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BRIGHAM YOUNG UNIVERSITY RESEARCH STUDIES

Geology Series Vol. 6 No. 6 August 19, 1959

STRUCTURE AND STRATIGRAPHY OF THE MOUNT NEBO - SALT CREEK AREA, SOUTHERN WASATCH MOUNTAINS, UTAH

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STRUCTURE AND STRATIGRAPHY OF THE MOUNT NEBO -- SALT CREEK AREA, SOUTHERN WASATCH MOUNTAINS, UTAH

A Thesis
submitted to
The Faculty of the Department of Geology
Brigham Young University

In partial fulfillment
of the requirements for the degree
Master of Science

by
Kenneth D. Johnson
August 3, 1959

ABSTRACT

The area between Mount Nebo and Salt Creek lies at the junction of three physiographic and structural provinces, namely, the Great Basin, the Middle Rocky Mountains, and the Colorado Plateaus. The southern boundary of the mapped area separates two local provinces -- those of the southern Wasatch Mountains and Gunnison Plateau.

The Mount Nebo -- Salt Creek area embodies two sequences of rocks: (1) An older sequence of Paleozoic sediments comprising the upper plate of the Nebo overthrust and (2) younger Mesozoic and Cenozoic sediments occupying the low foothills and valley areas, making up the sole of the thrust.

The area was subjected to compressive orogenic disturbances directed from the west in Middle and Upper Cretaceous times, resulting in the thrusting of Nebo and likely the Cedar Ridge thrust. Normal faulting of the Basin and Range disturbance in late Tertiary accounts for the Wasatch fault and most of the normal faults in the Salt Creek and Rees Flat area.

Water is the most important mineral resource at the present time. Several fans mantle the west face of the mountain, largest of which heads in Salt Creek Canyon. Wells recently drilled in Nephi produce an average of five to six second-feet of water per well. Further production is anticipated.

Large quantities of rock gypsum were taken from Red Canyon and Salt Creek several years ago. Workable deposits still exist but the structural attitude of the gypsum has discouraged further development.

ACKNOWLEDGMENTS

Most of this work was done with the counsel, guidance and cooperation of Dr. Harold J. Bissell, to whom the writer expresses gratitude, particularly for assistance in solution of paleontologic and stratigraphic problems as well as for reading the thesis.

Dr. George H. Hansen criticized some problems involved in this study and offered valuable suggestions. Information he made available and his support are especially appreciated. Mr. W.H. Brimhall also criticized parts of this paper and offered suggestions relative to the presentation of this thesis.

Thanks are due other geology faculty members for their assistance and suggestions in the final writing.

Sincere appreciation is expressed to my wife, Mary, for her constant encouragement in the completion of this manuscript. My parents, Mr. and Mrs. A.K. Johnson offered valued support during the course of this work.

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Correlation of the Arapien Shale of Salt Creek with that of the Wasatch Plateau.

INTRODUCTION

Location and Accessibility

The area under investigation is located in northeastern Juab County, Utah. It consists of 44 square miles between $39^{\circ}42'30''$--$39^{\circ}50'$ North Latitude and $111^{\circ}45'$--$111^{\circ}51'$ West Longitude. Parts of Townships 11 and 12 south, Ranges one and two east, Salt Lake Base Meridian, are included in the mapped area.

This region is accessible from the west by several dirt roads branching east from U.S. Highway 91 between Mona and Nephi, Utah. The best road leading into the western face of the southern Wasatch Mountains leaves the highway slightly south of Mona and reaches Left Fork, Water Hollow and Right Fork via Willow Creek.

The southern base of the High South Ridge is accessible by unimproved dirt roads branching north from State Highway 11. The Rees Flat road is graded as far north as Quaking Asp Canyon. The Foote's Canyon road borders the eastern limits of the mapped area.

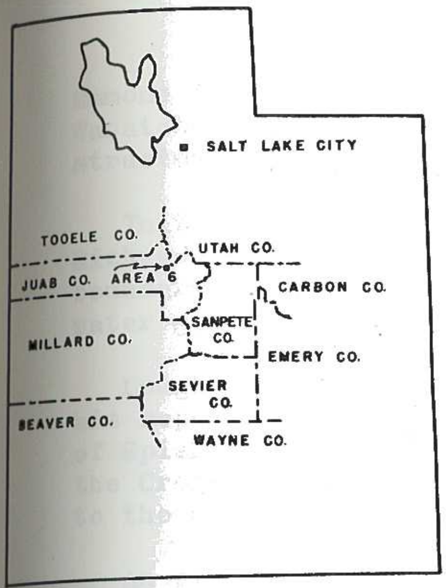
Mount Nebo and the top of the High South Ridge can be reached by a trail beginning up the North Fork of Salt Creek at the head of Andrew's Canyon.

Previous Investigations

Geologic investigations of the southern Wasatch Mountains and vicinity began with the early territorial and Fortieth Parallel Survey of the 1870's under the direction of Emmons (1877), Howell (1875), and Wheeler (1875). Beginning in 1900, Meinzer and Richardson reported on the ground water in Juab and adjacent counties. Investigations conducted by the U.S. Geological Survey from 1920 to 1945 were of reconnaissance nature only. Eardley (1932, 1933a, 1933b, 1934) added considerable data relating to this area from his studies of the southern Wasatch Mountains. More recently, students of Brigham Young University, Ohio State University, Iowa State College, and other institutions, have completed thesis work on this part of central Utah, but some of this is unpublished (see Plate 1).

In the early territorial surveys Wheeler (1875) pointed out that the structure of the southern Wasatch Mountains is anticlinal. Two years later Emmons (1877) briefly discussed the geology of Mount Nebo as follows:

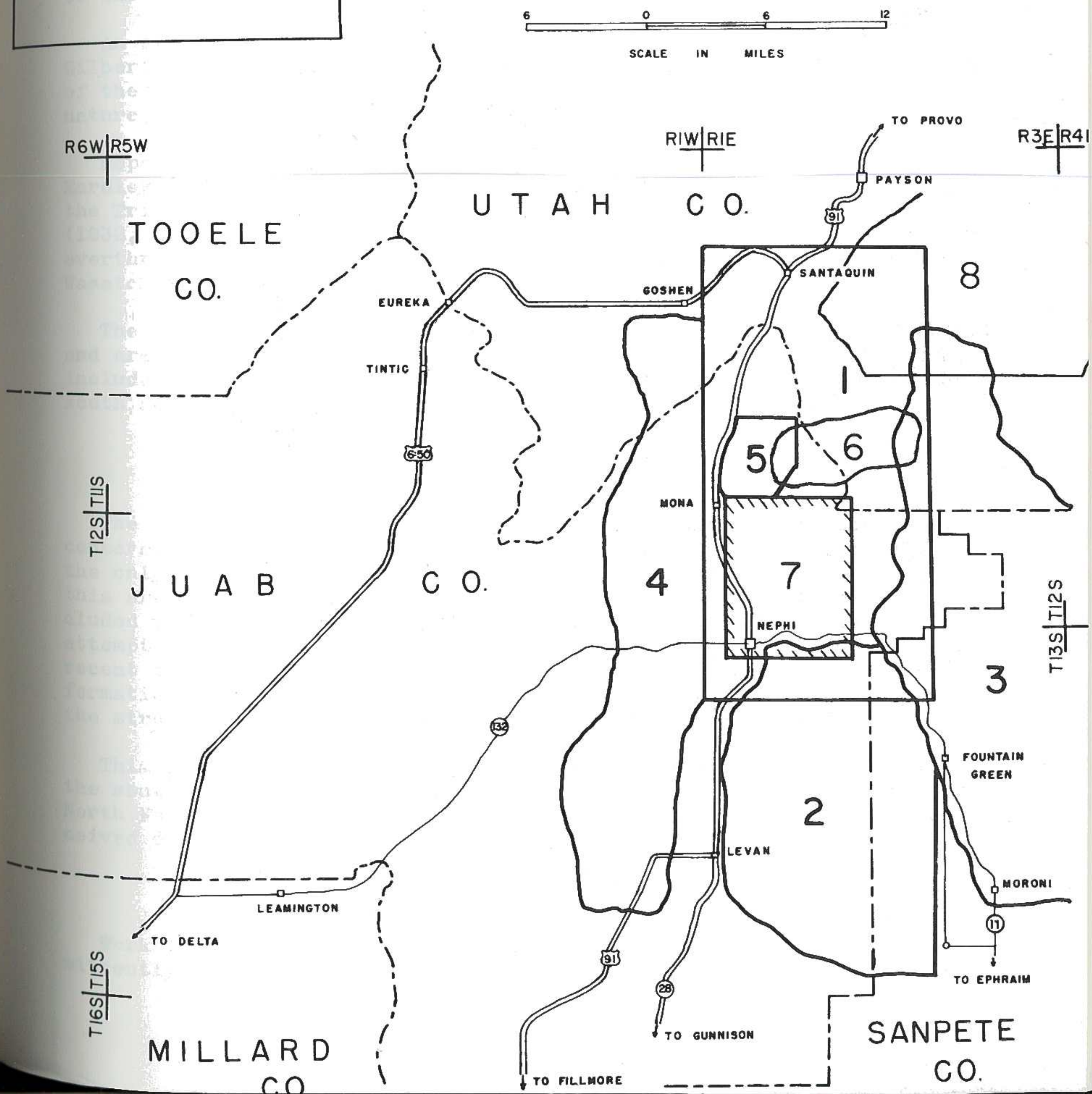
> The structure of this peak is that of a sharp anticline in which the western member is well developed, and indeed, forms the principle mass. The axis of the anticline is a little to the east of the summit, which is formed of thinly bedded limestones, and limy shales. On the east of the axis, the beds dip steeply, and soon disappear under the gently sloping sandstones of red and gray colors, which lie unconformably on the eastern flanks of the range, and are said to belong to the Tertiary formation (Emmons, 1877, p. 343-344).



INDEX TO MAPPING

PLATE I

1. Eardley (1933a, 1934)
2. Hunt (1950)
3. Schoff (1951)
4. Muessig (1951)
5. Smith (1956)
6. Phillips (1940)
7. This Report
8. Metter (1955)



Emmons is credited as the first to recognize the existence of the Wasatch fault. Later students have recognized this fault as a major structure of the Wasatch Mountains.

Initial ground water studies of central Utah were conducted by Richardson (1907). Although his report extended only into the eastern boundary of Juab County, Meinzer (1911) confined studies of ground water geology to Juab and adjacent counties.

Loughlin (1913) discussed the Santaquin -- Mount Nebo district in his report on the southern Wasatch Mountains. Following are the works of Spieker and Reeside (1925), which added considerable data regarding the Cretaceous and Tertiary systems of the Wasatch plateau, immediately to the southeast.

An extensive study of the Basin and Range structure was made by Gilbert (1928). The first 69 pages of his report include a discussion of the Wasatch Range, wherein considerable reference is made to the nature, location and interpretation of the Wasatch fault.

Reports related directly to this paper include the illustrations of Eardley (1933b, 1934, map 11). Prior to these reports, he discussed the Triassic, Jurassic and Tertiary systems located in Salt Creek (1932, 1933a). He was the first to recognize the existence of a major overthrust responsible for the position and structure of the southern Wasatch Mountains.

The Cenozoic rocks in the Cedar Hills were reported by Schoff (1951), and are correlated with those of Salt Creek. Other recent literature includes the reports of Smith (1956) to the north, Hunt (1950) to the south and Muessig (1951) to the west, as shown on Plate 1.

Purpose and Scope

The purpose of this project is to provide additional geologic data concerning the area between Mount Nebo and Salt Creek. Previously, the only attempt made to discuss the structure and stratigraphy of this area was made in writings by Eardley (1933a, 1934) where he included most of the Paleozoic rocks in the "Intercalated series". An attempt was made by the writer to re-evaluate the geology in light of recent findings, and to subdivide the Paleozoic rocks into series and formations. Further, additional information is furnished concerning the structural relationships and magnitude of the Nebo overthrust.

This paper nearly completes a sequence of recent studies made in the southern Wasatch Mountain area. Only a small area between the North Fork of Salt Creek and Foote's Canyon remains that has not received detailed investigation.

Methods of Investigation

Work in the field started in August, 1958, and proceeded intermittently until completion in August, 1959. Data gathered in the field was placed on aerial photos, scale 1:20,000 and was later transferred to topographic sheets of the same scale. Enlarged topographic sheets were used as a base map for final drafting.

A steel tape, Abney level and Brunton compass were used in measuring sections and recording attitudes respectively. Formational contacts, faults and other features were walked out in the field and recorded on the photos.

Thin sections and digestive samples were taken of fossils and rock specimens to aid in correlation. In addition, etchings and cellulose peels were made to identify certain fusulinids and rock textures.

MISSISSIPPIAN SYSTEM

Pine Canyon limestone

This formation outcrops in Dry Canyon and Couch Canyon in the SE¼ of Section 27 and NE¼ of Section 34, T. 11 S., R I E (see Plate 8), where it is responsible for domelike ridge patterns between the respective canyons. The Pine Canyon contact with younger formations can be traced continuously to the northern limits of the area discussed in this report. It extends farther northward in normal stratigraphic sequence to upper Payson Canyon where it passes beneath Tertiary volcanics (Peterson, 1956).

The upper contact of the Pine Canyon can be traced two miles southward from Bear Canyon to the mouth of Couch Canyon. At this point it is covered by landslides and is displaced by the Wasatch fault. Farther south the formation is present west of Juab Valley at Long Ridge, where outcrops are reported by Muessig (1951). The outcrops discussed above are correlated with the type locality in the Tintic district, where these strata were first defined by Lindgren and Loughlin (1919, p. 40). Recently, Morris (1957, p. 18-19) states that currently the U.S. Geological Survey is applying the name Deseret limestone to Lindgren and Loughlin's Pine Canyon limestone.

The Pine Canyon formation consists of marine limestone that is medium gray in color, with minor dolomite at the base. Although the limestones are predominantly medium-bedded and cherty, some of them are massive and relatively clean. Dolomites near the base are medium gray, weathering light gray, are medium to thick-bedded, and are medium crystalline. Some chert nodules, one to five inches in diameter are present. However, no defined chert bands were observed. The dolomites display meringue weathering.

A thin shaly phosphatic bed was noted near the base of the Pine Canyon in the Dry Canyon area. This can be correlated with the bed noted by Smith (1956) and Peterson (1956); however, a thickness of four feet was observed, indicating a thinning to the south. This bed was not located in Couch Canyon, suggesting that it disappears under the alluvium or pinches out. It is possible this bed may be correlated with a distinctive oolitic, phosphatic bone bed in Warm Springs Mountain east of Goshen, described by Sirrine (1953, p. 43).

Upsection, limestones of the Pine Canyon become fossiliferous with increasing amount of chert. Close examination of certain beds discloses recrystallized fossil "hash" and an abundance of crinoid ossicles 1 to 3 mm. in diameter. These encrinal limestones give way upward to thick-bedded limestones that are dark blue-gray and weather light gray.

The most striking lithologic character of the Pine Canyon limestone is the abundance of chert bands, nodules, and lenses comprising up to 50 percent of the formation. Chert bands, two to six inches thick, are interbedded with medium-gray limestone beds which vary in thickness from inches to one or two feet. This is especially characteristic midway in the formation. The chert bands are more resistant to weathering, giving this area a "wash-board" effect. Results of insoluble residue tests of rocks of this formation in the Keigley Quarries (Elison, 1952) show the interbedded silicious limestone to contain 67 percent insoluble material.

The formation becomes less fossiliferous but more calcareous near the upper contact. Bedding is thin, and gradational into the quartzites of the overlying Humbug formation. Chert occurs more in stringers rather than bands and nodules.

Topographically the formation is a ridge former. This is partially due to the vertical attitude of the formation in this area. Near the mouth of Couch Canyon vertical cliffs rise to heights of 200 to 300 feet, displaying a large step appearance where certain beds give way upward to vertical faces, assuming this pattern at intervals.

A complete stratigraphic section was not exposed in this area, but a partial section of 650 feet was measured up the north ridge of Dry Canyon. Other measurements in adjacent areas have been made as follows: 851 feet in North Canyon (Smith, 1956), 614 feet in Payson Canyon (Peterson, 1956), 538 feet in the northern part of Dry Canyon at Tie Canyon (Demars, 1956), 900 feet at Long Ridge (Muessig, 1951) and 1,000 feet at Tintic district (Lindgren, Loughlin, 1919). The latter two measurements indicate a thickening of the formation to the west (see Plate 7).

The contact of Pine Canyon with the Humbug formation has been mapped at the top of the thin-bedded calcareous limestone in the Pine Canyon formation. The base of the Pine Canyon is not exposed in this area; however, immediately to the north at the mouth of Bear Canyon it has been observed by Smith (1956) that the Pine Canyon lies conformably over the Gardner dolomite.

From fossil evidence collected by Lindgren and Loughlin in the Wasatch Mountains it was determined by Girty the lower and perhaps the greater part of the Pine Canyon limestone is of Upper Mississippian age. Gilluly (1932, p. 26) regarded the Deseret limestone in the Oquirrh Mountains as a partial correlative of the Pine Canyon. The Pine Canyon limestone of this area is easily correlated with that in other areas by lithological and stratigraphic evidences. The abundance of chert is characteristic of Mississippian strata. Its conformity with the Gardner dolomite is a regional feature. Lindgren and Loughlin (1919, p. 40-41) placed the base of the Pine Canyon at the alternating chert and limestone beds, which is the case at Bear Canyon.

Muessig (1951, p. 52-53) identified Syringothyris textus in the upper Pine Canyon on Goshen Hill. He concluded the formation to be of upper Madison age. Calderwood (1951, p. 39) reported a species of the genus Endothyra from the upper Pine Canyon in Cedar Hills; E.J. Zeller assigned the forms to lower Meramecian. From this evidence, the writer regards the Pine Canyon formation as Osagean and lower Meramecian age. The following fossils were collected from the Pine Canyon formation:

Lithostrotion sp.	*Ekvasophyllum* sp.
Lithostrotionella sp.	*Spirifer* sp.
Composita sp.	*Triplophyllites* sp.
	Crinoid fragments

Humbug formation

The Humbug formation comprises the valley at the heads of Bear and Dry Canyons, where it strikes west of south to form the floor of Couch Canyon. The formation forms characteristic valleys and slopes due to the platy weathering habit of the quartzites. A distinct valley is attributed to the Humbug formation, outlined clearly by the high massive ridges of the Pine Canyon and Great Blue formations on either side. In areas of gentle dip the Humbug assumes ledge and slope-forming characteristics.

Thickness estimations of 500 to 600 feet were made, because accurate measurements were inhibited by talus cones and steep slopes. In North Canyon 712 feet were measured by Smith (1956).

Resistant units in the Humbug are exposed at the head of Dry Canyon where the formation consists essentially of alternating light brown orthoquartzites and calcarenite beds. At the base of the formation, cross-bedded orthoquartzites predominate, and in certain thicknesses weathers medium brown to rust color. Midway in the formation the orthoquartzites grade into quartzitic sandstone and alternating thin to medium calcarenite beds. In the upper part of the Humbug formation medium gray carbonates grade into the overlying Great Blue formation, the contact being selected at the uppermost notable quartzitic bed of significance. Peterson (1956, p. 19) noted similar lithologic characteristics in the Humbug formation to the north, but the different bedding sequence suggests lateral facies changes and pinch-outs, a characteristic first noted by Spurr (1895, p. 372). Sirrine (1953, p. 48) reported this feature as characteristic of the Humbug formation at Warm Springs Mountains. Detailed lithofacies investigation of the Humbug in Central Utah are discussed by Livingstone (1955).

The Humbug formation rests conformably on the Pine Canyon limestone, where the contact was selected at the lowest notable beds of quartzite. Correlation of the Humbug formation with the type area in the Tintic district and other areas is based on characteristic lithology of interbedded siliceous sandstones, calcarenites, and orthoquartizites, as well as stratigraphic position. It can be correlated with the same units of Smith (1956) and Peterson (1956) in areas immediately to the north.

Lindgren and Loughlin (1919, p. 42) assigned an Upper Mississippian age to the Humbug formation, based on stratigraphic position and fossils identified by Girty. Livingstone (1955, p. 28), Weller, et al. (1948, p. 135) and others assign a Meramecian age to the Humbug formation.

Talus deposits and thick vegetation inhibited faunal collecting in the Dry Canyon -- Couch Canyon area. Unidentified fragments of corals and fossil hash located in wash deposits from encrinite beds constituted the only fossils noted by the writer. However, the writer feels the stratigraphic position of the Humbug formation and its characteristic lithologies are valid evidences to make accurate correlations and relative age determination.

Great Blue limestone

The nature of the Great Blue limestone is not considered in detail here because of the inaccessibility of the formation and its insignificant thickness as compared to adjacent areas. Most of the formation has been removed by faulting, leaving approximately 300 feet between the Humbug and Oquirrh formation. The bulk of this is brecciated and full of calcite veinlets.

The Great Blue limestone stands vertical near Cedar Ridge and becomes overturned as it extends to the northeast. From Cedar Ridge the formation crops out in a linear pattern across Couch Canyon and continues in a northeast direction to the head of Dry Canyon. Here it extends to Bear Canyon where the formation was mapped by Smith (1956, Plate 3).

The only section examined consists of massive limestone beds in gradational contact with the underlying Humbug formation. Although slope wash covered the contact a distinct break is readily seen due to the valley forming habit of the Humbug formation against the high ridges of the Great Blue limestone. From megascopic analysis the limestone appears to be a crystalline type, but calcite veinlets were so abundant that accurate determinations were not made. The veinlets are concentrated near the upper part, probably where the greatest fracturing occurred.

Most writers agree the Great Blue limestone to be of Chesteran age. Recent investigations conducted by Pitcher (1957, p. 7) firmly establish the Great Blue limestone of Jordan Narrows to be Chesteran. Possibly the lower member ranges into the lower part of the series, which may be the case in the southern Wasatch Mountains.

PENNSYLVANIAN AND PERMIAN SYSTEMS

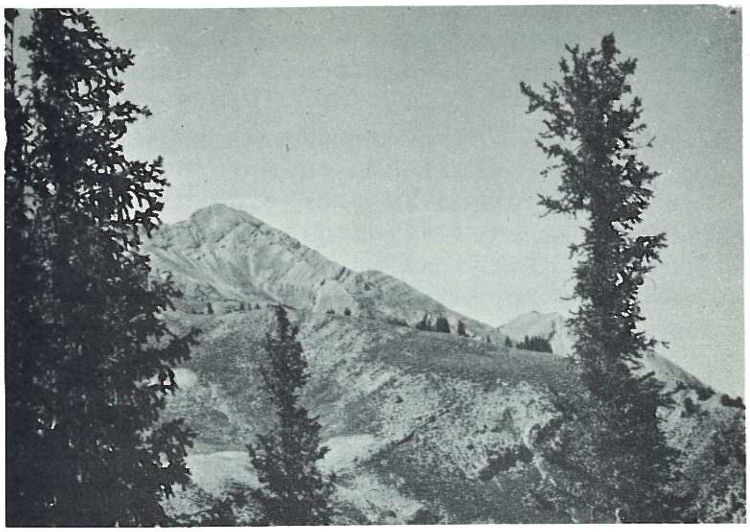
Oquirrh formation

The greater part of the mapped area, especially the high country, is composed of a thickness of over 11,000 feet of Oquirrh strata. It has been thrust to its present position by compressional forces from the west. Hell Hole Basin, the North-South-Middle Basins, Mount Nebo, and the High South Ridge are all composed of Oquirrh rocks.

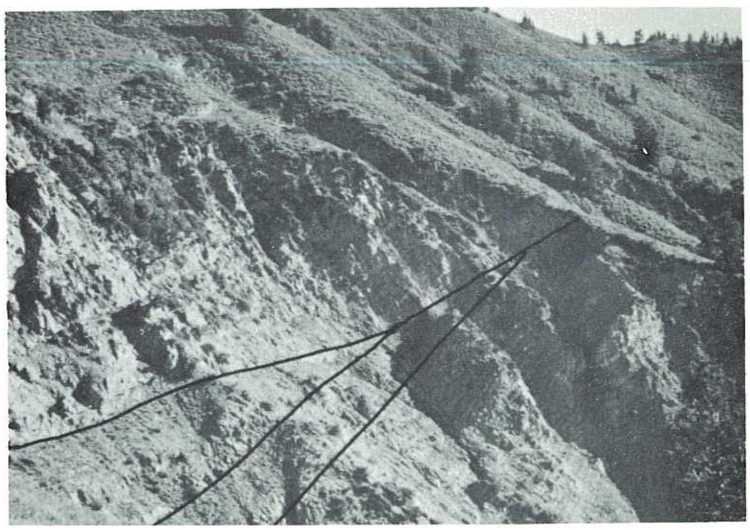
The upper limits of the formation first appear south of Ingram Canyon, where it rests in thrust contact with Arapien shales. From here it can be traced along the fault zone to Red Canyon where it emerges from the thrust zone and is in normal contact beneath the Kirkman limestone. The formation continues uniformly above Rees Flat to Quaking Asp Canyon where it veers to the northeast. The base of the

PLATE 2

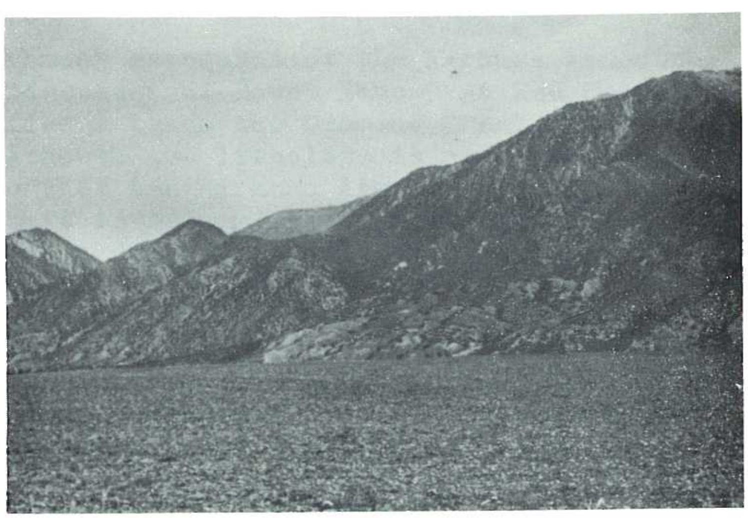
A. Photograph taken from the Nebo trail looking toward North Peak. The beds are overturned and compose the Oquirrh formation.



B. Beds pinching out in the Oquirrh formation



C. Landslide at the mouth of Couch Canyon.



formation emerges from fault breccia at Willow Creek. Here its strike continues northeastward across the head of Couch Canyon, then through the lower part of the North and South Basin.

The formation was measured by recording dips and strikes across a series of traverses, utilizing a topographic base of scale 1:12,000. Each traverse was taken where the slope and dip angle were uniform and in such a position as not to duplicate any beds. The thickness of each traverse was computed by trigonometric methods, arriving at a total exposed thickness of 11,500 feet.

Several thousand feet of the Oquirrh formation have been removed at one time or another by faulting. The Cedar Ridge fault and related imbricant thrusts are responsible for the greatest reduction of thickness. The presence of 5,000 feet of Springeran, Morrowan and Derryan strata in the south-central Wasatch Mountains and its absence in the Nebo district most likely indicates fault displacement rather than facies change or pinch-out. Such is probably the case directly west at Long Ridge where Muessig (1951, p. 57) reports Missouri and Virgil rocks, the former in thrust contact with Cenozoic rocks.

The majority of the Oquirrh rocks are overturned and dip to the northwest (see Plate 2a). In some areas the formation is vertical where normal faulting has readjusted the beds.

The rocks of the Oquirrh formation in this area are limited to Desmoinesian through Wolfcampian series. Faulting has removed older Oquirrh strata. Fusulina s. s. is abundant in the rocks at the base of the formation, a form common to Desmoinesian rocks. Overlying the Desmoinesian rocks are strata of Missourian and Virgilian ages, comprising the upper limits of Mount Nebo and the High South Ridge. Fossil zones near the upper contacts contain robust Triticites sp. and Schwagerina, common to Wolfcampian rocks. Lithologies are listed in the appendix.

PERMIAN SYSTEM

Kirkman limestone

To the present, the southernmost exposures of the Kirkman limestone have been reported to appear northeast of Mount Nebo. At Red Canyon a 300 foot unit of limestone lies between the Diamond Creek sandstone and the Oquirrh formation. Although the lithology is not consistent in all details with descriptions of the Kirkman limestone from other areas, the writer feels this unit to be similar or at least time equivalent of the Kirkman formation as described to the north. The stratigraphic position of the formation and the occurrence of robust Triticites sp. and Schwagerina, would favor its placement as Kirkman limestone. Some geologists feel the Kirkman limestone was deposited in an area adjacent to strong relief and under adverse shallow marine conditions. This would not only account for its haphazard nature of distribution along the base of the High South Ridge, but also its lithic variation from the norm.

The Kirkman limestone is not as continuous as related Permian formations, but exposures show it to trend in a similar direction along the base of the High South Ridge. Accessible outcrops appear at Red Canyon where the section was measured and described. Between Red Canyon and Foote's Canyon it is covered by alluvium and becomes incompetent, forming many of the valley floors along the base of the High South Ridge. From Foote's Canyon the formation strikes northeast to the North Fork of Salt Creek where it has been removed by faulting. It again appears as typical Kirkman limestone at Bennie Creek, northeast of Mount Nebo where exposures were reported by Bissell (1952, p. 588). The formation is topographically above the Diamond Creek sandstone because of the overturned nature of the beds in this area.

The base of the formation consists partially of a brecciated limestone, is dull gray, case hardened and exhibits good porosity. Generally, the lithology of the formation is consistent throughout, with the exception of a thin chert unit containing fusulinids midway in the formation. The upper part contains little breccia, is vuggy, and becomes arenaceous near the contact with the underlying Oquirrh formation. Total thickness is 300 feet.

Baker et al. (1949, p. 1187) assign Permian age to the Kirkman on the basis of Wolfcampian fusulinids from the upper part of the underlying Oquirrh formation and because the Kirkman appears to grade laterally and vertically into the overlying Diamond Creek sandstone which is inferred to be correlative with the Permian Coconino sandstone of the Colorado Plateau. Prior to this Baker and Williams (1940, p. 626) pointed out that the formation has no lithic counterpart in the Rocky Mountain region. Recently, Thompson and Bissell (1954, p. 27-31) have described Wolfcampian fusulinids from Central Utah.

The Kirkman limestone at Red Canyon is probably continuous with a 375 foot section of Kirkman limestone northeast of Mount Nebo at Bennie Creek. Between these two points the formation has been displaced by the Nebo overthrust.

In all areas examined the lower beds in the formation become arenaceous and grade into the underlying orthoquartzites of the Oquirrh formation. This would suggest a proximity to stable shelf deposition, not only on a broad scale but probably within its own basin of deposition. Basinward, relief increases, accounting for agitation and consequent reworked breccia in the lower part of the formation. Such phenomenon would provide a definite lithic break and furnish evidence for its unconformable nature with the Oquirrh formation.

Diamond Creek sandstone

Northernmost exposures of the Diamond Creek sandstone appear in North Strawberry Valley where 165 feet of sandstone was measured by Bissell (1952, p. 589). Southward, the formation thickens to approximately 1,000 feet at the type locality and to 1,140 feet in Spanish Fork Canyon near Castilla. From this point the formation thins southward to a thickness of 395 feet at Red Canyon, just north of Salt Creek (see Plate 3).

At the North Fork of Salt Creek outcrops of the Diamond Creek formation were reported by Baker et al. (1949, p. 1187), but faulting impaired accurate measurement. Muessig (1951, p. 61) reports 355 feet of Diamond Creek sandstone at Dog Valley, west of Nephi, Utah. The southernmost exposures of the formation in the Wasatch Mountains appear at the head of Red Canyon, where 395 feet of Diamond Creek sandstone is disconformable with the Kirkman limestone. Here it is overturned, dipping between 40 to 60° to the north and striking east-west along the base of the High South Ridge. At Foote's Canyon it swings northeasterly to the North Fork of Salt Creek where it intersects the Nebo overthrust.

Although the lithology of the formation is generally uniform throughout its entire thickness, a devision was made into two units on the basis of color, cross-bedding and minor features. An upper 45 foot unit consists of light brown sandstone with thin units of intercalated limestones. This is underlain by 350 feet of white to light pink cross-bedded sandstone.

Lithology and stratigraphic position allow accurate correlation of the Diamond Creek sandstone with sections to the west (Muessig, 1951, p. 61), to the north (Bissell, 1952, p. 589) and with the type locality at Little Diamond Creek.

According to Baker and Williams (1940, p. 625) the Diamond Creek sandstone may be continuous with the Coconino sandstone of the San Rafael Swell. This is based on the sandstone's position beneath limestone beds considered to be equivalent to the Kiabab limestone. The possibility does exist, however, that the Diamond Creek sandstone occupied a basin or depression apart from those of the San Rafael area and is a correlative with sections of this area on the basis of time and environment, rather than continuity. The rapid thinning of the formation, from 1,140 feet at the Right Fork of Hobble Creek to 395 feet at Red Canyon (see Plate 3) would suggest a complete pinching out as it approached the Wasatch line.

The age of the Diamond Creek sandstone is based on its stratigraphic position. Previous workers have reported no fossils in other areas to substantiate its age by faunal evidences. It is possible, however, to determine the age of the formation with reasonable accuracy on the basis of fossils in underlying strata. In the southern Wasatch Mountains Schwagerina is present in the upper or highest parts of the Oquirrh formation, indicating early Permian age. Baker and Williams (1940) placed the Pennsylvanian-Permian boundary somewhat below the top of the Oquirrh formation, supported by the presence of Pseudoschwagerina and Schwagerina. At Red Canyon, the Diamond Creek formation lies above a Schwagerina zone in the Kirkman limestone, placing it in the Permian. Muessig (1951, p. 61) reports the Diamond Creek sandstone in a position about 2,000 feet above the occurrence of Schwagerina.

Park City formation

The Park City formation has been traced northward into Idaho, to southwestern Montana, central and eastern Wyoming, northwestern Colorado, and in this report to the southermost extremity of the Wasatch Mountains. Here it can be traced as an almost continuous unit from the head of Red Canyon northeastward along the base of the High South Ridge to the head of Foote's Canyon. At this point exposures are continuous to the North Fork of Salt Creek where outcrops have been reported by Baker, et al. (1949, p. 1188). Accessible exposures occur along the base of the High South Ridge at the North Fork of Red Canyon. Other exposures crop out on each ridge adjacent to the head of Quaking Asp Canyon.

The Park City formation comprises the youngest Paleozoic rocks in the upper plate of the Nebo overthrust. At the head of Red Canyon it is overturned and rests in juxtaposition with the Triassic Nugget sandstone. Eastward it remains overturned, comprising in part the overturned limb of the large overthrust anticline. In localities where the formation is not in direct contact with the thrust zone, it is overlian by the Woodside formation of Triassic age. At Red Canyon, where the formation measured 646 feet, the beds dip 55° overturned to the north and retain this general attitude in all areas examined.

The Park City formation, considered to be the youngest Permian formation in the Wasatch Mountains, has been divided into a tripartite lithofacies by Baker, Huddle and Kinney (1949, p. 1188). These units persist in the formation throughout most of the southern Wasatch Mountains. Similar tripartite facies have been recognized in north Strawberry Valley (Bissell, 1952, p. 590) and near Thistle, Utah (Harris, 1953, p. 29). Lithologic descriptions given in this paper are correlated with the three-fold descriptions of the foregoing geologists (see Plate 3) as well as the terminology applied to the Park City formation by McKelvey et al. (1956).

Undoubtedly the shores of the Park City seas proximated the Salt Creek area as indicated by the regressive type sediments in the upper part of the formation and an overall thin section as compared with sections to the north. Although this is the case, still a similar three-fold unit persists which was described at the head of Red Canyon. Previously, the Park City outcrops at the North Fork of Salt Creek were considered to be the basal unit of the tripartite series, but lithologies of the formation in this area and its conformable nature with adjacent strata show the entire formation to be present, which is likely the case at the North Fork of Salt Creek. In this respect the formation can be deceiving; in certain areas thick units of sedimentary breccia persist in the upper part of the formation and tend to confuse analysis. Such was the case at Quaking Asp Canyon where nearly 200 feet of breccia compose the upper Park City formation. Immediately to the west, at Red Canyon, the upper unit is composed of matrix and fossiliferous limestone (see Plate 6a) and in some places chert bands comprise up to 70 percent of certain beds. Thin bedded, dark-gray to black shales and a minor thickness of phosphate are found at the base of the upper massive limestone unit.

In the lower member of the tripartite series calcarenites predominate, grading upward into fossiliferous-fragmental and cherty limestones. Directly beneath the phosphate bed lies a fossiliferous unit, composed mainly of brachiopod hash. Lithologies are similar between the upper and lower massive limestone units, but more chert and less arenaceous material characterize the upper member.

For correlation purposes the following terminology is applied to the Park City formation:

Units 5 and 6, as described in the appendix, were classed previously as the upper member of the Park City formation, and are referred to here as the Franson member. This name was applied by McKelvey et al. (1946, p. 2842) to exposures of light gray, cherty or carbonate rock, and calcareous sandstone that underlie the Woodside formation on the north side of Franson Canyon, in Summitt County, Utah. The Franson has been traced to Montana, Wyoming and Idaho, where it was considered to be a part of the Rex Chert member (Klepper, 1951, p. 61).

In eastern Utah and northwestern Colorado, the Franson is underlain by the Weber sandstone. In northernmost Utah, eastern Idaho, western Wyoming, and southwestern Montana the Franson interfingers basinward with the Rex, Tosi and Meade Peak members of the Phosphoria formation, and in Utah its upper beds intertongue shoreward with the red and greenish gray shales of the Woodside formation (McKelvey et al., p. 2843).

Evidence is lacking to prove the existence of a pronounced unconformity at the top of the formation. Eardley (1933a, p. 323) found no abrupt lithologic break or unconformity at the North Fork of Salt Creek. Here the contact between the Paleozoic and Mesozoic rocks was selected arbitrarily. At the base of the High South Ridge the Franson member is partly a conglomerate of breccia fragments, a feature also noted by Baker (1949, p. 1188) at the North Fork of Salt Creek and at Hobble Creek. This would suggest a period of reworking prior to the accumulation of Woodside sediments. This idea is favored and is consistent with the broad unconformity and erosional epoch that characterized most of the area at this time. McKee (1938, p. 54) describes such an unconformity ranging throughout the Colorado Plateau over an area of 80,000 square miles.

Unit 4 is correlated with the Meade Peak phosphatic shale member of the Phosphoria formation (see Plate 3). This name was derived from Meade Peak, about two and one-half miles south of Phosphoria Gulch. Meade Peak also refers to the phosphatic shale member of Richards and Mansfield (1912, p. 683) of Montana and to the middle shale member of the Park City formation (McKelvey et al., 1956, p. 2845). In most of Utah the Meade Peak tongue underlies the Franson member.

The lower member of the Park City formation is retained as a term including units 1, 2, and 3. Here it rests conformably on the Diamond Creek sandstone. Although the contact is gradational, a massive limestone bed appears at the base of the member to provide a lithic break where contact was selected. In northern Utah the lower member overlies the Weber quartzite and in Wyoming it overlies the Tensleep sandstone, the Quadrant quartzite in Montana, and according to McKelvey et al. (1956, p. 284), the Wells formation in Idaho.

The lower member of the Park City may be of high Wolfcampian age. In other areas it has been reported that both beds of Leonard age and

PERMIAN CORRELATION IN CENTRAL UTAH

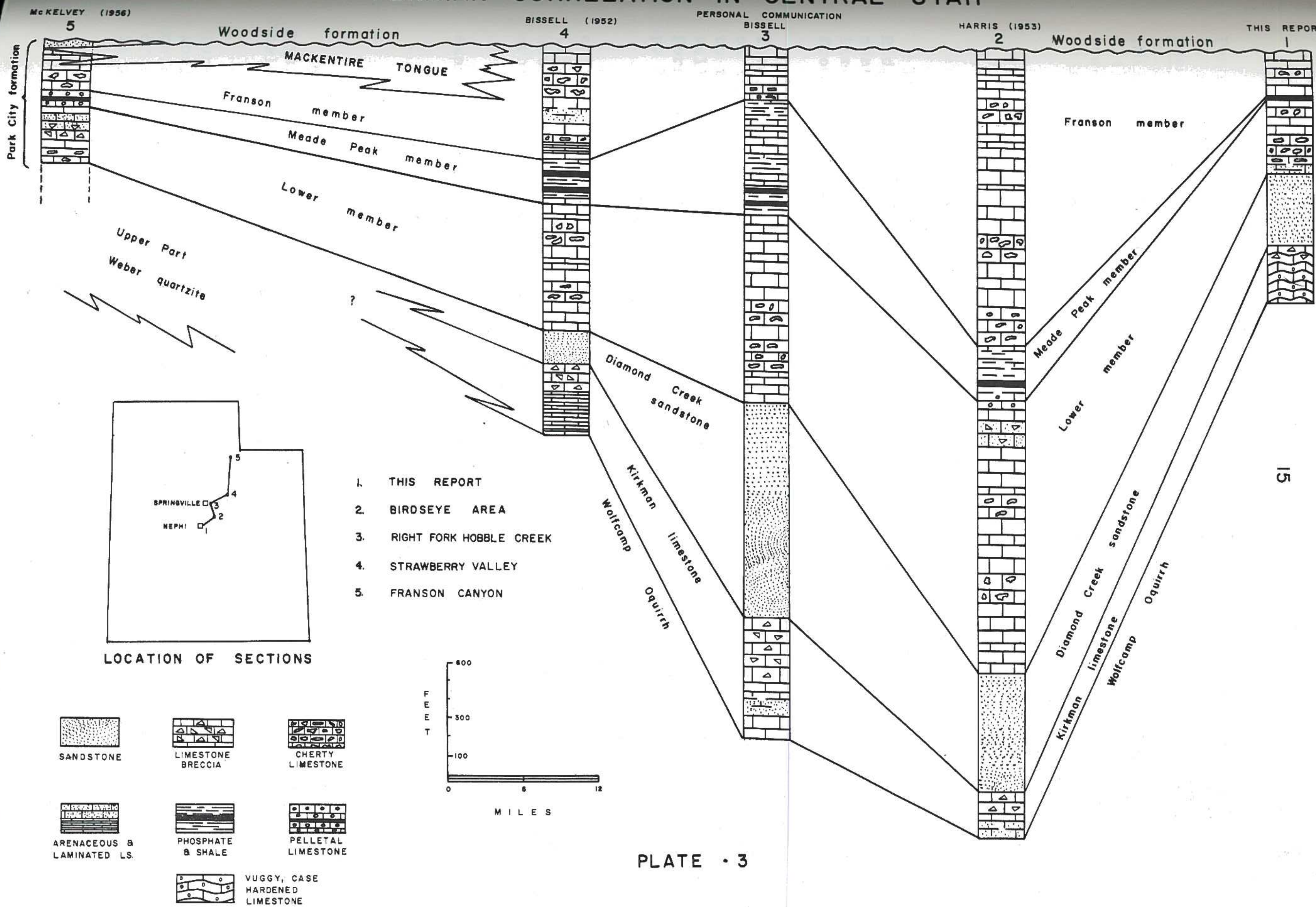


PLATE · 3

Pennsylvanian age occur in the lower member of the Park City (McKelvey et al., 1956, p. 2856). Beds of the Meade Peak member contain Pseudogastrioceras spp., a representative Leonardian Ammonoid found in the black calcareous shales at the Right Fork of Hobble Creek (Miller, et al., 1957, p. 1063-1064). Baker and Williams (1940, p. 624) reported a faunal element containing Dictyoclostus ivesi in the lower member of the Park City formation. This would indicate Kaibab or Toroweap age (Leonard equivalent) of the rocks.

TRIASSIC SYSTEM

Woodside shale

The Woodside is poorly exposed along the base of the High South Ridge. Outcrops yielding most data appear at the base of steep slopes near Rees flat where the formation is in contact with the Thaynes limestone. The lower beds in the formation are covered with debris from resistant overlying formations.

Characteristic valleys and gentle slopes eroded in the Woodside formation stand out in striking contrast to the ledges and cliffs of the Park City formation. On this feature alone it is possible to trace the formation in areas where outcrops are scarce. Such a valley exists northeast of Foote's Canyon and extends to the North Fork of Salt Creek where outcrops are reported by Eardley (1933a, p. 324).

A complete section was not available for measurement, but an estimated thickness would be approximately 300 or 400 feet. Eardley (1933a, p. 351) measured 200 feet at the North Fork of Salt Creek but pointed out that the lower limit of the formation is purely arbitrary and could without difficulty be shifted to lower horizons.

Only the upper part of the formation was exposed in all areas examined. Here the lithology consists of:

Sandstone: Maroon to dark red-brown; calcarenite in part to coarse grained calcareous sandstone; good porosity and somewhat friable; forms valleys; estimated thickness between 300 and 400 feet.

The Woodside contact with the overlying Thaynes limestone is visible in several localities. In all cases the contact was selected below the lowest limestone unit in the Thaynes formation.

Baker (1947) correlates the Woodside formation with the Moenkopi formation of the Colorado Plateau region on the basis of stratigraphic position and lithology. It is doubtful, however, that Baker had reference to the entire Moenkopi section. Based upon correlation of the Thaynes and Ankareh with the Chinle and Shinarump (see p. 19) it is likely that the Woodside is synchronous with the lower Moenkopi.

Thaynes limestone

Exposures of the Thaynes limestone in the Nebo area occur near the head of Mining Ridge. Only 300 feet of the formation are exposed here because of acute truncation by the Nebo overthrust. Eastward the thickness of the formation increases as it emerges from the thrust zone. From Mining Ridge the formation crops out intermittently on different ridges along the head of Rees Flat, until it reaches Foote's Canyon where the upper limestone beds are in contact with the overlying Ankareh formation. From this point the formation continues in a northeasterly direction until it crosses the North Fork of Salt Creek Canyon between Bear Hollow and Cow Hollow where exposures are reported by Eardley (1933a, p. 326).

The upper beds in the formation are in thrust contact with the Arapien shale, exposing only the base of the formation. Similar problems confronted Eardley at Salt Creek, where varying dips and acute truncation by the Nebo overthrust interfered with accurate measurement. Thickness of the formation increases to the northeast as it emerges from the thrust zone. In Salt Creek it reaches a maximum thickness of 1,000 feet (Eardley, 1933a, p. 326).

The Thaynes rests in apparent conformity with subjacent and superjacent formations. The only observed outcropping Thaynes-Woodside contact occurs on Mining Ridge where a lower limestone unit in the Thaynes marks the base. From this point there is an abrupt lithic transition into the red-brown sandstone of the Woodside. The contact is also expressed topographically on the ridge by a deep saddle formed in the friable Woodside sands.

At Foote's Canyon the Thaynes-Ankareh contact has not been disturbed by faulting. Most of the area is covered by talus but the relationship between the two appears to be conformable.

Similar lithologies, stratigraphic position, and fossil evidence enable the writer to correlate the Thaynes formation with the rocks described by Eardley (1933a, p. 326) which in turn are correlated with the type locality. Eardley's faunal collection include: Aviculepecten sp.; Pseudomonotis? sp.; Bakewellia? sp.; and Myacites. These fossils are congeneric with those found in the Thaynes of the Park City district.

In addition the writer found fair specimens of Meekoceras, a representative Lower Triassic ammonite and Pentacrinus whitei, which is common to basal limestone beds.

Ankareh shale

Ankareh exposures are confined to two localities: (1) At the mouth of Red Canyon, the distinct red shales can readily be seen against the light background of Arapien shale and Nugget sandstone. Here the formation assumes all possible attitudes and is highly contorted as a result of faulting. Its contact pattern with adjacent formations would indicate secondary compressional forces originating from at least two directions of different ages and at right angles to each other, probably from the north and west. (2) At the Left Fork of Foote's Canyon, the Ankareh has received relatively little disturbance, other than its vertical and overturned nature resulting from the Nebo overthrust. Its contact with the Nugget sandstone is conformable. From Foote's Canyon the formation thickens as it emerges from the thrust zone. It continues in a linear pattern to Andrews Canyon, where 1,500+ feet of Ankareh was reported by Eardley (1933a, p. 329).

A complete section was not exposed along the base of the High South Ridge as a result of faulting. At the mouth of Red Canyon it is approximately 400 feet thick. Midway up the canyon it disappears beneath the thrust zone and does not reappear agin until it reaches Foote's Canyon. Here 850 feet of Ankareh rock are exposed and increases in thickness to 1,500 feet at the North Fork of Salt Creek Canyon.

The thrusting has affected only the lower beds in the Ankareh shale. As the formation grades into the Nugget sandstone above, the contact is placed at the highest red shale beds.

Whether the Ankareh shale actually exists in the southern Wasatch Mountains has been a subject of controversy for several years. Eardley (1933a, p. 328) first described Ankareh exposures in the North Fork of Salt Creek as red sandstones and shale, with some limestone beds intercalated. Later it was pointed out (Spieker, et al., in Schoff, (1937, p. 27) that at least some, if not all, of the beds so mapped are actually Nugget rather than Ankareh. Muessig (1951, p. 65) made the following statement:

> The dominant lithology of the "Ankareh" mapped by Eardley is a thick, massive, red cross-bedded sandstone, a description which cries "Nugget" when uttered in the Wasatch Mountains.

The foregoing conclusions have more in common than appears at the first view. In certain respects there is fact in each observation, which is discussed below. My own conclusions follow more closely the thinking of Dr. Eardley. This is based on the following data:

(1) In spite of the intense distortion at Red Canyon, there exists a clear break between the red, friable Ankareh shales and the white Nugget sandstone; the contact was selected at this point.

(2) Only the upper beds of the Ankareh formation are exposed, still there is an excellent similarity of lithologies between the rocks here and those of the type locality.

(3) In all cases the lower member of the Nugget sandstone is white, overlain by beds of pink sandstone. At Foote's Canyon a massive red sandstone underlies the white member of the Nugget sandstone. This red sandstone in turn is underlian by shales characteristic of those found in Red Canyon. For the purpose of this report the massive red sandstone is included in the Ankareh formation which is correlated with the Ankareh sands of Eardley. Lithologically, the massive red sandstone may better fit into the

overlying Nugget, but here it is considered to be a lateral facies change within the Ankareh formation. To include the red sands in the Nugget would disrupt the continuity of the Ankareh shale as it thickens to the northeast. Again it would add a thickness and lithology to the Nugget which is not characteristic of the outcrops observed in the Nebo district.

(4) In many areas the Triassic beds undergo marked facies changes. According to Stokes (1949, p. 82) all Triassic formations experience rapid facies changes as they are traced eastward along the flanks of the Uinta Mountains.

(5) According to Eardley (1933a, p. 329) the Ankareh formation can be traced almost continuously down the east flank of the Wasatch Range from the type locality to the Nebo district.

In the foregoing discussion the red shales and massive sandstones would be restricted to the so-called upper red portion of the Ankareh rocks. In most areas the formation falls into a tripartite classification, a lower red portion, an intervening coarse-grained sandstone of conglomerate, and the upper red portion, the latter being present at Red Canyon and Foote's Canyon.

Thomas and Krueger (1946) restricted the name Ankareh to beds above the Thaynes and below the conglomerate stratum or intervening layer. For the conglomerate they proposed the name Gartra and for the beds between this and the main massive Nugget, the name Stanaker. In this sense the Ankareh rocks here would be correlated with the Stanaker of Thomas and Krueger. With this in mind, the Ankareh of the Nebo district (Stanaker) is correlated with the Chinle formation on basis of similar lithologies and their stratigraphic position below the Nugget sandstone. Baker (1947) correlates the intervening conglomerates (Gartra) with the Shinarump conglomerate. This being the case, the lower red portion of the Ankareh is probably a correlative with the upper Moenkopi.

JURASSIC SYSTEM

Nugget Sandstone

The white to pink, generally coarse grained, calcareous to quartzitic sandstone, which is here referred to the Nugget sandstone, crops out at the mouth of Red Canyon about two miles northeast of Nephi, Utah. The term Nugget is used here in keeping with prevailing usage throughout the Wasatch Mountains. To the south, the term Navajo is preferred.

Nugget exposures at Foote's Canyon crop out along the west side of the ridge that divides the Left and Right Fork of the Canyon. Here the formation is vertical to overturned. Certain areas of Nugget exposures are covered by the Salt Creek fanglomerate which impaired accurate measurement, especially at the Nugget-Arapien contact. At the mouth of the Left Fork, the Nugget is apparently conformable with the overlying Arapien shales. The boundary is abrupt from the massive oolitic limestone of the lower Arapien to the friable sandstones of the Nugget. Midway up the Left Fork, white sandstones rest conformably on bright red sandstone and shales, forming the Nugget-Ankareh contact. This contact appears gradational and the formations show perfect physical conformity. Faunal evidence is lacking to substantiate this observation which allows some possibility for a time-break to exist between these formations. The writer feels this is not likely, however, and considers the Nugget sandstone to be a partial correlative with the Navajo formation and possibly the Kayenta and part of the Wingate. Mathews (1931, p. 42) considers the top of the Nugget sandstone in the Wasatch Mountains as an unconformity, but it seems most likely that diastems would be characteristic rather than a regional unconformity.

The Nugget sandstone is continuous with the Navajo formation of southeastern Utah. This correlation is based on its stratigraphic position and distinct lithology. Possibly the Nugget-Navajo formations were deposited contemporaneously by eolian agents in a continuous basin. This basin has been recognized to the west by Longwell (1949, p. 961) where Nugget sands are represented by the Aztec sandstone in southeastern Nevada. The extreme western margin is unknown, but eastern Nevada would seem a reasonable estimate of its position. The typical Nugget sandstone of southwestern Wyoming probably best represents the northeastern limits of the formation. Because the Nugget is continuous with the Navajo sandstone, its margin of deposition to the south would be represented by the margin of the Navajo formation.

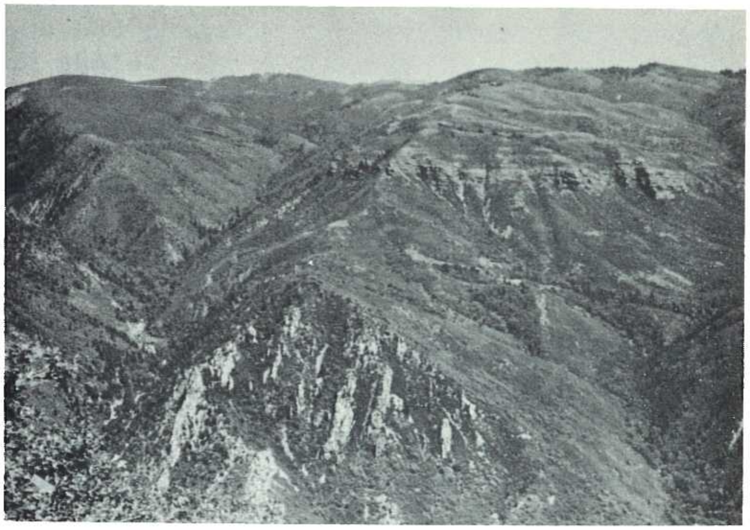
The age of the Nugget is questionable as diagnostic fossils are lacking. The only fossil reported from the formation is Trigonia, indicating a marine type environment. This is not consistent with the lithology of the formation in the Wasatch Mountains and it is doubtful that this fossil came from the Nugget. The counterpart of the Nugget formation in southern Utah has yielded few fossils. Geologists have found a small saurischian dinosaur near Kayenta, Arizona, and dinosaur footprints have been observed in the lower part of the Navajo formation on the east flank of the San Rafael swell, indicating post-Triassic age. In view of the foregoing, the Nugget most likely represents a time interval of late early Jurassic to late middle Jurassic.

Arapien shale

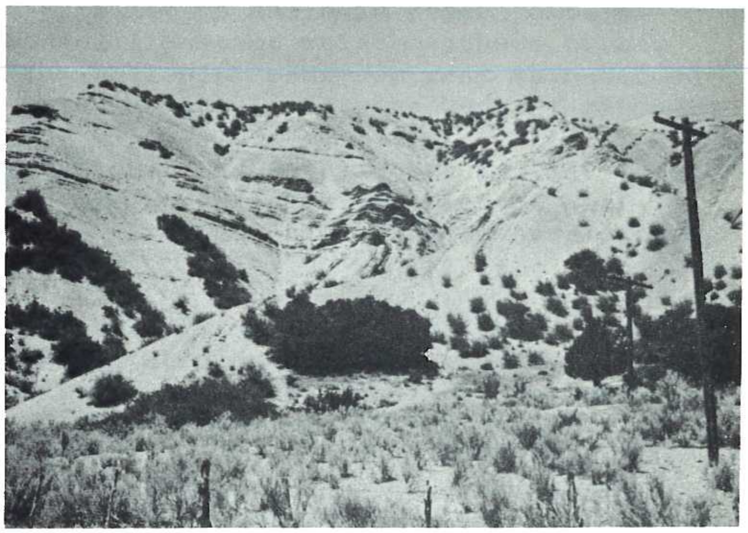
The name Arapien is applied by Spieker (1946, p. 123) to a sequence of red to gray shale and fine-grained sandstone, salt and gypsum-bearing in part, with Arapien Valley, south of Mayfield, Utah, designated as the type locality. Spieker divided the formation into the upper Twist Gulch member and the Twelvemile Canyon member below. Subsequently the term Arapien shale was restricted by Hardy (1952, p. 91-95) to the rocks formerly included in the Twelvemile Canyon member. He likewise raised the term Twist Gulch member to formational rank.

Originally five lithologic field types (not of formal rank) were recognized by Spieker (1946, p. 124); numerically younger:

PLATE 4



A. Photograph taken from Andrew's Ridge. It shows the Price River formation resting on vertical Paleozoic rocks.



B. Folding and thrusting in the Arapien shale at Salt Creek.

C. Distorted Arapien shale at Salt Creek.

5. Thin-bedded red siltstone and shale.
4. Compact red salt-bearing shale.
3. Gray gypsiferous shale with red blotches.
2. Light-gray siltstone and shale with occasional beds of ripple-marked sandstone.
1. Gray, thin-bedded limestone.

Spieker included types 1 to 4 in the Twelvemile Canyon member, and type 5 made up the Twist Gulch member.

Hardy (1952b, p. 15) further subdivided the Arapien shale into the following units:

E. Brick-red silty shale, locally salt-bearing.
D. Alternate layers of bluish-gray and red gypsiferous shale with blotched appearance.
C. Bluish-gray calcareous shale with gray thin-bedded calcareous sandstone.
B. Bluish-gray and red gypsiferous shale. Blotched appearance similar to unit D. Red gypsiferous shale in upper part.
A. Gray shale, gray thin-bedded limestone which weathers brown, red shale, gypsum in thin lenticular beds; or gray thin-bedded argillaceous limestone with massive lenticular beds of gypsum.

The lower units described by Spieker and Hardy occur in Salt Creek. Although additional lithofacies were noted in the Arapien of Salt Creek, a correlation has been made with the units of Spieker and Hardy (see fig. 1).

The Arapien shale is widely exposed in Salt Creek Canyon. Here it makes up the foothills along the southern base of Mount Nebo, and extends southward to form the hills west of the Gunnison Plateau. Eastward, near the North Fork of Salt Creek, the shales are covered by pyroclastic rocks and associated Tertiary formations. Schoff (1951, p. 623) reported an isolated outcrop of Arapien shale near the mouth of Red Creek in the Cedar Hills area. Outcrops of greater areal proportions occupy a long, wide belt extending from Gunnison to Richfield, Utah.

The distorted nature of the Arapien shale complicated stratigraphic analysis. In certain areas, beds have been duplicated, especially near the thrust zone. In other areas, this has always been a deterrent factor in measuring the Arapien shale accurately. Measurements made of the Arapien shale are as follows:

Spieker (1949)	Sanpete-Sevier Valley	10,000+
Hunt (1951)	Northern Gunnison Plateau	4,493+
Hardy (1952)	Wasatch Plateau	6,000+
Hardy and Zeller (1953)	West-Central Gunnison Plateau	4,400
This report (1959)	Salt Creek	8,500

Near the thrust zone in Red Canyon, lithographic and thin-bedded limestones predominate. A massive, oolitic limestone forms the lowermost exposed Arapien, above which workable gypsum deposits appear. The basal units of oolitic and lithographic limestones immediately over the Nugget sandstone at Red Canyon are not recognized on the east side of the Gunnison Plateau or in Sevier Valley. Of the five units retained by Hardy in the Arapien Shale (see page 22) only the lower three, and possibly some of unit four, appear in this area. Unit one, which crops out in Red Canyon and makes up the northern half of Mining Ridge, consists of a basal member of massive, oolitic limestone. The crest of the ridge consists of 80 feet of workable gypsum which strikes west-east where the unit has been overriden by the Mount Nebo overthrust. Between Mining Ridge and Quaking Asp Canyon the Arapien consists of lithographic and thin-bedded limestones with occasional layers of siltstone.

Unit one grades into the light gray to tan calcareous shales of unit two, which strike east-west and extend in thickness toward Salt Creek. Eastward, the strike of the beds swings slightly east of north into the thrust zone.

Overlying the red gypsiferous shales are the light gray calcareous siltstones and silt shales* of unit three. Excellent ripple marks in the thin-bedded shale are common, especially near the mouth of Salt Creek Canyon.

The red outcrops in unit four consist of selenite, platy gypsum layers and red shales. Here the formation has a blotched appearance, caused by scattered outcrops of gypsum crystals mixed in with crushed, red shales.

These units make up the Arapien shale between Salt Creek to the south, the High South Ridge to the north, and the North Fork of Salt Creek to the east. Occurrence of the Arapien shale previously reported along the south side of Salt Creek and eastward into the margin of the Gunnison Plateau has been reported by Hunt (1950, p. 30) to belong almost entirely to the Twist Gulch formation.

At Red Canyon the Arapien is underlian by the Nugget sandstone where Arapien exposures have not been covered by thrusting. Although the Twist Gulch formation is not exposed in this area, the assumption is made that it rests conformably on the Arapien. Reports to this effect have been previously discussed by Hunt (1950, p. 38) and Hardy (1952b, p. 18). Between the head of Rees Flat and Foote's Canyon, the Arapien shale is overlian in angular unconformity by the Price River formation and the Salt Creek fanglomerate respectively. At the North Fork of Salt Creek the formation is covered by Tertiary pyroclastics and the Indianola formation.

The units of the Twelvemile Canyon as recognized in this paper are correlated with the units described by Spieker and Hardy (see fig. 1). These units in turn are discussed by Spieker (1945, p. 123) who thought the Arapien shale of central Utah to be equivalent to the San Rafeal group. Gilluly and Reeside (1928, p. 73) correlated the Jurassic shales of Salt Creek with the Carmel formation of the San Rafeal swell and the Henry Mountains. The Carmel time-rock unit has been carried to southwestern Wyoming and the central Wasatch Mountains by Baker, et al. (1936, p. 6-7) where it crops out as the Twin Creek formation. More recently

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*Ingram, R.L. (1953).

<table>
<tr><th colspan="4">This Report</th><th>Hardy (1952b)</th><th>Spieker (1949b)</th></tr>
<tr><th>For.</th><th>Unit</th><th>Bed</th><th>Description</th><th colspan="2">Unit</th></tr>
<tr><td colspan="5">UPPER TRIASSIC
Twist Gulch formation</td><td>5</td></tr>
<tr><td rowspan="10">ARAPIEN SHALE</td><td>5</td><td></td><td>This unit not present on the north side of Salt Creek, with the possible exception of isolated outcrops of salt-bearing shale at the North Fork of Salt Creek.</td><td>E</td><td>4</td></tr>
<tr><td>4</td><td></td><td>Light gray calcareous silt shale with occasional red blotches from lenticular and gypsiferous shale.</td><td>D</td><td>3</td></tr>
<tr><td rowspan="2">3</td><td>2</td><td>Light gray thin-bedded ripple-marked silt shale.</td><td rowspan="2">C</td><td rowspan="2">2</td></tr>
<tr><td>1</td><td>Light blue-gray calcareous siltstone and silt shale.</td></tr>
<tr><td rowspan="2">2</td><td>2</td><td>Lenticular, red gypsiferous shale, interbedded gray silt shale.</td><td rowspan="2">B</td><td rowspan="2">3</td></tr>
<tr><td>1</td><td>Light blue-gray calcareous silt and clay shale.</td></tr>
<tr><td rowspan="4">1</td><td>4</td><td>Lithographic and thin-bedded limestone.</td><td rowspan="4">A</td><td rowspan="4">1</td></tr>
<tr><td>3</td><td>Massive lenticular bed of workable gypsum.</td></tr>
<tr><td>2</td><td>Light gray calcareous shales, lenticular gypsum beds. One massive bed of workable gypsum.</td></tr>
<tr><td>1</td><td>Gray to brown massive oolitic limestone underlying thin-bedded lithographic limestone.</td></tr>
<tr><td colspan="4">JURASSIC
Nugget sandstone</td><td colspan="2">?</td></tr>
</table>

Fig. 1 Correlation of the Arapien shale of Salt Creek with that of the Wasatch Plateau.

Hardy (1952, p. 26) suggested that the thick gray shale of the Twelvemile Canyon member (unit three this paper) is a probably correlative of the Carmel formation. He also indicated that the stratigraphic position and lithology of the Twist Gulch formation would place it roughly equivalent to the Entrada, Curtis, and Summerville formations of the San Rafeal Group.

The following fossils were collected by Dr. Eardley (1932, p. 330) from the Jurassic shales at Salt Creek: Pentacrinus asteriscus Meek and Hayden, Ostrea strigilecula White, and Camptonectes stygius White. These were identified by Reeside to be Upper Jurassic. Fossils collected by Spieker (1946, p. 125) in his unit two were assigned by J.B. Reeside to the Upper Jurassic. Faunal collections from Red Creek by Schoff (1951, p. 24), from the Gunnison Plateau by Hunt (1950, p. 39), and from the Sevier Valley by Hardy (1952, p. 67) point out the Arapien shale to be of Upper Jurassic age. The fauna collected by Eardley (1932, p. 330) and the writer (below) are congeneric with those found in the adjacent areas listed above. This would indicate the Arapien shale of Salt Creek to be of Middle to Upper Jurassic age. The Twist Gulch formation is restricted to Upper Jurassic (Hardy, 1953, p. 1266). Fossils collected on Mining Ridge include Camptonectes sp. and Ostrea strigilecula.

CRETACEOUS SYSTEM

Price River formation

The Price River formation forms the northeastern boundary of Rees Flat of the mapped area. From Rees Flat, the Price River formation extends northeasterly to the head of Foote's Canyon. The northwestern boundary of the formation parallels the base of the High South Ridge of Mount Nebo. The strike of the formation is east-west and the southerly dip increases from 10^{o} at Rees Flat to 25^{o} at Foote's Canyon. The highest elevation of outcrops of the Price River formation is directly east of the head of Rees Flat and is visible from Nephi, inasmuch as the formation weathers to a red color.

At Rees Flat only the conglomeratic facies is present. Here it is red conglomerate with red, calcareous matrix. Ridges formed from the massive conglomerate cap the areas of greatest relief in the formation. The larger boulders range from one to two feet in diameter and are mostly quartzites, likely derived from upper Paleozoic formations. Some limestone fragments of pebble and cobble sizes were observed but were not abundant. The quartzite boulders and pebbles are generally well-rounded, but limestone clasts are generally less abraded.

The coarse material is well cemented by a calcareous matrix of silt, sand and angular granules. Red iron oxide stain has colored the boulders and pebbles as well as the matrix.

Eastward, lenticular sandstones interfinger with the conglomerates. The red sandstones are medium to coarse grained, slightly calcareous and constitute approximately 30 percent of the total thickness. Stratification and cross-bedding are characteristic of these sandstones.

ERA	SYS.	STAGE	FORMATION	THICK.	LITHOLOGY	Fossils
CENOZOIC	QUATERNARY	RECENT	Alluvium			
CENOZOIC	QUATERNARY	RECENT	Landslides			
CENOZOIC	QUATERNARY	RECENT	Young and old gravels			
CENOZOIC	QUATERNARY	RECENT	Young and old fans			
CENOZOIC	QUATERNARY	PLEISTOCENE	Salt Creek fanglomerate			
MESOZOIC	CRET.	MONTANA	Price River formation	350'		
MESOZOIC	JURASSIC	UPPER / MIDDLE	Arapien shale	8500'		Camptonectes sp. Ostrea strigilecula
MESOZOIC	JURASSIC	MIDDLE	Nugget sandstone	0-300'		
MESOZOIC	TRIASSIC	UPPER	Ankareh shale	0-700'		
MESOZOIC	TRIASSIC	LOWER	Thaynes limestone	300' to 900'		Meekoceras sp. Pentacrinus whitei
MESOZOIC	TRIASSIC	LOWER	Woodside shale	400'		
PALEOZOIC	PERMIAN	LEONARDIAN	Park City formation	646'		
PALEOZOIC	PERMIAN	WOLFCAMPIAN	Diamond Creek sand.	395'		
PALEOZOIC	PERMIAN	WOLFCAMPIAN	Kirkman limestone	300'		Triticites sp. Schwagerina
PALEOZOIC	PERMIAN / PENNSYLVANIAN	WOLFCAMPIAN / VIRGILIAN / MISSOURIAN / DESMOINESIAN	Oquirrh formation	11,500'		Fusulina s.s.
PALEOZOIC	MISSISSIPPIAN	CHESTERIAN	Great Blue limestone	400'+		Lithostrotion whitneyi
PALEOZOIC	MISSISSIPPIAN	MERAMECIAN	Humbug formation	600'		
PALEOZOIC	MISSISSIPPIAN	OSAGEAN	Pine Canyon formation	650'+		Ekvasophyllum sp.

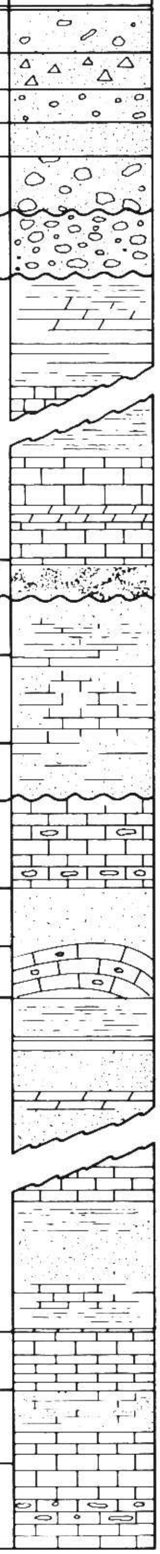


Plate 5

Summary Chart of the Stratigraphy of the Mount Nebo - Salt Creek Area

Outcrops of the Price River formation at Rees Flat are correlated with the conglomeratic unit of Schoff (1951, p. 626) and with the massive conglomerate unit of Spieker (1946, p. 131) on the basis of lithology and unconformable nature with the Jurassic rocks. Although the conglomerates at Rees Flat are separated from those in adjacent areas by erosion, the stratigraphic relation and lithology agree well enough with outcrops to the northeast (Devils Kitchen) and to the south (Gunnison Plateau) so that correlation is made without evident difficulty. Spieker (1946, p. 132) correlates the post-orogenic conglomerates discussed above with the type Price River formation. Fossils listed from the Castlegate sandstone member (Spieker, 1925, p. 446) place it as a probable equivalent to the Fruitland and Kirtland formations of the San Juan region. In Wyoming the Price River formation is equivalent to part of the Lewis shale (Reeside, 1933).

Intercalated sandstones in outcrops of the Price River at Rees Flat have yielded no fossils. The finer intercalated sediments with the dominant coarse conglomerates of the Wasatch Plateau have yielded few fossils, which have been identified by Reeside to be characteristic of late Montana age in the Upper Cretaceous of the Western Interior. In the Cedar Hills, Schoff (1951, p. 628) assigns post-Colorado age to the Price River on the basis of its relationship to the Indianola group of Colorado age.

The continental clastics which border the western margins of the Price River basin were derived from a westward highland created during the Laramide orogeny. According to Schoff (1951, p. 268) streams flowing eastward from the newly elevated mountains dumped coarse gravel and sand over the area of the Cedar Hills and northwestern Wasatch Plateau and carried finer-grained materials into the sea to the east forming the Castlegate sandstone.

Uplift and stream action appeared to be more active during early Price River time, followed by alternating periods of quiesence, rapid uplift, and subsidence as evidenced by the intercalated sandstone facies with coarse, poorly sorted conglomerates. Spieker (1949, p. 23) describes the Price River formation as the first mass of rubble to swept eastward during the early erosional stages of the Wasatch Mountains in Late Cretaceous times.

QUATERNARY SYSTEM

Salt Creek Fanglomerate

The Salt Creek fanglomerate occurs at the mouth of Foote's Canyon where it can be seen as a red cap on ridges of Arapien shale. Better exposures are to be seen at the Left Fork of Foote's Canyon where it overlies vertical beds of the Nugget and Ankareh formations. As pointed out by Eardley (1933a, p. 337) the beds show a low dip away from the High South Ridge, most likely a result of post-fanglomerate uplift.

The formation comprises a mixture of poorly sorted angular rock fragments, ranging from pebbles to boulders in size. The matrix is a poorly cemented, red to brown silt with occasional angular granules dispersed throughout. Close examination of the boulders and pebbles disclosed the fragments to belong to Paleozoic and Cenozoic sediments, indicating a source immediately to the north.

The youngest rocks in this area capped by the fanglomerate are Jurassic shales. More extensive outcrops of the formation occur at the North Fork of Salt Creek, and are in such a position as to provide more accurate determinations. The sediments in the area were reported by Eardley (1933a, p. 337) to be of the following age:

> The Salt Creek fanglomerate overlies volcanic deposits unconformably. The former, is therefore, decidedly younger than the latter, which in turn is younger than the Eocene deposits. No fossils have been found in either the fanglomerate or the volcanic deposits by which a definite age of one or both could be determined, although separation from Eocene deposits by two unconformities suggests late Tertiary or Pleistocene age for the fanglomerate.
>
> The physiographic setting, however, lends some aid to the solution of the problem. The fanglomerate rests on an old, mature, valley floor which has since been incised to a depth of about two hundred feet where the fanglomerate occurs. The rejuvenation is due to block-faulting of the Basin and Range age which has lowered the base of deposition of Salt Creek. If this old valley upon which the fanglomerate lies can be shown to be of prefaulting age, then the fanglomerate must also be of prefaulting age and, therefore, probably Pliocene. But there exists certain evidence which suggests that the older valley was eroded during an interim of faulting, in which case the fanglomerate would correspond in age to an epoch of time in the Pleistocene.

Young and Old Fans

The sediments of the young fans include material now being deposited into the valley and the now-existing fans which have received little erosion. The younger fans show no apparent dissection, while the older fans are principally erosional remnants.

Along the Nebo front, the young fans coalesce, forming a piedmont slope. It is the piedmont, rather than individual fans, that grade out into the flat bottom of Juab Valley. This piedmont was recognized by Eardley (1933a, p. 338), in addition he describes one of similar extent between the upper part of Salt Creek Canyon and the north end of the Gunnison plateau.

Many older fans lie at greater depths along the piedmont; those lying in the lower areas date back to the initiation of Wasatch faulting, and possibly pre-Wasatch faulting. A traverse drawn from the valley floor to the mountain front would cross individual fans which become younger as the line approaches the mountains.

Young and Old Stream Gravels

Most of the exposed stream gravels are of recent age, clearly pointing out periods of uplift during this period. Rees Flat is composed of gravels washed down from the base of the High South Ridge, extending nearly to Salt Creek Canyon. Where Quaking Asp Canyon intersects Rees Flat, old stream gravels are clearly exposed. These gravels range from 30 to 100 feet in relief above the present stream surface. On aerial photos it is clearly visible where the present streams have cut around the old gravel deposits.

At least three stages of stream incisions are evident at Rees Flat; two of which probably correlate with the recent uplifts along the Wasatch fault.

Landslides

A major landslide is visible at the mouth of Couch Canyon (see Plate 2c). Here it covers nearly a square mile and extends well out onto the piedmont. The bulk of the material was principally derived from the valley forming Humbug formation. In addition, cherty limestone and fractured limestone were present from the Pine Canyon formation and Great Blue limestone respectively.

The landslide occurred during one of the recent uplifts of the Wasatch fault, at which time movement was initiated and through a period of adjustments traveled nearly 2 miles to its present position. Reworked sediments mixed in with the slump blocks suggest different intervals of movement, some relatively slow.

STRUCTURE

Folding

The dominant structure of the Nebo district is the remnant of the east recumbent limb of a large, near-isoclinal anticline consisting principally of Oquirrh rocks. The fold makes up the greater part of Mount Nebo and the High South Ridge, the recumbent limb of which extends north-south through the entire area, giving extreme dips in some areas. The projected axis of the fold does not extend any great distance past the North Fork of Salt Creek Canyon as the strata there assume a vertical attitude. As the fold is traced eastward, the overturned limb becomes covered in Tertiary sediments and the eastward limb becomes the predominating structure.

Intense folding is clearly evident in the Arapien shales, originating as a result of several epochs of crustal deformation (see Plates 4b & c). Most of these structures are of local nature, but include folds of many conceivable types. The nature of the greater part of the folds indicates compressional forces originating from the west, probably contemporaneous with the major folding. Eroded surfaces of eastward dipping strata are common through the formation; these are remnants of recumbant and overturned folds as indicated by the attitude of ripple marks and other sedimentary structures.

Hunt (1950) suggests that the regional structure of the Arapien beds in Salt Creek is that of a dome.

Faulting

Wasatch fault

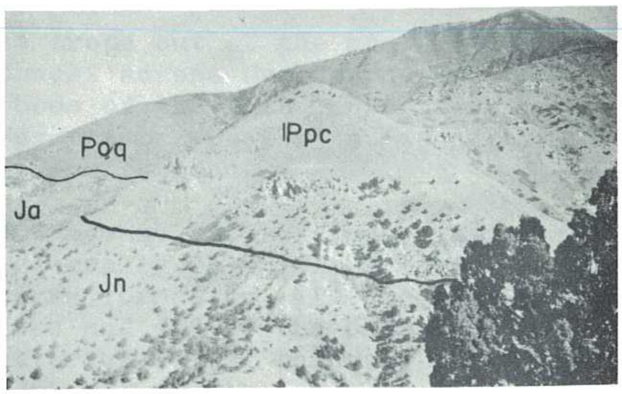
The Wasatch fault extends along the western base of the Wasatch Mountains. Northeast of Nephi the fault disappears under valley fill, but is evidently expressed farther south. The dip of the fault plane, as measured at Little Birch Creek is 55° west, indicating a high-angle normal fault.

The southern Wasatch Mountains are not entirely a result of the Wasatch fault. It has been pointed out that a large overfold was thrust into position before the Wasatch fault occurred. Likely there was an area of strong relief before faulting, a feature first noticed by Eardley (1933b, p. 243).

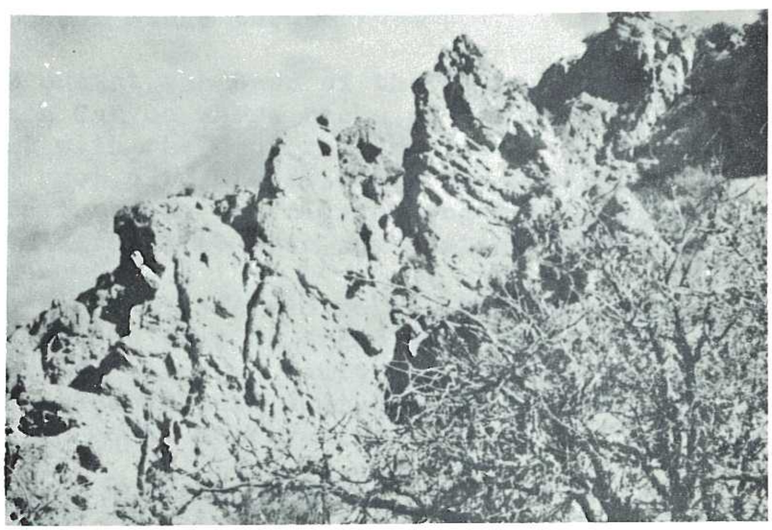
A breccia zone associated with Wasatch faulting crops out at the mouth of Willow Creek (see Plate 6c). Angular fragments of quartzite make up the breccia, loosely cemented by a fine powder. The breccia easily crumbles in the hand. Other evidence for Wasatch faulting is shown by the fault scarp which extends along the base of the mountains.

PLATE 6

A. Coquinoidal zone in the Park City formation



B. Mining Ridge looking north toward Red Canyon. Line represents trace of Nebo overthrust.



C. Fault Breccia at the mouth of Willow Creek Canyon

In many areas the scarp is void of vegetation. At the mouth of several canyons the young alluvial fans have been displaced by recent movements along the fault.

The age of the Wasatch fault (associated with Basin and Range faulting) cannot be accurately dated in the Nebo district because no Tertiary rocks have been involved in the faulting. The young alluvial fans are an exception, but these only date recent movements of minor magnitude. According to certain accepted interpretations, normal faulting was widespread and of long duration in Utah during Late Tertiary stages, possibly ranging from early Eocene or early Oligocene to present in western Utah. Others have suggested normal faulting at intervals from Miocene or Pliocene to Recent time in central Utah. Exactly to which period the major amount of normal faulting of the Nebo district can be related remains open for investigation of the related unstudied Tertiary rocks in some adjacent areas. Probably the area has been seismically active throughout much of Tertiary time since Eocene or Oligocene time.

Tear faults -- bedding plane faults

A noticeable bedding plane fault crops out at the southern ridge of Bear Canyon. Here it strikes southwest across Dry Canyon to Couch Canyon. The fault is confined to beds of the Pine Canyon formation without any great displacement. Several prospect pits lie along the fault zone, where samples of galena are abundant.

A major tear fault was noted on the east face of Nebo, just outside the mapped area. The fault plane generally parallels the Middle Basin and has displaced rocks of the Oquirrh formation. The magnitude of fracture is not great, but the strike and dip of the beds vary considerably from the normal northeast trend of the rocks.

These faults are most likely associated with diastrophic adjustments which occurred during Basin and Range faulting.

Cedar Ridge thrust

A prominent fault crops out at the base of the Oquirrh formation between Dry Canyon and Couch Canyon where rocks of the Great Blue limestone are in thrust contact with the Oquirrh formation. To the east other imbricant slices may crop out, upsection in the Oquirrh rocks, but this feature is only inferred as the alternating lithologies of the Oquirrh formation make it difficult to note any distinct breaks.

The thrust fault, which is here referred to as the Cedar Ridge fault, has displaced approximately 2,000 feet of Great Blue limestone. The base of the Great Blue, where exposed at fault contact, is severly fractured while the Oquirrh rocks appear undisturbed, indicating a thrust type movement of older rocks over younger.

The Manning Canyon shale, which appears in normal stratigraphic sequence above the Great Blue limestone, is absent. Thickness of this formation to the north would indicate that at least 1,500 feet of shale has been removed by the fault. The Manning Canyon shales probably provided a lubricant and an incompetent zone for thrusting to take place.

Desmoinesian rocks are in fault contact with the Great Blue limestone. It is difficult to estimate the amount of displacement in the Oquirrh formation by reasons of the nature of the Oquirrh basin in the Nebo district. The sediments of the Oquirrh thin in the direction of the Nebo area (see Plate 2b), and the great thickness reported to the north would not be valid for a normal Oquirrh section in the southern Wasatch Mountains. The complete absence of Springeran, Morrowan, and Derryan rocks would suggest displacement of nearly 3,000 feet. In addition, a displacement of the same figure is estimated for Desmoinesian rocks. In total, the Cedar Ridge fault involves over 9,500 feet of strata.

Cedar Ridge faulting was synchronous with the Nebo folding and thrusting. During stages of recumbent folding, the Manning Canyon shale fractured and gave way to a series of ruptures which continued throughout Late Montana time, resulting in the lower few hundred feet of Great Blue limestone being displaced on Desmoinesian Oquirrh rocks.

Two types of fault breccia are common at Willow Creek. Fairly well cemented angular fragments of limestone appear to be overlain by quartzite fragments loosely cemented in a matrix of unconsolidated powder. The strike of the Cedar Ridge fault terminates at Willow Creek and can be projected into the limestone debris. No fossil evidence was available to correlate the breccia with any particular formation, but the limestone breccia is highly fractured and full of calcite veinlets, a description fitting the Great Blue limestone. From this data it is apparent that the limestone breccia is a result of Cedar Ridge faulting, while the quartzite breccia is associated with a later period (Wasatch fault).

Nebo Overthrust

General statement: Overturned Pennsylvanian, Permian, and Triassic rocks in the Nebo area, which are truncated on the west by the Wasatch fault, and are overlain on the east by Cretaceous and Tertiary rocks, constitute the upper plate of the Nebo overthrust. The thrust plane appears in Gardner's Canyon and extends southwest where it has been displaced downward a great but at present unknown distance by the Wasatch fault. The thrust fault veers northeast from midway up Gardner's Canyon, then extends south and east around to the head of Red Canyon. From Red Canyon it crosses Mining Ridge and disappears under Rees Flat stream gravels, then reappears at the base of the ridge adjacent to the east margin of Quaking Asp Canyon. From here it crops out low on the sides of the High South Ridge and extends northeast to Cow Hollow where Eardley (1934) reports the northernmost exposures of the Nebo thrust plane.

Eardley (1934, p. 381) listed certain evidences to prove the existence of the Nebo overthrust. In addition to these the writer adds the following:

1. At Red Canyon the Ankareh and Nugget formations have been pressed into an arc as to indicate compressional forces from the west.

2. In Gardner's Canyon Desmoinesian Oquirrh rocks are in contact upon Jurassic Arapien shale.

3. Near Red Canyon Permian Park City rest upon Jurassic Nugget sandstone (see Plate 6b).

4. At the head of Red Canyon the Arapien shale is overridden by the Park City formation, Woodside sands, and the Thaynes limestone.

Thrust plane: The sole of the thrust is irregular, with regional dips varying between five and eleven degrees to the west. The dips become steeper near the mountain front, where zones of weakness are greater.

During Tertiary time the attitude of the thrust surface was tilted to the east and the Nebo block became part of the foot wall of the Wasatch fault. The maximum eastward dip imparted by Wasatch faulting is unknown; however, attitudes of volcanics at the North Fork of Salt Creek show an eastward dip between three and five degrees, indicating the thrust plane received a tilt of at least the same amount. Thus the initial dip of the pre-Wasatch volcanics and thrust plane has been modified by tilting accompanying normal faulting. The Salt Creek fanglomerate, which overlies the volcanics, is pre-Wasatch fault, and dips to the east and south.

Muessig (1951, p. 138) reports overturned Oquirrh rocks in Dog Valley which he considers lateral equivalents of those on Nebo. A mile west of Dog Valley Pass he reports a possible remnant of the upper limb of the overturned anticline, the strike of which is northwest. If this is the case, it would follow that the thrust zone could be projected to Long Ridge. Considering the tilt imparted to the thrust zone by the Wasatch fault and the net-slip of the latter, the projected thrust would pass in the bedrock beneath Juab Valley to intersect bedrock of Long Ridge at great depth. Contrary to this, I believe the thrust plane projects near the present surface of Long Ridge and terminates somewhere in Dog Valley, as no visible exposures of the thrust plane have been reported at Long Ridge.

Displacement: Thrust movement affected the rocks in the vicinity of Juab Valley and the southern Wasatch Mountains. As a result of movement the Nebo block now lies east of the mountains immediately to the north. Displacement of this block is not in excess of five miles, in view of the following:

1. Triassic and Jurassic sediments in the lower plate lithologically correspond to those in the upper plate. Thicknesses of these sediments are comparable but not definite as the strata in the lower plate are highly deformed.

2. The stratigraphy of the area is continuous with sections to the west (see Plate 7 and conclusions).

3. Stratigraphic displacement caused by thrusting dies out rapidly to the north as shown by increasing amounts of younger sediments occupying the northern portions of the upper plate.

4. The sediments of Tintic and Long Ridge are in place (see conclusions).

5. Minimum stratigraphic displacement in the Nebo district due to faulting is 14,900 feet; this is calculated where Desmoinesian Oquirrh rocks are in juxtaposition with unit two of the Arapien shale. The maximum displacement would be greater as complete thicknesses of all formations included in thrusting could not be determined.

Age: The first movement of the Nebo block is inferred from the coarse conglomerates of the Indianola, which indicate large, active streams with high gradients and suggest that erosion had been accelerated by folding or uplifting of mountains. The eastward gradation of the Indianola into shale and sandstone suggests that a provenance lies to the west of the Cedar Hills.

The date of this movement would be after deposition of the Arapien shale (Upper Jurassic) and before the Indianola (Upper Cretaceous), placing the orogeny as pre-Colorado if the Indianola formation in the Cedar Hills has been dated correctly.

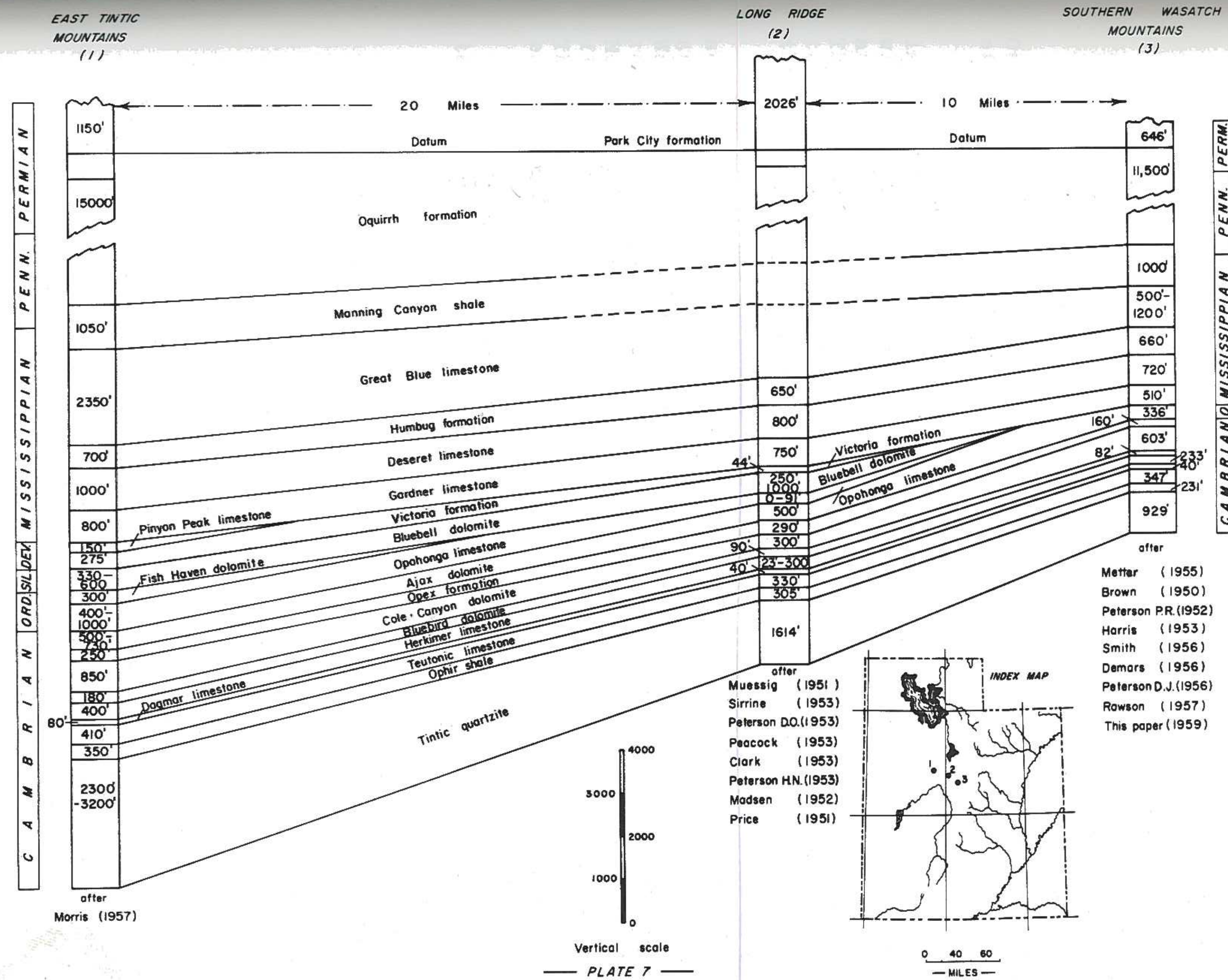
A late Indianola orogeny is recorded in the Cedar Hills as indicated by the coarse conglomerates in the upper unit of the formation (Schoff, 1951, p. 624). Evidently renewed uplift and folding of the Nebo block accounted for a great part of the debris that was shed eastward at this time.

Continued folding and thrusting of the strata in the Nebo block probably occurred during Montana time. This disturbance is not older than Colorado as it affected the Indianola group, imparting an eastward dip to the beds. Schoff (1951, p. 625) describes fossils of Colorado age from the Indianola formation in the Cedar Hills area. He also dated the Price River formation as late Montana age, which indicates thrusting not to be younger than this age as the thrust plane disappears under the Price River formation.

Conclusions: Investigations in the Nebo district provided the following criteria concerning thrusting of Mount Nebo:

1. The extent of thrusting of the Nebo block is limited to the vicinity of Juab Valley and possibly extends to the central parts of Long Ridge. The western limb of the fold crops out in Long Ridge and may extend into Dog Valley.

2. Compressive forces originated from the west and northwest, causing maximum displacement where the base of the High South



— PLATE 7 —

PROGRESSIVE THINNING OF PALEOZOIC ROCKS FROM THE EAST TINTIC MTNS. EASTWARD TO THE SOUTHERN WASATCH MOUNTAINS

Ridge is terminated by the Wasatch fault. Prior to Wasatch faulting this area was probably a zone of weakness.

3. The folding and thrusting of Mount Nebo follows similar trends as many structural features to the north and west. Rather than comprising a huge block moving several tens of miles, it is a local thrust and is correlated with such occurrences as the Allens Ranch thrust of the East Tintic Mountains and many of the major thrust faults in the Sheeprock Mountains and Long Ridge.

Other features were noted and are included in the following discussion, offered in support of the foregoing statements.

The Paleozoic and Mesozoic stratigraphy of Mount Nebo and vicinity is best correlated with that of Long Ridge. Lithologies are comparable with the exception of minor facies changes occurring between the two areas. Thicknesses are uniform, and in some formations the same. The correlation of the Nebo stratigraphy with Long Ridge also applies to the stratigraphy of northern Long Ridge, indicating that effects of thrusting at Dog Valley Pass, if any, are negligible.

Cambrian strata gradually thin eastward from Tintic district to the southern Wasatch Mountains; Ordovician, Silurian, and Devonian rocks gradually pinch out eastward across Long Ridge, and are absent in the Wasatch Mountains (see Plate 7). This correlation can be made with rocks as far south as Dry and Couch Canyons in the southern Wasatch Mountains. Vertical beds of Mississippian age in Dry Canyon show the first effects of Nebo thrusting in the southern Wasatch Mountains. Thus, the Nebo block hardly can be considered an allochthon of large eastward movement from the Tintic area.

In view of the foregoing, the structural history of Mount Nebo in terms of movement is summarized as follows:

1. Compressional forces originating from the west and northwest in Late Cretaceous time imparted a vertical attitude to the eastward dipping strata of the Nebo district at Bear and Dry Canyons.

2. As the strike of the formation is traced southward the beds progressively become overturned as the magnitude of compressional forces becomes greater.

3. As the beds become overturned the eastward limb ruptures and strata are displaced eastward over Triassic and Jurassic sediments. The Nebo block now rests east of the north-south trend of mountains immediately to the north. From a topographic viewpoint the southern Wasatch Mountains would appear as a hook, with the Nebo block comprising the curved portion.

4. Maximum eastward displacement of the Nebo block occurs near the head of the North Fork of Salt Creek. From this point the beds veer southwest and finally directly west at Foote's Canyon.

5. Greater forces affected the area near Red Canyon, where stratigraphic displacement is maximum. From this point movement diminishes to the west; some displacement may occur near Dog Valley Pass at Long Ridge where thrusting related to the Nebo area has been discussed by Muessig (1951, p. 138).

SUMMARY OF GEOLOGIC HISTORY

Events that took place in the Nebo district began with Mississippian sedimentation. Geologic history prior to this period has been well covered in literature of adjacent areas.

Toward the close of Mississippian, and into Pennsylvanian, sediments become chiefly clastic, with intercalated sands and limes. These are shelf sediments as indicated by rapid thinning of Paleozoic rocks toward the east.

Rapid subsidence characterize Pennsylvanian time with the deposition of over 12,000 feet of Oquirrh formation. Deposition of this formation continued uninterruptedly into Lower Permian.

Early Permian sedimentation was controlled by tectonics that influenced Pennsylvanian deposits. Later in the period deposition changed to the limy, case hardened and brecciated muds of the Kirkman limestone. As the seas moved westward eolian agents deposited lenses of cross-bedded sandstone (Diamond Creek sandstone). Seas again invaded the area depositing the clastic limes of the Park City formation during Late Permian. Slight epirogenic uplift preceeded Triassic deposition, reworking some of the upper Park City beds.

Early Triassic marine waters entered from the west, depositing the Woodside sands in a shallow shelf environment. As the area became stablized a thick sequence of limes was deposited which characterize the Thaynes limestone. The Ankareh shales were laid down in close proximity to the shelf area.

The Nugget sandstone represents a period of aridity, followed by a marine invasion from the north during Late Jurassic. This invasion supplied sediments for the Arapien basin, but shortly after deposition of the oolitic limestone the area became restricted and a thick sequence of gypsum, anhydrite, and shales was deposited.

Tectonics critical to the Nebo district began prior to Colorado time when uplift provided a western highland in the vicinity of Mount Nebo. This highland furnished a major source of material for the Indianola formation. Compressional forces during late Montana time steepened the existing fold and finally the overturned limb broke and moved several miles eastward over younger rocks. Erosion of this mass accounts in part for the Price River formation.

The pre-Flagstaff orogeny of Spieker (1946, p. 155) reached as far west as the Nebo district. Disturbance of greatest intensity occurred east of the mapped area, while only minor waves of pressure influenced the Nebo district, tilting the Price River formation to the south.

During Late Tertiary Basin and Range faulting the Wasatch frontal scarp was formed and the Nebo fault plane was displaced downward a great but at present unknown distance. Quaternary and recent sediments formed along the scarp have since been cut by recent movements along the Wasatch fault.

ECONOMIC CONSIDERATIONS

Water

At the present, water possibilities are of greater economic value than mining or petroleum. The major stream of the district is Salt Creek, receiving the run-off waters from the east face of the mountains. Salt Creek is a perennial stream and provides some of the culinary water for Nephi. Entering Nephi it is estimated to carry twelve second-feet of water.

The high watershed on the west slope of the mountains supplies the water for the streams in Willow Creek, Couch Canyon and Gardner's Canyon. In total these streams carry approximately six second-feet of water. Porous material at the mouth of each canyon has made it necessary to build concrete ditches to convey the water to reservoirs and irrigation ditches.

Within the last few years several wells have been drilled in Nephi, supplying the town and farmers with additional water. Most of these wells are located in Nephi and produce on the average of five to six second-feet of water per well. The wells have been drilled adjacent to Salt Creek and flow directly into the streams.

Recharge waters drain westward toward Juab Valley, which enter the porous gravels and sands of recent fans and Lake Bonneville sediments which fringe the mountain front. These gravels and sands are normally sealed by layers of silt and clay and constitute aquifers through which the confined water moves valleyward. The larger wells in Nephi tap the confined waters while those drilled at the mouth of Salt Creek Canyon have bottomed in the water table.

Attempts to drill above the present wells should be discouraged. New wells should be drilled valleyward toward the toe of the large fan that heads in Salt Creek Canyon. Here artesian pressures would be more suitable for wells of greater capacity. It appears, however, that recharge waters are limited and some means of control would be required if any great number of wells are drilled.

In addition, the volume of water available in Nephi can be increased by fully developing the available springs and seeps. Efforts in this direction would not only bring water to land not under cultivation, but it would better supply the recharge area, thus increasing the flow of the present wells to maximum.

Further production is highly anticipated if the ground water program of Juab Valley is planned under the direction of capable hydrologists.

Mining

Metallic minerals taken from this area have come from Bear Canyon. Smith (1956, p. 28) has briefly outlined the production and history of these mines.

A few prospects and adits are located near Dry and Couch Canyon, mostly along slightly mineralized fault zones. These are generally shallow and appear to show little promise for future development.

For many years large quantities of gypsum were taken from Rowley's mine and from an open pit at the mouth of Salt Creek. More accessible deposits to the south at Chicken Creek near Levan attracted the attention of the U.S. Gypsum Company who abandoned the operation at Nephi for these deposits.

A processing mill was located at the mouth of Salt Creek Canyon; it presented hazards and was torn down during the summer of 1959. Gypsum from Rowley's mine was transferred from Mining Ridge to this mill by means of an aerial tramway. Deposits elsewhere were brought to the mill by truck.

The gypsum on Mining Ridge comes from a bed 80 feet thick, stratigraphically above the massive oolitic limestone of the basal Arapien. From the western point of Mining Ridge the bed strikes west to east for approximately one mile where thrusting has covered it with the Thaynes limestone.

A drift was tunneled through the gypsum between 50 and 60 feet underground, with occasional shafts extending downward following rich deposits of gypsum. Because of the vertical nature of the gypsum bed. the accessible deposits were soon exhausted and mining efforts were transferred to Chicken Creek where the gypsum could be strip-mined. Before the drift was abandoned it was blown in, leaving a series of open pits along the ridge.

APPENDIX

STRATIGRAPHIC SECTIONS

Stratigraphic section of the lower part of the Thaynes limestone measured by the writer on Mining Ridge in Sec. 26, T 11 S., R 1 E., Salt Lake Base Meridian.

Unit	Description	Thickness (feet)
	Note: This section terminates in thrust contact with the Arapien shale.	
4	Limestone: Light brown-red to lavender calcarenite; thin-bedded and in part shaly; stringers of red calcareous material present.	35
3	Limestone: Medium blue to gray; medium bedded crystalline type limestone; side views of pelycepods common where calcareous matrix has been removed.	25
2	Shale and Sandstone: Deep brown red, weathers same; shales intercalated in coarse grained, calcareous sandstone; fair specimens of Meekoceras common.	210
1	Limestone: Medium blue-gray, thin to medium bedded and well stratified; some coquinoidal beds containing pelycepod fragments.	30
	Total	300

Gradational contact
Woodside shale

Stratigraphic section of the Park City formation measured by Dr. Bissell and the writer at Red Canyon in Sec. 26, T 11 S., R 1 E., Salt Lake Base Meridian.

Woodside shale
- - - Disconformity - - -

Unit	Bed	Description	Thickness
6		Limestone: Matrix, slightly dolomitic, light blue-gray; thin to medium bedded forms resistant ledges; some chert globs; fossil hash abundant.	45
5	3	Limestone: Matrix, medium to light blue-gray; black and purple chert comprising up to 40 percent of the unit.	60

	2	Limestone: Light brown-gray, slightly dolomitic; chert in globs and bands comprising up to 70 percent of the unit	28
	1	Limestone: Same as above, chert becoming light black to dark red, occurring in bands 12 to 16 inches thick; varicolored chert globs give rock a "rotton" appearance.	93
4		Phosphate and Shale: Phosphate black, hard, medium grained texture; shale siliceous, black, laminated.	3
3	2	Limestone: Skeletal-detrital, dark blue-gray; bioclasts predominantely brachiopod hash; one foot shale unit at base.	25
	1	Limestone: Detrital-matrix, medium gray-brown; thin to medium bedded; chert similar to that of unit two, but not as abundant; dolomite locally present.	50
2		Limestone: Matrix, becoming arenaceous; medium blue-gray; scattered globs of chert, chert bands not present.	100
1	5	Limestone: Calcarenite, mouse gray; beds becoming massive and well-bedded; some cross bedding.	85
	4	Limestone: Calcarenite, light blue-gray, medium bedded; small amount of brown chert nodules; aqueous cross-bedding.	100
	3	Sandstone: Calcareous, medium brown; medium sized grains porrly sorted.	5
	2	Chert: Massive, hard, white.	2
	1	Limestone: Calcarenite, medium gray; forms hard resistant ledges in contact with the Diamond Creek sandstone.	50
		Total	646

- - - Disconformity (?) - - -
Diamond Creek sandstone

Stratigraphic section of the Diamond Creek sandstone measured by the writer at the head of Red Canyon in Sec. 26, T 11 S., R 1 E., Salt Lake Base Meridian.

Park City formation
- - - Disconformity (?) - - -

Unit	Description	Thickness
2	Sandstone: Silicarenite, light brown, fine to medium	

grained; sub-rounded quartz grains; occasional thin units of limestone interbedded with sandstone. 45

1 Sandstone: Calcarenite in part, white to light pink, medium to coarse grained; cross-bedded near base; quite porous where friable. 350

Total 395

- - - Disconformity (?) - - -
Kirkman limestone

Stratigraphic section of the Oquirrh formation was measured by traverses taken in the following areas, beginning at the basal Oquirrh: West Nebo Ridge; High South Ridge; Andrew's Ridge.

<u>Kirkman limestone</u>
Gradational contact

	Description	Thickness
Wolfcampian Oquirrh	Limestone and Shale: Clay shale, indurated and siliceous, very fissile, blue gray limestones intercalated throughout shales; beds of orthoquartzites and detrital limestones common; lower contact made at first appearance of *Schwagerina*.	2500
Missourian & Virgilian Oquirrh	Orthoquartzites, Limestone and Sandstone: Orthoquartzites tan to light brown, weather blocky, forms hard resistant ledges, one of which caps the High South Ridge; limestones are crystalline to arenaceous, gradational with adjacent sandstone units, some limestone beds are coquinoidal, consisting of fusulined tests and bryozoans, lenses of argillaceous and calcareous sandstone intercalated.	3600
Desmoinesian Oquirrh	Orthoquartzites and Limestone: Orthoquartzites are light brown, alternate throughout limestone; down section orthoquartzites become more abundant, interbedded limestones become argillaceous; lower unit are calcareous sandstones; *Fusulina s.s.* abundant in limestones overlying the Arapien shale.	5400
	Total	11,500

- - - Fault - - -
Great Blue limestone

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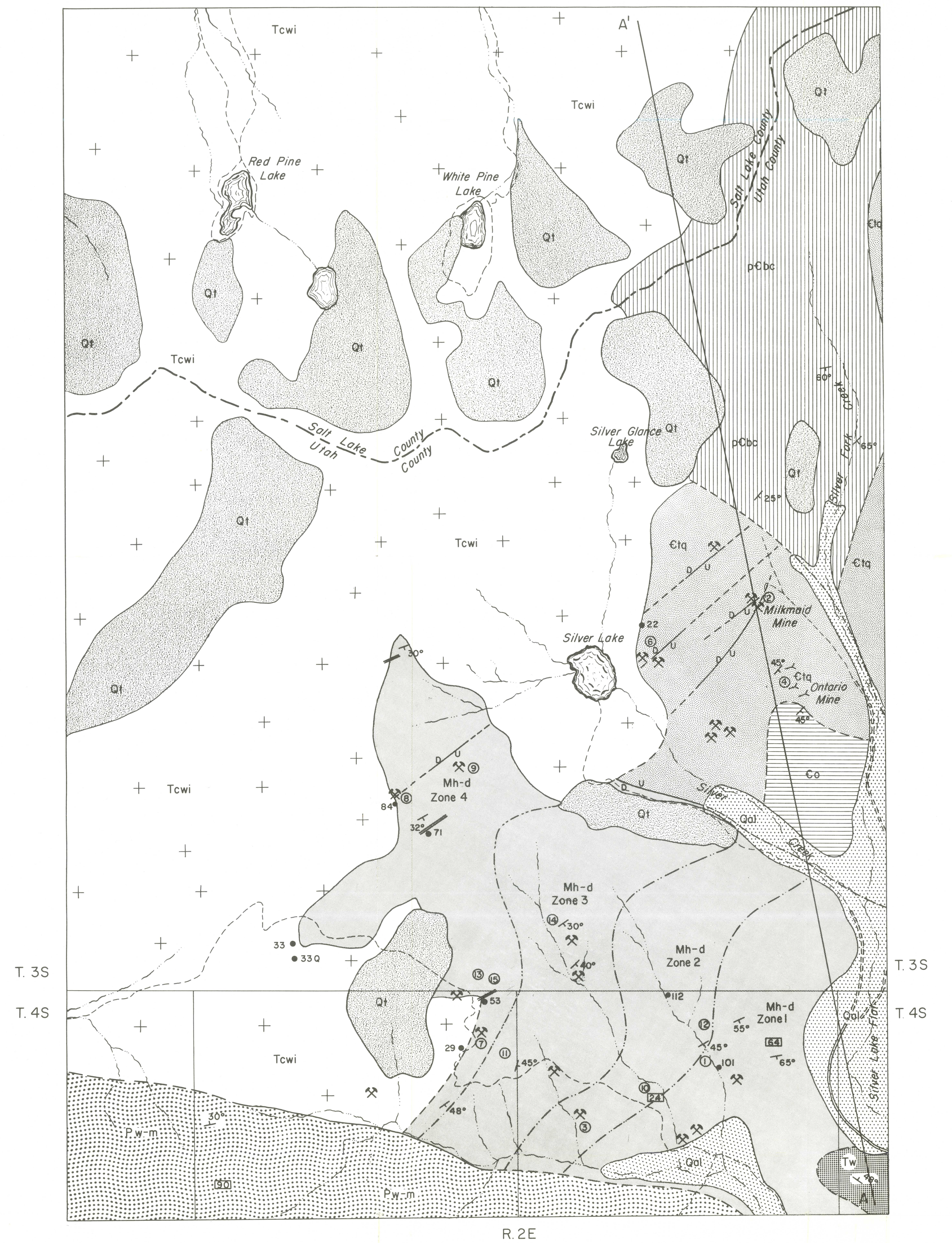
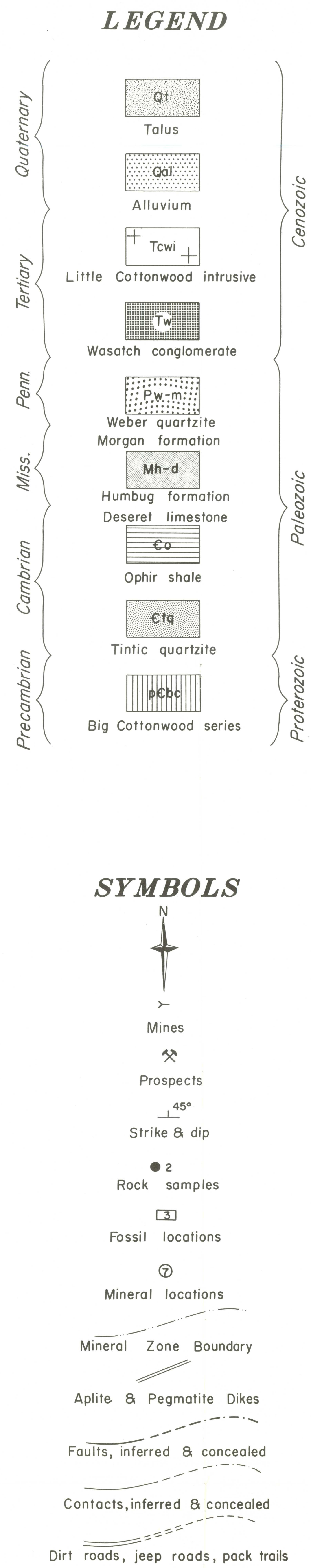
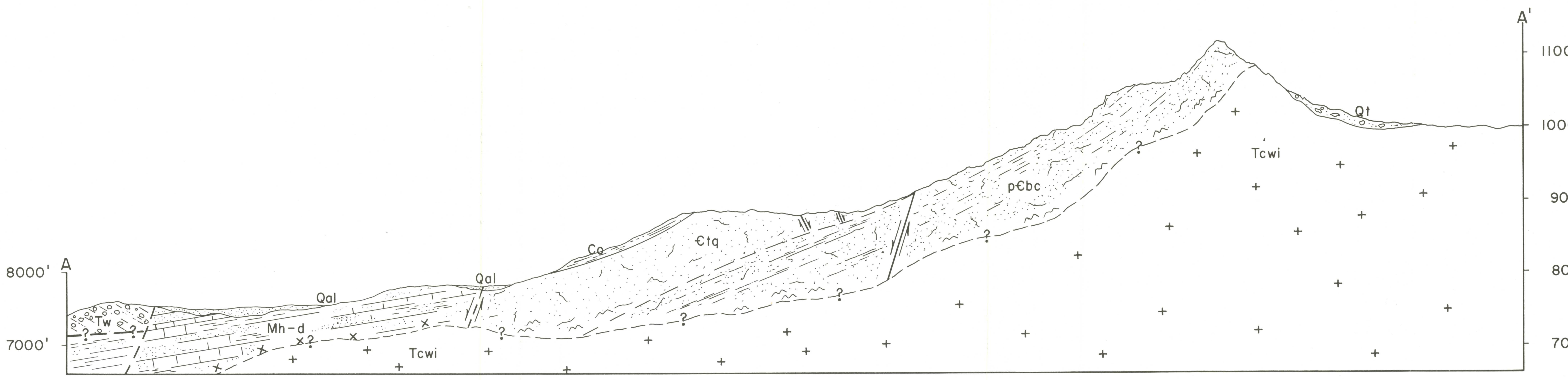
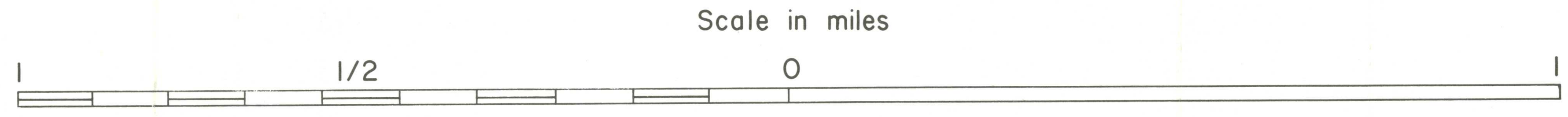






Scale in miles



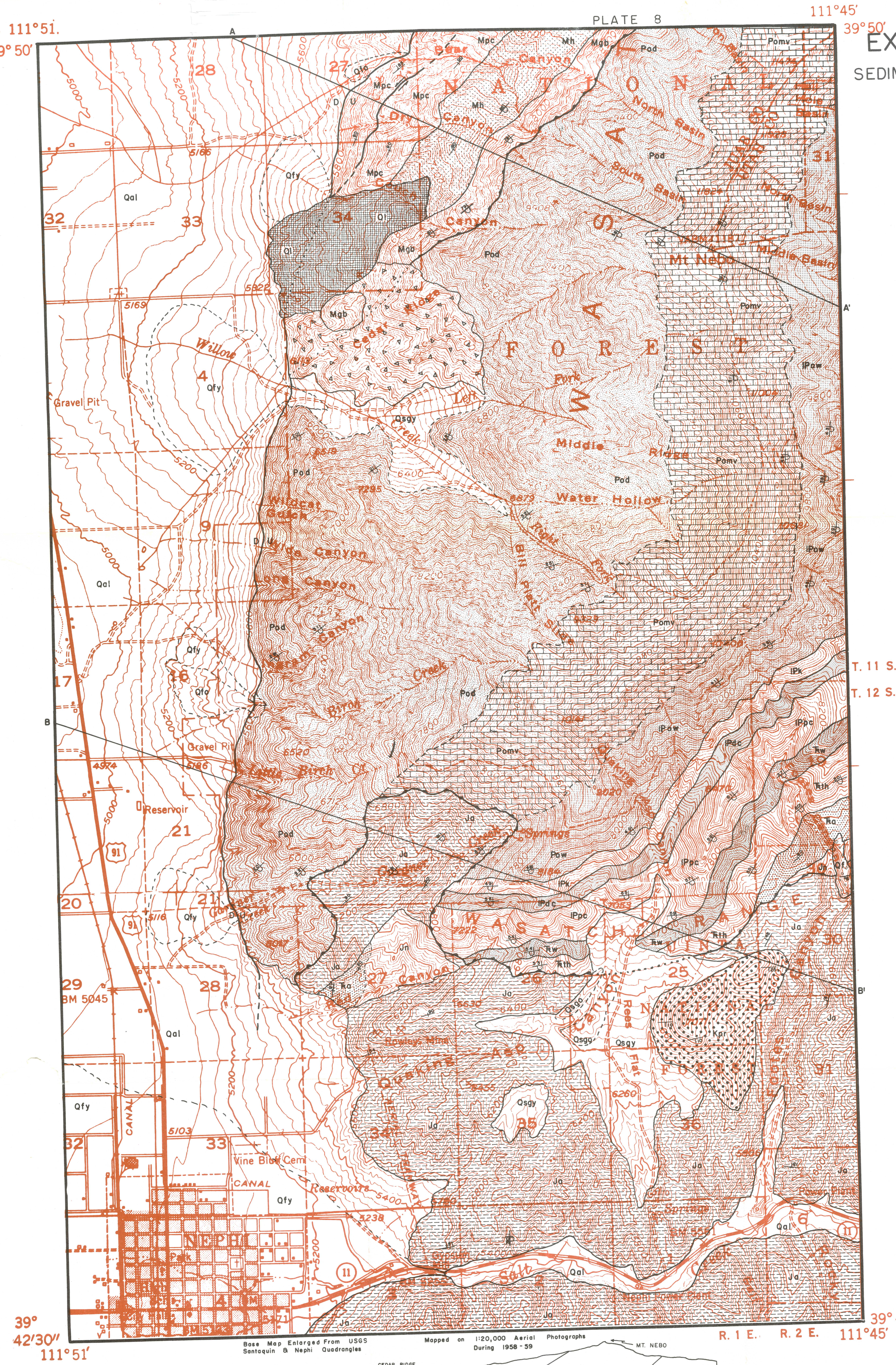
A GEOLOGIC MAP OF THE SILVER LAKE AREA, UTAH

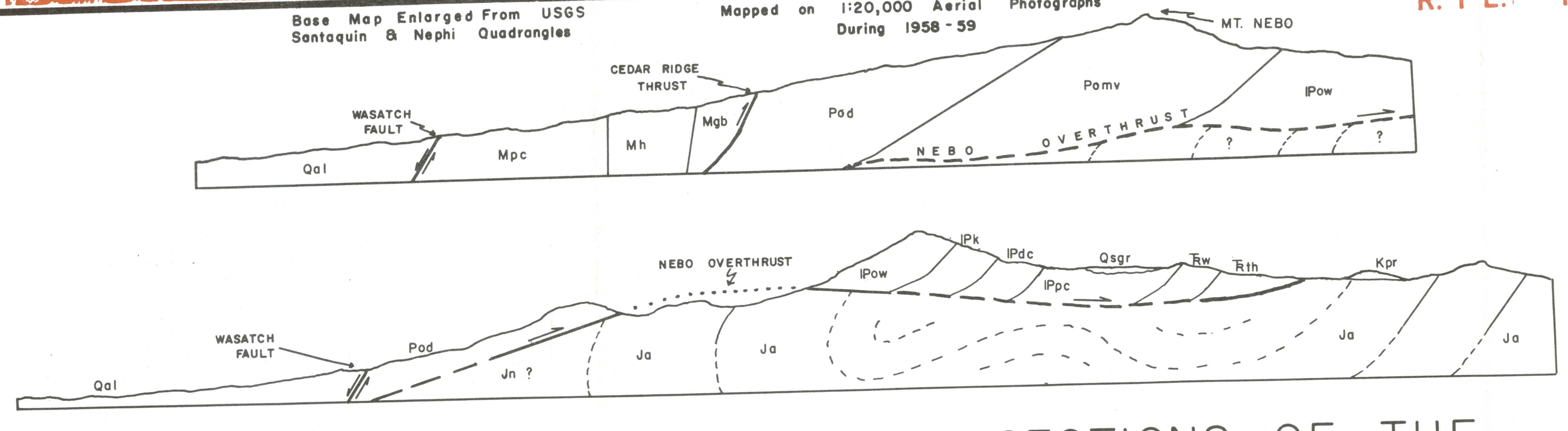
by

Donald L. Burge

1959

PLATE 8





EXPLANATION

SEDIMENTARY ROCKS

QUATERNARY
- Qal — Alluvium
- Ql — Landslides
- Qsgy, Qsgo — Young & Old Stream Gravels
- Qfy, Qfo — Young & Old Fans
- Qf — Salt Creek Fanglomerate

CRET.
- Kpr — Price River formation

JURASSIC
- Ja — Arapien shale
- Jn — Nugget sandstone

TRIASSIC
- Ra — Ankareh shale
- Rth — Thaynes limestone
- Rw — Woodside shale

PERMIAN
- IPpc — Park City formation
- IPdc — Diamond Creek sandstone
- IPk — Kirkman limestone
- IPow — Wolfcamp

PENN. (OQUIRRH FORMATION)
- Pomv — Missouri — Virgil
- Pod — Desmoines

MISSISSIPPIAN
- Mgb — Great Blue limestone
- Mh — Humbug formation
- Mpc — Pine Canyon formation

SYMBOLS

THRUST FAULT (Hachures on Upper Plate)

NORMAL FAULT (U, Upthrown side; D, Downthrown side; Dashed where approximated; Dotted where inferred)

FAULT SHOWING RELATIVE MOVEMENT

STRIKE AND DIP OF BEDS; OF VERTICAL BEDS; OF OVERTURNED BEDS;

ADIT

MINE

FORMATION CONTACT INFERRED

SPRINGS

FAULT BRECCIA

TRUE NORTH, MAGNETIC NORTH 16½°

0 1 MILES 3

CONTOUR INTERVAL 40 FEET

GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE MOUNT NEBO--SALT CREEK AREA, UTAH

by
Kenneth D. Johnson
1959