result of autobrecciation (Blank, 1959, p. 48). The maximum thickness of the Little Creek breccia is 1,200 feet.

Harmony Hills tuff

Unconformably overlying the Little Creek breccia, the Bauers tuff, and in places the Leach Canyon tuff, is the Harmony Hills tuff, composed of lightly to moderately welded, dacitic or quartz latitic crystal tuff (Colored Scene 9). The Harmony Hills tuff has a maximum thickness of 550 feet in Washington County; in places it includes at least two ignimbrites (Blank, 1959, p. 49-51). The tuff is 60 to 70 per cent crystalline; most of the crystals are plagioclase but about one-fourth are biotite flakes, conspicuous in hand specimen and outcrop and arranged in eutaxitic foliation. A fresh surface of the tuff is red brown to purplish brown. In some sections there is a basal black glass zone up to 35 feet thick. In general the rock forms massive, resistant outcrops.

An unconformity at the top of the Quichapa formation is marked in several places by lenses of white limestone and gravel. In other places, where the contact with the succeeding ignimbrite appears gradational, the overlying tuff contains abundant quartzite pebbles, probably swept from the erosion surface and incorporated into a *nuée ardente*.

Rencher formation (Tvr)

A complex assemblage of welded tuff and tuff-breccia, mudflow breccia, flows and flow breccia, volcanic-derived sandstone, and limestone and conglomerate lenses, with a maximum thickness of 600 feet in the Pine Valley Mountains and much more than this in the Bull Valley district, overlies the Quichapa formation unconformably. These rocks are called the Rencher formation. The period of their accumulation was a time of great intrusive deformation in northwestern Washington County. Intrusion formed domal masses which arched the overlying rocks so abruptly that some of these covering rocks slid toward marginal synclines (Blank, 1959, p. 158-159; Mackin, 1960). In Bull Valley an intrusive body broke to the surface and boiled out, spreading as flows and *nuées* (Blank, 1959, p. 51-53).

The lower members of the Rencher formation fill depressions in a surface of folded and eroded Quichapa rocks. Most of the Rencher tuff is brown, biotitic, crystal-vitric, and dacitic. In hand specimen it resembles the Harmony tuff. Rock of closely similar chemical and mineralogic composition in the Rencher is found in the form of tuff, volcanic mudflow deposits, and flows; and these lithologically similar extrusive rocks, as shown by Blank (1959, p. 51-107), in turn closely resemble and grade into a "vent phase" enclosed within intrusive monzonite of the Bull Valley district.

Blank distinguished two main extrusive phases in the Rencher formation: a lower "white tuff" and an upper "rusty tuff."

The "white tuff" near the Bull Valley vent has a maximum thickness of 500 feet. It is actually a tuff-breccia in many outcrops because large cognate and foreign inclusions are abundant, especially within a mile or two of the Bull Valley intrusive body. Near the vent the "white tuff" grades down into dark-red latite that grades laterally into black glass, then down into light-tan latite, and then basal tuffaceous sandstone (Blank, 1959, p. 62). Farther away the unit is composed of uniform, light-gray to white, nonwelded to lightly welded crystal tuff.

The "rusty tuff" grades laterally as well as downward into unbroken vent phase flow rock (Blank, 1959, p. 106). The rock is a rust-red, locally tan or gray, tuff-like latite porphyry. According to Blank, the contact with the "white tuff" below is abrupt in some places, in others apparently gradational within a few feet. In most places the material is brecciated. Although in the Bull Valley district the unit becomes increasingly tuffaceous away from the source area, there is hard, dense, brecciated flow-like rock overlying the "white tuff" in the northern Pine Valley Mountains that fits Blank's description of the "rusty tuff" but does not have any obvious tuffaceous characteristics. This Pine Valley "rusty tuff" may reflect another vent or it may mean that the lateral transition from flow rock into tuff-like rock described by Blank is not so regular as it appears in the Bull Valley district. Although broken phenocrysts and crystal fragments are abundant in the Rencher rocks, no recognizable glass shard were found by Blank.

Shoal Creek breccia (Tvsc)

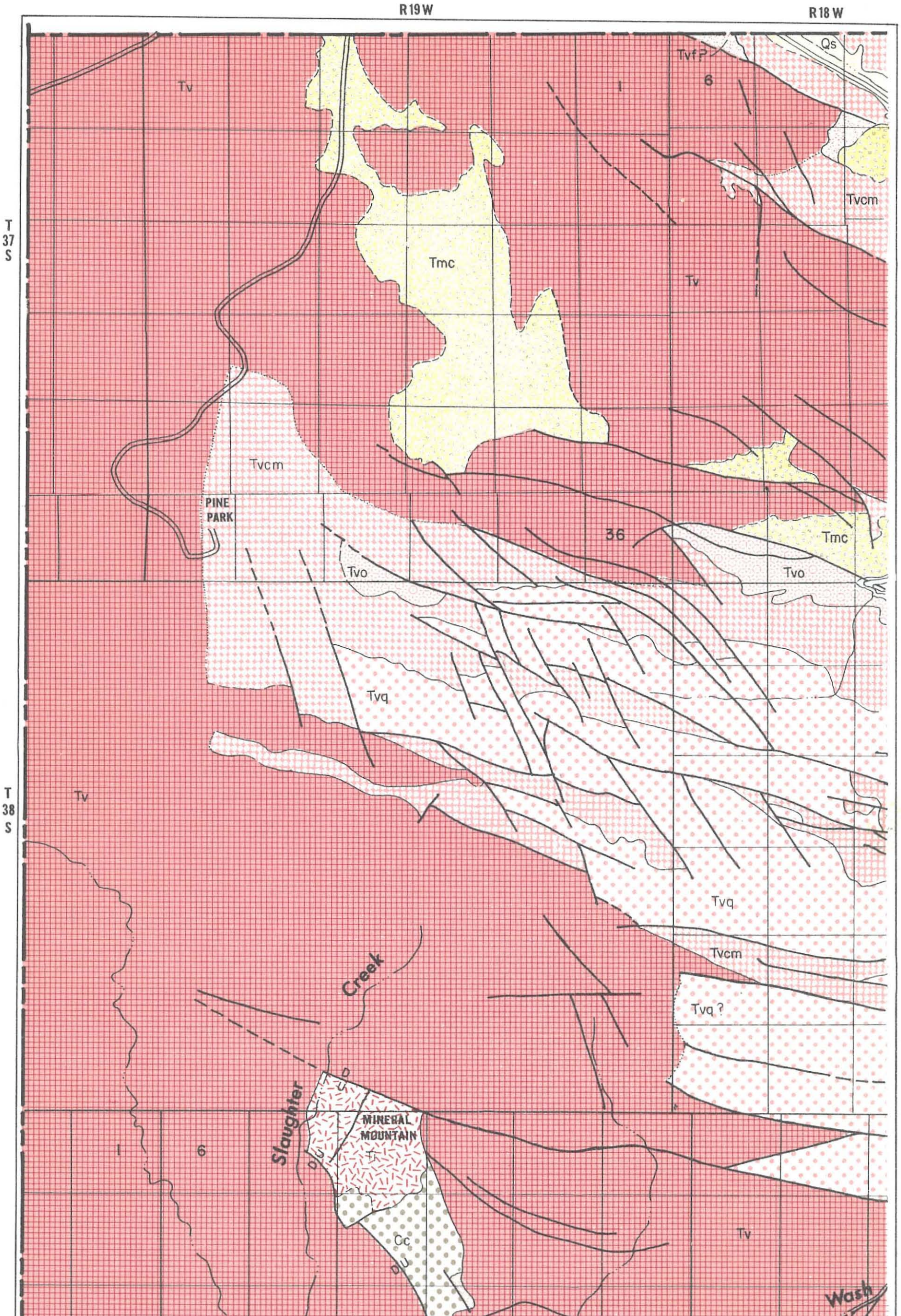
In portions of the Bull Valley district, especially along Shoal Creek west of Enterprise, the Rencher formation is overlain by the Shoal Creek breccia (Blank, 1959, p. 108-110) consisting of dark, massive to rudely bedded deposits of hypersthene-augite-hornblende andesite(?) with a maximum thickness of at least several hundred feet.

Maple Ridge porphyry (Tvmr)

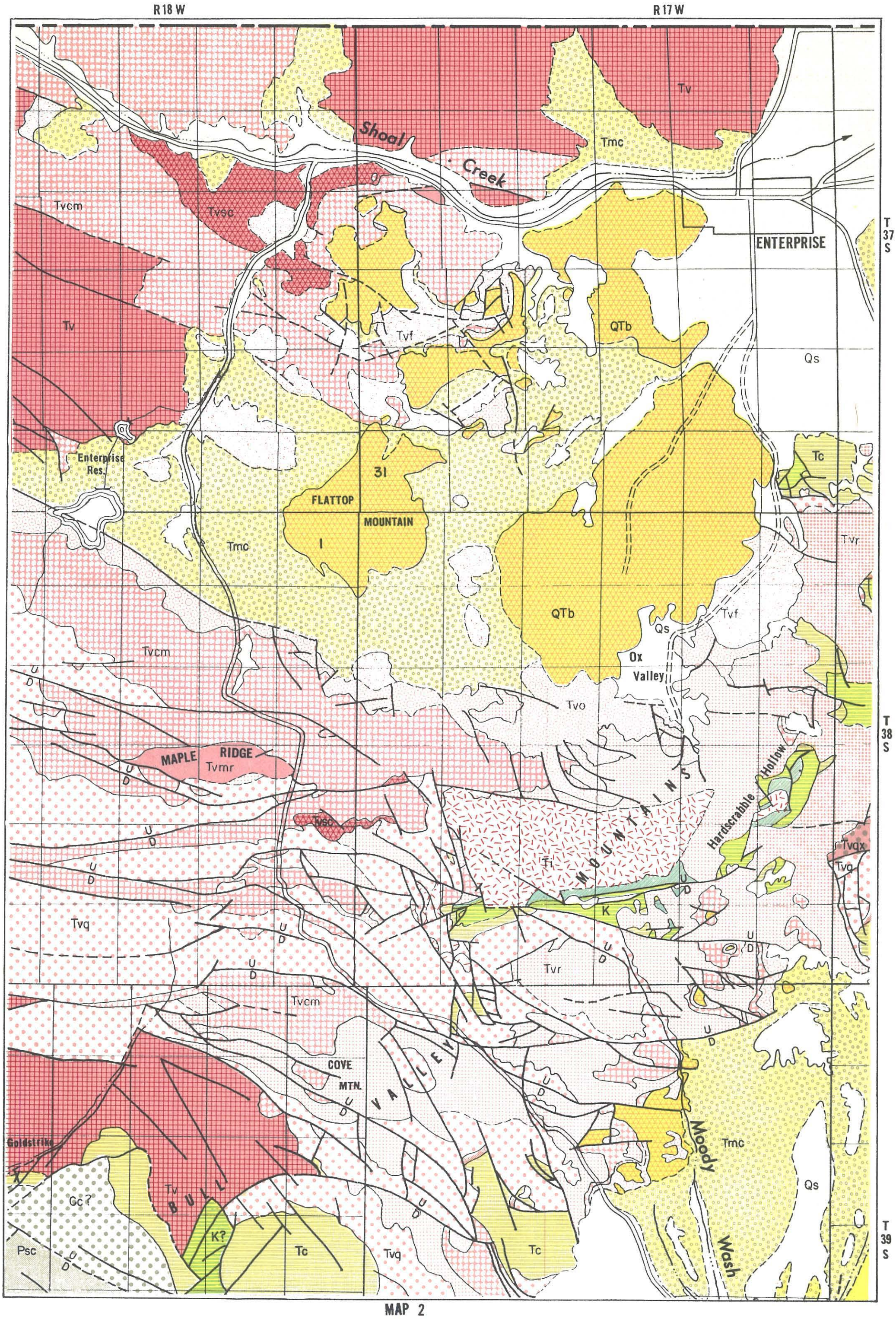
A flow unit of dark biotite-augite andesite(?), making up most of Maple Ridge in the west-central part of the Bull Valley district, overlies the Shoal Creek breccia. Named by Blank (1959, p. 110-111), the Maple Ridge porphyry has a maximum thickness of 300 feet.

Pine Valley latite (Tvp)

The northern portion of the Pine Valley Mountains is largely made up of a series of peculiar latite flows that appear to be roughly equivalent in age to the Maple Ridge porphyry and somewhat


R19W
R18W
T 37 S
T 38 S
T 39 S
Tv
Tvf?
Qs
Tvcm
Tmc
Tvo
Tvq
Tvq ?
PINE PARK
36
Slaughter
Creek
MINERAL MOUNTAIN
Ti
Cc
Tc
Cc?
Psc
Beaver
Dam
Wash

MAP 1


R18 W
R17 W
T 37 S
T 38 S
T 39 S
Shoal Creek
ENTERPRISE
Enterprise Res.
FLATTOP MOUNTAIN
31
Ox Valley
MAPLE RIDGE
Hardscrabble Hollow
MOUNTAINS
COVE MTN.
VALLEY
BULL
Goldstrike
Moody Wash
Tv
Tmc
Tvcm
Tvsc
Tvf
QTb
Qs
Tc
Tvr
Tvo
Tvmr
Ti
K
Tvqx
Tvq
Gc?
K?
Psc

MAP 2

similar to it in lithology as well. These latite flows have been named the Pine Valley latite.

The formation was built up by a number of viscous flows that appear to have sealed the vent from which they issued, forcing the remaining magma to intrude beneath the sticky seal in the form of a thick sill or laccolith, now known as the Pine Valley laccolith.

The formation, composed of augite-biotite latite porphyry, is characterized by eutaxitic structure that induces a platy parting and a pronounced illusion of bedding. The maximum remaining thickness is 2,000 feet. Because no formation now lies upon it the original thickness is impossible to compute. In places the basal portion of the formation is a dark-gray, glassy, porous rock with contorted microfluidal structure.

Cove Mountain formation (Tvcm)

Stratigraphically next above the Maple Ridge porphyry in northwest Washington County is the Cove Mountain formation of Blank (1959, p. 112-120). Outcrops of the Cove Mountain are widespread. In part it is equivalent to the Page Ranch formation of the northern Pine Valley Mountains. To the west it extends into Nevada through the area of Washington County in which the Tertiary volcanic units have not been differentiated.

The Cove Mountain formation consists of four units. However, the top and bottom units, composed largely of volcanic sediments and airfall tuffs, are of limited distribution. A third unit consists of flow basalt.

The most important unit in the Cove Mountain is the Racer Canyon tuff (Blank, 1959, p. 112), a succession of rhyolitic ignimbrites with a maximum thickness of about 1,500 feet. According to Blank, the Racer Canyon tuff is equivalent to the Kane Point tuff, the upper unit of the Page Ranch formation. The rock making up the Racer Canyon tuff is white, gray, pale-pink or pale-yellow, nonwelded to moderately welded, vitric-crystal tuff in which red or purple lithic fragments are generally abundant and conspicuous. It commonly weathers in spectacular "hoodoos" (Colored Scene 13).

Page Ranch formation (Tvpr)

Irontown member ($Tvpr_1$)

The Page Ranch formation at its type locality (Cook, 1957, p. 61-62) just north of the Pine Valley Mountains consists of two units, both named by Mackin (1960, p. 97). The lower unit, called the Irontown member, is a group of rudely bedded tuff-breccias of probable lahar origin. A lahar is a volcanic mudflow that may be caused either by the incorporation of abundant water, say from a crater lake, into the material of an eruption or by the saturation through abundant rainfall or by snow melt-water of unstable volcanic slope material. At the type locality the Irontown member overlies Rencher "white tuff." Farther south the Irontown member overlies various earlier units, including the "rusty tuff" of the Rencher. Mackin (1960, p. 97) points out that the Irontown member of the type section is clearly the filling of a synclinal trough developed north of an intrusive arch; so may it be south of the same arch, in view of its thickening in the vicinity of Pinto Spring.

Kane Point tuff ($Tvpr_2$)

The Kane Point tuff, overlying the Irontown member at the type locality of the Page Ranch formation, is a lightly to moderately welded, vitric, rhyolitic ignimbrite with fairly abundant lithic inclusions. Absence of the Kane Point tuff south of the intrusive arch previously mentioned may be due to the height of the arch and, locally, to the topographic obstacle presented by the Pine Valley latite. However, it is not certain that the mountain of latite was already formed when the Kane Point tuff was deposited: the relative age assignment of the Pine Valley latite has been made on the basis of the absence of the Kane Point beneath the latite.

Ox Valley tuff (Tvo)

The Ox Valley tuff (Blank, 1959, p. 120-123) lies above the Cove Mountain formation in the Bull Valley district. The Ox Valley is a lightly to moderately or highly welded, rhyolitic vitric-crystal tuff some 400 feet thick in its thickest measured section. It is light grayish-blue to pink or purple and contains very sparse lithic fragments. It is characterized by the presence of clear phenocrysts of sanidine showing blue iridescence. Quartz, sanidine, and plagioclase are the main visible minerals.

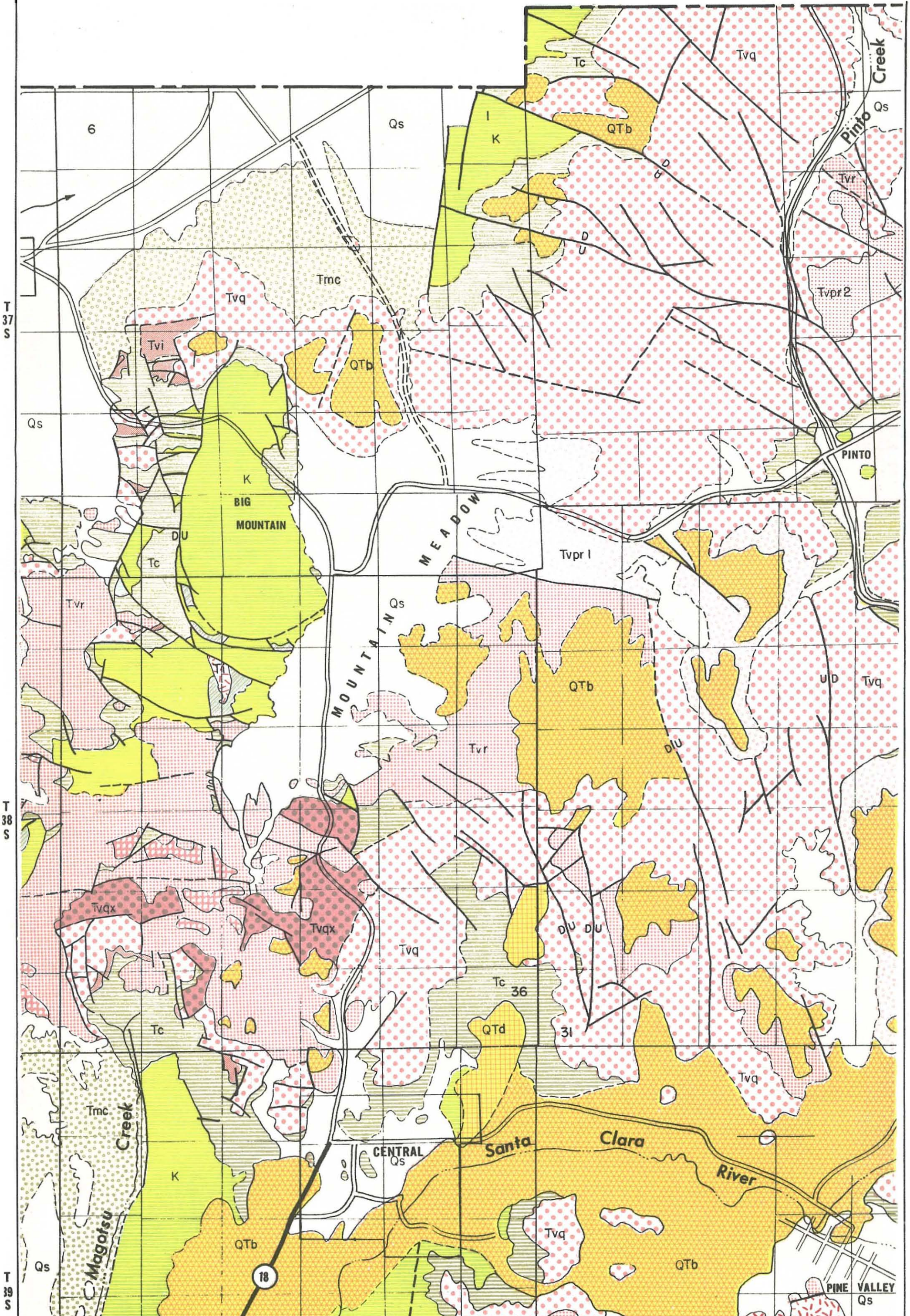
Flattop Mountain suite (Tvf)

The Flattop Mountain suite of Blank (1959, p. 123-136) is a complex of flows and small intrusive masses that represents a period of eruptive activity in a restricted center. Rocks of the suite range from highly siliceous rhyolite to rhyodacite. Colors range from white through bluish purple to almost black; the red-browns of the tuffs are conspicuously absent. Strong flow layering is seen in some units and is locally contorted. Phenocrysts are generally sparse.

No total thickness can be given for the extrusive units of the Flattop suite. However, such a figure, from Blank's descriptions, would exceed 1,000 feet.

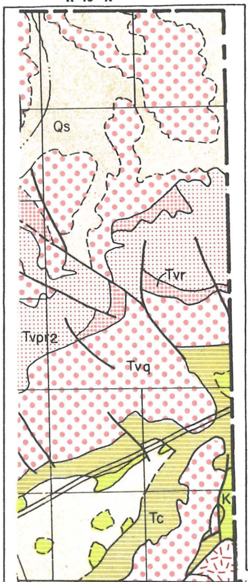
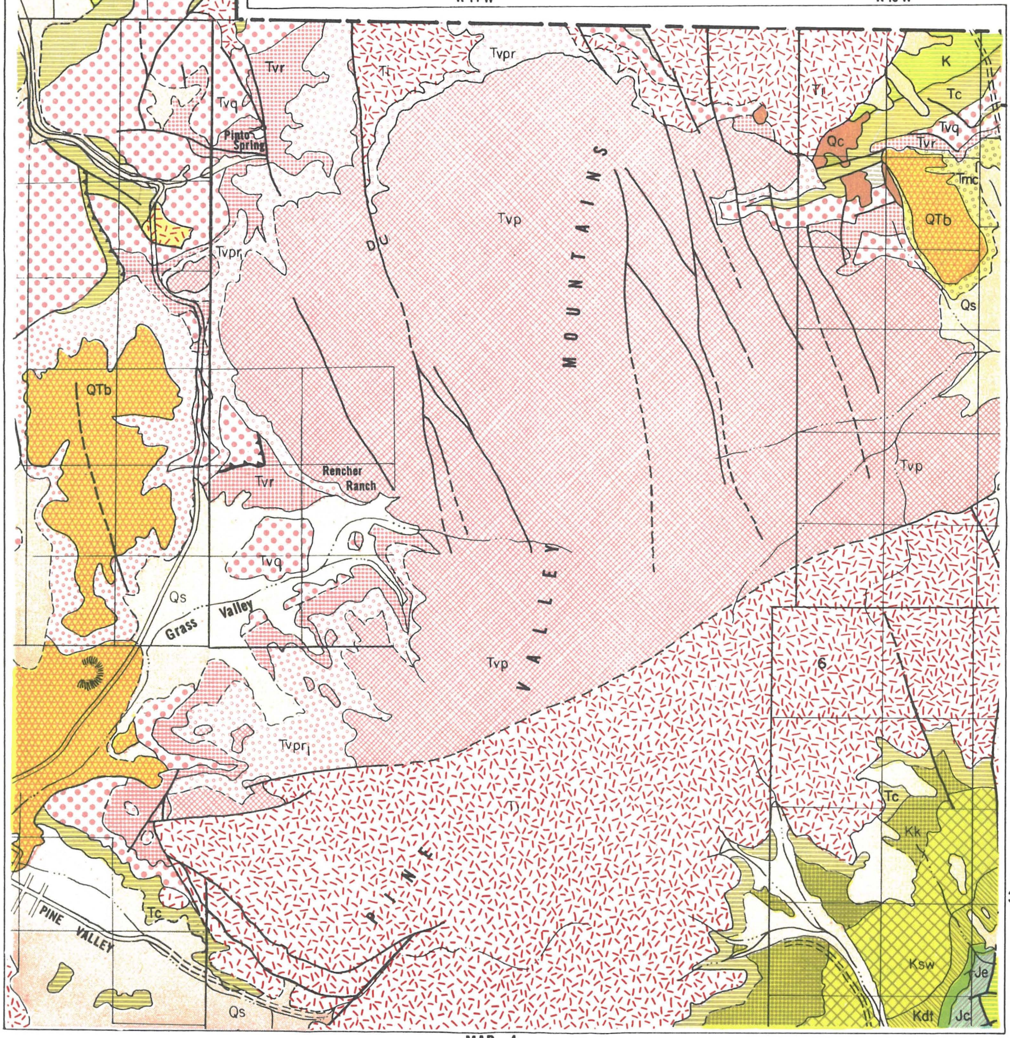
"Muddy Creek" formation (Tmc)

A time during which generally fine, light-colored, locally tuffaceous, sediments were being deposited in troughs and basins is represented by the "Muddy Creek" formation. Correlation with known beds of the Muddy Creek in southern Nevada has not been established. Beds in Beaver Dam Wash regarded as "Muddy Creek" in the mapping for this bulletin are called Muddy Creek by C. M. Tschanz (personal letter) of the U. S. Geological Survey. Elsewhere in Washington County, the "Muddy Creek" as mapped includes Blank's Reservoir formation (1959, p. 28-30) and Cook's Parunuweap(?)


T 37 S
T 38 S
T 39 S
6
Qs
Tmc
Tvq
Tc
QTb
K
Tvr
Tvpr 2
Tvpr I
Tvi
Pinto Creek
PINTO
BIG MOUNTAIN
MOUNTAIN MEADOW
Ti
Tvqx
QTd
36
31
Santa Clara River
CENTRAL
PINE VALLEY
Magotsu Creek
18
D U
U D

MAP 3

Colored Scene 9. Prickly pear in bloom growing on residual "soil" developed on Harmony Hills welded tuff northwest of New Harmony. --Photograph by Earl F. Cook--

formation (1957, p. 38). The Muddy Creek of southern Nevada is medial Pliocene in age; the Reservoir formation is regarded by Blank as Pliocene(?) and early Quaternary; the Parunuweap was assigned a Pliocene(?) age by Gregory. The age of the "Muddy Creek" of the Washington County map is thought to be mainly Pliocene, although it probably includes some early Quaternary sediments.

Resting in most places with marked angular unconformity on all older rocks, the "Muddy Creek" is a sequence of loosely consolidated silt and sand, derived from nearby hills, generally with a pale-pink cast on fresh exposures. In the northern part of the Bull Valley district the formation includes nonwelded tuff, agglomerate, and volcanic conglomerate. Its finer sediments are tuffaceous and it has a maximum thickness of about 1,400 feet.

Dips up to 35 degrees are not uncommon in the "Muddy Creek," which in many places is unconformably overlain by coarse gray gravel of more gentle inclination. The unconformity at the top of the formation represents a period of folding, faulting, and erosion prior to deposition of the coarse gravel (Fig. 3). In some places, however, the upper "Muddy Creek" sediments seem to merge with the Quaternary gravels.

Late Cenozoic basalt (QTb)

Thin basalt flows and basaltic cinder cones are prominent features of the low-lying areas east, south, and west of the Pine Valley Mountains, as well as on the plateaus east of the Hurricane Cliffs. In the northwest part of Washington County basalt flows form nearly horizontal mesa caps as well as valley fills. Basalt has plainly been erupted in southwest Utah intermittently over a long period of time, starting with the formation of a basalt member of the Cove Mountain formation and continuing into Recent time. The basalt of the Cove Mountain formation may be of Miocene age; the basalt that has flowed from the southern end of Diamond (Damron) Valley toward Santa Clara and St. George is but a few thousand years old. In other words the time span represented by the basalt of Washington County is in all likelihood nearly 20,000,000 years.

The cones commonly are formed of stratified cinders (Plate 3) piled up on a low lava mound. Most of the cinders are vesicular to scoriaceous basalt fragments under three inches in diameter. The youngest cones have so perfectly retained their form and have so little vegetation on them that they must be of Recent age. Most of the basaltic cones and vents in the Zion Park region appear to be located along master joints or intersections of joints (Threet, 1958, p. 1069); those west of the Hurricane fault are more likely related to faults.

Some interesting lava tubes and blowholes in the basalt flows of the Gunlock-Veyo-Diamond (Damron) Valley area have recently been explored and described by Arthur Bruhn in an unpublished manuscript.

Late Cenozoic hornblende dacite (QTd)

A peculiar hornblende dacite crops out one to three miles northeast of Central. It flowed down an ancient valley that descended to the south from Eight Mile Spring. Two units make up the dacite: a lower cliff-forming dacite 50 to 100 feet thick, principally composed of glass tabulae, overlain by denser porphyritic dacite at least 200 feet thick. The lower unit has a porous, fluidal structure and is probably the product of a froth flow.

Tertiary(?)-Quaternary sediments (QTs)

In places where sediments clearly older than the Recent alluvium but younger than Parunuweap could be delineated they were mapped as Tertiary-Quaternary sediments. Most of these sediments are relatively coarse, loosely consolidated gravels and are probably of Pleistocene age.

Culbert breccia (Qc)

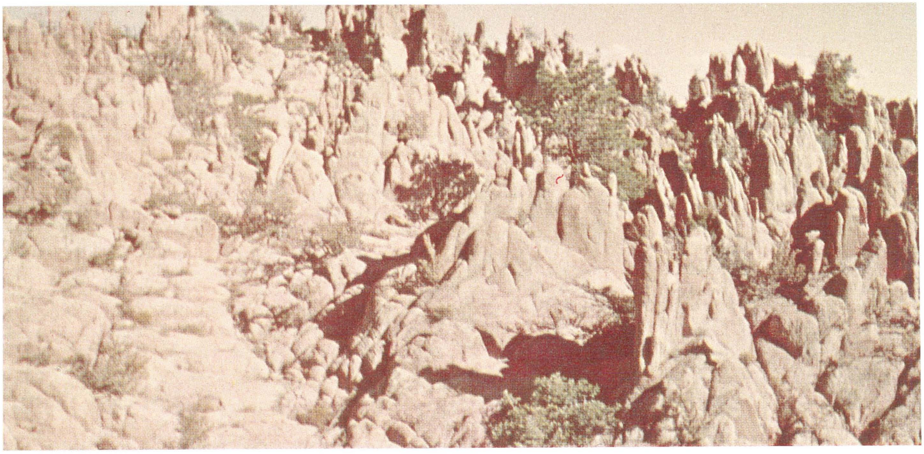
Exposed in small patches northwest of New Harmony is a mudflow breccia composed of angular to subangular blocks of monzonite porphyry to five feet in diameter. The mudflows originated inside the peripheral shell of the eroded Mount Stoddard intrusive body (Cook, 1957, p. 39). The breccia was certainly once much more extensive than its present outcrops which are erosional remnants capping divides and clinging to mountain sides. The Culbert breccia is probably of Pleistocene age and is probably the age equivalent of the extensive high-level boulder alluvium (Gardner, 1941, p. 243; Proctor, 1953, p. 39-41) that is found around the southeastern flanks of the Pine Valley Mountains.

Quaternary sediments (Qs)

In general there appear to be two groups of unconsolidated Quaternary sediments in Washington County; at first glance they seem to defy the law of superposition of sedimentary strata, for the older group is in most places the higher of the two. However, it turns out that the higher group of sediments has been stranded by one of the vagaries of geomorphic history far above the high-water mark of present day streams.

The upper, older sediments are for the most part coarse gravels that in many places mantle a pediment cut, almost independent of rock resistance, on formations as diverse as the strong Navajo sandstone and the weak "Muddy Creek" formation. These gravels, however, do not form an ordinary pediment mantle because their poor sorting and gross nature do not harmonize with the concept of transportation by the agents that cut the pediment. More likely the gravels were deposited by torrents and mudflows during the Pleistocene (Proctor, 1953, p. 41). Modern streams have dissected the pediment to depths of several hundred feet (Plate 4).

The younger sediments form narrow alluvial strips, bars, and benches in modern valleys, as well as local deposits of landslide, hillwash, and dune material.

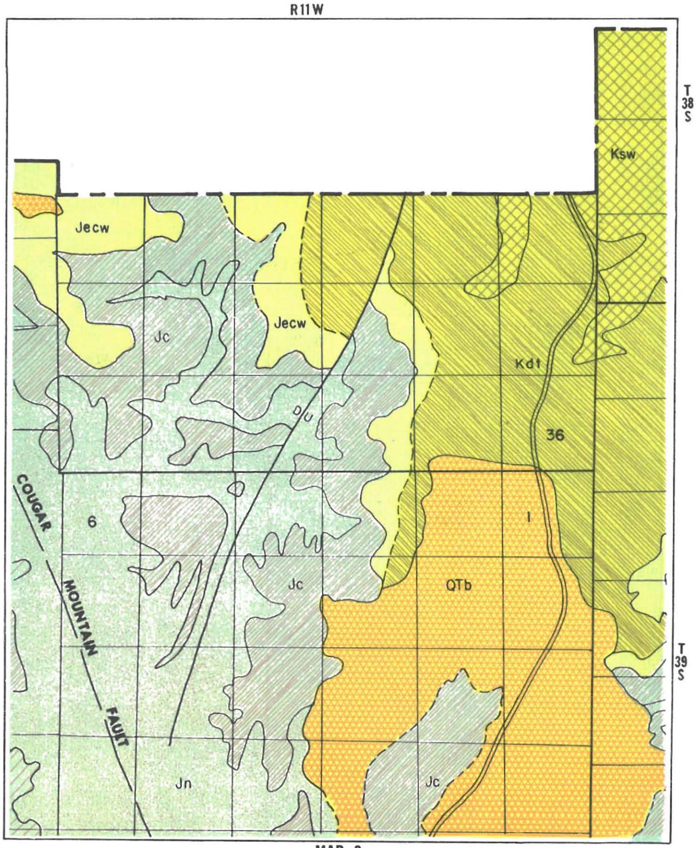


Colored Scene 10. Strange erosion forms in the southern part of the Pine Valley laccolith. --Photograph by Earl F. Cook--

MAP 5

Map explanation continued from page 39.

TRIASSIC (UPPER)	Ŧmo	Moenave formation
TRIASSIC (UPPER)	Ŧc	Chinle formation
TRIASSIC (UPPER)	Ŧs	Shinarump conglomerate
TRIASSIC (LOWER)	Ŧm	Moenkopi formation
PERMIAN	Pk	Kaibab limestone
PERMIAN	Psc	Supai-Coconino sandstone
MISSISSIPPIAN	Cc	Callville limestone
MISSISSIPPIAN	Mr	Redwall limestone
DEVONIAN & ORD.?	ꞒOD	Limestone
CAMBRIAN	Ꞓp	Pioche shale
CAMBRIAN	Ꞓpm	Prospect Mountain quartzite
PRECAMBRIAN	PꞒ	Gneiss, schist, granitic rocks.



MAP 6

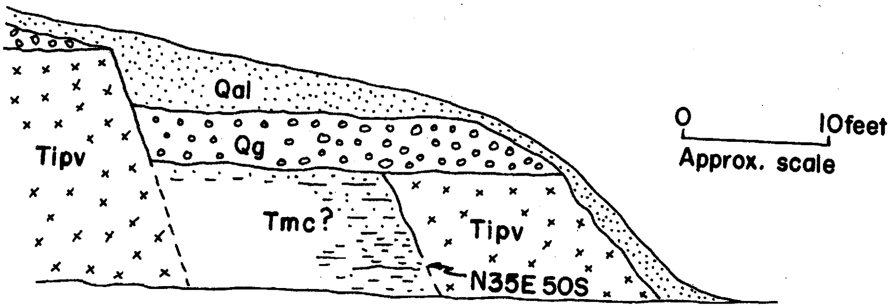


Figure 3A. Sketch of relations in outcrop one mile west of Pintura where "Muddy Creek" formation (Tmc?) has been faulted prior to deposition of Pleistocene(?) gravel (Qg). Both have been faulted before deposition of Recent alluvium (Qal). Tipv is monzonite porphyry of the Pine Valley laccolith.

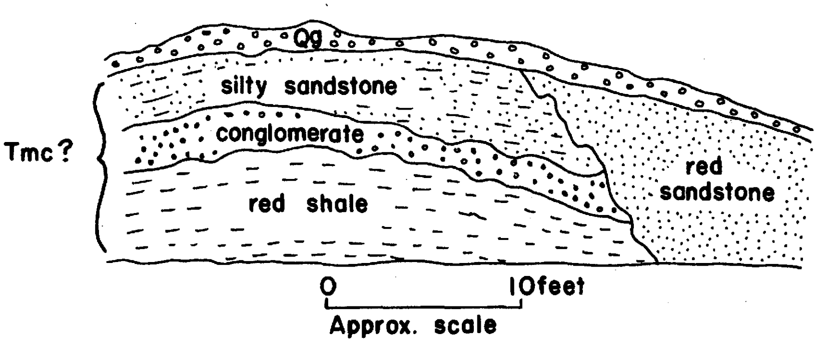


Figure 3B. Sketch of relations in outcrop about 2 miles east of New Harmony. Sediments of the "Muddy Creek" formation have been folded, faulted(?), and eroded prior to deposition of Pleistocene (?) gravel (Qg).

INTRUSIVE ROCK BODIES

General features

Except for those granitic bodies in the Precambrian of the western Beaver Dam Mountains that may be intrusive, the intrusive rocks of Washington County are restricted to the northwest part of the county, are closely related to the Tertiary volcanic rocks, are of monzonite porphyry composition, and are of relatively shallow origin. Evidence indicates one great period of intrusion, extrusion, and associated deformation, followed by one or more similar episodes of lower degree.

Following deposition of the Quichapa formation, magma was injected beneath an anticline that had previously formed near the close of the Cretaceous or shortly after the beginning of the Eocene epoch and which extended from the Iron Springs district southwest into northwest Washington County. Structurally high portions of this large intrusive mass are reflected in Pinto dome, Big Mountain, and exposed intrusive rock in Hardscrabble Hollow and Bull Valley. Mineral Mountain may also be a bulge or boss of the same intrusive body. Little is known of the Mineral Mountain intrusion, except that it intruded Callville(?) limestone of a thrust sheet which has been turned into marble for several hundred feet from the intrusive body. Only within the Bull Valley intrusion has flow structure and fragmental material indicative of break-through to the surface been found.

Somewhat later, the Pine Valley laccolith spread as a bulgy sill-like intrusion beneath an extrusive cover. Still later occurred the rhyolitic intrusive-extrusive episode of Flattop Mountain, forming ill-defined bosses and stocks of aphanitic to glassy rock.

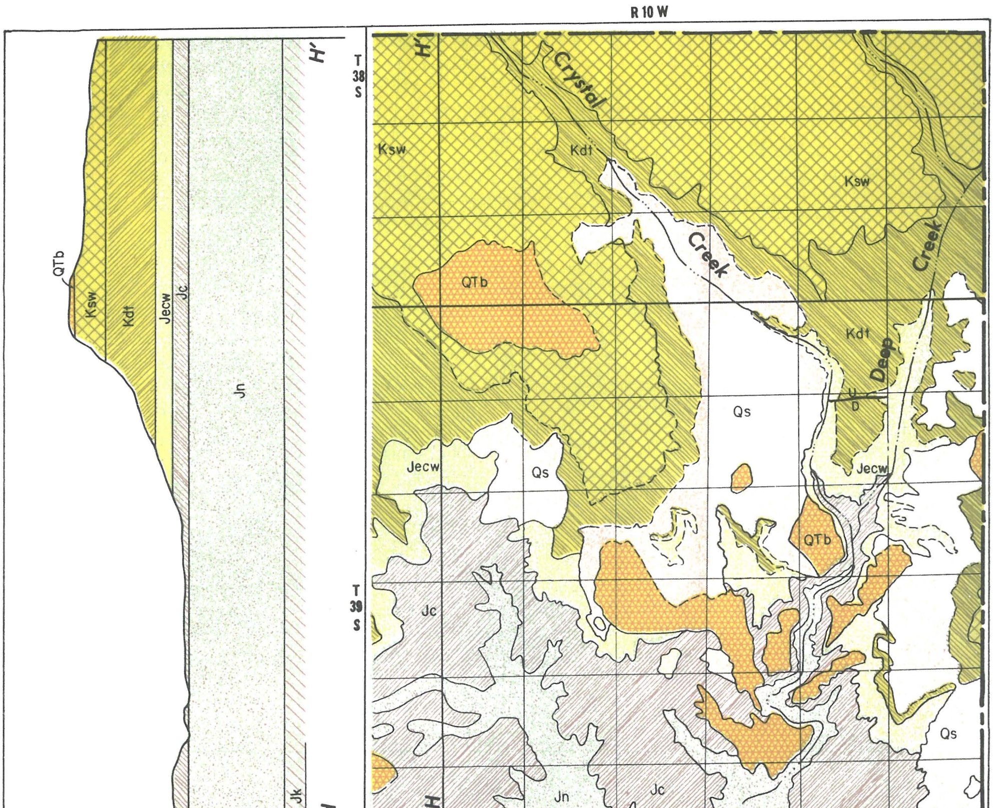
In terms of extrusive units, the ages of these intrusive bodies are: Big Mountain-Bull Valley--early Rencher; Pine Valley--medial Page Ranch; Flattop Mountain--"Muddy Creek"; Mineral Mountain--unknown.

Pine Valley laccolith

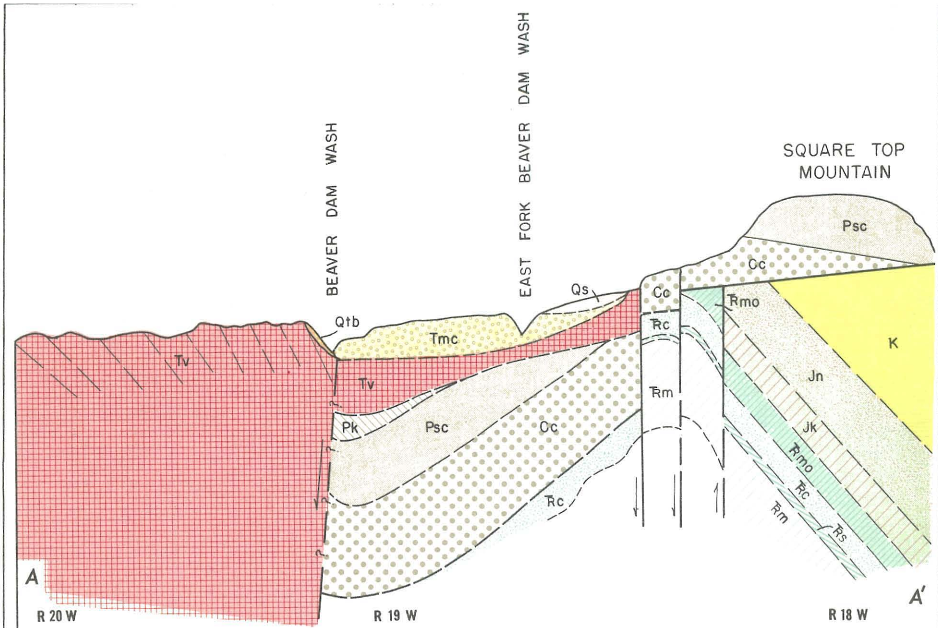
The Pine Valley laccolith, if the term is correctly applied, is the world's largest known laccolith: its maximum remaining thickness is 3,000 feet and it covers 70 square miles. The rock is monzonite porphyry, containing about 50 per cent phenocrysts, mostly of plagioclase, subordinately of augite, hypersthene, and biotite, in a crypto-crystalline, microgranular, or fine-grained groundmass. Much orthoclase and some quartz are found in the finely crystalline groundmass. Magnetite is abundant in all sections studied; it averages about 5 per cent of the rock.

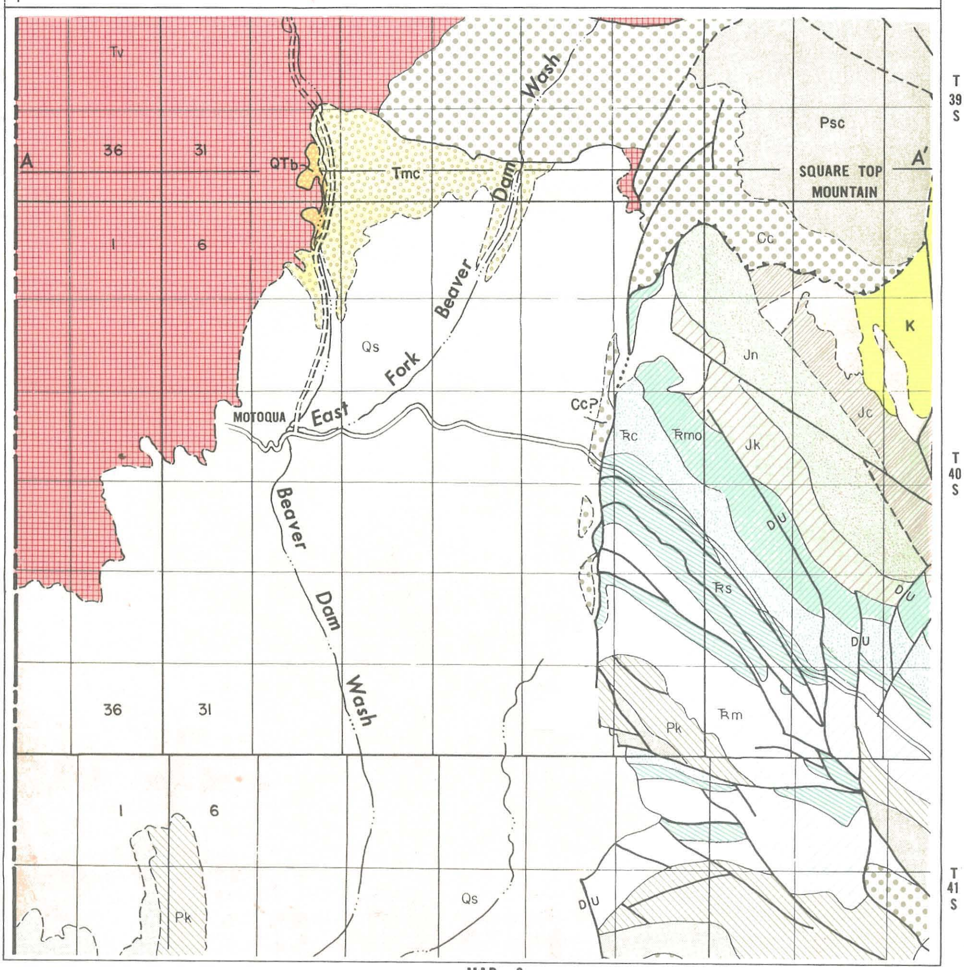
The cover of the laccolith has been entirely removed by erosion (Plate 5). The identification of the body as intrusive rather than extrusive is based on the evidence of the basal contact (Plate 6) and the lateral contact on the north, both of which clearly show intrusive features, as well as by the absence of any contacts within the 3,000-foot thickness that would suggest separate flows.

Colored Scene 11. Timber Top--the unscaled member of the Kolob Buttes (shown in Colored Scene 1) with Pine Valley Mountains to the west forming the skyline.
--Photograph by Arthur F. Bruhn--



MAP 7


BEAVER DAM WASH
EAST FORK BEAVER DAM WASH
SQUARE TOP MOUNTAIN
Psc
Cc
Qs
Ŧmo
Ŧc
Qtb
Tmc
K
Tv
Tv
Jn
Ŧm
Pk
Psc
Cc
Jk
Ŧmo
Ŧc
Ŧc
Ŧm
Ŧs
A
A'
R 20 W
R 19 W
R 18 W


Tv
T 39 S
Wash
Psc
A
36
31
QTb
Tmc
Dam
SQUARE TOP MOUNTAIN
A'
1
6
Cc
Beaver
K
Qs
Jn
Fork
MOTOQUA
East
CcP
Jc
Ŧc
Ŧmo
Jk
T 40 S
Beaver
D U
Ŧs
D U
Dam
D U
Wash
36
31
Pk
Ŧm
1
6
Qs
D U
Pk
T 41 S

MAP 8

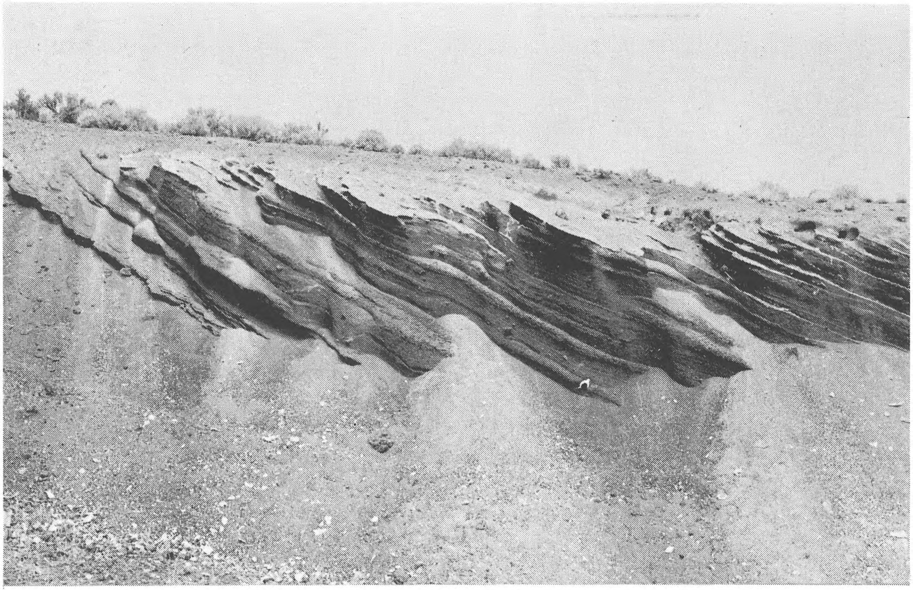


Plate 3. Pediment cut on stratified cinders of volcanic cone north of Pine Valley. --Photograph by Earl F. Cook--

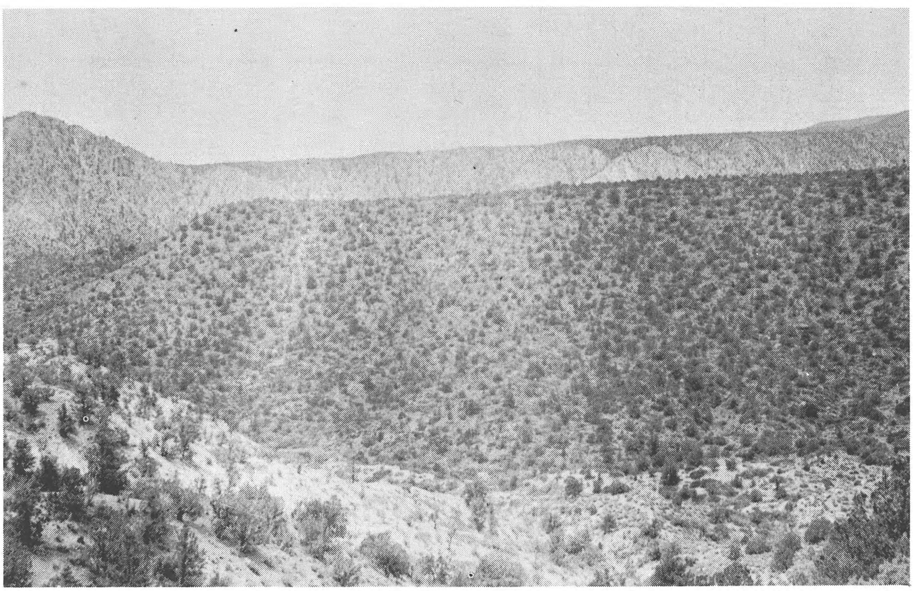


Plate 4. Dissected pediment cut on Navajo sandstone, southeast of Pine Valley Mountains. Pediment is mantled with coarse gravel and has been dissected to depths of several hundred feet by modern streams.
--Photograph by E. F. Cook--

On any extensive vertical exposure the Pine Valley intrusive body shows roughly horizontal gradational color bands, from bottom to top: a thin dark-brown zone; a brown zone; a central white zone; and an upper purple zone. These color designations are only approximations, but the reality of the zoning is demonstrated by specific gravity curves that show a relation between the zones and the specific gravity of the rock in the zones (Cook, 1957, p. 78-79). The explanation of the color zones seems to lie mainly in the varying mafic content of the rock, which in turn depended partly on gravitative settling of the heavier minerals in the intrusive magma and partly on the intensity of deuteric alteration of the mafic minerals.

S T R U C T U R A L G E O L O G Y

TECTONIC STRUCTURES

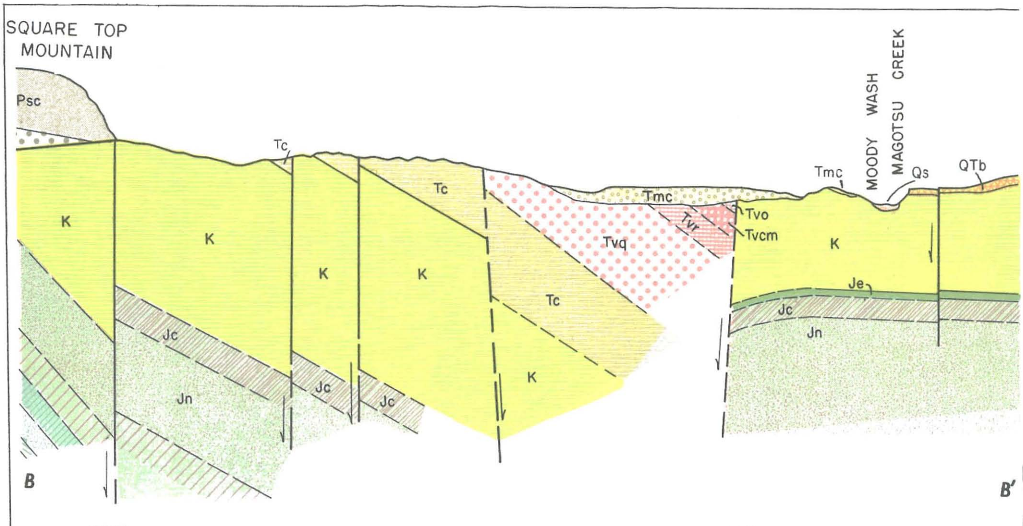
Structural trends

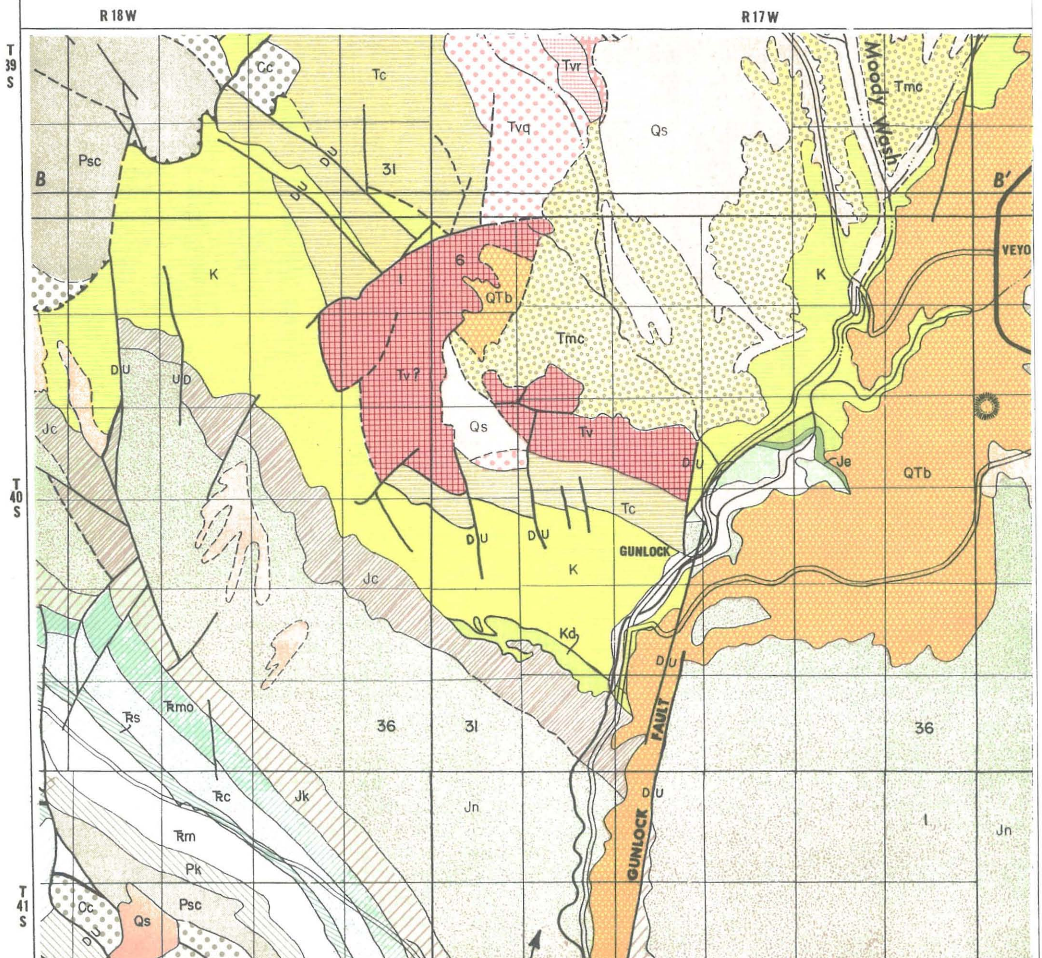
Two structural trends intersect in Washington County. A well-defined set of structures, developed during the Laramide orogeny in an older zone of demarcation between foreland to the east and geosyncline to the west, trends northeasterly and is shown by aligned intrusive bodies, folds, and faults, The second set of structures, developed during the Tertiary, is expressed principally by north-south faults. Late Cenozoic movements have followed both structural trends: a case in point is the Hurricane fault, which follows a Laramide anticline for part of its length, then leaves the Laramide structure abruptly to follow the Tertiary trend southward into Arizona.

Hurricane fault

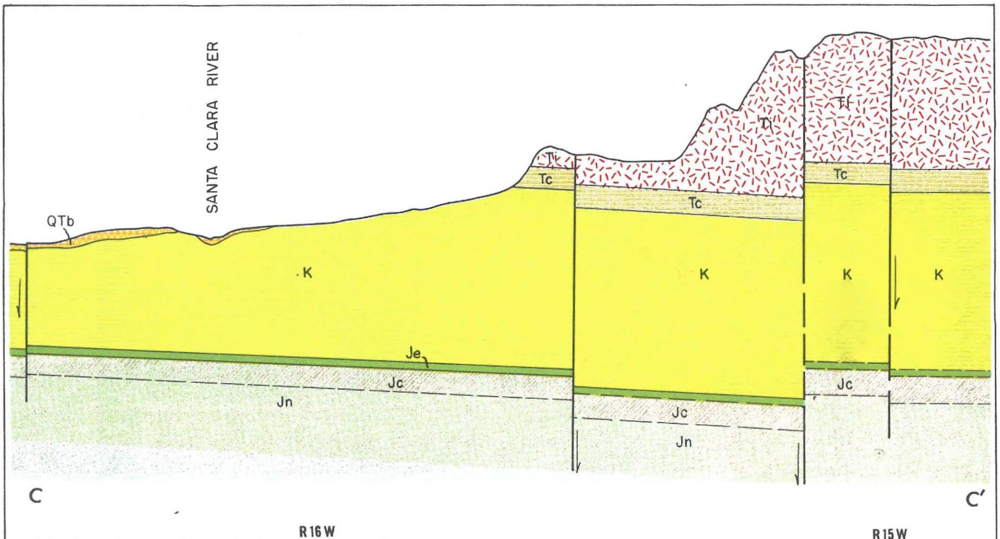
The Hurricane fault, one of the most prominent structural features of Washington County, is marked by a high, west-facing escarpment known as the Hurricane Ledge or the Hurricane Cliffs. North of Toquerville the Hurricane scarp is over 1,500 feet high; the edges of Permian and Triassic strata in the upthrown block near the fault are in general bent sharply up from their nearly horizontal attitude in the plateau country to the east. Northward the east dip of the beds forming the back slope of the ledge continues to increase, until, in the vicinity of Kanarraville, a few miles into Iron County, the beds are overturned. The east-dipping strata in the Hurricane Cliffs north of Toquerville represent the east flank of an assymmetrical, locally overturned, Laramide anticline along the axial plane of which, in this portion of its course, the Hurricane fault later formed. The ancestral structure was named the Kanarra fold by Gregory and Williams (1947).

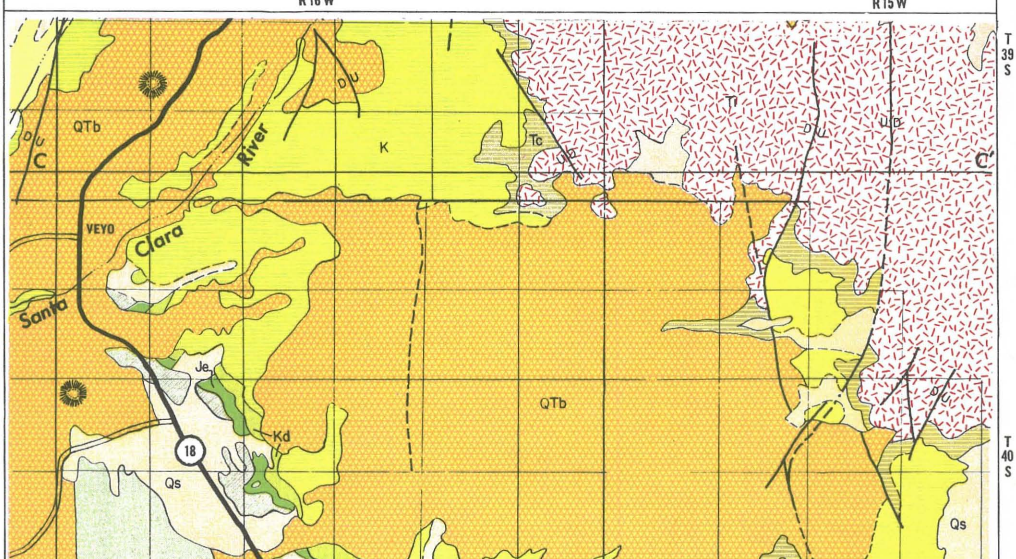
The most recent displacement along the fault is strikingly shown by horizontal basalt remnants on the upthrown side that formerly were parts of flows, the bulk of which remain on the downthrown side, 1,500 feet below the skyline louderbacks. To the surprise of the observer impressed by the imposing scarp, the recent displacement represents the lesser of two periods of normal faulting that were separated by a long inter-fault erosion cycle


SQUARE TOP MOUNTAIN
MOODY WASH
MAGOTSU CREEK
Psc
Tc
Tmc
Qs
QTb
K
Tvq
Tvr
Tvo
Tvcm
Je
Jc
Jn
B
B'


R 18 W
R 17 W
T 39 S
T 40 S
T 41 S
B
B'
Moody Wash
VEYO
GUNLOCK
GUNLOCK FAULT
Cc
Tc
Tvr
Tvq
Qs
Tmc
Psc
K
QTb
Tv?
Tv
Je
Jc
Kd
Jk
Jn
Ꞧmo
Ꞧs
Ꞧc
Ꞧm
Pk
D U
U D
31
6
1
36

MAP 9


SANTA CLARA RIVER
QTb
Ti
Tc
Tc
Ti
Ti
Tc
K
K
K
K
Je
Jc
Jn
Jc
Jn
Jc
C
C'


R 16 W
R 15 W
T 39 S
T 40 S
T 41 S
QTb
C
D U
Santa
Clara
River
VEYO
K
Tc
Ti
C'
Je
Kd
18
Qs
QTb
Qs
K
Jc
Diamond
Valley
31
31
Jn
6
QTb
QTb
Tc
K
Jc

MAP 10

Plate 5. In the background the Pine Valley laccolith rises above its less resistant sedimentary pedestal. In the foreground is the eroded Shinarump carapace of the Virgin anticline. --Photograph by Arthur F. Bruhn--

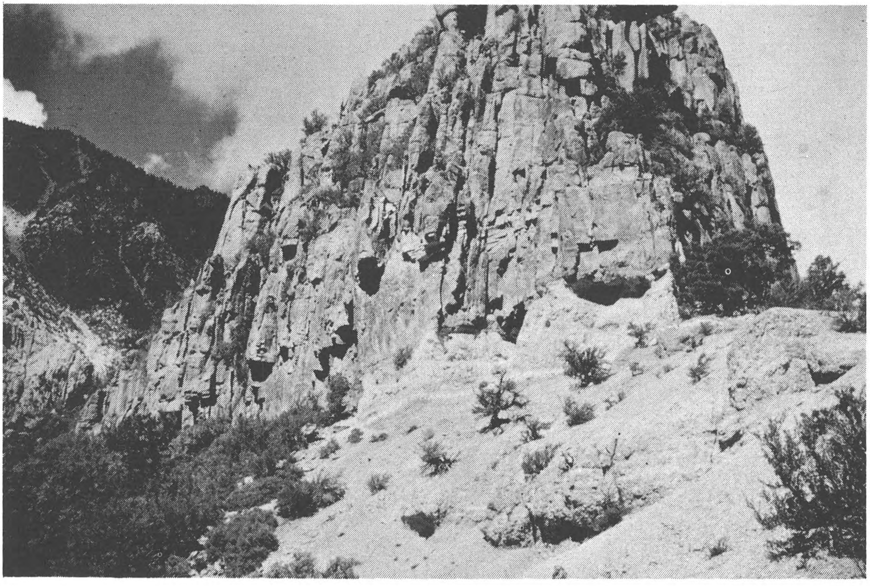


Plate 6. Base of the Pine Valley laccolith exposed near the headwaters of Cottonwood Creek in the southern part of the Pine Valley Mountains. The contact is intrusive and accordant on the Claron formation.
--Photograph by Earl F. Cook--

during which the physiographic evidence of the greater dislocation was erased (Huntington and Goldthwait, 1904, 1905).

About three miles north of Toquerville the Hurricane Ledge forms a massive corner, marking an abrupt change in direction of the fault (Plate 7). After paralleling the Kanarra fold southwesterly for more than 20 miles, the Hurricane fault veers to the south and cuts across the Laramide structure. Southward the ledge is lower and, for a few miles, less well-defined.

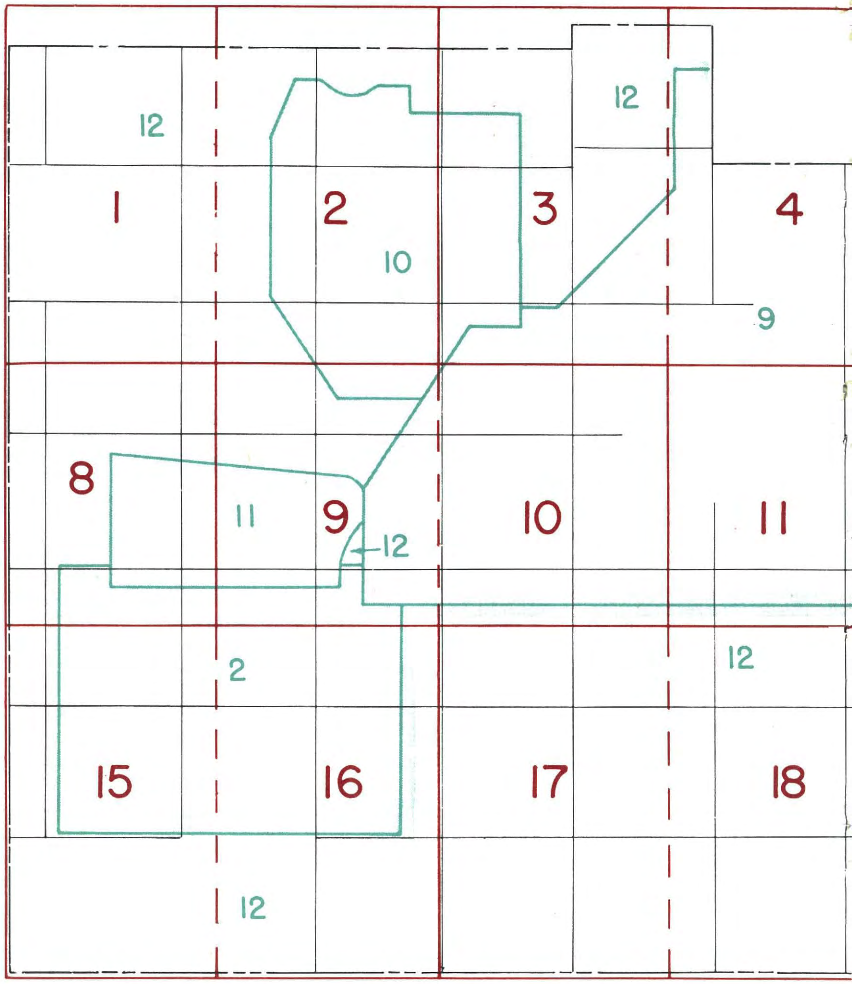
The pre-Quaternary rocks of the downthrown side are, in most places along the fault trace, concealed by alluvium, hillwash, and basalt. However, in at least three places in the Hurricane-Toquerville district, portions of the fault plane can be seen. In each of these outcrops the fault plane dips 60° to 75° west and is overlain by Moenkopi beds with a roughly parallel attitude and is underlain by Kaibab limestone. The inclination of the beds in the downthrown block to parallel the fault plane makes accurate estimation of the fault displacement impossible. Dobbin (1939) estimated the displacement at not less than 7,800 feet where the fault crosses Virgin River and not less than 15,000 feet in the Pintura area, 1,400 feet of it produced by the more recent faulting. Gregory (1950, p. 144), on the other hand, although admitting that the displacement at Virgin River exceeds 5,000 feet, estimated a maximum displacement of only 8,000 feet, in the neighborhood of Kanarraville.

Perhaps, in discussing relative movement along a fault of this nature, one should speak in terms of slip, throw, and shift. In Toquerville Hill, for example, the stratigraphic throw along the Hurricane fault (or a branch of it) is 2,500 feet; in the Pintura area, shift (taking into account displacement by flexing of strata near the fault) is estimated at about 10,000 feet and slip at less than half that (Cook, 1957, p. 93-96).

North of the "corner" a belt, about five miles wide, of northerly trending high-angle faults and minor cross-faults lies west of the Hurricane Ledge. This fault zone can be traced southwesterly from the Harmony area into the Silver Reef and Harrisburg districts where it dies out.

Virgin anticline

The Virgin anticline is the main structural feature of the St. George Basin. It cuts diagonally in a southwest direction across the basin for about 20 miles. It is a broad generally symmetrical fold with maximum flank dips on the order of 25° to 30°; in some places the northwest limb is steeper than the southeast. The oldest formation exposed along the crest of the anticline is the Kaibab. For most of its length the topographic expression of the Virgin anticline is controlled by the disposition of the resistant Shinarump conglomerate and the relatively weak Moenkopi. The Shinarump forms an eroded carapace or shell around and partially over the anticline, a shell that is wider and higher where it outlines three domes, or structurally high portions of the fold. Because of the poor resistance to erosion of the Moenkopi shales, the central portions of these domes are topographic depressions. Where erosion has reached the Kaibab it forms a low, cigar-shaped hill along the axial trace. The three domes along the



INDEX TO

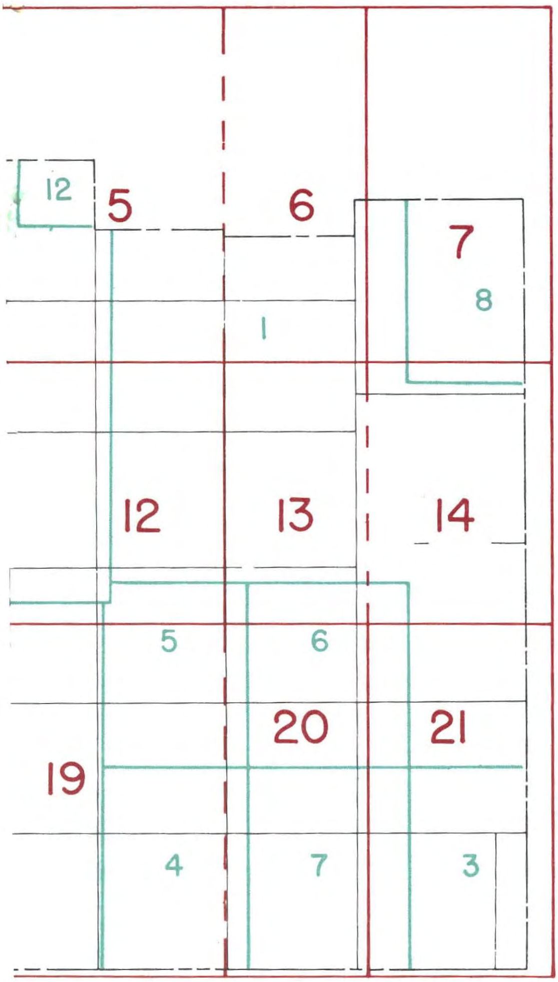
GEOLOGIC ATLAS OF UTAH
WASHINGTON COUNTY

Scale of maps

1 1/2 0 1 2 3 4 5

Scale of index

6 3 0 6 12 miles



SOURCES OF INFORMATION

1. GREGORY, H.E. (1950) modified by COOK by photogeology for this bulletin.
2. REBER, S.J. (1952)
3. PILLMORE, C.L. (1956a)
4. MARSHALL, C.H. (1956a)
5. MARSHALL, C.H. (1956b)
6. MARSHALL, C.H. (1956c)
7. PILLMORE, C.L (1956b)
8. PILLMORE, C.L. (1956c)
9. COOK, E.F. (1957)
10. BLANK, H.R. (1959)
11. MCCARTHY, W.R. (1959) and photogeology by COOK.
12. COOK, E.F. - photogeology and surface reconnaissance for this bulletin.

Red numbers correspond to map numbers.

Blue numbers correspond to sources of information

N
W — E

Map explanation on page 39 and with map 6.

Colored plates available in a single map--RS-84, $1.00

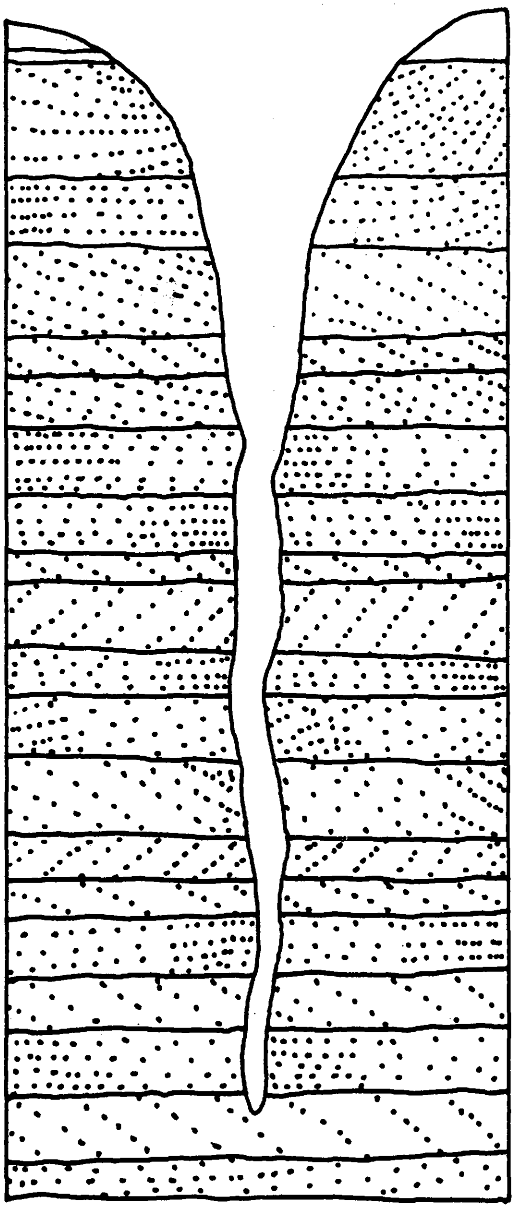


Figure 4. The Virgin Narrows of Zion Park, between walls of Navajo sandstone. Depth 1,800+ feet, width at base 25+ feet. From a reproduction in Gregory, 1950, p. 164, of a drawing by G. K. Gilbert, 1872.

Virgin anticline are the Harrisburg Dome, the Washington Dome, and the Bloomington Dome. Harrisburg Dome, the widest, is crossed by the Virgin River and State Highway 17 between the towns of Hurricane and Washington. The Virgin anticline dies out a few miles southwest of St. George against the broad northeast flank of the Beaver Dam Mountains uplift.

The Virgin anticline, because it is a logical geometrical extension of the Kanarra fold and because the Claron formation unconformably overlies the Navajo sandstone at the north end of the anticline (as now expressed at the surface), is regarded as a Laramide structure.

Gunlock-Shebit-Cedar Pocket Canyon fault line

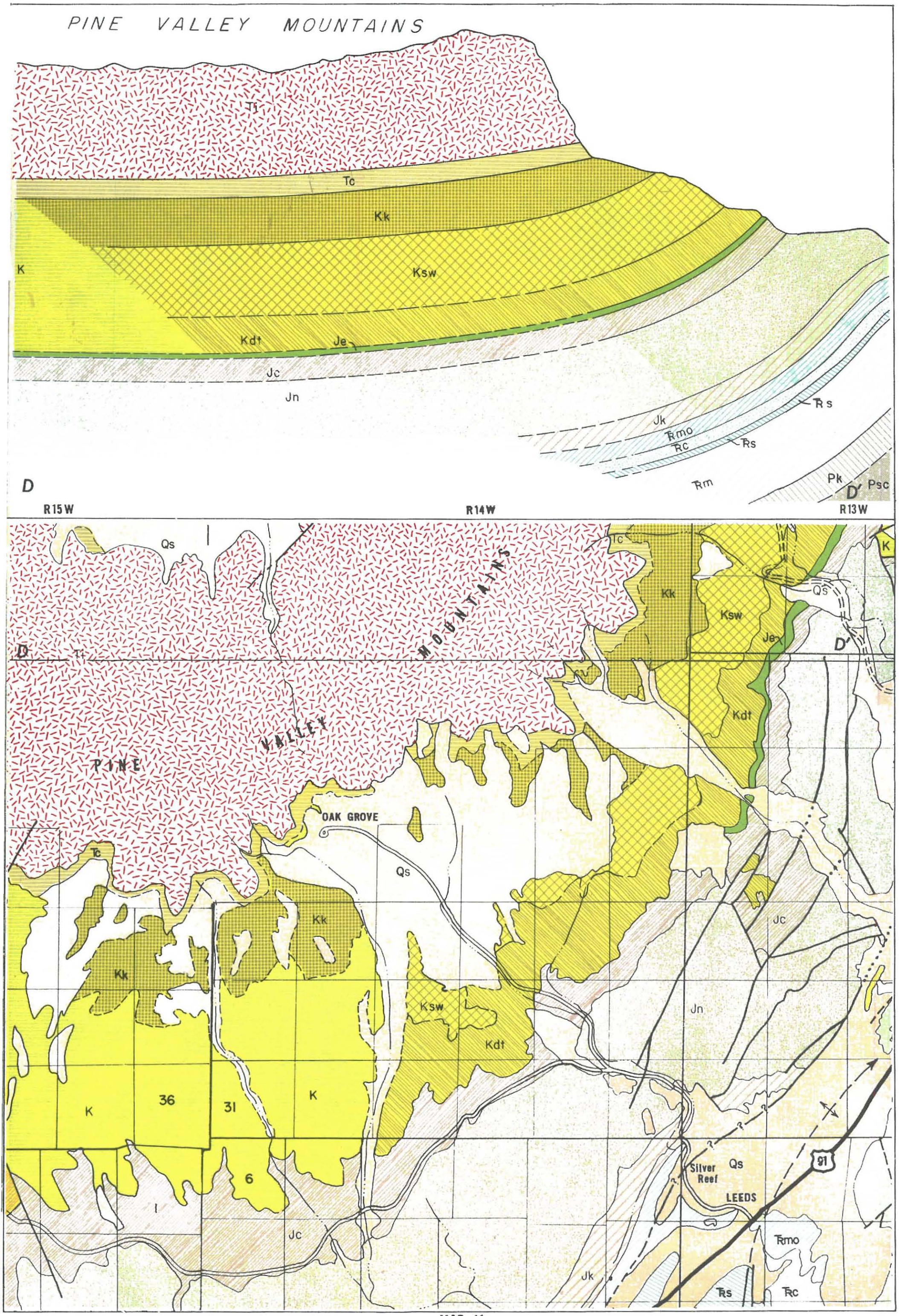
The western margin of the Pine Valley Mountains-St. George Basin structural block is defined by a more or less continuous fault line which, however, has at least three distinct segments with different names.

Directly west of the Pine Valley Mountains the boundary fracture is the Gunlock fault, traceable from a point about two miles north of Gunlock to the Shivwits Indian reservation where it dies out to be replaced by the Shebit fault. Downthrow is to the west on the Gunlock fault, to the east on the Shebit fault. Shebit fault in turn passes southward into the Cedar Pocket Canyon fault, which has its downthrown side on the west.

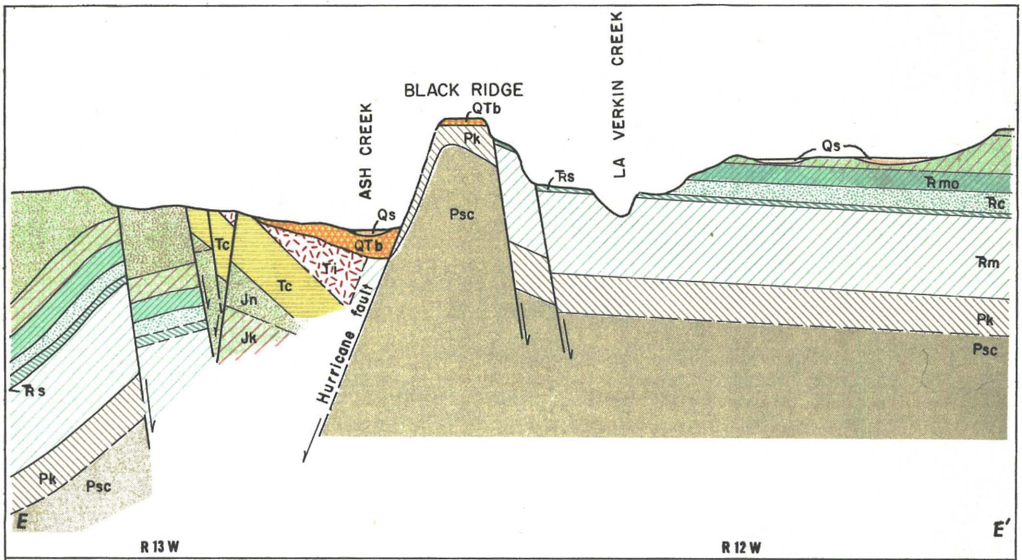
The greatest stratigraphic displacement along the Gunlock fault, nearly 4,000 feet, is just north of Gunlock, where the base of the Claron formation on the west lies against a horizon about 100 feet below the top of the Navajo sandstone in the upthrown block (Dobbin, 1939, p. 135). Dobbin estimates the maximum stratigraphic displacement on the Shebit fault at 2,350 feet.

The Gunlock and Cedar Pocket Canyon faults are normal faults, the Shebit a reverse fault. The Cedar Pocket Canyon fault appears to pass into the Shebit fault without offset, the two forming in reality one fault, the name of which changes at the point where the relative displacement changes. On the other hand, the Shebit fault does not appear to form a continuous break with the Gunlock fault but is offset from the latter by the north end of the Shebit anticline, a curious structure whose origin must certainly be related to the history of this entire line of faults and for that reason will be discussed here.

The Shebit anticline is a north-south fold about four miles long distinguished by its striking asymmetry and its parallelism to the nearby Shebit fault. Whereas dips as high as 60° are found in the Moenkopi strata that dip from the axis westward into the Shebit fault, dips on the east limb are about 7°. The east limb of the anticline forms part of a broad, north-east dipping homocline. In a sense, the Shebit fold is not really an anticline at all: it has been formed by the local dragging down of the edge of an obliquely faulted homocline. To put it another way, the Shebit anticline is a drag fold along a fault cutting a tilted plateau. The anticline is the logical southward extension of the Gunlock fault.


PINE VALLEY MOUNTAINS
Ti
Tc
Kk
K
Ksw
Kdt
Je
Jc
Jn
Jk
Ꞧmo
Ꞧc
Ꞧs
Ꞧm
Pk
Psc
D
D'
R15W
R14W
R13W
Qs
PINE VALLEY MOUNTAINS
OAK GROVE
36
31
6
Silver Reef
LEEDS
91

MAP 11


BLACK RIDGE
ASH CREEK
LA VERKIN CREEK
QTb
Pk
Psc
Qs
Tc
Ti
Jn
Jk
Hurricane fault
Ꞧs
Ꞧmo
Ꞧc
Ꞧm
E
E'
R 13 W
R 12 W


Je
Jc
K
Qs
Jn
Tc
E
E'
FAULT
HURRICANE
Ash
Creek
91
15
QTb
Psc
Pk
La Verkin
Creek
Ꞧm
Ꞧc
Ꞧmo
Ꞧs
Jk
6
36
TOQUERVILLE
PIONEER MESA
U D
D U

MAP 12

The relative displacement on the Shebit fault, however, presents a paradox if the adjacent "anticline" is regarded as a drag fold. Obviously the Shebit fold could not have formed coincident with the reverse movement on the fault; only normal movement would be accordant with the development of the Shebit drag fold. It is here proposed that the Shebit fault did originate as a normal fault representing a rupture of strata that had reached their limit of bending in a fold represented today by the Shebit anticline and the Shebit syncline, and that later differential uplift of the central Beaver Dam Mountains reversed the earlier movement on the fault, at the same time steepening the west limb of the Shebit syncline, which had been only another drag fold.

The shift of the two crustal blocks separated by the Gunlock-Shebit-Cedar Pocket Canyon fault line was accomplished in the general area of the Shivwits Reservation largely--and in one short stretch, exclusively--by monoclinal folding. It is significant that this short stretch of folding coincides with the crossing of the fracture line by the incompetent beds of the Triassic system, which could bend to a greater extent than could either the massive limestones below or the thick sandstones above.

The high-angle faults of the Gunlock-Shebit-Cedar Pocket Canyon set cut across, from north to south, a great structural half-dome, the Precambrian center of which is in the western Beaver Dam Mountains. With a single possible exception, every period of the Paleozoic and Mesozoic eras is represented in the formations that spread in concentric bands outward to the north and northeast from the central core.

Beaver Dam Wash fault

Except for an isolated outcrop near the Utah border, sedimentary bedrock is terminated westward in Washington County by the Beaver Dam Wash fault and related high-angle faults that drop bedrock on the west below the thick alluvial fill of Beaver Dam Wash.

The northern part of the Beaver Dam Wash fault line is straight and well-defined. Paleozoic and Mesozoic beds striking northwest bend sharply west near the fault and in some places seem to have been dragged around parallel to the fault trace and broken off. Several isolated outcrops of limestone along the fault trace belong to the Castle Cliff thrust sheet and may be part of the downthrown block or may be isolated portions of the thrust mass embedded in the soft formations of the upthrown block. The evidence suggests diagonal-slip along this portion of the Beaver Dam Wash fault, the western block having moved down and south relative to the eastern block.

Southward, along the northern part of the Beaver Dam Mountains, the marginal fault is broadly arcuate, concave westward; lateral drag in the exposed ends of formations is not evident. The west edge of the central and southern Beaver Dam Mountains is determined by an irregular line of short, connected arcuate faults that outline recesses and embayments in the mountain front. In this latitude the main fault may pass beneath alluvium, west of the front, some of its displacement being appropriated by the traceable marginal faults.

Castle Cliff thrust

The Castle Cliff thrust sheet, first recognized and mapped by Dobbin (1939, p. 129-131), has several segments in western Washington County. In the southwestern Beaver Dam Mountains the thrust plate, made up entirely of Callville limestone, is exposed at Castle Cliff where it has overridden Precambrian and Cambrian rocks; the thrust plane dips about 5° west at this locality.

Northwest of Castle Cliff the thrust sheet crops out in a low, narrow band along the mountain front for about four miles, the dip of the thrust plane increasing to about 25° west.

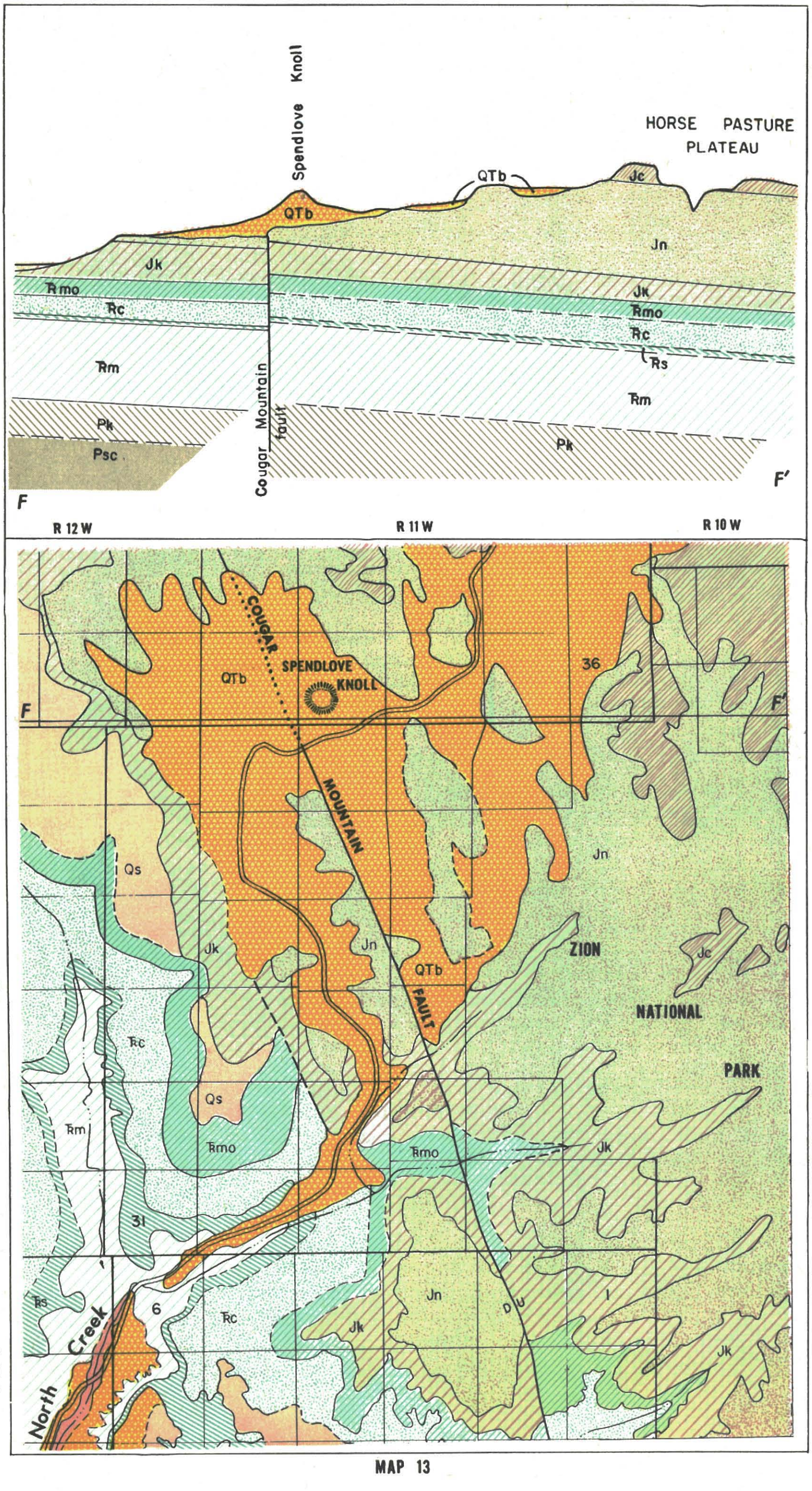
About 2 1/2 miles north of Castle Cliff a relatively high klippe of Mississippian limestone may be a remnant of the Castle Cliff thrust sheet; the base of the klippe dips about 10° west.

The largest segment of the thrust sheet exposed in Washington County forms Square Top Mountain and the neighboring hills 7 to 11 miles northwest of Gunlock, where it is composed of both Callville limestone and Supai-Coconino sandstone thrust over Jurassic and Cretaceous rocks.

The thrust sheet again appears, made up mainly of Callville limestone, in Mineral Mountain, where the limestone has been extensively converted into coarsely crystalline white marble by the contact action of an intrusion.

The Castle Cliff sheet moved from the west toward the east and may have been an erosion thrust moving forward over an erosion surface, the low parts of which were covered by a blanket of thrust-derived sediments. One good exposure of the base of the thrust sheet in the western Beaver Dam Mountains reveals a few feet of shaly, clayey gouge between Pennsylvanian limestone of the thrust sheet and the underlying Precambrian gneiss. There is no evidence of an erosion thrust in this outcrop. In the Square Top Mountain area, on the other hand, Upper Cretaceous sandstone overridden by the thrust sheet could easily have been derived from it; when, in addition, it is considered that this same Cretaceous sandstone is overlain, with no angular discordance, by Claron conglomerate spread as a sheet from the front of the thrust plate, evidence for the erosion nature of the thrust, at least in this area, becomes convincing. In addition, the relations just described serve to date the thrust. The Cretaceous sandstone overridden by, and possibly derived from, the thrust plate is the probable lateral equivalent of the Kaiparowits formation, of Montana age in the Colorado Plateau. In other words the thrust plate had possibly started to move eastward in the waning part of the Cretaceous period and it reached its present position sometime during the span of time that includes the latest portion of the Cretaceous and the Eocene.

The problem of dating the thrust is identical with the problem of dating the lower part of the Claron (Wasatch). On the one hand, the Claron conglomerate east of Square Top Mountain by its parallelism with the underlying Cretaceous rocks suggests that the hiatus represented by the disconformable contact was of no great duration. But elsewhere in the region, as in the area northwest of Pintura, we find a sharply contradictory relation, in that the same conglomerate overlies an erosion surface that cuts down into the Navajo sandstone, proof that about 5,000 feet of sedimentary rock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Cougar Mountain
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COUGAR
SPENDLOVE
KNOLL
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36
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MAP 13


HORSE PASTURE
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MAP 14

was removed by erosion between Kaiparowits (Montana) time and the laying down of the basal Claron. The only additional evidence we have to help evaluate the unconformity at the base of the Claron is the tentative dating of the uppermost part of the formation, on the basis of regional stratigraphic relations of volcanic rocks and some widely separated age measurements, as between 34 MY and 28 MY. The age of the basal Claron, so far unknown, remains the key to the age of the emplacement of the Castle Cliff thrust sheet.

Minor folds and faults

Cougar Mountain and Beartrap faults

In the western part of Zion Park, north of Grafton, the Navajo sandstone and subjacent formations are dropped as much as 480 feet on the west side of the Cougar Mountain fault, a high-angle normal fault that trends northwesterly, parallel to the Toquerville section of the Hurricane fault a dozen miles to the west.

Near the northern end of the Cougar Mountain fault the Beartrap fault, apparently also sympathetic to the Hurricane fault, branches to the northeast. Its displacement is small, on the order of a few hundred feet.

Grafton fold

At only one locality is the regular northeast dip of the rocks in the plateau portion of Washington County interrupted by anticlinal folding (Wegemann and Bauer, 1952). That is in the vicinity of Grafton. About 1.5 miles south of Grafton, in the valley of South Wash, a sharp, narrow anticline may be seen; it dies out farther south. The Grafton fold may be traced north to the flat of the Virgin River, appears in Coalpits Wash north of the river, and extends 1.5 miles up the Wash, beyond which point it gradually dies out.

Washington fault

The St. George Basin is almost bisected by the Washington fault, a normal fault trending slightly west of north from Arizona across the Virgin River, past the town of Washington, and into the foothills of the Pine Valley Mountains. Downthrow is on the west, and displacement south of the Virgin River probably ranges from several hundred feet to an estimated 2,500 feet at the Arizona line (Dobbin, 1939, p. 136).

Pine Valley syncline

The Pine Valley laccolith is cradled in a broad, shallow, northeast-plunging syncline that may have developed contemporaneously with the intrusion. However, the Cretaceous rocks immediately beneath the Claron formation appear to dip into the syncline at slightly greater angles than the Claron, and the syncline disappears southward at about the same latitude at which the more or less parallel Virgin anticline dies out. These relations suggest that the Pine Valley syncline started as a Laramide downwarp that was further depressed during the intrusion of the Pine Valley laccolith.

Jackson Wash fault

The Jackson Wash fault is in the northern part of the Beaver Dam Mountains. It trends north several miles from the southernmost point where it can be recognized, with apparent downthrow on the east. About midway of its northern course the apparent throw reverses. The rocks on the east are more or less parallel to the fault whereas those on the west strike into it diagonally and are cut off by it. In the northern foothills of the Beaver Dams the Jackson Wash fault swings to the west and ends coincident with the truncation of the Callville limestone on its northeast side. An unnamed distributive fault zone with downthrow on the west continues northward from the end of the Jackson Wash fault.

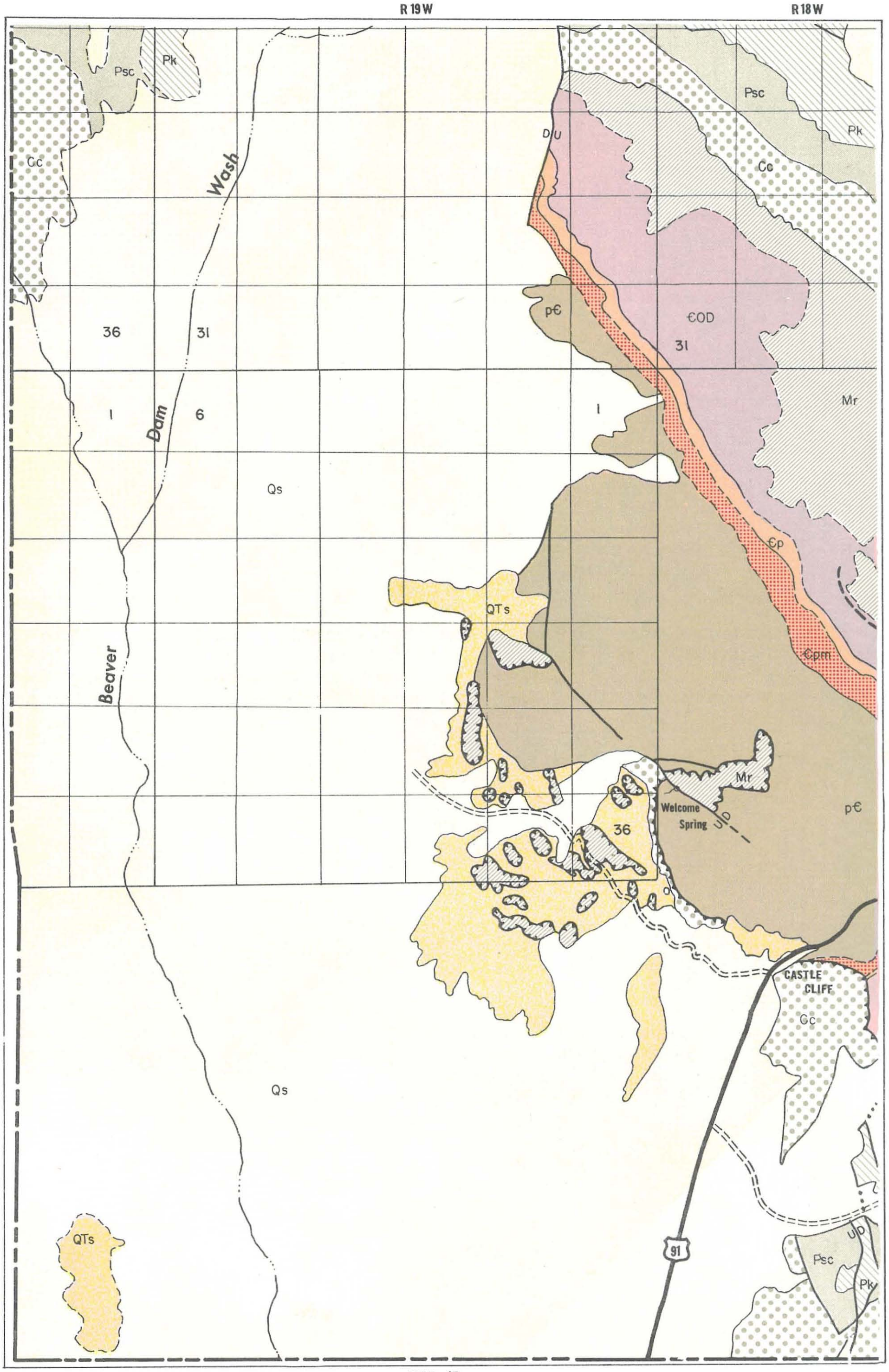
The striking feature of the Jackson Wash fault is the discordance of attitude of the beds on opposing sides of the fault. From the northwest, the Callville, Supai-Coconino, and Kaibab formations strike obliquely into the fault; the fault affects neither their strike nor their northeast dip, ranging from a few degrees to 35 degrees. On the opposite side of the fault, the same formations parallel the fault and dip almost vertically, gradually assuming a 35 degree northeast dip about a mile away from the fault. The Jackson Wash fault may be the product of diagonal slip on a near-vertical fault that cuts diagonally across a northeast-facing monocline, the vertical part of the monocline being raised on the east side of the fault and at the same time moved northward. This postulated combination of left-lateral movement and upward movement on the east is the same as that indicated on the Beaver Dam Wash fault. The reversal of displacement on the southern part of the fault may be due to late uplift of the central Beaver Dam Mountains, the same uplift that is believed to have caused reversal on the Shebit fault.

The Jackson Wash fault is probably Tertiary or younger because a northern extension of the fault cuts the Square Top Mountain portion of the Castle Cliff thrust sheet, emplaced in the very Late Cretaceous or early Tertiary, and because movement on the fault appears to be sympathetic to movement on the Beaver Dam Wash fault which cuts Tertiary volcanic rocks.

IGNEOUS STRUCTURES

Intrusive domes

Field evidence indicates that the intrusive bodies of northwest Washington County have in general made room for themselves by uparching and uplifting the roofing rocks. In this manner Pinto dome and the dome of Big Mountain were formed. Although intrusive rocks crop out only in a few places on Big Mountain and not at all on Pinto dome, these structures are on a line of intrusions that extends from Stoddard Mountain, northwest of New Harmony, to Mineral Mountain near the Nevada line. Diamond-drilling and magnetic measurements have virtually proved the existence of a continuous intrusive body between the Mount Stoddard area and Bull Valley. The domal structures probably represent bosses or upward bulges of the larger body.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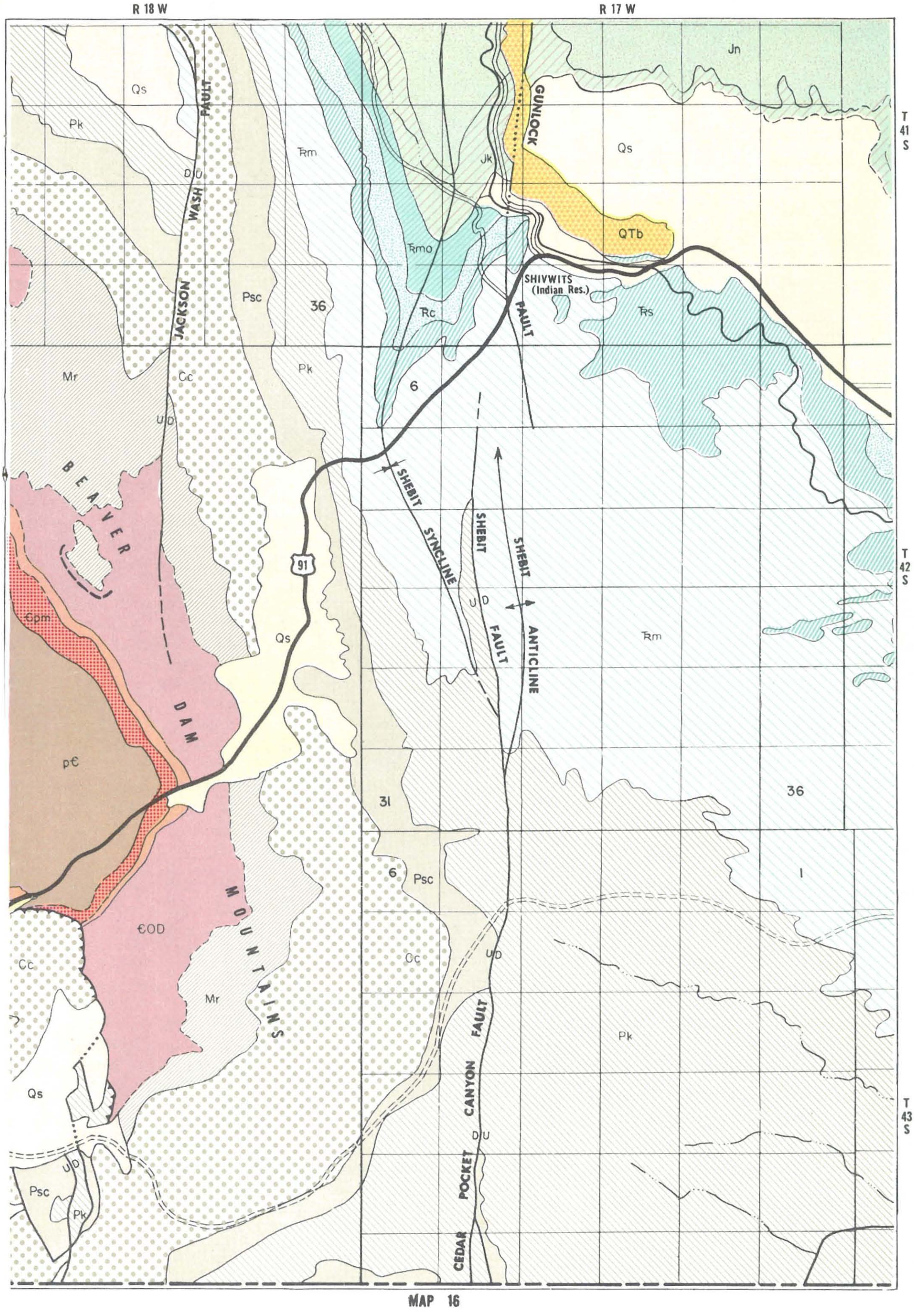
CASTLE CLIFF
91

MAP 15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Cc
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BEAVER DAM MOUNTAINS
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CEDAR POCKET CANYON FAULT
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MAP 16

Volcanic adjustment faults

In the volcanic terrain of northwest Washington County there is a much greater fault density than in the sedimentary terrain of the county. Many of these faults cut post-Rencher formations and are therefore probably not related to the forces of intrusion. Because they have formed late in the volcanic-intrusive history, because they form a pattern that roughly parallels the line of intrusions and the outer margin of the Great Basin volcanic province, and because they are not related to the regional fault pattern, these faults are believed to represent crustal adjustment, after some lapse of time, to the extrusion of thousands of cubic miles of volcanic material.

It is interesting to note that Dobbin (1939, p. 127) thought that most of the faults of southwestern Washington County (even those outside the volcanic terrain) "presumably resulted from relaxational movements along lines of weakness initiated by compression and later recurrent withdrawals of enormous amounts of lava."

GRAVITY STRUCTURES

Rapid uplift by intrusion has probably caused gravity sliding of masses of volcanic rock in several areas of Washington County. In the area north of Grass Valley units of the Quichapa formation and the uppermost part of the Claron formation are repeated by low-angle normal faulting; presumably a large slice of rock slid west off the uparched roof of an intrusive body the top of which is exposed 3 1/2 miles south-southeast of Pinto; the rock mass moved without breaking up. Other slide masses of Quichapa, however, that probably slid from the roof of the Big Mountain intrusion became extremely brecciated as they slid and today are found as chaotic masses disconformably beneath unbrecciated Rencher rocks; similar masses slid from the roof of the Bull Valley intrusion (Blank, 1959, p. 158-159). The age of the sliding off the Bull Valley and Big Mountain intrusions is closely dated by the relations of the slide breccias to units of the Rencher formation; sliding occurred within Rencher time. The slide sheet north of Grass Valley, on the other hand, slid over the Rencher formation and is overlain by rocks of the Irontown member of the Page Ranch formation. Because the Irontown member may be at least in part the age equivalent of the upper Rencher in the Bull Valley district, the Grass Valley slide could have occurred during the Rencher intrusive-extrusive activity. However, the Grass Valley slide did not come from the roof of the Pine Valley laccolith because that immense mass had not yet been formed: the laccolith intruded Pine Valley latite which overlies the Irontown member.

In a recess of the western front of the Beaver Dam Mountains about 25 separate masses of brecciated Mississippian limestone rest on poorly sorted, unconsolidated gravel and sand of probable late Pliocene or Pleistocene age. Previously interpreted as remnants of a Tertiary thrust sheet (Dobbin, 1939, p. 131; Reber, 1952b, p. 107), these breccia blocks probably were not pushed into their present positions but slipped from the adjacent mountain slopes where they had been parts of a thrust sheet. Evidence for this slipped-klippe hypothesis is found in the geometric relations of the breccia block area, the structure of the blocks, and the presence on the hill above the blocks of an unbrecciated klippe of the same rock.

In light of the Pleistocene(?) age of some of the overridden gravel and evidence suggesting that the sliding took place more or less abruptly, it seems probable that Pleistocene rainfall was at least a contributory factor in the slipping of the klippes off the Beaver Dam Mountains. Although the primary cause of sliding was probably slope steepening brought about by tectonic or intrusive deformation, the advent of a pluvial cycle may have induced sliding sooner than it otherwise would have occurred by creating an unprecedented hydrostatic head in the pendant slabs and by facilitating the development of internal mobility in the basal shear zone.

G E O M O R P H O L O G Y

GENERAL FEATURES

In eastern Washington County the outstanding topographic features are cliffs, platforms, and canyons produced by erosion of nearly horizontal rocks. Sparse, spasmodic rainfall, scant vegetation, and a youthful landscape combine to accentuate the topographic expression of differences in rock resistance. The landscape is angular. Broadly speaking, it is the result of differential uplift of broad segments of the crust along northerly trending faults and the wearing down of the uplifted rocks according to their resistance.

Folds, faults, homoclinal structures, and intrusive domes are revealed in the land forms west of the Hurricane fault. And one great intrusive mass, the Pine Valley laccolith, rises on a sedimentary pedestal above the surrounding country (Colored Scene 18).

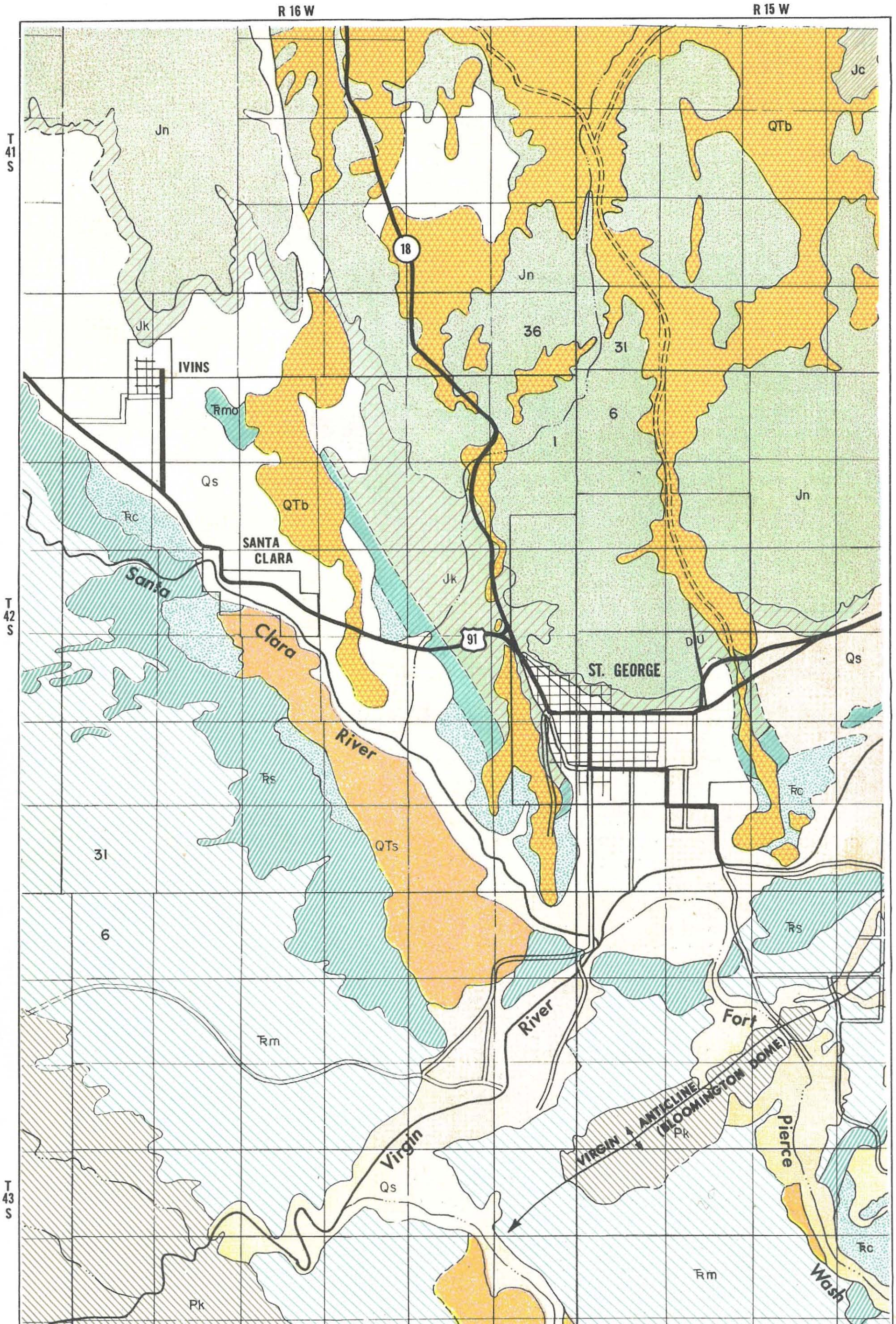
There is very little alluvium in most of Washington County. Only in the southwest corner of the county, west of the Beaver Dam Wash fault, is there an intermontane valley with thick alluvial fill of the type so common in the Basin-Range province.

The physiographic history of the plateau portion of the county in post-Oligocene time is the story of the stripping of 2,000 to 10,000 feet of Mesozoic and Cenozoic strata from the uplifted plateau. Denudation in the country between the Hurricane and Beaver Dam Wash faults was locally even greater, because of greater uplift. As Dutton pointed out (1882, p. 72): "The Grand Canyon district has undergone an enormous amount of upheaval during Tertiary time. The minimum is nearly 12,000 feet and the maximum is about 18,000 feet."

The uplift in Washington County has been differential, the plateau area rising more than the area west of the Hurricane Ledge. Dutton stated this as a general conclusion when he said (1880, p. 23) that "since the Eocene, the High Plateaus have risen from 10,000 to 12,000 feet, while the adjoining Basin areas have risen from 5,000 to 6,000."

The denudation of the uplifted plateau country was vividly described by Gregory (1950, p. 153):

> "....the streams seem not content with removing the products of weathering; they dig deep trenches into the rock and remove the intervening material by a process of lateral mining. Great plateau blocks are first out-



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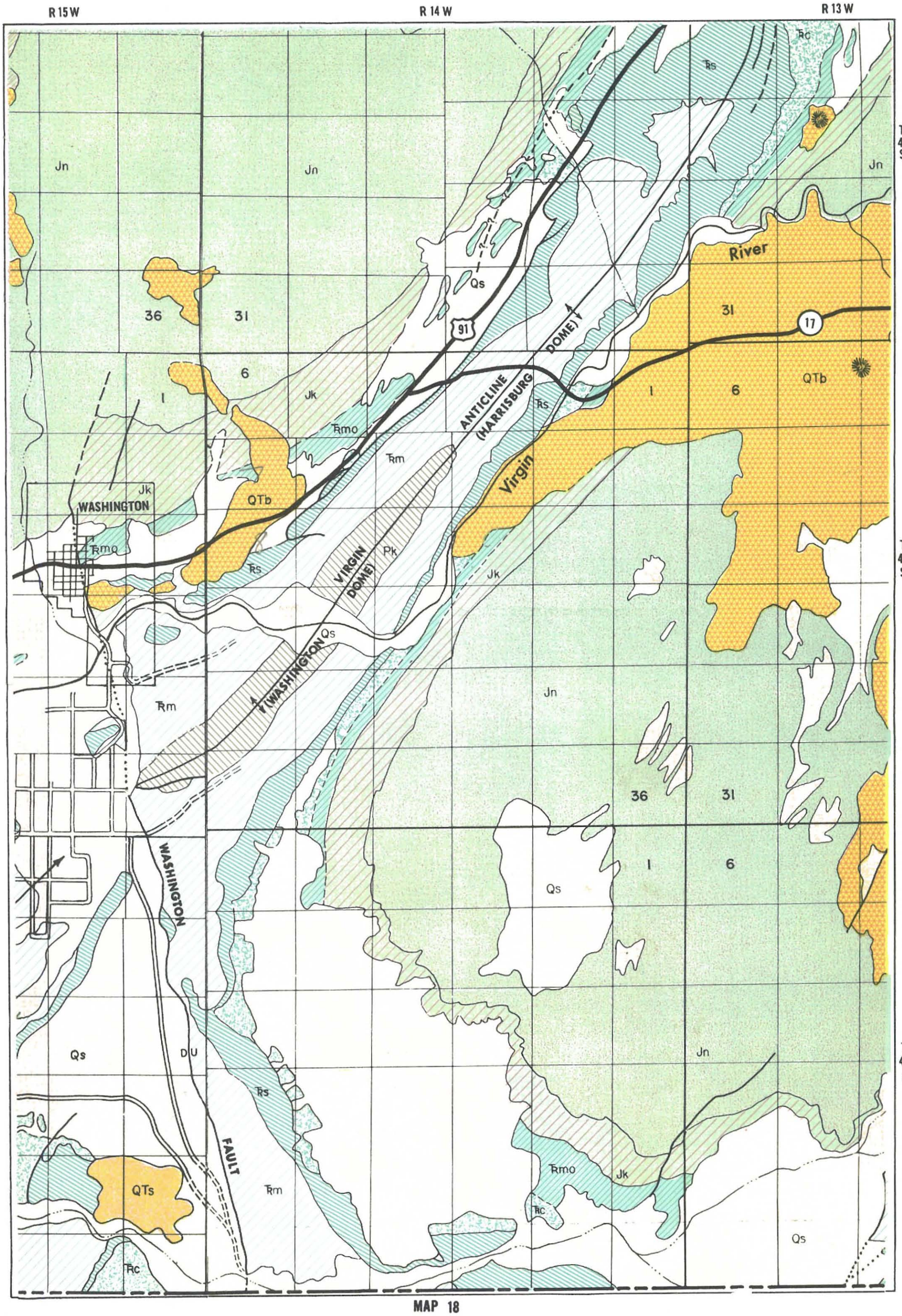
MAP 17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MAP 18

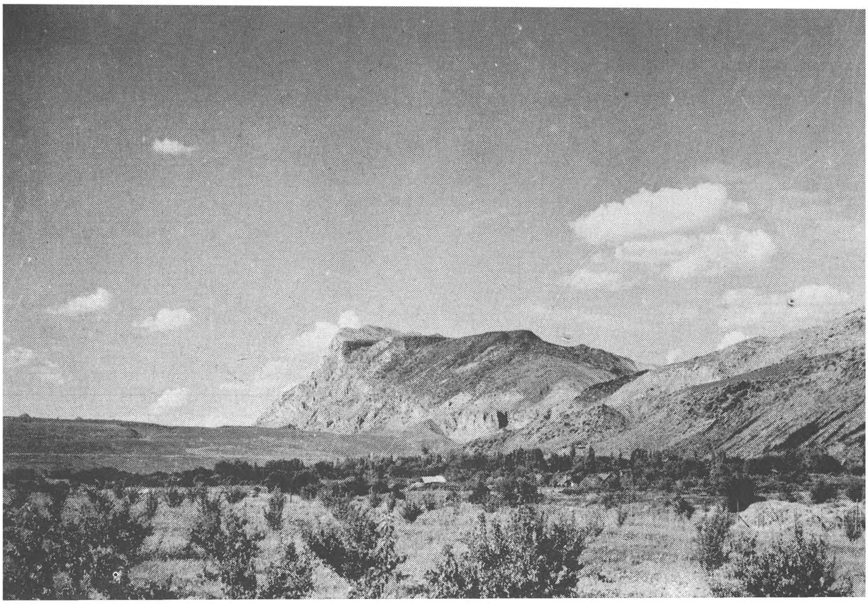


Plate 7. Hurricane Ledge north of Toquerville with three louderbacks of basalt, uplifted remnants of the basalt mass in left middleground.
--Photograph by Earl F. Cook--

Plate 8. Beaver Narrows, incised canyon of the Virgin River between Beaver Dam Mountains and Virgin Mountains. --Photograph by Arthur F. Bruhn--

lined by a series of master trenches.....; secondary trenches divide the block into mesas and elongated ridges, and trenches of the third and fourth order break the original earth block into innumerable varied forms. The resulting landscape appears in general views as a succession of terraces miles in width separated by escarpments hundreds of feet high; of broad surfaces and straight lines of cliffs that extend on and on until they fade into distant horizons, but the highland and lowland surfaces are so intricately dissected by deep, narrow canyons that most viewpoints reveal a ruggedness comparable to that of elaborately carved mountains.....

"In a few places the work of the quarrying streams is complete--the surrounding land has been reduced nearly to the level of the stream bed--but generally the streams are vigorously at work in the bottom of canyons where waterfalls and rapids are common.....In a physiographic sense the region is youthfall."

One of the points stressed by all the geologists who have attempted physiographic interpretation in this region--the general independence of major streams and major structures--is well illustrated in Washington County by the Virgin River, not diverted in its course by such major structures as the Hurricane fault, the Virgin anticline, and the Beaver Dam Mountains uplift, all of which it crosses in an independent fashion. It has sawed deep notches in the resistant rocks at the edge of the plateau and in the Beaver Dam Mountains, but it has not been deterred by the resistance of these rocks upraised across its path from pursuing the course it had acquired on a surface no longer represented in the landscape.

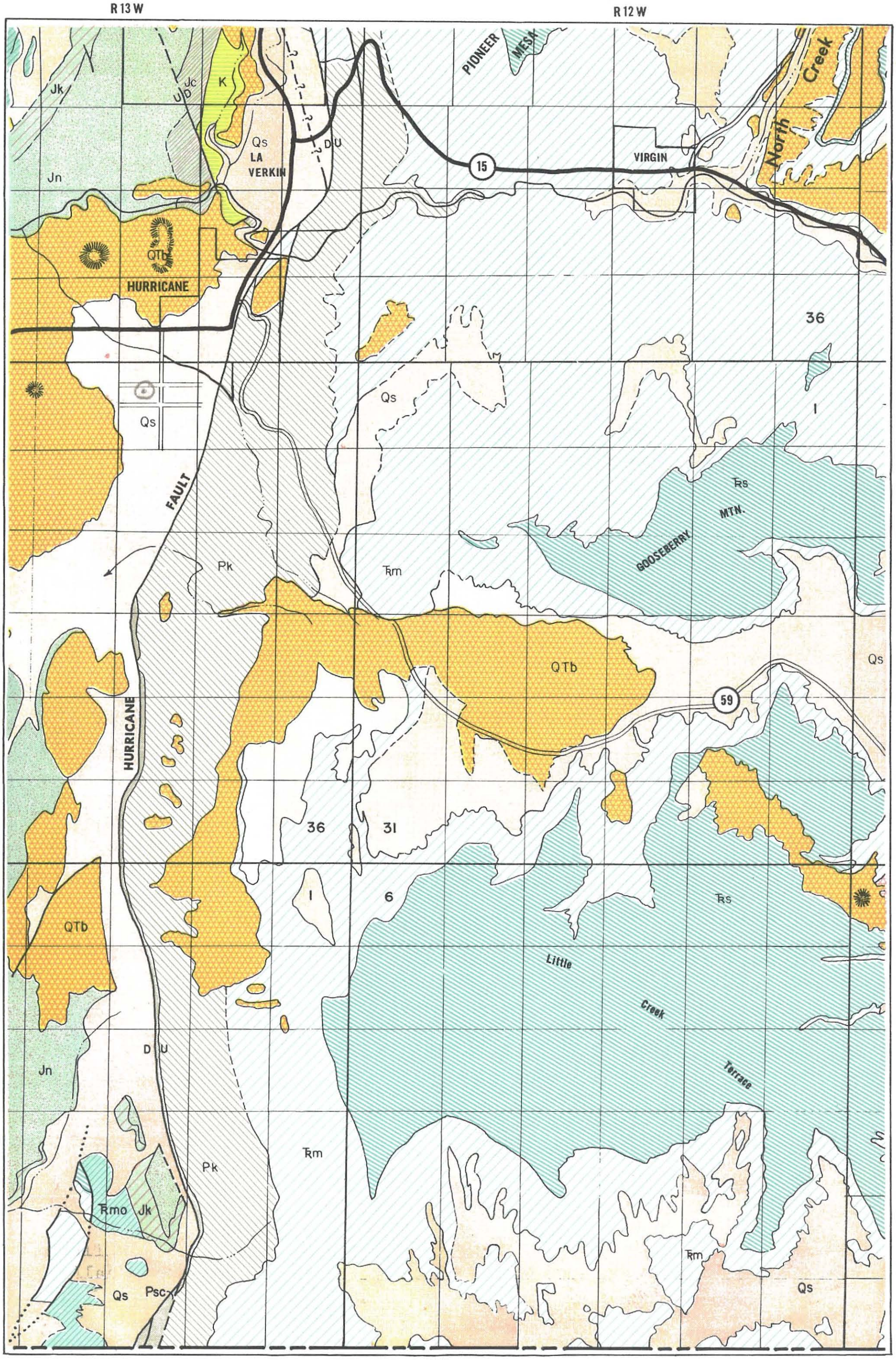
Except for the surface of Beaver Dam Wash (Colored Scene 19) and minor valley areas, the landforms of the county are erosional rather than depositional. They result from the efforts of streams and mass-wasting processes to tear down or denude uplifted blocks of the earth's crust and from the differential resistance to these efforts afforded by alternating hard and soft rock.

To a remarkable degree the rate and manner of erosion are controlled by the composition and attitude of the rocks. The stripping of weak formations from strong ones and the undermining of strong formations by the erosion of weak ones is a process of major importance. Quoting again from Gregory (1950, p. 156):

"Relative rock hardness controls not only the development of the plateaus, terraces, and cliffs but in a large degree determines the form of valleys. Where stream channels are cut entirely in hard rocks their sides are precipitous, and their floors are narrow and steeply inclined..... Some are mere slots barely wide enough to permit passage on foot.....

"Where soft rocks alone form the stream channels the valleys tend to be broad, shallow, and flat-sided."

Erosion is rapid in this region. Great variation in temperature from day to night, sparse vegetation and clear air that allow rapid penetration of the sun's heat into bare rock and equally rapid cooling under the stars, promote mechanical weathering.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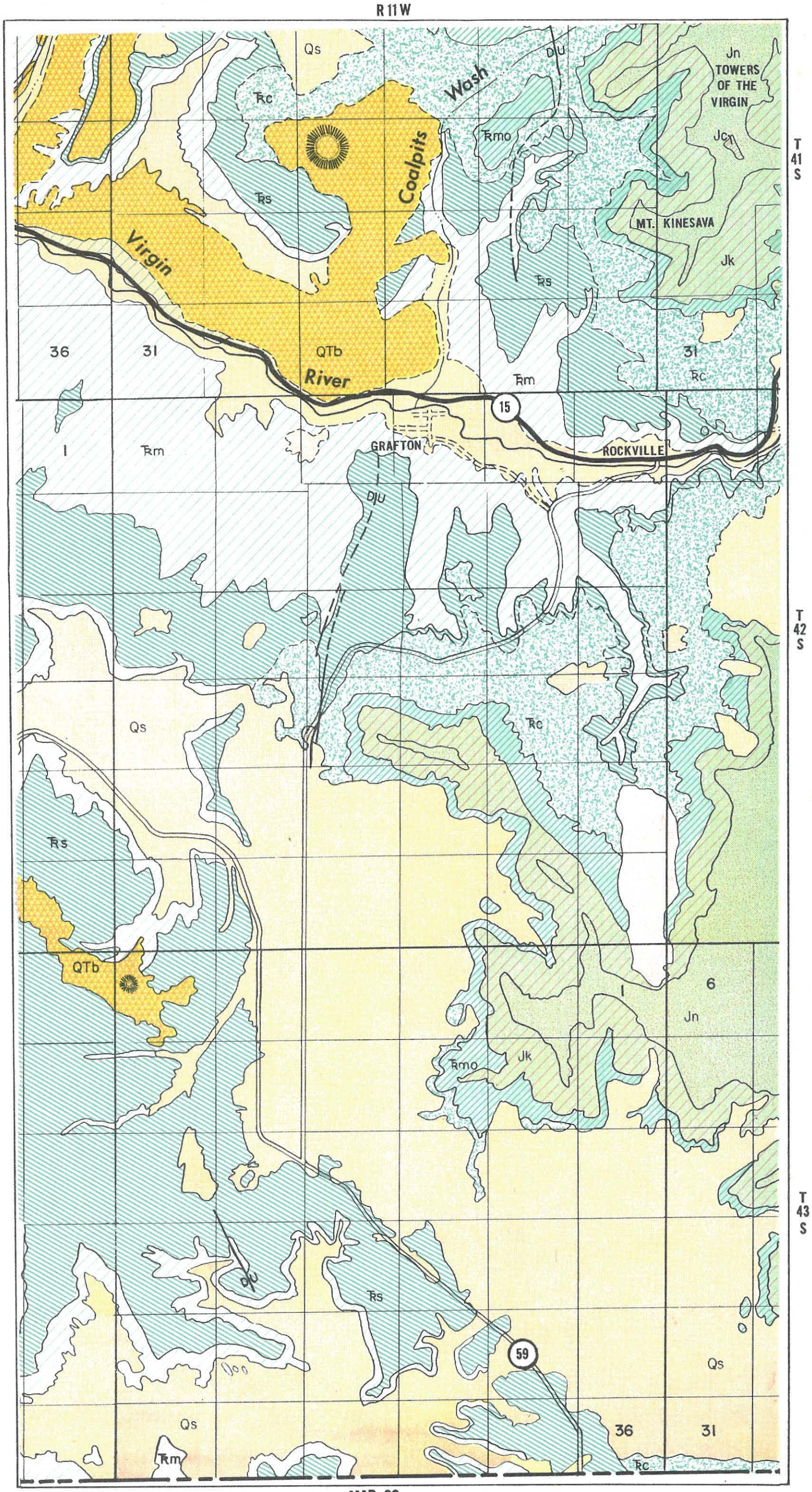
MAP 19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MAP 20

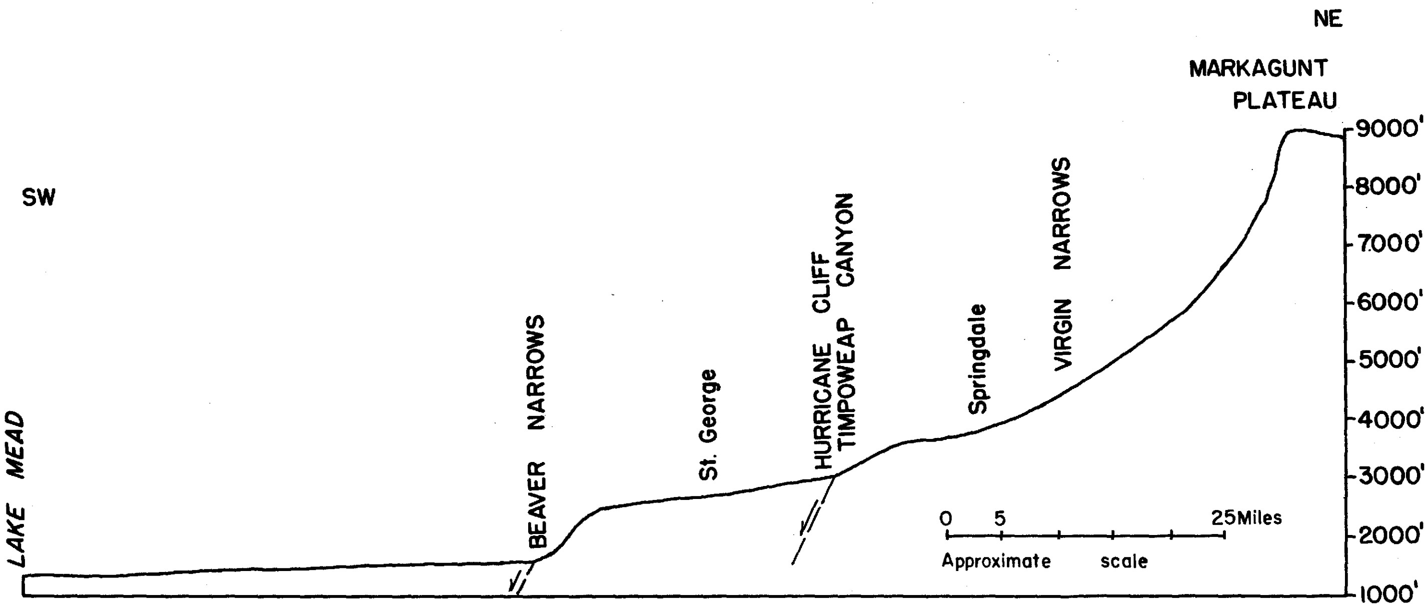


Figure 5. Longitudinal profile of the Virgin River. After a drawing by Gregory, 1950, p. 159. Note relation of oversteepened portions of this profile to faults.

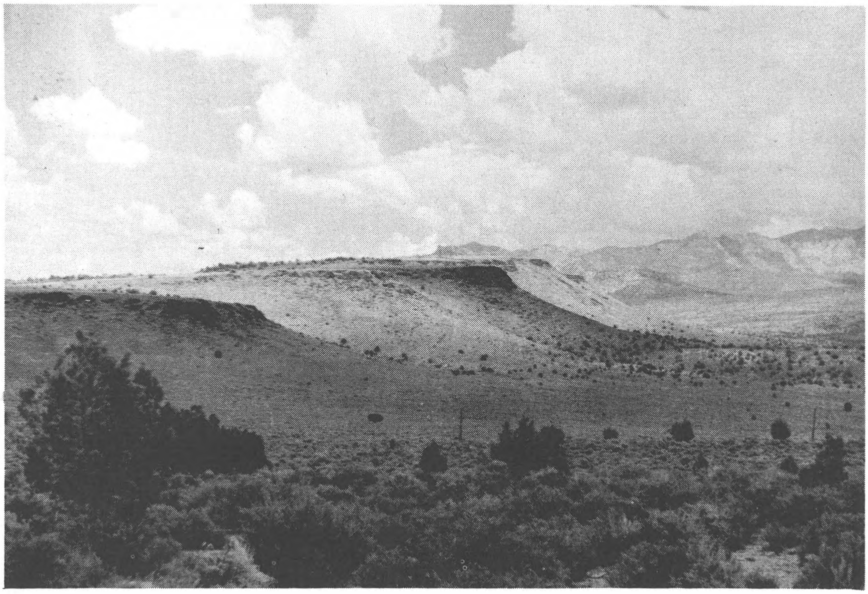


Plate 9. Lava-capped ridge, perched lava stream, or lava esker near Veyo.
--Photograph by Earl F. Cook--

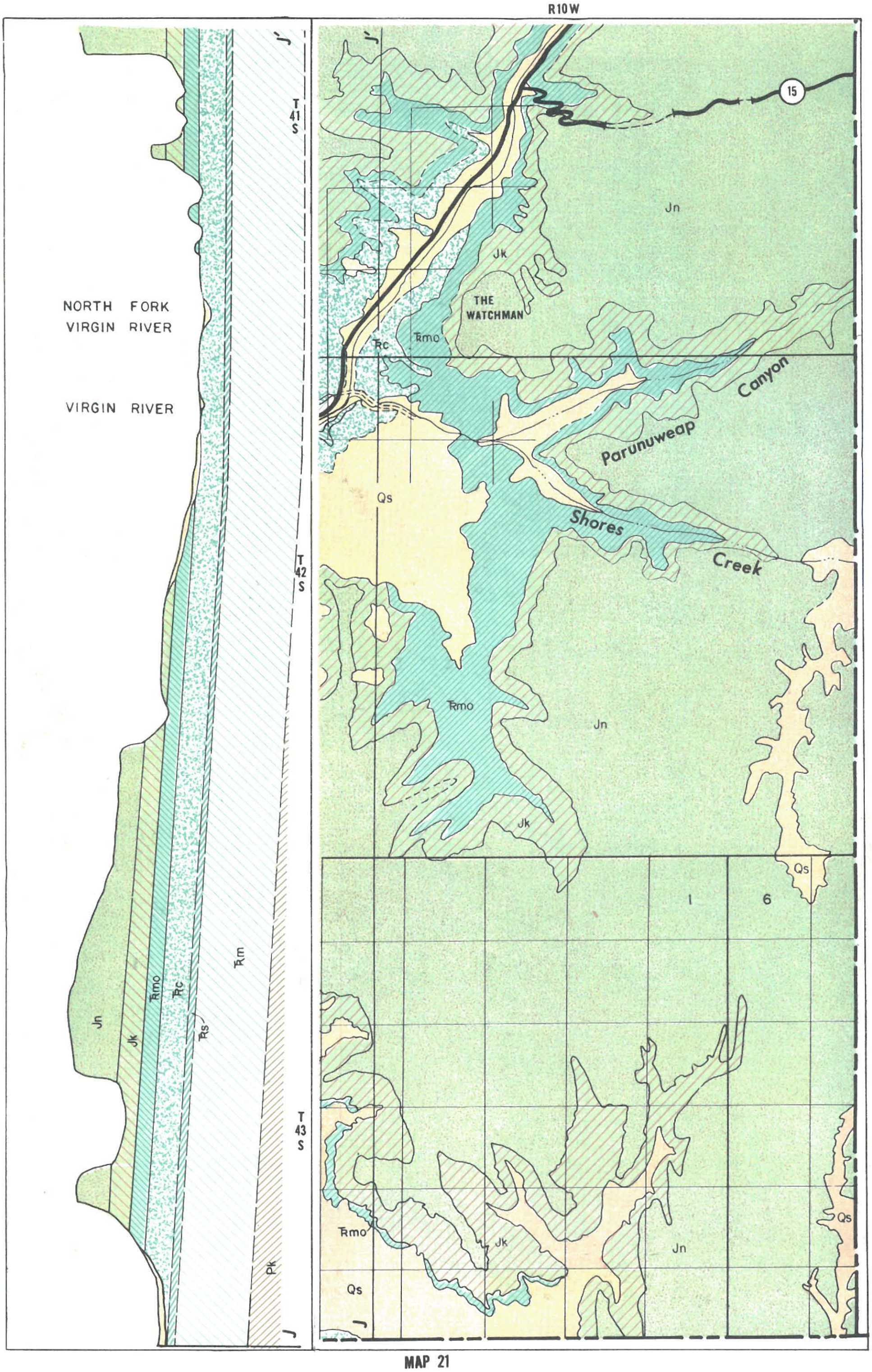
Frost is an active agent in the disintegration of the rocks. Despite the sparseness of rainfall, its marked concentration in space and time makes the occasional streams of this desert region remarkably powerful agents of erosion. Boulders weighing tons are moved during flash floods, canyons are scoured, and weathering debris is swept downslope by sheets of water. Because of the high gradient of the master streams, the abundant debris supplied to them can readily be removed from the area. In addition to people, one of the greatest "exports" of Washington County is comminuted rock, conveyed to Lake Mead by the Virgin River.

In contrast to the major valleys, many of the minor valleys are controlled by the structure of the rocks in which they are cut. The striking trellis drainage of the Zion Park region is controlled by prominent fractures in the Navajo sandstone. The lower portion of Ash Creek follows the Hurricane fault. Many tributary valleys in the Beaver Dam Mountains and in the foothills of the Pine Valley Mountains are subsequent on tilted soft formations.

SPECIAL FEATURES

Incised canyons of the Virgin River

In three stretches the Virgin River flows through spectacular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THE WATCHMAN
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Parunuweap Canyon
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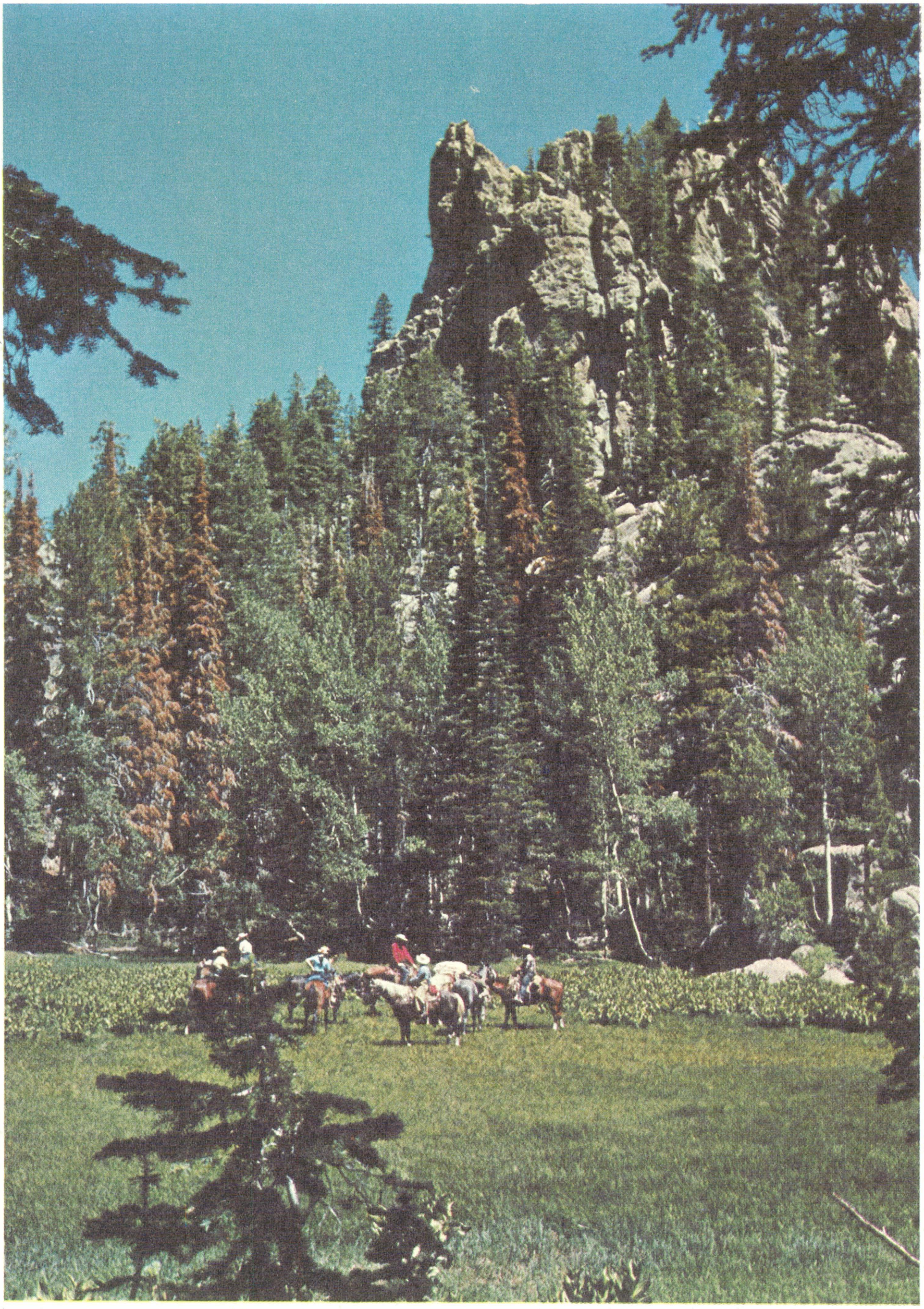
MAP 21



Colored Scene 12. Hidden Valley high in the Pine Valley Mountains showing vegetation typical of the Alpine life zone, in sharp contrast to the desert vegetation only a few miles away. --Photograph by Arthur F. Bruhn--

Plate 10. Santa Clara Creek south of Gunlock illustrating what is called a lava esker because, like real eskers which are narrow ridges of gravel and sand deposited by subglacial streams, this lava now forms a subgraded bench on the side of the valley. But this lava "esker" originally floored the stream channel which then became entrenched on the west, leaving the old floor stranded. Beneath the flow are gravels like those found in today's bed of the Santa Clara, which flows alongside and below the western margin of the lava flow. The Old Spanish Trail from Mountain Meadows followed down the Magotsu branch of Santa Clara Creek and around the distant spur to near the foreground of this picture. Approximately opposite the second lava lobe from the viewer, the trail turned southwest, leaving the creek, going through the low pass northwest of the Beaver Dam Mountains, and following down the Beaver Dam Wash to its confluence with the Virgin River. In May 1861 Brigham Young followed the Old Spanish Trail from Mountain Meadows to this point, continued down the stream to the recently settled town of Santa Clara and to Tonaquint where, at the junction with the Virgin, there were then twelve families. Turning northeast through the site of future St. George (Colored Scene 18) he visited Washington (settled in 1857) and ascended the Virgin as far as Grafton before returning via Toquerville, Harmony, Cedar City, and Parowan, arriving in Salt Lake City June 8, 1861. --Photograph by Arthur F. Bruhn--

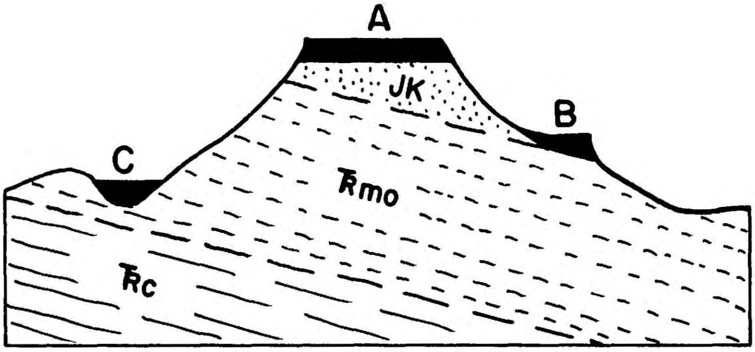


Figure 6. Cross-section through perched lava streams near St. George airport. Uppermost flow is the oldest and lies on a mature erosion surface ("Mohave peneplain"?). Flows B and C record later stages of denudation.

incised canyons. In its upper reaches in Zion Park it has cut a canyon so narrow (Fig. 4) that no road or trail can be constructed through it and which can only be traversed at low water by a person willing to wade and swim. This Virgin Narrows canyon has a depth of over 1,800 feet and a width at the base of 24 to 135 feet. Downstream from the Narrows the canyon of the Virgin is still about 2,000 feet deep but, because of the sapping or undercutting action induced by the softer sandstones and siltstones that are found at the base of the cliffs along this portion of the river, the valley floor is wider, averaging about one-half mile in width through the nine miles of Zion Canyon.

Near Virgin begins another narrow cleft, the river descending into Timpoweap Canyon, a groove up to 500 feet deep cut in Kaibab limestone. From this canyon the river emerges abruptly through the Hurricane Cliffs at LaVerkin.

Below St. George, after passing across the St. George Basin, the Virgin River cuts in another deep, narrow chasm through the southern Beaver Dam Mountains, to emerge from Beaver Narrows (Plate 8) into the intermontane basin of Beaver Dam Wash. Beaver Narrows is mainly in Arizona.

Although the larger tributaries of the Virgin meet the master stream at grade, most of the smaller tributaries reach the main river by plunging down steep slopes or over canyon rims. In other words they have hanging valleys.

The longitudinal profile of the Virgin River (Fig. 5) shows that Timpoweap Canyon and Beaver Narrows contain the only two over-steepened portions of the profile and that these stretches are related to prominent faults. In each case the oversteepened stretch is on the upthrown block immediately upstream from the fault trace.

Colored Scene 13. Pyramidal weathering of nonwelded tuff of the Cove Mountain formation in Pine Park west of Enterprise reservoir in northwestern Washington County. --Photograph by Earl F. Cook--

Colored Scene 14. Pine Valley Mountains from the southwest, from a point approximately four miles north of Gunlock and five miles west of Veyo. Note orange-red band of Claron formation (which extends under the laccolith) in the middle background. An extensive pediment, in part lava-capped, extends toward the viewer from the mountains.

--Photograph by Walter P. Cottam--

Perched lava streams

Peculiar, long, narrow lava-capped ridges rise above the southern and southwestern slopes of the Pine Valley Mountains (Plate 9, Colored Scene 17). Some of the late basalt flows came in thin ribbons down stream channels (Plate 10). After they hardened, continuing erosion wore down the softer sedimentary rocks faster on both sides of the lava-protected channels, leaving sinuous ridges. At one locality near St. George and at another near Veyo successive flows are found at successively lower elevations, recording continued erosion and intermittent extrusion. At the outcrop near St. George (Fig. 6) the highest flow appears to have been poured out onto the mature surface of the Hurricane interfault cycle. The successively lower flows, resting on bedrock, suggest Quaternary uplift of the St. George area.

Cinder cones

In a number of places in the St. George Basin as well as in the Zion Park region, dark basaltic cinder cones (Plate 11) rise abruptly above more or less level surfaces cut on more brightly colored rocks. Among the most recent of these cones are two in Diamond (Damron) Valley (Plate 12, Colored Scene 15) both of which were remarked by Howell (1875, p. 254):

> "[The larger] is a perfect cone, 300 or 400 feet in height, and about 400 feet in diameter at the top, with a regularly formed crater, 75 feet to 100 feet deep. A few small streams of lava have issued from the same vent, but none have extended more than a quarter of a mile."

> "...another stream of lava has flowed from the southern end of Diamond Valley, nearly to St. George. Over the vent from which this issued another fine cinder cone has been formed.

The cones are unmarked by natural agencies of erosion, although the regular crater wall of the larger has been breached by bulldozer in recent years. Vegetation is meager on their flanks. The cinder cones of Washington County appear to mark the position of faults which parallel, but are subordinate to, the major dislocations of the area.

G E O L O G I C   H I S T O R Y

PRECAMBRIAN

One or more periods of sedimentation, folding, metamorphism, and intrusion are represented by the Precambrian gneiss, schist, and granitic rocks of the western Beaver Dam Mountains. An erosion surface of low relief was developed on these rocks in late Precambrian time.

PALEOZOIC ERA

A long history of quiet sedimentation, dominantly marine, with several episodes of uplift and minor erosion but without folding was initiated in the Early Cambrian with the deposition of well-sorted quartz sand, later compacted to form the Prospect Mountain quartzite. This sandstone was laid down during a slow transgression of the sea from west to east over an eroded Precambrian terrain.

Gradual subsidence is indicated by the change from sand to shale to carbonate deposition that took place within the Cambrian period. A major Middle-Late Cambrian regression is suggested by thin-bedded dolomitic limestones in the upper part of the Cambrian sequence (McNair, 1952, p. 48).

Uplift in the east and slight regional tilting in the Ordovician or Silurian is indicated by the fact that Devonian rocks lie unconformably on Ordovician(?) in the Beaver Dam Mountains and, within the region, but not in Washington County, on rocks as old as Middle Cambrian. The Devonian rocks represent a sea again transgressing from west to east.

No definite unconformity is known in the limestone sequence that represents the Devonian, Mississippian, and Pennsylvanian periods.

Within the Permian, however, the Supai-Coconino appears to overlie the Callville limestone unconformably. An aeolian origin has generally been postulated for the Coconino sandstone. The unconformity at the base of the sand sequence may represent withdrawal of the sea from east to west, followed by wind working of some of the regressive beach sands.

Marine deposition recommenced with the Kaibab. The Kaibab includes both marine and terrestrial sediments. McKee (1938) recognized a regional unconformity within the Kaibab involving local warping and general erosion. Concentrations of gypsum and red mudstones at several levels within the Kaibab indicate shallow-water deposition in a sea that was evaporating. The upper part of the formation was developed under conditions of a regressing sea; continental sedimentation advanced westward; residual ponds, lagoons, or embayments of the sea served as local centers for limestone, dolomite, and gypsum precipitation (McKee, 1952, p. 54):

> "Following withdrawal of the shallow Kaibab sea, a long interval of nondeposition and erosion occurred, result-

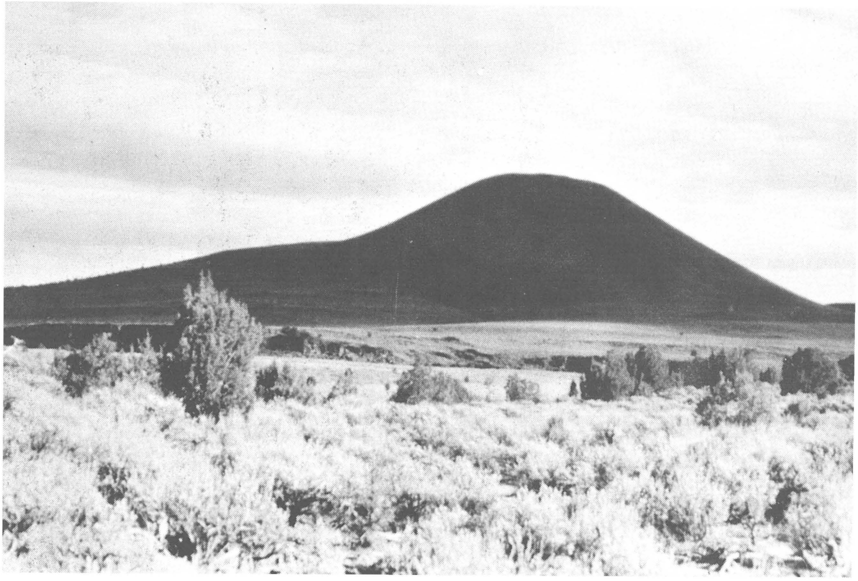
Colored Scene 15. The grave of Perry Tuttle and Jerry Slone--alleged horse thieves who were shot and buried in the approximate area indicated with an "X" east of the road. Basalt here covers Navajo sandstone south of Damron Valley. Both Damron Valley volcanos can be seen in this air photograph. The lower cone in the middle left center is at the head of Snow Canyon (just out of the photograph to the left). The upper cone, with its apron of recent lava flows, is shown to the right farther in the distance. Far to the north, on the skyline, is the rim of the Great Basin formed by [illegible] of Enterprise and southwest of the Iron Springs district. --Photograph by Arthur F. Bruhn--

Colored Scene 16. Upper Snow Canyon, in late evening, below the "Blowholes" where recent basalt lava cascaded over the northeast rim from the lower cinder cone (see Colored Scene 15) of Damron Valley, engulfing cross-bedded Navajo sandstone as it flooded the bottom of the gorge and floored the valley for several miles--as far south as the town of Santa Clara.
--Photograph by Arthur F. Bruhn and Arthur L. Crawford--

Colored Scene 17. Grapevine Gap from U. S. Highway 91 southeast of the old Bastian ranch west of the Black Ridge east of Washington, with the Pine Valley Mountains in the background. The "Gap" is shown in the middle distance as a V-shaped notch in the "fossil" stream of basalt which poured out of a volcano in pre-historic time. Projected Interstate Highway 15 will pass through Grapevine Gap, will pass north of Washington, and will intersect U. S. 91 east of Middleton.

--Photograph by Lynn Fausett--

Colored Scene 18. St. George. Air view from the south with the Vermilion Cliffs and cloud-draped Pine Valley Mountains in the background.
--Photograph by Arthur F. Bruhn--



.ate 11. Cinder cone south of Veyo on a low mound of basalt.
--Photograph by Walter P. Cottam--

Plate 12. Cinder cones in Diamond (Damron) Valley.
--Photograph by Earl F. Cook--

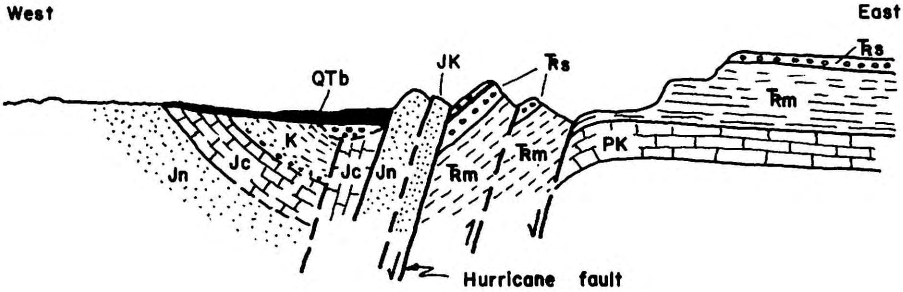


Figure 7. Section across Hurricane fault zone south of Toquerville. East-dipping formations on the left of the sketch represent the east limb of the Virgin (Kanarra?) fold.

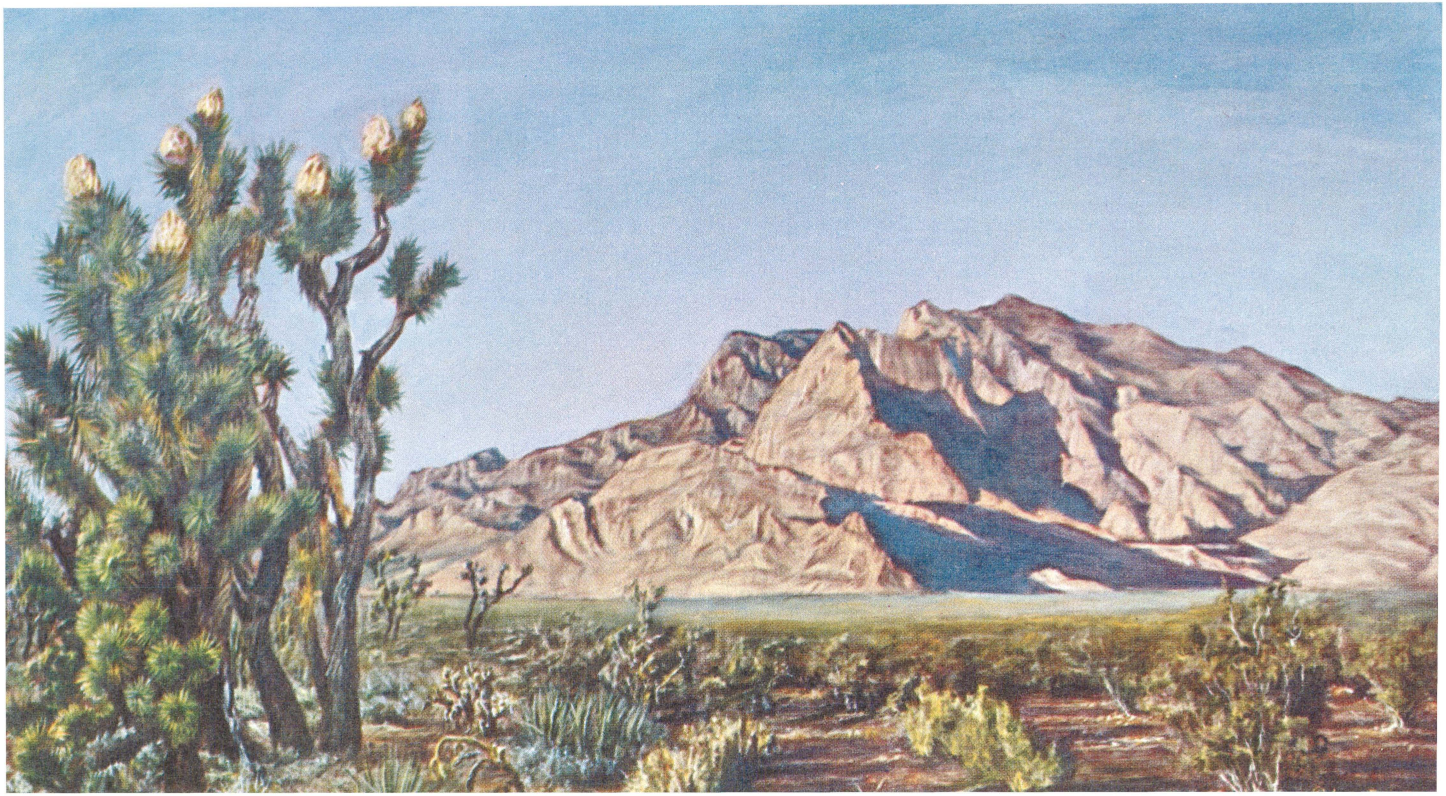
<u>Cretaceous period</u>

Sometime in the Late Jurassic or Early Cretaceous, southwest Utah was moderately warped, and Upper Jurassic rocks were beveled by erosion. Geosynclinal or foreland trough sedimentation began in the early Late Cretaceous with the deposition of a basal conglomerate followed by a thick accumulation of shale and sandstone. This type of deposition was interrupted once by uplift about the end of Colorado time. Renewed sedimentation began, probably in Montana time, with the spreading of the basal conglomerate of the Kaiparowits formation, apparently recording an orogenic pulsation to the westward. Characteristic of Colorado sedimentation was the alternation of marine and terrestrial sediments. Gregory (1950, p. 105) mentions that, at one locality, within a vertical distance of 200 feet some strata of the Tropic formation contain marine fossils, others brackish-water fossils, and still others fresh-water forms.

Montana (Kaiparowits) sedimentation was entirely terrestrial. Fresh-water mussels and land snails, turtles, and dinosaurs are represented in fossils collected from the Kaiparowits formation.

POST-KAIPAROWITS EROSION INTERVAL

Following deposition of the Kaiparowits formation, the major folding of southwest Utah occurred. The folding was sharply localized so that, although in many places the Kaiparowits appears to grade upward into the post-orogenic Claron (Wasatch) formation without a break, in other places the contact is an abrupt angular unconformity representing removal of 5,000 feet of sedimentary rock during the post-Kaiparowits, pre-Claron interval. In the west the Castle Cliff thrust sheet appears to have reached its present position at the close of this erosion interval, for the Claron in its vicinity is thrust-derived.



Colored Scene 19. Sunset on the Beaver Dam Mountains just north of where U. S. Highway 91 passes from Utah into Arizona. The giant Joshua of the Arizona desert here crosses the Utah line but does not occur north of the Beaver Dam Mountains. The Creosote bush, the tree cactus, and other vegetation typical of this life zone are also a part of this colored scene painted specifically for this bulletin by Lynn Fausett, Utah's celebrated landscape artist. The southern portion of the Beaver Dam Mountains, composed mainly of tilted and deformed Kaibab, Supai-Coconino, Callville, and Redwall formations. Because of a marginal fault, the mountain mass rises abruptly from an extensive alluvial (Bajada) plain.

--Painting by Lynn Fausett

The two folds which developed during this erosion interval had northeast trends. One was the Kanarra-Virgin anticline, the other a southwestward extension of the Iron Springs Gap anticline (Mackin, 1947). Although the Kanarra-Virgin fold was truncated down to the Navajo along its crest, the Iron Springs Gap anticline was worn down only to the Tropic formation or the lower part of the Straight Cliffs sandstone. This probably means that the Kanarra-Virgin was a larger fold than the other.

The numerous orogenic pulsations recorded in the thick Cretaceous and Tertiary sediments of central Utah (Spieker, 1946; 1949) apparently did not affect southwest Utah. The absence of evidence of major movement within the Upper Cretaceous rocks and within the overlying Claron formation closely brackets the main Laramide movement in this area, even though it is uncertain whether the basal Claron is Upper Cretaceous or Eocene.

After the Laramide folds had been planed off by erosion, advance of the Castle Cliff thrust sheet and renewed uplift in the west sent the Basal Claron conglomerate spreading eastward over the truncated Mesozoic formations.

CENOZOIC ERA

Igneous activity, differential vertical movements of the crust, and rapid erosion are outstanding features of the Cenozoic history of Washington County.

Deposition of the lacustrine limestones and fluvial-lacustrine siltstones of the Claron was still going on when the first Tertiary volcanic material was laid down. Crystal tuff of *nuée ardente* origin, representing the thin edge of a widespread sheet, deposited in late Claron time, records the prologue to an extensive and violent series of eruptions and associated intrusions that resulted in the formation of ignimbrites, lava flows, volcanic mudflows (lahars), flow breccia, autobreccia, and laccoliths.

The earliest ignimbrites in this area were probably formed in the Oligocene. Following the spreading of the early group of ignimbrites more or less concordantly over the Claron, an Oligo-Miocene intrusive episode brought about widespread deformation and erosion of the pre-intrusive sequence. The intrusive episode culminated in the extrusion of the varied rocks of the Rencher formation, including ignimbrites, airfall and waterlaid tuffs, flows, froth flows, lahars, and tuffaceous rock that may result either from deposition by density currents arising from frothy lava or from intense autobrecciation of such lava. Rudely bedded nonwelded tuff-breccia in the Rencher possibly represents mudflows from abruptly uplifted volcanic formations. During the Rencher intrusive-extrusive episode, in addition to rapid erosion, there was gravity sliding of material from the flanks of intrusive arches and domes. In places this slide material was covered by late Rencher tuffs, in other places by the Irontown member of the Page ranch formation.

In the Pine Valley area, following the main Rencher intrusive episode, some sliding of material from the intrusive domes, and much accumulation of post-intrusive detritus along the flanks of domes, the Pine Valley latite welled out and piled up at least 2,000 feet

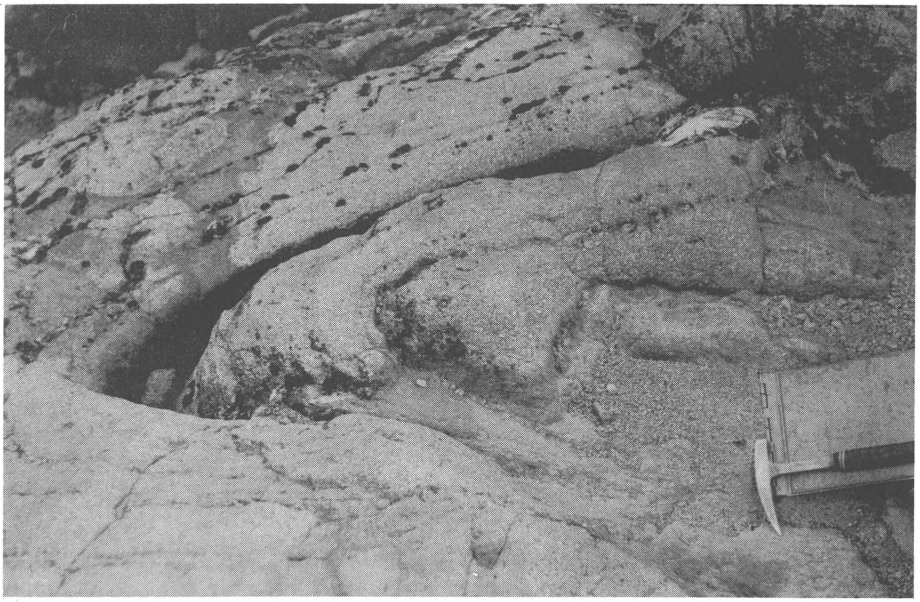


Plate 13. Tightly folded Pine Valley latite. The latite was plastic at the time of folding, which was probably shortly after, or even during, extrusion. --Photograph by Earl F. Cook--

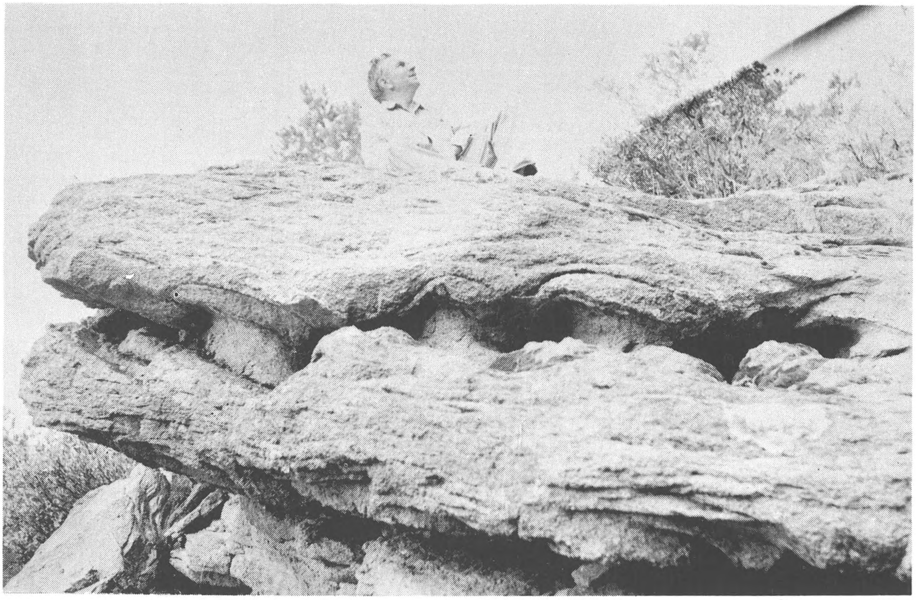


Plate 14. Rolled flow structure in Pine Valley latite, formed transverse to direction of flowage of sticky lava. --Photograph by Earl F. Cook--

thick. When this sticky, mushy lava (Plates 13, 14) had piled up to such depth that it sealed the vent or vents whence it issued, the remaining magma intruded between the Claron and the Quichapa, finally raising its roof along marginal intrusive faults, and pushing up, along with Quichapa and Rencher rocks, the heavy seal of latite.

Numerous unconformities within the volcanics, some of them marked by deposits of lacustrine limestone and quartzite gravel, probably record periods of intrusive folding rather than orogenic disturbances.

Folding during or shortly after intrusion of the Pine Valley laccolith produced a broad asymmetrical anticline in the Hurricane fault zone, superimposed on the west flank of the Laramide Kanarra fold. Whether this fold was the result of compression or of collapse due to withdrawal of enormous amounts of magma (or both) is not clear.

HISTORY OF THE HURRICANE FAULT ZONE

The evolution of the Hurricane fault zone tells much about the Cenozoic structural and physiographic history of Washington County.

As previously mentioned, the Hurricane fault north of Toquerville more or less follows the axial plane of the Kanarra fold. South of Toquerville the Hurricane fault cuts obliquely across the east limb of the Virgin (Kanarra?) anticline (Fig. 7). The Kanarra fold was planed off by erosion before deposition of the Claron (Wasatch) formation.

Although small-scale displacements may have taken place in the Hurricane zone during the formation of the Tertiary volcanics, the first major displacement occurred later and may have been contemporaneous with the period of platy latite extrusion and laccolithic intrusion. This suggestion is made because no remnant of either the latite or the laccolith, which crops out on the downthrown side only a few hundred feet from the fault, is known on the upthrown side of the fault. The lower member of the Quichapa formation appears on the upthrown side near Cedar Breaks, lying on Wasatch rocks. No great movement could have occurred on the Hurricane fault prior to the formation of this Quichapa unit, else it would either be missing from the upthrown block or resting on stratigraphically lower rocks.

Following the first major faulting (Miocene?), the area was reduced to low relief by erosion. A low scarp remained on the resistant Kaibab limestone of the upthrown eastern block. Boulder alluvium spread from the Pine Valley Mountains to the base of the scarp and, in at least one place near Kanarraville, spread across the fault line onto the upthrown block. Basalt flowed down the valley at the base of the scarp, being contained on the west by the foothills of the Pine Valley Mountains and on the east by the scarp of Kaibab over which it could flow in only a few places. Then came the second period (Quaternary) of major faulting in which the basalt was broken and its eastern segments raised. Vertical displacement during the later movement was about 1,500 feet in the area east of Pintura, about 500 feet along the fault south of Hurricane. In most places both the earlier and later movement took place along the same

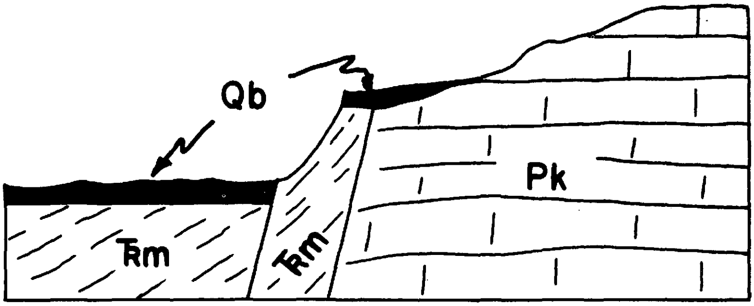


Figure 8A. Section across Hurricane fault zone at Virgin Canyon near LaVerkin. After Huntington and Goldthwait, 1904, p. 225, fig. 5.

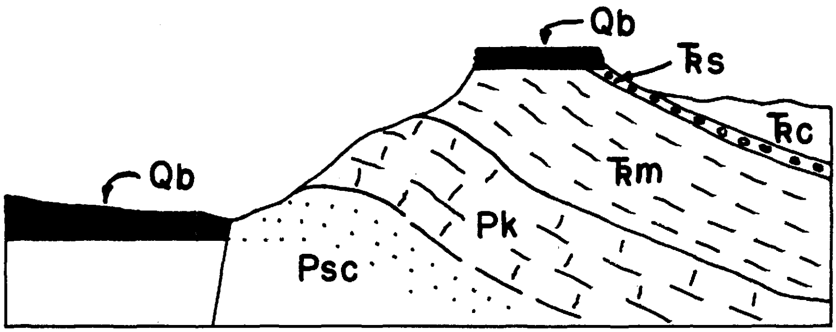


Figure 8B. Section across Hurricane fault and Black Ridge, north of Pintura.

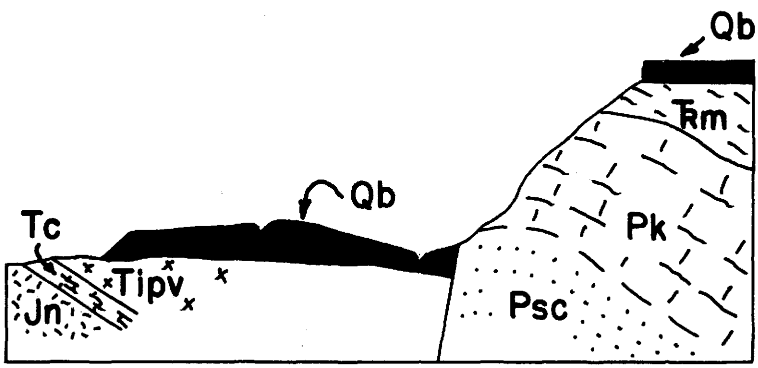


Figure 8C. Section across Hurricane fault and Ash Creek three miles north of Toquerville.

break; in such places (Fig. 8C) the two episodes can be distinguished only by the fact that dislocated basalt rests on considerably older rocks east of the fault than it does on the west. In a few places (Fig. 8A) the later movement caused a new break; and the relations clearly record two distinct periods of faulting.

E C O N O M I C G E O L O G Y

WATER

The most valuable mineral resource in Washington County is water (Colored Scene 8). Surface water is used chiefly for livestock and for irrigation. Because of its great fluctuation in volume and high silt content surface water is sometimes a mixed blessing.

Most of the water for human consumption as well as much of that used for livestock and irrigation comes from springs and wells. It is ground water. Several formations in southwest Utah are natural water reservoirs. The greatly jointed Pine Valley laccolith is one of these. Meltwater from the heavy winter snows seeps into the laccolith along joints and is discharged in springs at the base of the intrusive body, above the relatively impermeable Claron limestone. Springs are absent on cliff faces of the monzonite porphyry, but are numerous at the foot of the mountain. Water from springs at the southern end of the mountain is piped to St. George for municipal supply. Other springs feed creeks whose waters, if they get far enough away from the mountain, are diverted for irrigation; Leeds Creek is one such stream. The Santa Clara River is fed largely by springs that issue from the base of the laccolith in the Pine Valley area. Several good springs are found along the intrusive fault that marks the northern boundary of the laccolith. Some of these feed small streams used by the inhabitants of New Harmony; water from others flows into Grass Valley on the west side of the mountain.

In eastern Washington County the base of the Navajo, another good reservoir rock, is marked by seeps and springs. The water supply for Springdale and Zion Park campgrounds and hotel comes from the Navajo sandstone (Gregory, 1950, p. 196). Springs issuing at the base of the Shinarump supply water for Virgin.

In addition to their appearance at the base of a pervious formation overlying an impermeable one, springs in southwest Utah are also found along faults. A well-known example is La Verkin Hot Springs near the point where Virgin River crosses the Hurricane fault.

SILVER-URANIUM

An area of about two square miles near Leeds produced nearly $8,000,000 in the ten years following the discovery, in 1875, of rich silver ore in the sandstone which became known as the Silver Reef (Plate 15, Colored Scene 7). Where the sandstone contained fossil plants it was especially rich; one petrified log yielded 17,000 ounces. Minerals containing copper, vanadium, and uranium are associated with the silver minerals.

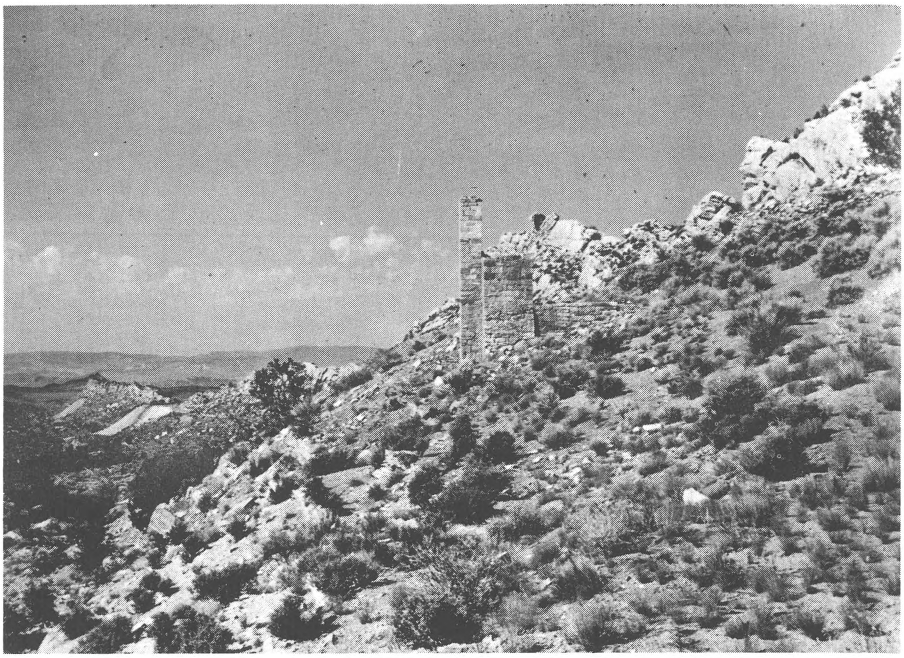


Plate 15. Old structure at Silver Reef, probably dating from the boom days of the 1870's. --Photograph by Earl F. Cook--

Proctor (1953, p. 4) gives a detailed account of the geology of the deposits; his theory of their origin is as follows:

> "It is believed that the metals in the Silver Reef sandstone were primary constituents of original volcanic tuffs in the Chinle formation. These metals were dissolved and/or mechanically transported by streams which were eroding the tuffaceous sediments. They were deposited with the sandstones and shales of the Silver Reef area. Further concentration of the metals in the Silver Reef sandstone was (1) by solution in circulating ground waters and (2) by precipitation because of contact with entombed plant debris and associated bacteria."

Silver was first discovered in this district in 1869 by John Kemple who found float near Harrisburg. He and others organized the Harrisburg district. It was not until August 1875 however, that the existence of rich deposits at Silver Reef, a short distance to the north, became known. The first shipment of 20 tons to Salt Lake City is reported to have netted $5,700. In 1876 or 1877 two stamp mills were built. A newspaper, the Silver Reef Echo, commenced publication in 1877. Peak annual production of 995,315 ounces of silver was reached in 1879. Operations declined rapidly after that and by 1891 only leasers were working in the district. The total value of silver produced from Washington County, largely from Silver Reef during the period 1875-1909, is recorded as $7,767,432.

An attempt to revive the district was made by the American Smelting and Refining Company. After intensive development in 1928 and 1929, they suspended their Silver Reef operations in 1930.

In 1952 the Western Gold and Uranium Company started developing an ore body at Silver Reef containing uranium, reported to be the only known commercial grade uranium-silver ore body in the nation. The firm built a 200-ton mill in 1956-57 to process their ore. Average U_3O_8 in the uranium-silver ore is about 0.14 per cent; this low concentration is upgraded to 0.25 per cent in the mill; dumps from abandoned diggings in 1958 were yielding 6 to 16 ounces of silver per ton when processed by the new mill (Intermountain Industry, January, 1958, p. 20-21). From a production of 9 ounces of silver in 1955, output of the Silver Reef district rose to 72,835 ounces in 1957.

COPPER

The Tutsagubet district, west of St. George, organized in 1883, has been the source of most of the copper produced in Washington County. The Dixie or Apex copper mine has been the biggest operation. Other well-known mines of the district were the Paymaster and the Black Warrior. In 1890 important shipments began from the Dixie Mine. Freight on the ore to the rail shipping point at Milford cost $30 per ton but the ore contained 54.2 per cent copper and 4 ounces of silver per ton (Mineral Resources of the United States for 1913, part I, p. 412-413). In 1891 a copper furnace was erected near St. George and is said to have produced three to four tons of copper daily. In October 1899 a new company was organized and shortly thereafter a smelter was built. From this time blister copper was shipped until 1906, when the plant was closed. Total production of copper in Washington County during the period 1889-1909 had a recorded value of $1,530,849. Grade of the copper ore has continued high. Finding much of it has been the problem. In 1930, for example, the Dixie mine produced 750 tons of 31 per cent copper ore containing azurite, malachite, cuprite, and native copper (Mineral Resources of the United States for 1930, part I, p. 608). At that time the ore was being hauled only 80 miles, to the railhead at Cedar City. It was reported that the mine had been developed by a 600-foot vertical shaft, a tunnel 850 feet long, and 10,000 feet of drifts. The mine has produced some ore almost every year and is still active.

GOLD

Except as a by-product in the silver and copper ores produced in the Silver Reef and Tutsagubet districts, gold has been produced in Washington County only from the Goldstrike district, a few miles southwest of Bull Valley. Rich gold ore was found by lessees operating the Hamburg group of claims in the East Fork of Beaver Dam Wash. They erected a three-stamp amalgamation mill (Plate 16) in the latter part of 1914 and created the short-lived mining camp of Goldstrike. In 1915 two operators produced 173 tons of ore averaging $72.20 per ton in gold and silver (Mineral Resources of the United States for 1915, part I, p. 419). Exceptional specimens of free gold were found with well-crystallized calcite in fractures in limestone. The limestone is probably part of the Tertiary Claron (Wasatch) formation. Lower-grade ore was reported in or near porphyritic intrusions (probably ignimbrites) so highly altered as to obscure their nature.

Plate 16. Three-stamp mill at Goldstrike, erected in 1914. Now abandoned and surrounded by desert vegetation. --Photograph by Earl F. Cook--

The Hamburg group produced a small quantity of high-grade gold ore in 1929, and apparently has been idle since.

IRON

Promising iron deposits occur around the flanks of Big Mountain and in the Bull Valley District. In both localities, the ores are spatially and genetically associated with intrusions of Rencher (Oligo-Miocene) age. The intrusive bodies themselves carry a relatively high iron content and are thus able to cause magnetic anomalies.

The iron ores of the Bull Valley district occur chiefly as replacement and vein deposits in sedimentary and volcanic rocks (Zoldak and Wilson, 1953, p. 1). In an area (Pilot group of claims) near the main Bull Valley intrusive body hematite and magnetite are the main ore minerals. At Cove Mountain, between the Pilot claims and Goldstrike, the ores consist of massive, siliceous hematite. Neither the ores nor the country rock show contact metamorphic features. During intrusion the overlying rocks were fractured, causing a sudden release of pressure and liberating iron-bearing gas along tension fractures (Wells, 1938). The gaseous emanations deposited iron in structurally and chemically favorable places.

Oil was found in 1907 near Virgin. The Virgin field is the oldest in Utah. The small but steady production from the basal member of the Moenkopi formation has stimulated oil exploration in southwest Utah for more than 50 years.

The information in the following paragraph has been supplied by Edgar B. Heylmun, consulting geologist of Salt Lake City:

> Most of the production is from shallow wells in the narrow valley of North Creek one to two miles north of Virgin. The producing zone is a sandy limestone that ranges between 1 and 8 feet in thickness at the top of the Timpoweap or Rock Canyon member of the Moenkopi. The depth of the producing zone ranges between 475 and 800 feet. About 140 wells have been drilled in the Virgin field and vicinity. The deepest test to date went to a total depth of 4,538 feet in 1958, bottoming in Mississippian limestone. About 30 wells have been productive, and approximately 40 acres are proved. The cumulative production to date is 193,022 barrels. There are now five wells in the field capable of producing oil. A few wells had initial production rates over 35 barrels per day. The oil has a paraffin base and is dark brown with a gravity averaging about 32° A.P.I. Structurally, the Virgin field lies in a small synclinal pocket on a broad, plunging anticlinal nose.

There have been a number of test wells drilled on the domes of the Virgin anticline (Boshard, 1952). The first test was started in 1918 on the Harrisburg dome and reached a depth of 3,400 feet. Between 1929 and 1936 a well was drilled to a depth of 2,540 feet. Bloomington dome has had three deep test holes, to depths of 2,530; 4,114; and 6,347 feet. At least five shallow wells had previously been drilled on the dome. The 6,347-foot well was drilled in 1951 by the California Company.

In 1951 a well was drilled to a total depth of 5,496 feet by the Sun Oil Company on the so-called Pintura structure about three miles west of Pintura.

Two small domes in the southern part of the St. George Basin, called Bee Hive dome and White Butte dome, have had shallow wells drilled on them.

A recent development is the drilling of an exploratory well by the Intex Oil Company in section 28, T 43 S, R 13 W, about 15 miles south of Hurricane and one and a half miles west of the Hurricane fault. The well, started in November 1959 is now (May 1960) suspended at a depth of 3,000 feet; it is on the crest of a small fold expressed at the surface in the Moenkopi formation. The well has passed through the Supai-Coconino sandstone and has penetrated 250 feet of dense dolomitic limestone, probably of the Pakoon limestone.

According to William Whitley, geologist with Intex, a pre-Coconino carbonate sequence is exposed in the Hurricane cliffs about two miles north of Toquerville. In that locality the Supai-Coconino is underlain by gypsiferous red beds and thin limestones, then by a possible reef structure, and then by dense, dark-gray limestone. This description is not out of harmony with those given by McNair (1951, p. 524-525) for the Pakoon limestone in northwest Arizona, where he found large colonies of tubular corals in the formation.

No reliable shows of oil have been reported from test wells drilled west of the Hurricane fault. Heylmun reports, however, that numerous oil shows have been encountered in the Kaibab east of the fault and that the 1958 test in the Virgin field had good oil shows in the Permian Pakoon formation. The existence of favorable source beds and untested structures in Washington County will probably lead to more exploration in the future.

NONMETALLIC MINERALS

There is a deposit of perlite near Enterprise from which Utah's first production came in 1947 (Utah's Mining Industry, Utah Mining Association, 2nd edition, p. 102).

Sand and gravel is produced every year in Washington County. There is a commercial pit on the Shivwits Indian Reservation and a crushing, screening, and washing plant at St. George. The Road Commission also has several pits.

Silica sand has been produced intermittently from a deposit between St. George and Veyo. There is reported to be a good deposit near Hurricane.

Sandstone is produced for building purposes and flagstone in the Oak Grove area northwest of Leeds. "Utah picture rock," sandstone with ornamental bands and convolutions of iron oxide, is produced near Washington.

VALUE OF MINERAL PRODUCTION

The total value of minerals produced in Washington County to date is probably about $12,000,000, most of which was accounted for by the boom production of silver at Silver Reef in the first ten years after 1875. In recent years production has averaged about $150,000 annually; the major mineral commodities produced have been uranium, silver, copper, sand and gravel, and stone. Production figures for the period 1952-1958, taken from the Minerals Yearbooks of the U. S. Bureau of Mines are:

Year	Gold	Silver	Copper	Lead	Total of all Minerals
1958	$770	$50,814	$ 14,255	$ 58	$138,230
1957	280	66,314	60,591	300	169,588
1956	385	10,629	94,180	1,099	134,223
1955	350	540	129,058	596	158,746
1954	232	------	49,123	-----	84,560
1953	---	2,241	8,610	6,550	85,935
1952	---	982		4,830	7,012

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