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GEOLOGY OF THE SOUTHERN WASATCH MOUNTAINS AND VICINITY, UTAH

CONTENTS

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Geology of the Southern Wasatch Mountains and Vicinity, Utah

a symposium

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Extra copies of map available at $1.00 each.

Contents

Geology of the Southern Wasatch Mountains and Vicinity, Utah

INTRODUCTION

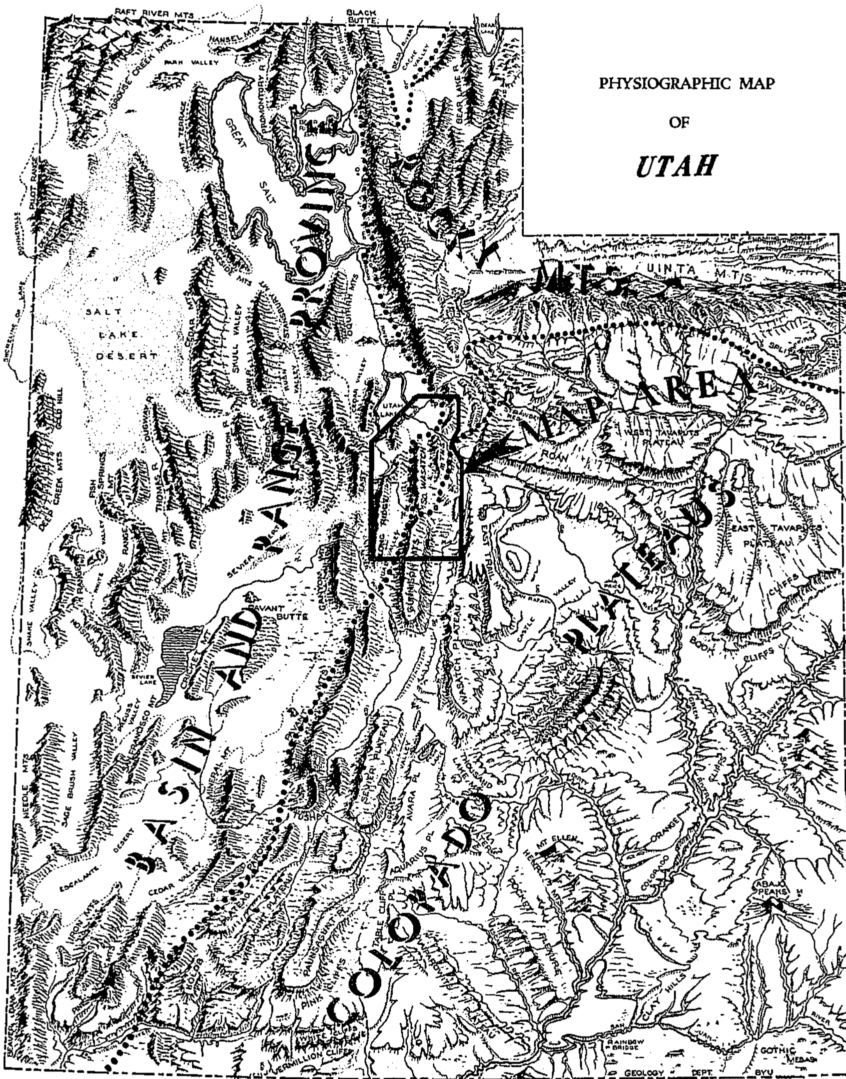
Utah is blessed with geologic features of unusual interest and great variety. The Canyon Lands, the Henry Mountains, the San Rafael Swell, the High Plateaus, the features of Lake Bonneville, the famous mining districts of Tintic, Bingham, and Iron Springs, the magnificent stratigraphic sections exposed in the Book Cliffs and in the Basin Ranges, all have revealed to geologists the tremendous sweep of geologic history and have been made classic through the writings of such pioneer geologists as C. E. Dutton, William M. Davis, C. D. Walcott, and G. K. Gilbert. So complex is Utah's geologic history and so numerous its problems that further detailed work, using improved procedures, continues to increase our understanding of this fascinating area. Each year some aspect is clarified and we wonder why it did not seem more obvious to us before.

In this light we embark on a summary of the current knowledge of the geology of the Southern Wasatch Mountains. The area lies at the junction of three major physiographic divisions: the Middle Rocky Mountains, the Colorado Plateaus, and the Basin and Range Province. It includes sedimentary, igneous, and metamorphic rocks ranging in age from Precambrian to Quaternary, and representing dominantly marine deposits of the Early Paleozoic Cordilleran miogeosyncline, the later Paleozoic Madison and Oquirrh Basins, the Cretaceous Rocky Mountain exogeosyncline, and Cenozoic deposits in freshwater lakes. The area has been involved in major structural deformation in Precambrian time, in folding and thrusting in Late Cretaceous (Laramide) time, and in block faulting in later Cenozoic time. In all, a greater variety of geologic features can scarcely be found in so limited an area.

The area is part of what is sometimes referred to as the "transition zone" in Utah. The transition involves more than the change from Basin and Range landforms to those of the Plateaus, it also involves older transitions from Cretaceous orogenic elements on the west to depositional sites on the east, from Paleozoic cratonic deposition on the east to geosynclinal behavior on the west. Two previous guidebooks have discussed the transition zone in Utah: to the north the Intermountain Association of Petroleum Geologists 10th Annual Field Conference in 1959 considered the Wasatch-Uinta Mountains transition area; to the south the Utah Geological Society 4th Annual Field Conference in 1949 traversed the transition between the Colorado Plateaus and the Great Basin in central Utah.

GEOLOGIC MAP

The geologic map accompanying this report was compiled from a great many sources, most of them published and unpublished theses by graduate students of Ohio State University and Brigham Young University (see "Index to sources of data" printed on the map). The original mapping was done on a variety of base maps, some prepared by plane table, some from air photos, and some on U.S.



INDEX MAP.—Shows Southern Wasatch map area in relation to physiographic provinces.

Geological Survey topographic quadrangles. In transferring the mapping from these diverse bases to the common base used innumerable minor adjustments were made in order to fit the original mapping to the new base as well as possible. Air photos aided in making the transfer for it was sometimes necessary to transfer data from the original map to the photos and thence to the final map in case the original map was too distorted to use directly.

In addition, in cases where adjacent mappers disagreed, the compiler has attempted to resolve their differences as best he could in order to eliminate map boundary faults. Many problems, yet to be solved, became apparent during the compilation and it is hoped that the present map may serve as a means of pointing out these problems in their regional setting for the benefit of future students of this complex and interesting area.

ACKNOWLEDGMENTS

Although many famous pioneer geologists such as William M. Davis and G. K. Gilbert had made reconnaissance observations pertaining to the Southern Wasatch Mountains, the first modern areal mapping in the area was done by Armand J. Eardley in the early 1930's. All later workers are indebted to the perspicacity of his observations.

Impetus for further work in the area came from Professor Edmund M. Spieker who extended his earlier interest in the Mesozoic problems of central Utah by directing Ohio State University graduate students in areas surrounding that of his initial work with the U.S. Geological Survey. Under him, S. L. Schoff's work in the Cedar Hills in 1937 was followed by that of many others of whom the following did work in the area of the present report: Dorothy Taylor, H. D. Zeller, R. E. Hunt, S. J. Muessig, R. E. Metter, A. C. Fograscher, J. E. Cooper, M. A. Khin, R. E. Mase, J. D. Hayes, and G. E. Thomas. Professor George E. Moore, Jr., of Ohio State University acted as graduate thesis advisor for some of these students.

For the past 25 years Professor Harold J. Bissell has been involved in problems relating to Utah Valley and the adjoining ranges. He has inspired a number of students to work in the West Mountain-Long Ridge-Southern Wasatch area and has served as adviser to most of the following Brigham Young University graduate students who have worked in this area: W. O. Abbott, R. S. Brown, R. S. Clark, L. C. Demars, J. H. Elison, D. R. Foutz, P. W. Gaines, R. W. Gates, T. A. Gwynn, H. D. Harris, R. A. Hodgson, K. D. Johnson, J. W. Madsen, D. F. Mecham, C. H. Peacock, H. N. Petersen, D. J. Peterson, D. O. Peterson, R. P. Peterson, J. R. Price, R. R. Rawson, J. A. Rhodes, S. F. Schindler, G. K. Sirrine, C. V. Smith, J. W. Swanson, and B. O. White.

Arthur A. Baker of the U.S. Geological Survey has mapped in the Wasatch Range from Spanish Fork Canyon northward and his work and advice have served as a guide to many of the above listed workers. In addition to the many people whose field work has made the present compilation possible, I wish to acknowledge the efforts of the authors of the papers in the present volume. I also wish to thank Professors Clyde T. Hardy and J. Keith Rigby for help in preparing the road log, and Mr. Colbeth Killip for drafting the geologic map.

The Editor

Structure of the Southern Wasatch Mountains and Vicinity, Utah

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It would be hard to find a more conspicuous example of Basin and Range normal faulting than that represented by the Wasatch Fault system, movement along which has created the contrast in elevation between the Wasatch Mountains and the adjacent valleys to the west. These normal faults were observed nearly a century ago by S. F. Emmons of the 40th Parallel Survey (Emmons & Hague, 1877) and they have been the subject of papers by many geologists since then. Equally intriguing, but topographically less conspicuous, are the pre-fault structures within the mountain range itself. As seen by an observer on the valley floor, the Southern Wasatch Mountains seem to be made up mostly of layered sedimentary strata which are tilted moderately eastward. This apparent simplicity belies the actual structural complexity of the Southern Wasatch Range for it contains overturned folds, thrust faults and major angular unconformities resulting from Cretaceous Laramide disturbances.

Pre-Cretaceous movements in the region were probably mainly epeirogenic in nature with the exception of those which metamorphosed the Precambrian basement rocks. Paleozoic structural events are summarized in the stratigraphic papers in this volume so that emphasis in this paper is on Mesozoic and Cenozoic structural events. Little attempt will be made to describe details of local structure and the reader interested in such details is referred to the original sources of data as shown on the geologic map accompanying this volume. Nor is it the purpose of this paper to discuss the regional aspects of Laramide disturbances as this has been recently done by Eardley (1951). Rather this paper summarizes structures present within the map area.

PRE-INDIANOLA NORMAL FAULTS

Earliest normal faulting reported in the area occurs in the northwest part of the Gunnison Plateau near Nephi. Here Hunt (1950, p. 128) reports more than 1000 feet of displacement within the Arapien Shale, the Twist Gulch Member being faulted out near the heads of Andrews Spring Canyon and Salt Spring Canyon. The faults are concealed by the overlying Indianola Group as shown on the geologic map.

CEDAR HILLS OROGENY

Earliest orogenic disturbances reflected in the map area are recorded by the abrupt change in sedimentation which occurred between Jurassic and Cretaceous time. Late Jurassic Arapien marine limestones, and shales and siltstones with evaporites, are overlain by coarse deposits of the Indianola Group which attains a thickness of almost 15,000 feet in the Cedar Hills. Spieker (1946, p. 150) and Schoff (1951, p. 641) show that the orogenic belt must have risen to the west of the map area since the Indianola is coarsest toward the west in the Cedar Hills and Gunnison Plateau. Eardley (1951, p. 274) has termed this early or mid-Cretaceous event the Cedar Hills Orogeny.

LARAMIDE DEFORMATIONS

Pre-Price River and Pre-North Horn Unconformities

The most important relationship for dating Laramide orogenic events within the map area is shown on the North Fork of Salt Creek where pre-Cretaceous folded and overthrust rocks pass beneath a cover of Price River conglomerates. Thus, much of the Laramide structural deformation within the Southern Wasatch Mountains may be dated as post-Arapien (late Jurassic) and pre-Price River. Because of its conglomeratic lithology the Price River of the Cedar Hills and Gunnison Plateau has yielded few fossils, but Schoff (1951, p. 628) believes that it may be correlated with typical Price River of late Montanan age in the Wasatch Plateau to the east. Indianola beds were involved in pre-Price River folding and erosion for they may be seen to be truncated beneath Price River beds at Wales Gap.

A later Cretaceous regional unconformity, the significance of which has not been generally recognized, is present immediately beneath the North Horn Formation. This formation lies with regional angular unconformity on all older beds including the Price River Formation as can be seen by relationships shown on the geologic map accompanying this volume. Burma and Hardy (1953, p. 551) mapped this relationship in detail south of Wales Gap, showing post-Price River faulting being concealed beneath North Horn beds. They differ markedly with Spieker's (1946, p. 129) interpretation of an essentially continuous succession from Price River into North Horn.

The author, in compiling the geologic map for this volume also differs from earlier mapping by Schoff (1951) in the North Horn-Price River relationship shown near the head of Hop Creek in the Cedar Hills. In one of the most striking examples of angular unconformity the writer has ever seen on aerial photographs, the North Horn Formation may be seen to truncate the folded Indianola and Price River beds beneath the unconformity. Field relationships in this area as seen from the ground are confusing, as pointed out by Schoff (1951, p. 630) who did not have aerial photographs available when he did his mapping.

In the area north and east of Thistle, Baker has mapped "Price River" beds immedately beneath Flagstaff Limestone, whereas other mappers south and west of Thistle refer to the same beds as North Horn. Baker's assignment probably stems from that made by Spieker (1946) for the conglomerates in Red Narrows east of Thistle, just off the east edge of our geologic map. The conglomerate in Red Narrows cannot be traced physically into typical Price River because of intervening faulting. Hence their assignment to the Price River is open to question, particularly since Spieker himself seems inclined to exclude red beds from the Price River elsewhere. Boyd and others (1959, p. 211) called the conglomerates in Red Narrows "North Horn". In view of the disagreement about the proper assignment for these beds east of Thistle, outcrops mapped by Baker as "Price River" are shown on the present map as "Price River(?)-North Horn".

Laramide Folding

Broad open folds characterize much of the Southern Wasatch Mountain-North Gunnison Plateau area as can be seen from the broad patterns on the geologic map. But tight folds are present locally as described below.

Provo Rock Canyon Overturned Anticline

Precambrian rocks are exposed in the core of this fold in the mouth of Rock Canyon northeast of Provo. The east limb of the fold is overturned and dips 70 degrees westward just east of the axis. Baker (1959, p. 154) suggests that the Charleston thrust underlies the fold. Inferred eastward movement on this thrust is in accord with eastward overturning of the anticline. But perhaps part of the overturning has resulted from eastward tilting during Cenozoic uplift of the Wasatch Range along the Wasatch Fault.

The anticlinal axis is doubly plunging and roughly parallels the trend of the Wasatch Fault. The fold is somewhat faulted by normal and reverse faults which parallel its axis. Some of these faults are best considered contemporaneous with the Laramide folding, while others seem part of the Cenozoic Wasatch Fault system. The faults most readily assignable to Laramide age are strike faults which cut the Ophir and Manning Canyon shales and represent bedding plane slippage and faulting along these incompetent beds. Faults most readily assignable to Cenozoic normal faulting occur along the range front where horses of Mississippian limestone are downdropped against Cambrian units along slivers of the Wasatch Fault.

Folds in Spanish Fork Canyon near Castilla

Paleozoic and Mesozoic beds generally dip southeastward from the mouth of Spanish Fork Canyon to the eastern limit of their exposure near Thistle. Exceptions to this generalization occur in the vicinity of Castilla where local fold axes parallel the regional strike. Kirkman Limestone is exposed in the core of the westernmost syncline, the axis of which follows Pole Canyon. Diamond Creek Sandstone forms the exposed core of the Castilla Anticline, parallel to and east of the Pole Canyon Syncline. Small tight folds involve beds of the Park City, Woodside and Thaynes formations between Castilla and Diamond Fork.

Mount Nebo Overturned Anticline

Eardley (1934) first described the great fold which constitutes the Southern Wasatch Mountains. North of Mount Nebo only the eastern limb of the fold is preserved and, so far as it is exposed, the beds are not overturned. From North Canyon southward on Mount Nebo, the beds are carved from the lower limb of the overturned fold, which at the south end of Mount Nebo, lies immediately above the exposed Nebo overthrust. Observed overturning of beds in Provo Rock Canyon, described above, is similar to that on Mount Nebo above the thrust, and, although the thrust plane is not exposed in the Provo area, it should, by analogy, be not far beneath the present ground surface. In the area between Mount Nebo and Provo Rock Canyon, the thrust plane likely passes deeper beneath the surface if overturning of beds be used as the criterion for nearness to the thrust plane.

Eardley (1934, p. 385) estimated, by analysis of a reconstruction of the Mount Nebo Anticline, that crustal shortening in the Mount Nebo area due to folding amounted to approximately twelve miles, and that an additional mile of shortening may have occurred in the thrust itself.

Folding of Arapien Shale of Gunnison Plateau

Foothills below the Cretaceous cliffs along the west side of the Gunnison Plateau are composed of two dome-like structures within the Arapien Shale. One dome centers on Deep Creek, and the other on Salt Creek Canyon. Axes of the domes trend northward and apex near the west edge of the hills. Arapien Shale contains salt and gypsum beds and yields disharmonically to beds beneath. Original thickness of disharmonically crumpled strata is uncertain as flowage of beds has probably increased apparent thickness. Typically intricate minor folds and faults are well exposed in Salt Creek Canyon along State Highway 11.

Folding of Eastern Half of Gunnison Plateau

Thomas (1960, p. 74), slightly modifying Hunt's (1950) earlier findings, discerns two periods of synclinal folding for the east half of the Gunnison Plateau. The older synclinal structure formed during the post-Indianola, pre-South Flat interval, and a younger, broad, synclinal structure, superimposed on this, has folded beds of the South Flat, Price River, North Horn, and Flagstaff formations.

Laramide Normal Faults

Although the most conspicuous normal faults in this area are those of general north-south trend related to the Cenozoic block faulting, there are also a number of east-west normal faults that are definitely older and are probably related to Laramide movements. Most of these older normal faults are found on the east face of the Southern Wasatch Mountains between Mona and Payson, and in the northern Long Ridge-southern West Mountain area. They are, for the most part, faults of relatively small displacement, and they cut transversely to the trend of the Mount Nebo Anticline.

A rash of normal faults in Payson Rock Canyon on the west flank of Loafer Mountain is closely associated with Laramide thrusting there as mapped by Metter (1955) and Peterson (1956). Sets of normal faults cutting Paleozoic beds on the north end of Long Ridge and the south end of West Mountain seem to be pre-thrust as mapped by Swanson (1952) on the south end of West Mountain. Elsewhere on Long Ridge the normal faults cut Paleozoic beds but are concealed beneath the early Cenozoic volcanics.

Laramide Thrust Faults

Nebo Overthrust

Nearly vertical Pennsylvanian, Permian, and Triassic beds, truncated on the west by the Wasatch Fault, and overlain on the east by Cretaceous Price River Formation, constitute the upper plate of the Nebo Overthrust. The thrust plane is best exposed in the vicinity of Gardner and Red Canyon near Nephi where Upper Paleozoic rocks are thrust on Jurassic shales. The overthrust has been traced eastward to the North Fork of Salt Creek Canyon but relationships in this area are not clearly known because the fault apparently rises in the stratigraphic section of the upper plate, becoming nearly a bedding plane fault within Mesozoic shales. Also the exposures are masked by much talus and vegetation in the North Fork area.

Muessig (1951, p. 139) discussed the possible extension of the Nebo Overthrust into the Long Ridge area west of Nephi and concluded that Paleozoic and early Mesozoic beds in Dog Valley were part of the upper plate of the Nebo Overthrust and that the lower plate of the thrust is not exposed there. However, an alternative explanation of the relations in Dog Valley might include the Jurassic Nugget Sandstone there as part of the lower plate since there is a cover of Cenozoic rocks a mile wide covering the zone where the thrust could be.

Eardley (1934, p. 385) thought that movement on the thrust might be as little as one mile, noting that apparent stratigraphic displacement decreases from Gardner Creek northeastward. Johnson (1959, p. 34) felt that displacement need not exceed five miles. Both figures represent minimum displacement estimates based on apparent stratigraphic displacement and it could be argued that almost any amount of additional displacement might have occurred by movement along bedding planes.

Santaquin Overthrust

Bedding plane slippage in the incompetent Ophir Shale has omitted this formation in places along the west face of Dry Mountain. This fact, coupled with anomalous position of Carboniferous limestones faulted against Cambrian and Precambrian units in Santaquin Canyon near Trumbolt Park led Eardley (1934, p. 383) to suggest existence of a possible major thrust which he called the Santaquin Overthrust. Relationships near Trumbolt Park are still not certainly known and, although Metter (1955) partially revised Eardley's earlier mapping, the area should be remapped in detail. Until this is done it may be prudent to withhold judgment as to the nature and extent of the Santaquin Overthrust for it may only represent bedding plane slippage in the Ophir Shale during Laramide folding of the Nebo area. The anomalous position of the Carboniferous units against the Cambrian and Precambrian may be the result of Cenozoic and/or Laramide normal faulting.

Payson Canyon Thrusts

Brown (1952), Metter (1955), and Peterson (1956) have each mapped thrust faults in the Payson Canyon area but their interpretations of the trend of the faults vary somewhat and Metter and Peterson even disagree as to the identification of upper and lower plates of the thrust in Payson Rock Canyon. The geologic map compiled for this volume differs somewhat from any of the source maps as the compiler has selected what seemed to him the best interpretation from the various sources.

The north end of Dry Mountain (Red Point) near Payson exposes Oquirrh Formation and a smear of Manning Canyon Shale overthrust on Mississippian units. Trend of the thrust beyond the immediate vicinity of Red Point is not certain. It may trend southward under the alluvium in Payson Canyon. Brown (1952) suggests that a right-hand tear fault follows Payson Canyon and has displaced the thrust. Metter shows the thrust trending southward from Red Point following a strike valley on the east slope of Dry Mountain, but Metter may have mistaken a shale member in the Great Blue Limestone for the Manning Canyon shale and consequently erred in his mapping of the trend of the thrust on Dry Mountain. Soil and vegetative cover hamper field work in this area but it should be rechecked to see if the problems can be more certainly resolved.

In Payson Rock Canyon Metter (1955) and Peterson (1956) agree on the location of the thrust fault separating Cambrian-Mississippian units from the Oquirrh Formation, but they disagree as to which constitutes the upper plate. The writer concurs with Metter in showing Oquirrh on the upper plate and thinks that possibly the Rock Canyon area is a window. Further field work is needed to clarify relations here.

West Mountain and Long Ridge Thrusts

Nearly vertical Oquirrh and Kirkman rocks are thrust over Cambrian-Mississippian strata at the south end of West Mountain. From this point southward two miles to the Keigley Quarries other thrusts of smaller apparent stratigraphic displacement cut Paleozoic beds. Trend and apparent direction of displacement varies in the several thrusts mapped south of West Mountain but it is tempting to regard the northernmost thrust as part of the same thrust sheet exposed at the north end of Dry Mountain near Payson.

Price (1951) has mapped a thrust fault within the Tintic Quartzite near Goosenest Canyon on Long Ridge. As is the case with the thrusts on West Mountain, it is impossible to accurately ascertain the amount of movement represented by this thrust.

Age of Laramide Deformation

Map relationships show rocks up to and including Jurassic Arapien Shale involved in Laramide folding and thrusting, and overlain by Cretaceous rocks assigned to the Price River Formation. Intra-Laramide movements as discussed above include pre-Price River, pre-South Flat, and pre-North Horn angular unconformities of various magnitudes.

Amount of Crustal Shortening Represented by Folds and Thrusts

Crustal shortening in the Southern Wasatch Mountains due to folding has been estimated by Eardley (1934, p. 385) to be approximately twelve miles on the basis of his reconstruction of the Mount Nebo Anticline. Shortening resulting from thrust-faulting is much more difficult to estimate. Eardley (1934, p. 385) estimated that one mile of shortening would account for the features along the Nebo Overthrust. Johnson (1959, p. 34) stated that displacement on the Nebo Overthrust need not exceed five miles. Johnson compared the stratigraphic section exposed in the upper plate in the Southern Wasatch Mountains with that exposed on Long Ridge and in the East Tintic Mountains and demonstrated a progressive thinning from west to east consistent with a normal stratigraphic succession. One must conclude that if any great amount of horiontal displacement is postulated for the upper plate on the Nebo Overthrust then Long Ridge and East Tintic areas were also involved in this horizontal translation. The problem then becomes regional in scope and is best attacked by comparing regional stratigraphy.

Eardley has attempted regional syntheses of the structure of northern Utah in several publications. His latest suggestion (1951, p. 330) is that the Nebo thrust may connect with the Willard thrust near Ogden, and that the Willard may becontinuous with the Bannock thrust in southeastern Idaho. According to this hypothesis, eastward thrusting of as much as 75 miles in places is postulated.

Crittenden (1961, p. 129) has attempted to estimate extent of thrust faulting in northern Utah by isopaching three parts of the Paleozoic sequence on the upper and lower paltes. He concluded that 40 miles of displacement was likely. The method used by Crittenden is valid but one questions that the amount of stratigraphic data presently available is sufficient to support the isopachs he drew. Rapid thinning of formations in northern Utah, attributed by Crittenden to thrust juxtaposition, has been usually regarded by stratigraphers as due to depositional thinning at the margin of basins and/or erosion of units of intra-Paleozoic uplifts. Crittenden himself admits that different assumptions would yield considerably different results. The problem merits continued critical examination.

Metamorphism Accompanying Laramide Deformation

In the Southern Wasatch Mountains, as elsewhere in belts of Laramide thrusting and folding, it is remarkable that so much movement is postulated and so little metamorphism has occurred. There is no metamorphism of rocks in the area due to Laramide deformation beyond local brecciation of strata next to fault planes and in the centers of tight folds.

CENOZOIC FOLDS

A conspicuous broad downwarp trends northwestward across the Southern Wasatch Mountains in the vicinity of Payson Lakes. North Horn, Flagstaff, and Moroni formations are preserved in its trough. The downwarp is cut by the Wasatch Fault and the North Horn and Flagstaff formations are preserved west of the fault, on Long Ridge, and on the top of West Mountain.

A second, smaller downwarp is present in the northwest part of the Gunnison Plateau where the Salt Creek Fanglomerate (?) occurs between two anticlinal uplifts of Arapien Shale.

Cooper (1956) described three anticlines and two synclines in the southern part of the Cedar Hills. The structures involve rocks of the Moroni Formation and trend slightly east of north for several miles north of the town of Moroni.

CENOZOIC NORMAL FAULTS

Pattern

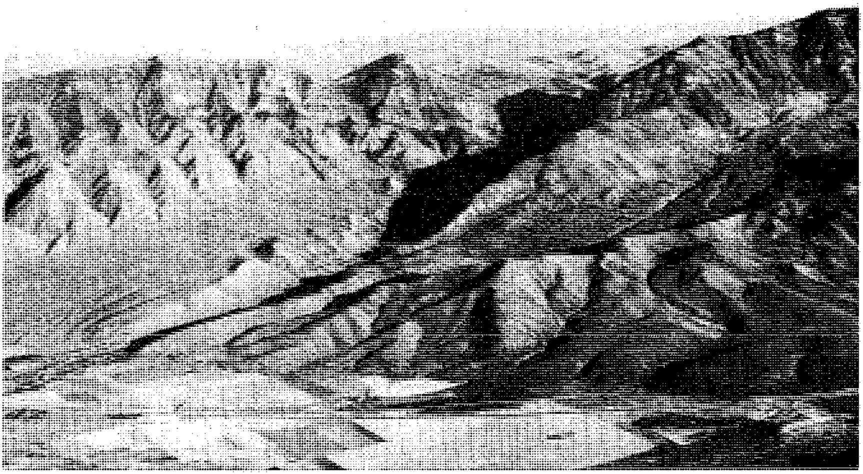
The Wasatch fault system has been discussed by many writers. Davis (1905), Gilbert (1928), Nolan (1943) and Eardley (1951) wrote some of the best known papers. Faulting is evidenced by triangular facets, piedmont scarps, stratigraphic displacement, and exposure of slickensided fault planes. The general trend of the Wasatch Fault is N. 10° W. north of Provo. South of Provo it describes an arcuate course to the mouth of Spanish Fork Canyon and from

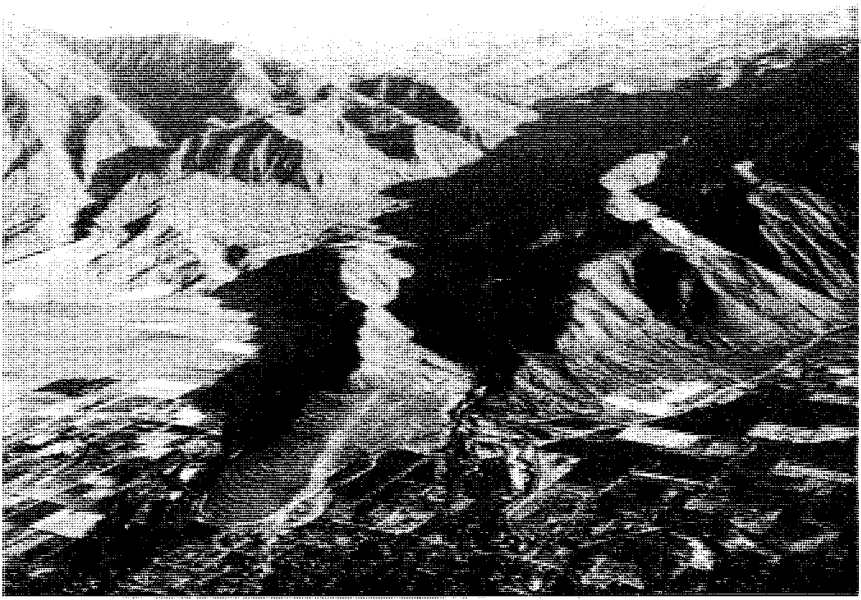
EXPLANATION OF PLATE 1

FIG. 1.—Low oblique air view of mouth of Santaquin Canyon. Wasatch Fault at base of Dry Mountain in left half of photo cuts across canyon near photo center. Hills to right of Santaquin Canyon expose Mississippian and Pennsylvanian rocks faulted against Cambrian.

FIG. 2.—Low oblique air photo of mouth of Payson Canyon. Oquirrh Formation exposed at canyon mouth above Lake Bonneville shorelines. Branch of Wasatch Fault at base of Santaquin Peak on left side of photo passes behind Dry Mountain to right of photo. Cedar Hills form rolling topography in middle distance.

HINTZE—PLATE 1





there to Mount Nebo it breaks into a series of *en echelon* faults of smaller displacement. The fault resumes its unity south of Mendenhall Canyon on Mount Nebo and continues along the west foot of the Gunnison Plateau to the south end of Juab Valley.

Long Ridge and West Mountain are also bounded by normal faults, the surface expression of which is not as obvious as the Wasatch. Cook & Berg (1961) infer the existence of these and other faults concealed beneath the valley alluvium on the basis of their regional gravity survey along the Wasatch Front.

Normal fault displacement along the east edge of the Gunnison Plateau is confirmed by Tennessee Gas Transmission's dry hole a mile south of Moroni which penetrated the sequence exposed on the plateau at depths indicating a vertical displacement relative to the plateau of about 5000 feet.

A few Cenozoic normal faults have been recognized within the Wasatch Mountains. Most trend northward and those near the range front are downfaulted on the west and seem to represent part of the Wasatch fault system. Others within the range are downfaulted to the east. A rash of faults of small displacement has been mapped by Muessig (1951) on Long Ridge southwest of Nephi. Two or three sets can be identified similar to fault sets found in the plateaus south of the edge of our map.

Amount of Displacement

No wells have been drilled in Utah Valley or Juab Valley entirely through the valley fill into the bedrock below. Thickness of valley fill, and hence displacement of valley relative to Wasatch Mountains is best estimated, therefore, from study of regional gravity patterns. Cook & Berg (1961) show that the greatest gravity anomaly yet found in their regional gravity survey of the Wasatch Front occurs in Utah Valley where the center of the gravity low, with a closure of about 22 milligals, lies 6 miles northwest of Spanish Fork. Because of lack of well control here it is not possible to directly convert the milligal figure into feet of alluvial fill but a reasonable conversion based on other areas would indicate valley fill as being 5000 to 8000 feet thick under Utah Valley. Juab Valley shows a gravity low of 18 milligals which would indicate a slightly shallower trench than that of UtahValley.

Along the Wasatch Front outcrops of bedrock are frequently exposed west of the main fault as horses representing partial downdropping along slivers of the Wasatch Fault system. Such a partially downdropped block is exposed at the mouth of Spanish Fork Canyon where Baker (1959, p. 157) notes that a displacement of 6000 feet or more is necessary to account for the present position of the Diamond Creek Sandstone.Vertical displacement along the Wasatch Fault system in Utah Valley may be estimated by adding the depth of valley fill to the height that the mountains project above the valley level. On this basis 10,000 to 13,000 feet of vertical movement has occurred along the Wasatch Fault in Utah Valley.

Age of Displacement

From a study of the entire Basin and Range region Nolan (1943, p. 183) concluded that block faulting probably began in Oligocene time and has been more or less continuous since. Topographically expressed faults, however, probably date back only to late Pliocene or early Pleistocene, although earlier movements may have occurred along them. No direct evidence is found in the

Southern Wasatch area to date the faults more closely. The faults here cut the early Tertiary volcanic rocks and have apparently been active into Recent times since they cut Lake Bonneville sediments at various places along the Wasatch Front. A fresh looking fault scarp at the base of Mount Nebo between Nephi and Mona has cut the heads of alluvial fans. There has, however, been no historic record of movement along the Wasatch Fault since pioneers came into the area more than 100 years ago.

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