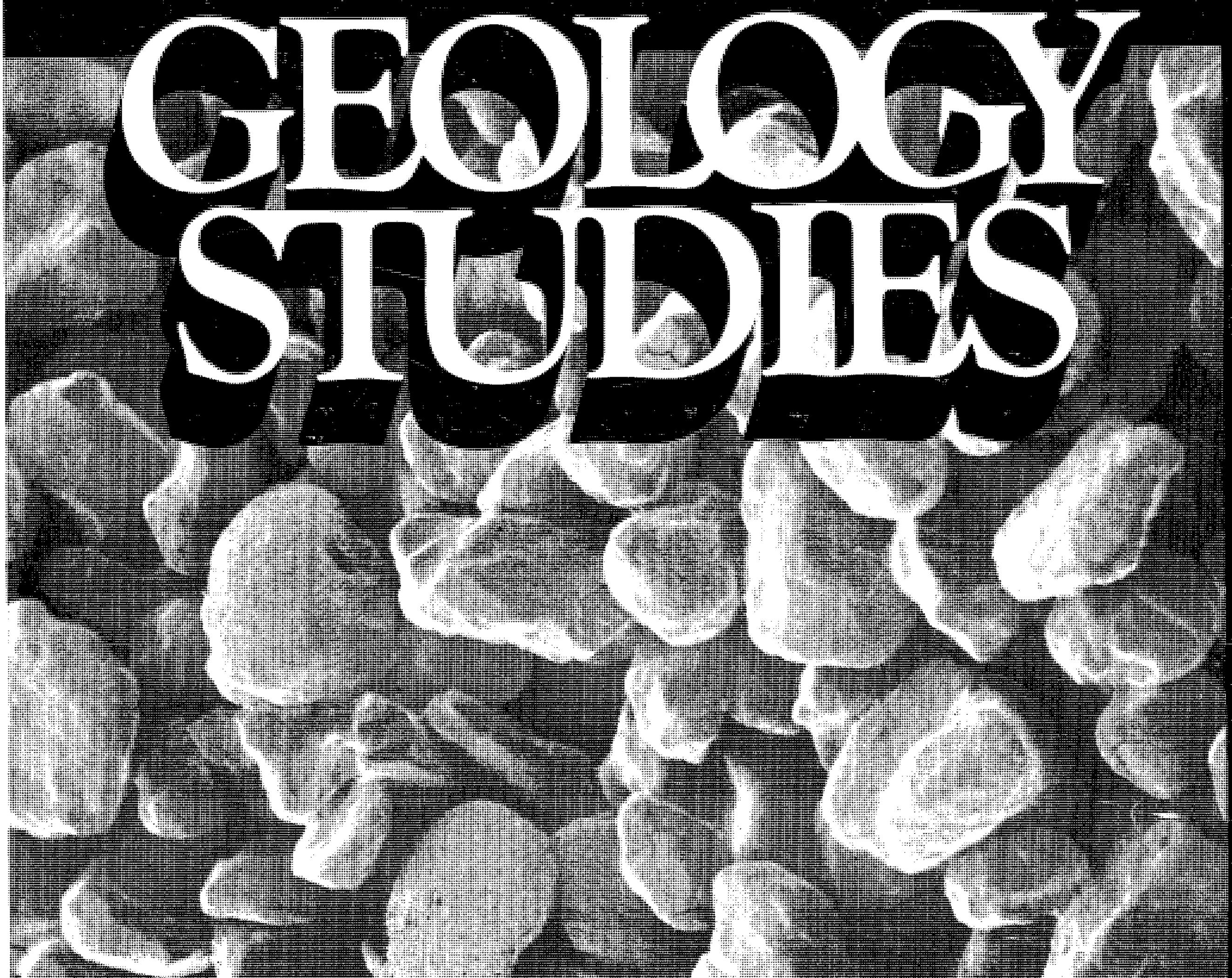
BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES



VOL. 24 PART 2 DEC. 1977

Brigham Young University Geology Studies

Volume 24, Part 2

CONTENTS

THE GLORY OF GOD IS INTELLIGENCE

Cover: Sahara dune sand, X130. Photo courtesy Amoco Production Research, Tulsa, Oklahoma, contributed by Paul E. Potter, Department of Geology, University of Cincinnati, Cincinnati, Ohio 45221.

A publication of the
Department of Geology
Brigham Young University
Provo, Utah 84602

Brigham Young University Geology Studies is published semiannually by the department. *Geology Studies* consists of graduate-student and staff research in the department and occasional papers from other contributors. *Studies for Students* supplements the regular issues and is intended as a series of short papers of general interest which may serve as guides to the geology of Utah for beginning students and laymen.

ISSN 0068-1016
Distributed December 1977
Price $5.00
(Subject to change without notice)
12-77 525 28856

CONTENTS

Structure, Stratigraphy, and Tectonic History of the Indianola Quadrangle, Central Utah*

DAVID M. RUNYON
Southland Royalty Co., Denver, Colorado 80012

ABSTRACT.–Three diapirs have been discovered in southern Utah and northern Sanpete counties. These piercement structures have recurrently upwelled and collapsed, creating local unconformities, faulting, doming, overturning of strata, and a variety of possible hydrocarbon traps. Ground-water systems have removed the upper portions of the diapirs, thus initiating surface collapse breccias. These aquifers subsequently deposited the evaporites into the Great Salt Lake Basin.

The presence of silicified oolitic limestones located adjacent to volcanic boulder deposits makes implication of concealed source vents for the Oligocene volcanics which lie within and adjacent to the Indianola quadrangle.

The study area has been actively involved in the birth and destruction of two geosynclines; the Cordilleran and the Rocky Mountain. It lies near the triple intersection of the Colorado Plateau, Basin and Range, and Central Rocky Mountain physiographic provinces. Magnetic data suggest the presence of the cratonal edge beneath the Wasatch monocline, and it is felt that this "hinge line" region may make added contributions to a plate tectonic model for central Utah concerning a possible Jurassic rift basin and a Cretaceous subduction zone.

The Sevier orogeny, Laramide epeirogeny, and Great Basin taphrogeny are considered as separate, distinct tectonic events which have made significant contributions to structural and stratigraphic expressions in central Utah.

INTRODUCTION

The challenge of the thesis was to produce a ground-proven map of the Indianola quadrangle and to unravel the sequence of tectonic history. Previously this same area was investigated by Khin (1956) and Mase (1957), and they produced a broad-scale geologic study. The present study has produced a detailed map using a topographic base map and conventional stereo high-altitude aerial photographs. Secondarily, remote sensing techniques analyzing Sky Lab III photos and ERTS imagery were employed, as well as low oblique late afternoon shadow photography. In addition, verbal communication of interpretations made from seismic and gravity data were offered to me by a petroleum company. These modern investigative tools, coupled with standard ground procedures, led to the discovery of some unexpected newly recognized diapiric structures and also aided in solving some perplexing stratigraphic problems in the area.

Acquisition of these new data allows a new interpretation concerning the geologic evolution in this part of the state. However, at the outset one must realize that to make long-range extrapolations about such things as plate encounters from such a small portion of the globe is like viewing a distant planet through the wrong end of a giant telescope. Although it does seem futile to discuss hinge-line tectonics without enlightenment from such a rich source of theories, far-reaching conclusions which outstretch solid data are really only speculative and will be presented in this discussion with appropriate qualifications. Established acceptable data will be stated factually, and speculation will be treated for what it is: thought provoking, but not absolute.

Acknowledgments

Numerous people and organizations have contributed aid toward this study. I hope this recognition will be accepted as only a small portion of my gratitude for their unselfishness.

The following made financial and logistical contributions: Sigma Xi (The Scientific Research Society of North America), American Association of Petroleum Geologists, Lloyd Traupe of Marathon Oil Company, Mr. and Mrs. G. D. Runyon, and the Utah National Guard. Special thanks are due Max G. Pitcher of Continental Oil Company who made his expertise and a number of Conoco facilities accessible. Neil Foreman provided remote sensing analysis techniques. E. J. Nieves examined and interpreted samples processed for pollen and spores. Karl W. Schwab (and William C. Elsik of Exxon Company) also made palynological interpretations and took photomicrographs. Dennis E. Palmer (and Mike Pinnell of Union-Texas) proofread and made organizational suggestions.

Alan T. Washburn (formerly of Union Oil Company) offered valuable interpretations of seismic and gravity data concerning tectonics.

Morris Peterson of Brigham Young University assisted with low oblique aerial photography, and George E. Young proofread and assisted measuring stratigraphic sections. James Stolle assisted in field flora identifications, and Lehi F. Hintze suggested the thesis problem and served as committee member. Special gratitude is extended to James L. Baer, who served as committee chairman and supplied invaluable expertise in the field.

Finally, I am grateful to my loving wife who excused many extended absences from the family.

Previous Work

Central Utah has attracted the attention of many geologists since the late 1880s. Gilliland (1951), who worked the Gunnison quadrangle, and Harris (1953), who worked the Birdseye quadrangle, both give good accounts of reconnaissance efforts by pioneer scientists. While doing a ground-water study, Richardson (1907) produced a general recon map which included some simplified structure and stratigraphy. Eardley (1932, 1934), Hintze (1962), and Stokes (1956a) have done some regional geologic analysis of the southern Wasatch Mountains and vicinity. Schoff (1951) investigated the Cedar Hills, and Pinnell (1972) produced an accurate map and unraveled the tectonic history of the Thistle quadrangle. McGookey (1960) contributed some valuable stratigraphic data south of Indianola, and Hardy (1952) made significant geologic contributions, also to the south.

The most comprehensive work in specific detailed areas began in the early 1900s and was done by Spieker (1936, 1946, 1949a, 1949b) and Spieker and Reeside (1925). Khin (1956) and Mase (1957), working under Spieker's direction, completed master's theses that taken together included the Indianola quadrangle. Because neither adequate topographic base maps nor aerial photographs were then available, their geologic map is not desirable for an accurate representation of the geology present. Therefore, I have endeavored to update the geology of the Indianola quadrangle.

*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, August 1976: James L. Baer, thesis chairman.

GEOLOGIC EVOLUTION AND REGIONAL SETTING

Since Cambrian times the Indianola area seems to have been situated on the western edge of the stable shelf during the existence of the Cordilleran geosyncline. Except for local disturbances—the Tooele Arch (Ordovician), the Stansbury Conglomerate (Devonian), and the Oquirrh Basin (Pennsylvanian-Permian)—the Cordilleran miogeosyncline remained relatively calm from late Precambrian until the Jurassic, receiving mostly only clean carbonate and sandstone sediments (Hintze 1973). The sediment transport prior to the Jurassic was from the east and southeast, at least in the central Utah area—for example, the Moenkopi and Shinarump formations were derived from the ancestral Rocky Mountain highlands in Colorado and northern New Mexico. In Early to Middle Jurassic the depositional pattern began a gentle shift due to the distant Nevadian orogeny. Seas invaded now from the north, and this region in Utah must have contained some enclosed basins and tidal flat environments, possibly created by a rift valley, which produced the mud and thick salt deposits of the Arapien and the silt of the Twist Gulch Formation. Then during Morrison times there was apparently another gradual regional shift in the drainage pattern as stream and lacustrine sediments began to appear in the central Utah region (W. K. Hamblin 1973 pers. comm.). This fluviatile system was being built from west to east on the piedmont surfaces of the uplifting Mesocordilleran high within the miogeosynclinal belt. Previous to this time and through this regional change the central Utah area was near sea level and had a warm climate which lasted until late Tertiary times (McGookey 1972).

The aforementioned drainage shift constitutes the beginning of the Sevier orogeny as defined by Armstrong (1968). First came the uplift and possibly some folding in Late Jurassic, and then in Early Cretaceous the thrusting began. It was not a single event of upheaval and erosion, but rather a sequence of numerous orogenic pulses, at least three major ones. They were eastward-migrating pulses that were accompanied by an asymmetric foredeep positioned east of the orogeny. This foredeep consumed the majority of the sediments produced by denudation of the highlands. The sediments were deposited on the western flank of the mobile foredeep and were continually cannibalized and recycled thus creating some clastic deposits composed of multiple second-generation clasts. This sediment consumption was accentuated by the beginning of an imbricate gravity glide system. Denudation and gliding were aided by east-sloping surfaces which developed structural weaknesses caused by abnormally high pore pressures in the natural aquifers created by the migrating pulses of energy (Eardley 1967). The result was that by Early Cretaceous, compressional thrusting was well under way and was shoving the thick miogeosynclinal sediments over the unstable shelf and onto the cratonal edge over the thin shelf sediments of the Colorado Plateau as we know them today. The next structural development was to lead to the birth of the Rocky Mountain geosyncline. The flood of sediments shed from the dying thrust belt accumulated to great thicknesses and represent a basin filled with high-energy "Gilbert" deltas, marine sandstones, and thick lacustrine sequences.

As noted by Armstrong (1968) the structural weaknesses which served as glide planes for Sevier thrusting were usually in Eo-Cambrian quartzite and shale beds. He accounts for a gravity-thrusting mechanism by the allochthonous plates being thin, one to two miles thick, and unmetamorphosed at their bases, except for some specific instances in the hinterland of the Sevier belt in western Utah and eastern Nevada. Listric faults, older fault planes folded by the occurrence of younger structurally lower positioned thrusts, also support the idea of gravity gliding during the Sevier orogeny.

The problem of crustal foreshortening has been studied by several authors, and most have agreed on an average figure of 65–95 km regionally although in some places, such as the Nebo, Canyon, and Pavant ranges, the shortening is believed to be 15–25 km of horizontal translation (Hintze 1962).

Regionally this disturbed belt stretches from southern Nevada to Alaska and came into being from Late Jurassic until the Eocene (McGookey 1972). Locally, however, in eastern Utah a more applicable date would be Early Cretaceous to latest Mastrictian times, when Price River conglomerates were laid over the thrust plates. In most cases they have not subsequently been displaced by compressional forces.

Regionally this zone of major crustal deformation is a belt approximately 150–250 km wide. There are numerous differences of structural styles on a local basis, but they may be due simply to different degrees of uplift and relative ages of individual disturbances within the orogenic belt.

Overlapping the Sevier orogeny chronologically but demonstrating a significantly different structural style was the Laramide orogeny, or perhaps more correctly the Laramide epeirogeny. It was a linear belt east of the Sevier highlands which extended from Mexico to Canada. Its movement began in Late Cretaceous and continued through Eocene times in vertical and asymmetrical uplifts many of which are fault bounded at depth. They created a new episode of minor local gravity sliding, new sediment sources, and basins of local-deposition. The Flagstaff and Green River lakes were important features of this time. This disturbance is attributed by Eardley (1963) to gabbroic intrusions beneath the sial.

Oligocene time brought on numerous volcanic events throughout Utah. The eruptions were basically silicic and intermediate types of ash falls and agglomerates. The newly recognized hot water vents north of Thistle (Young 1976) and possibly the vents located in the Tintic mining district are believed to be responsible for the Tertiary age volcanic conglomerates within the Indianola study area (Morris 1957).

The Basin and Range taphrogeny postdates the Oligocene volcanic events, begins in Early Miocene, and continues through present times. It is a system of steep normal faults with roughly a north-south orientation that has produced horst and graben, range and valley, and also the internal drainage characteristic of the Great Basin physiographic province. Concurrently the accompanying explosive volcanic suites changed from Oligocene felsic and intermediate types to dominantly basaltic extrusive floods (Eardley 1963).

The final main event of tectonic history began when the eastern Great Basin and adjacent foreland were uplifted 3,000–25,000 m regionally. This movement has continued to the present and has produced such renowned features as the entrenchment of the San Juan and Colorado rivers and the existing topography.

This entire sequence of evolution from the Jurassic until today is believed to have begun with a plate collision between the Pacific and American plates which instigated the Sevier orogeny. The Laramide epeirogeny was a result of continental override of a Cretaceous subduction zone where the Farralon plate was being consumed. The Basin and Range crustal extension and extrusive change to basalt floods was from the collision of the East Pacific Rise and mid-Tertiary trend along the North American continental margin (Atwater 1970).

This brief geologic review has brought us to the main topic. Hopefully it has given us the necessary background to realize the implications of the problems which lie within the Indianola quadrangle.

PRESENT-DAY SETTING

Indianola (fig. 1) is now cradled in the heart of a triple intersection of physiographic provinces. Fenneman's boundaries place the eastern half of the study area in the Colorado Plateau. To the west is the eastern Great Basin section of the Basin and Range province, and to the north is the southern tip of the Central Rocky Mountains. The study area has been located within or near two separate geosynclinal hinge lines for most of its geologic existence. These are the Rocky Mountain and Cordilleran geoclines, according to the tectonic model constructed by Robert Dietz (1972). Analysis of basement faulting does reveal that the mapped area is an expression of a tectonic triple junction and represents the deposition and destruction of a hinge-line geosyncline.

Topographic evaluations at Indianola range from 1800 meters in the valley to almost 2750 meters atop Brown's Peak. In general, normal faults, collapsed salt domes, and a major monocline control the topography. The fault blocks are downthrown to the west and have been tilted to the east, thus presenting a rugged steep western front and a gentle eastern slope. Valleys eroded along the lines of displacement reveal the geology with a clarity not often found. Sanpete and Sevier valleys have developed along extensions of the Sevier and Markagunt faults on the downthrown side of the Wasatch monocline (Buss 1963). Generally the western valley fronts are steepest because of a complication of faulting and monoclinal folding, and the eastern front, if steep, is erosional.

The terrain is reasonably accessible for eight months of the year by four-wheel-drive vehicles or horseback and hiking. The climate is semiarid. Numerous species of wildlife are abundant. The land is cared for in the valley and foothills by farmers and ranchers and in the highlands by the U.S. Forest Service.

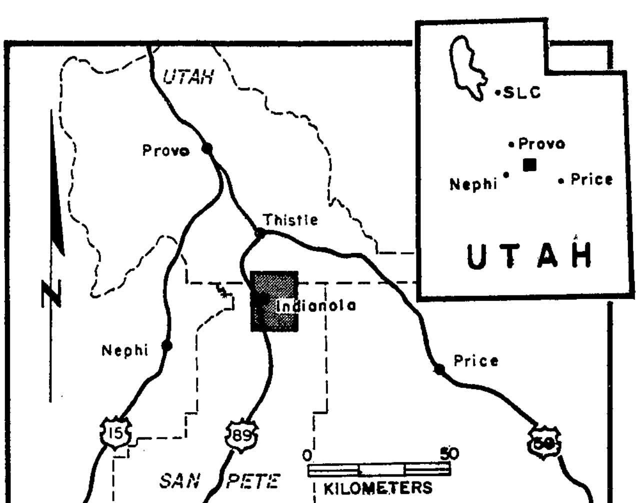


FIGURE 1.–Index map.

STRATIGRAPHY

From Late Cretaceous on, the Indianola area was effectively removed from marine invasion and was completely dominated by continental orogenic processes. The sedimentary record from Cretaceous to Oligocene (fig. 2) is the foundation of proof for the Sevier and Laramide orogenies and their recurrent effects on the Rocky Mountain geosyncline. Sedimentation was then dominated by fluvial systems, Gilbert-type deltas, intense subaerial erosion, and widespread lacustrine environments. The interaction of these systems created thick deposits and formations which more often than not have an exceptionally high number of lateral facies changes. Lithologies are commonly monotonous and their boundaries transitional or gradational. It is certainly not uncommon even for an experienced geologist to mistakenly confuse one formation with another on the basis of rock type or color alone. Fossils are unusually rare, and when found they are not likely to yield a diagnostic age, although they may be reliable environmental indicators. For these reasons I attempted to collect a few pollen-prone samples from critical locations in the hope that some of the stratigraphic dilemmas might be resolved. Unfortunately, this endeavor met with limited success.

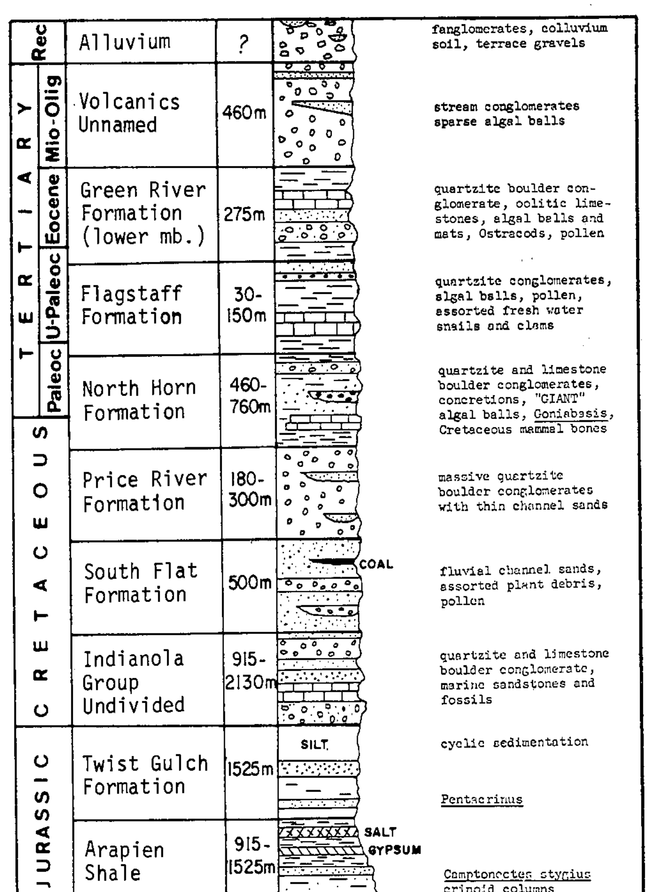


FIGURE 2.–Stratigraphic column of rocks exposed within the Indianola quadrangle.

JURASSIC

Arapien Shale

The type section is located in Arapien Valley which parallels the Wasatch Plateau near Gunnison, Utah. Exposures are also found along Twelve Mile Creek west of the valley. E. M. Spieker (1946, p. 123-24) named this formation and defined two members, the lower member being the Twelve Mile Canyon and the upper being the Twist Gulch. However, since the Twist Gulch has been raised to formation rank (Spieker 1946, Hardy 1952), the Arapien is now considered to be a formation containing only the Twelve Mile Canyon Member, which name seems to have faded from usage. Hardy (1952) recognized five units, A through E, within the Arapien separate from the Twist Gulch. Gilliland (1951) also made some refinements on the Arapien terminology.

The base of the Arapien Formation has not been observed at the surface in Sanpete or Sevier County. It was presumed by Spieker to overlie the Navajo Sandstone, and his presumption has been verified by drill bit as reported by Ritzma (1972) in the Levan and Sigurd areas. The Arapien lithology is exposed in the study area at one small linear outcrop on the southwest wall of Little Clear Creek Canyon in sections 7 and 8. It is mostly covered except for an isolated spot exposed at the intersection of East Lake Fork Canyon. Here the rocks dip very steeply and may even be overturned (?). They are overlain by the Price River Conglomerate to the east and overturned South Flat (?) Sandstone to the west. Pinnell (1972) considered this contact to be a sedimentary angular unconformity, but I believe the Arapien has been emplaced next to the Price River by diapiric drag faulting, which has resulted in the subsequent overturning of the South Flat (?) and even some Price River rocks. Although no salt or gypsum is present on the surface because of removal by solution activity, the Arapien is known to produce numerous other diapiric structures in Sanpete Valley. Gypsum outcrops and is being mined from an exposed diapir at the mouth of Salt Creek Canyon near Nephi, Utah.

FIGURE 3.–Vertical outcrop of Twist Gulch rocks in stream cut of Hjork Creek. Width of photo is 5 m.

Piercement structures caused by the mobility of the Arapien have played an important role in the geologic evolution of the Indianola area. Three diapiric structures are clearly expressed at the surface, as shown in figure 19, but only the one at East Lake Fork actually exposes the Arapien lithology. The conical hill in section 16 near Hjork Creek was described by Khin (1956) as Arapien rocks exposed within a complex maze of tear faults. I disagree with his stratigraphic identification and structural interpretation. It is an uplifted, radially faulted dome, a diapir which has upwelled and partially collapsed because of various effects on the underlying Arapien evaporites. The exposed sediments, which have been stretched and folded, belong to the Twist Gulch Formation (fig. 3). The third structure interpreted as a collapsed diapir forms low-relief hills of brecciated Green River sediments at the base of the frontal scarp of the faulted Wasatch monocline in sections 12, 13, 17, and 18 (fig. 4).

These piercement structures which have penetrated to the surface are the first to be recognized this far north in central Utah. It is believed that they have an important structural significance related to the present-day valley.

As was noted by Khin (1956), a major drainage divide is formed within the Indianola quadrangle. North San Pitch Creek and everything south via the San Pitch River flows into the Sevier Lake drainage basin. All the streams north of the divide dump into Thistle Creek and eventually discharge

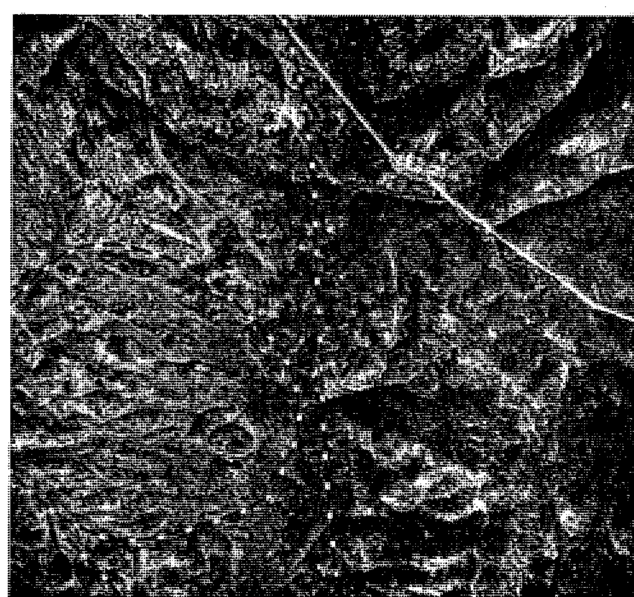


FIGURE 4.–Vertical photograph of the N. San Pitch River collapsed diapir. Diameter of the diapir is approximately 1.5 km. Dashed pattern denotes faulted frontal scarp of Wasatch Plateau on right side of photo. North is at top of photo.

into the Great Salt Lake. Since the origin of the high concentrations of salt and gypsum of the Salt Lake has been somewhat puzzling, I agree with H. J. Bissell's (1970 pers. comm.) observation that the Arapien sediments in Sanpete Valley may have contributed a significant portion of the Great Salt Lake evaporites.

The lithology of the Arapien exposures (see appendix) in East Lake Fork consists predominately of light cream and buff-colored shale, thin-bedded mudstone, and fine-grained sandstone, some of which show oscillation ripple marks. The only fossils from this section were reported by Pinnell (1972). They were white crinoid fragments and *Camptonectes stygius*. I collected samples for pollen and spore analysis, but they proved to be barren of any diagnostic forms. However, E. J. Nieves (1974 pers. comm.) mentioned that floral fragments suggested a near-shore, possibly tidal-flat, environment.

Lithologically the Arapien of East Lake Fork appears equivalent to the Twin Creek exposed near Thistle. The units do have some basic differences, but Imlay (1967) suggests they are at least time equivalent if not facies related, as noted by J. L. Baer (1974 pers. comm.). The Arapien is also believed equivalent to the Carmel of the San Rafael Group. Baker, Dane, and Reeside (1936, p. 6) assigned it an age of Upper Jurassic. Imlay (1948) speculates an age as old as Middle Jurassic for the Arapien as well as for the lower part of the Carmel. Thus, without further fossil evidence it seems appropriate on a regional correlation basis to assign an age of Middle and/or Upper Jurassic to the Arapien of East Lake Fork Canyon.

Twist Gulch Formation

The type section is located on the north wall of Salina Canyon in central Utah, where its basal contact with the underlying Arapien is not exposed. The upper contact is with variegated shales and diverse strata of the Morrison (?) Formation. It was originally named by Spieker (1946, p. 124) and intended to be a member "above the red salt bearing" Twelve Mile Canyon Member of the Arapien. But, as previously discussed, it was later separated out and raised to formation rank because of its distinctive color, lithology, and regional distribution.

Khin (1956) and Mase (1957) reported the Twist Gulch underlying Morrison (?) strata immediately south of Smith's Reservoir. I searched for this Morrison (?) unit and decided that either we disagree on the identification or that the exposure lies to the north beyond the boundary of the Indianola guadrangle.

The Twist Gulch was mapped at two locations within the quadrangle. It was reported at a third locality by Spieker (1946, p. 136-37, 1949b, p. 88-89). This latter occurrence was supposedly northeast of Blackhawk at Indian Graves hogback. There, in linear outcrop approximately "one hundred feet long at the bottom of a small valley, steeply-dipping Twist Gulch was seen to be overlain by nearly horizontal Flagstaff Limestone.". Mase (1957) reports searching for this exposure in the summer of 1955 without success. I too, searched on more than one occasion for the described outcrop but also met with disappointment. This relationship of the Twist Gulch and Flagstaff obviously has some important tectonic implications.

One of the two mapped Twist Gulch exposures is adjacent to Hjork Creek in section 16. It was described in the Arapien stratigraphic section as the center of a domal uplift. This is a series of red silt, sand, and shale which dips from 38° to vertical (fig. 3). The lower contact has collapsed and is faulted against the upper portion of the Indianola Group. The upper contact may also be faulted but is in near proximity of depositional contact with the stratigraphically overlying Indianola Group (fig. 19).

The other diapir is a linear outcrop of Twist Gulch which forms the lower portion of the west canyon wall of Little Clear Creek. It has been brought up with the same diapiric action that overturned (fig. 19, A-A') the South Flat(?) which forms the opposite canyon wall and the lower structural contact. The upper contact on the west side of the outcrop was believed by Khin (1956) to be a fault contact, but I interpret it as a depositional feature where the stream deposits of the Oligocene volcanic rocks were laid in angular unconformity against the Twist Gulch and other units as indicated in figure 19.

At both these locations the sections are incomplete. A section was measured in Little Clear Creek Canyon and is contained in the appendix of this paper. The lithology is a repetitive cyclic sequence of thin- to medium-bedded red sandstone, laminated to thin-bedded green and red siltstone and brick red-brown mottled shale. *Pentacrinus* is the only reported fossil (Baer 1974 pers. comm.) except for unidentifiable carbonized woody material in the crinkled shales at the base of the measured section.

The Twist Gulch correlates regionally with the Entrada, Curtis, and Summerville formations of the San Rafael Group. Hardy (1952 p. 27-28) compares the lower 850 m of Twist Gulch in Salina Canyon with the Entrada and the upper 60 m with the Curtis and Summerville. Others (Wright & Dickey 1963, Spieker 1946, 1949b) make similar correlations.

The drastic thinning of the Twist Gulch Formation in the Indianola area is due to drag faulting caused by the diapiric upwelling of the underlying Arapien, not by depositional differences as Pinnell (1972) suggested.

Samples for spore and pollen analysis were collected from the Twist Gulch at the locality of the measured section, but the results were negative. Although no other diagnostic fossil data has been reported, field relationships indicate its age to be Upper Jurassic (Imlay 1967, chart p. 20; see appendix).

CRETACEOUS

Indianola Group

The Indianola Group was named by Spieker (1946, p. 126) and lies between Hjork Creek and Dry Creek about 6 km north of the Indianola townsite. These rocks are the oldest Cretaceous units known in central Utah and represent a drastic change in the pattern of sedimentation from the Cordilleran geosyncline of the continental shelf to the Rocky Mountain geosyncline of the continental interior. Spieker (1946) made some suggestions of correlation and subdivision but later had to go to other localities to set apart distinguishable formations, thus describing the type section as "Indianola (undifferentiated)." In ascending order the formations of the group are the following:

1. Sanpete Formation, which is described as a basal group of sandstone, conglomerate, and minor shale containing fossils of Colorado age. Its type locality is south of Manti, Utah, on the east side of the valley exposed as a series of hogbacks. Lithology suggests correlation between it and the lower conglomerates on Hjork Creek and in the Cedar Hills, as noted by Schoff (1951), and the Gunnison Plateau, as noted by Hunt (1954).
2. Allen Valley Shale, largely consisting of a uniform,

even-bedded, gray marine shale containing fossils of Middle Colorado age. Its type locality is in Allen Valley about 4 km southwest of Manti. It does not seem to have a correlation equivalent in the group (undifferentiated).

3. Funk Valley Formation is a sand-shale sequence of marine origin that yields fossils of Niobrara age. The type section is in Funk Valley 6.5 km southwest of Manti. The marine sandstone of Dry Creek is the group (undifferentiated) equivalent although Spieker states that nonmarine strata of the same age are probably abundant and widespread at the group type section.

4. Sixmile Canyon Formation is a thick succession of coarse-grained, gray sandstone and conglomerate containing a coal-bearing member. Fossils collected from the coal indicate an age of Early or Middle Montana, but not younger. The type section is in Sixmile Canyon immediately east of the Funk Valley Formation.

Spieker (1946, p. 129) illustrates in his cross-section from Hjork Creek to Little Clear Creek that the coal-bearing sandstone of the Sixmile Canyon Formation is involved in an anticlinal structure. However, I have identified this feature as overturned beds of South Flat rocks. Previous to the naming of the South Flat Formation, Little Clear Creek is the only locale other than the type section that he speculated on as an occurrence of the Sixmile Canyon strata. He has since changed his mind because of Hunt's (1954) work and allowed this speculation to be corrected. Thus the Sixmile Canyon Formation is believed to exist only at its type locality adjacent to Funk Valley.

Spieker (1946) and Khin (1956) measured the Indianola Group (undifferentiated) and came up with about 610–915 m at Dry Creek and 2130–2440 m at Hjork Creek. Schoff (1951) reports over 460 m in the Cedar Hills 13 km west of the type section. It is obvious that these are very thick units of mollasse type sediments (fig. 5). They are traceable to theeast as they interfinger, fine, and become correlatable with the Lower Mancos and possibly some of the Middle Mancos of Colorado. They are also believed equivalent to the Kelvin Formation of the southern Wasatch Mountains (Eardley 1932).

Generally the lithology of the undifferentiated group consists of alternating conglomerate, sandstone, shale, and a few thin beds of fresh-water limestone. Oncolites are common in the sandy, silty units and seem to be most directly associated with the red-orange oxidized sediments. The average bedding thickness ranges from 30 cm to more than 20 m. Pebbles in the conglomerate range from 2.5 to 30 cm in diameter and consist of quartzite of various colors and dark gray to blue-black Middle Paleozoic limestones. Limestone cobbles are abundant in some beds and scarce in others. Sandstones are commonly light gray, orange, or yellow-brown and are often highly calcareous in the lower part of the section. Some of the red-orange sands near the upper section, especially the ones containing algal balls, bear a remarkable resemblance to the North Horn sediments. This resemblance can be confusing at times. For example, I am not sure that in section 17 the stratum identified as Indianola is not really North Horn. Here they demonstrate identical lithologies. This apparent unconformity, if actually present, seems a real possibility since Pinnell (1972) reports just such a relationship in the Lake Fork area. Unfortunately there is no fossil evidence to give any support to the idea, so the stratum has been mapped as originally defined by Spieker.

Within the study area the units on Dry Creek and Hjork Creek appear to be different, in part because of some perplexing structural problems and rapid facies changes.

The rocks which Spieker (1946) photographed north of "Hjork Creek Dome" may not be Price River, as he calls them. Lithologic composition and interpretations made from seismic data reveal that these rocks may belong to the Indianola Group (fig. 5) and present a major unconformity between the Indianola Group and the North Horn Formation. If it is the correct relationship, which seems plausible, it contributes even stronger support for the model of diapirism in that it represents a local hiatus rather than a regional erosional break.

Spieker (1946) and Khin (1956) report some marine brachiopods from the uppermost sand unit on Dry Creek which yielded a Coloradoan age. I unsuccessfully tried to confirm this age with a pollen sample.

South Flat Formation

The type section was named by Hunt (1954, p. 121) and is located in the northern half of the Gunnison Plateau. It is separated from the underlying Indianola Formation and the overlying Price River by angular unconformities. The South Flat is lithologically uniform and does not demonstrate the rapid facies changes of most other Cretaceous units in the central Utah area. This uniformity is one reason it has been equated with the Blackhawk Formation (Pinnell 1972, p. 100). Concerning this, Spieker (1946, p. 130) states:

> Attention may be directed to the fact that the westernmost Blackhawk rocks exposed are no coarser in grain than those to the east. This suggests that by middle Montana time the highlands from which the coarse sediments of Colorado age were derived had been worn down. It seems likely that by middle Montana time the rate of subsidence in the geosynclinal belt had slowed down. It might also be noted that the western outcrops of the Blackhawk Formation are so close to the belt of Laramide folding that the original presence of early and middle Montana sediments in the folded belt seems almost certain.

Hunt (1954) suggests that the South Flat was being deposited in piedmont and flood-plain environments of the orogenic belt while the littoral marine Blackhawk Formation

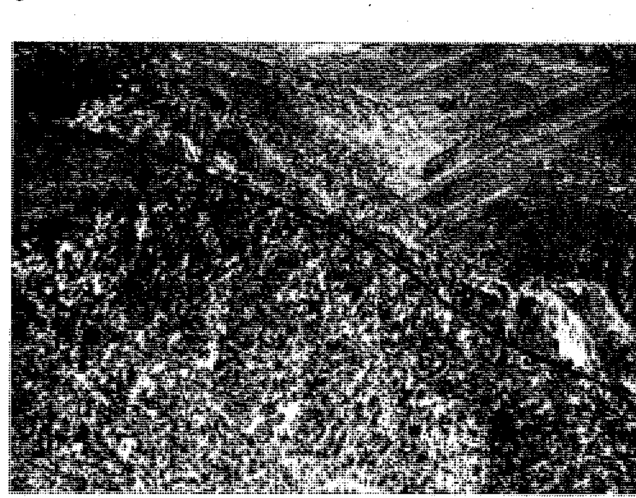


FIGURE 5.–Outcrop of vertical Indianola–Price River? rocks on Hjork Creek. Black line is a fault.

was being deposited farther east. Whether this unit has recorded a dying phase of the Sevier orogeny (Armstrong 1968) or an early pulse of the Laramide orogeny (Armstrong 1968) is hard to say at this point. One confusing fact about the South Flat Formation is that, where the section was measured at Little Clear Creek (see appendix), there is a minimum thickness over 600 m of almost entirely fluvial sand. It is considered a minimum thickness because the base of the formation is not exposed, and the measurement was taken from a fault contact. Yet only 3 km to the northwest, at the head of Hjork Creek, the unit is completely absent. This presents a picture of erosion and rugged topography in the Late Cretaceous, but the sediments do not reflect any coarse, high energy deposition. The upper contact is not exposed well enough to determine if it really is conformable to the Price River Formation on Rock Creek, but measurements on either side of the creek suggest a possible ten-degree divergence. Khin (1956) reported it as a conformable contact. Actually the disagreement may be only minor, and, for the purpose of recreating a sequence of tectonic events, this upper contact will be treated as at least a disconformity if not an angular unconformity.

The South Flat rocks in the northern portion of Little Clear Creek Canyon (fig. 6) have been overturned by the collapse of a diapir (fig. 7), the feature that Spieker (1946) mistakenly called an anticline.

The exposure of the South Flat Formation north of Indianola is the only one known exclusive of the type section in the Gunnison Plateau. Because of the confusion expressed by several other workers in identifying these rocks, I traveled to the Gunnison Plateau to examine the outcrops as they were originally defined. I found that they do bear a remarkable resemblance to the rocks near Indianola, not only lithologically, but especially in the common occurrence of iron (limonitic) concretions and some plant debris. Hunt (1954, p. 126) found six different flora in the Gunnison Plateau, and I found three types north of Indianola, all three of which commonly agree with those reported by Hunt. They are:

Cinnamonum affine Lesquareux
Sabalites montanus (Lesquareux) Dorf
Fragments of dicotyledonous leaves

FIGURE 6.–Massive conglomerates of the Price River Formation in background outcrop on the east face of Rock Creek Canyon. In foreground, the dashed fault pattern denotes contact of overturned South Flat rocks on the left with right-side-up South Flat rocks on the right.

R. W. Brown of the USGS identified these plants found by Hunt in the type section as Upper Cretaceous in age. These fossils are preserved in light gray, fine sandstone and without exception have been replaced by limonite.

One thin discontinuous coal seam at Rock Creek was sampled for spores and pollen. No diagnostic forms were preserved, but Schwab (1974 pers. comm.) said that the plant debris present indicated a fresh-water flood-plain environment. So, on the basis of plant leaves and stratigraphic position, I agree with Hunt (1954) that the best assignment for age is Early and/or Middle Montana. I also agree with Spieker, Khin, and Hunt that the best name for the rocks exposed on Little Clear Creek is South Flat Formation.

Price River Formation

The Price River was named by Spieker and Reeside (1925, p. 445–48) from exposures in Price River Canyon near Castlegate, Utah. It is a succession of gray sandstone, grit, conglomerate (fig. 6), and minor amounts of shale that lie between the Blackhawk Formation below and the North Horn Formation above. The Price River at the type locality consists of two members: a basal, cliff-forming unit, the Castlegate Member (Clark 1928, p. 20), composed of massive, white-to-brown, medium-to-coarse sandstone containing lenses of quartz and chert pebbles; and an upper, less massive, slope-forming member of similar lithology. Progressing westward from the Castlegate area the facies coarsen drastically and become dominant cliff-forming masses of high energy clastics. It is this boulder-sized unit which exclusively com-

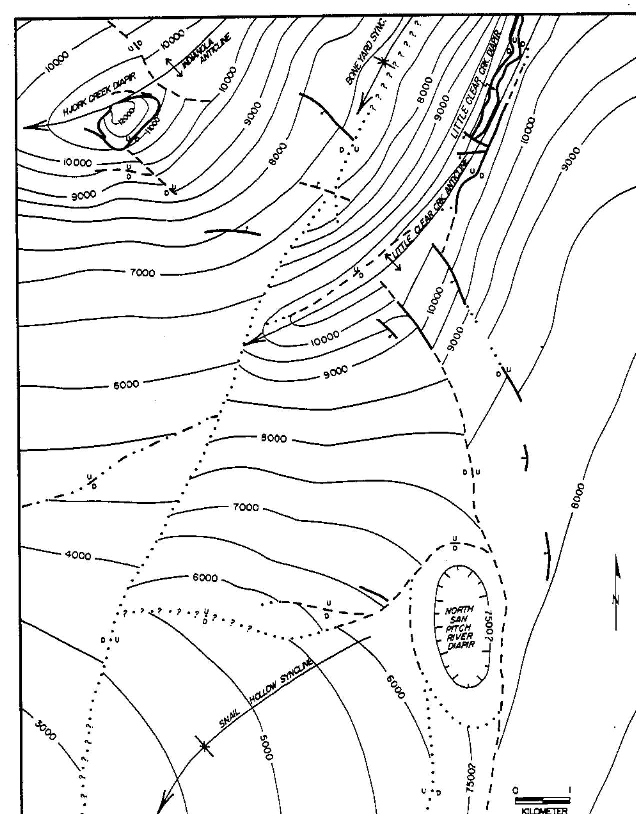


FIGURE 7.–Formline contour map of the study quadrangle. The elevation contours are drawn on top of the North Horn Formation. Contour interval is 150 m.

prises the Price River lithology of the Indianola district. Here it is relied on as a marker unit. It is this coarse lithology, and in part its stratigraphic relationships, that prompted Moussa (1965, p. 113) to call the unit at Rock Creek the Bennion Creek Formation. However his conclusions come only on the basis of literary research since he never personally inspected this unit near Indianola. Also he made this deduction from Mase's (1957) observation that the "overlying North Horn was a conformable contact," and this is not the case in the East Lake Fork Canyon.

There are two major exposures of the Price River Formation contained within the Indianola quadrangle. One is on Dry Creek where it clearly overlies the Indianola Formation with angular discordance. The other is a much thicker section on the eastern face of Rock Creek Canyon, where it extends continuously northward across the drainage divide for several kilometers out of the study quadrangle. On the west side of Rock Creek Canyon atop the drainage divide and continuing northward there is a thin section of Price River several thousand meters long which has been faulted, tipped vertical, and slightly overturned along with the South Flat Formation. It has been overturned by collapse of the linear diapir at Little Clear Creek. At the Rock Creek section of Price River rocks, the lower contact with the underlying South Flat is very near conformity, unlike the exposures at Dry Creek and Hjork Creek.

Another exposure, at the head of Hjork Creek, is an impressive outcrop of massive conglomerates which stand on end and form enormous bulbous pinnacles (fig. 5). The base of these rocks appears to represent an angular discordance with the underlying Indianola formation, but this relationship is most likely due to complex faulting and masking by erosion. These are the rocks which Spieker (1946) called Price River. A close inspection of the clast composition reveals a difference from other nearby exposures in that quartzite no longer predominates, but there is rather an abundance of Jurassic age sandstone clasts. Also seismic interpretations made by Alan Washburn (1975 pers. comm.) show that in the subsurface this horizon forms an unconformity with the overlying North Horn. For these reasons the outcrop is shown with a questionable designation of affinity in figure 19.

At all the described localities the Price River grades transitionally into the overlying North Horn Formation lithologically, but in the East Lake Fork Canyon there seems to be a slight angular discordance of about 10°. However, this relationship dies out, and the contact appears concordant further south. For mapping purposes the contact was placed atop the uppermost, massive, quartzitic conglomerate. It is a simple boundary to pick, not only because of the massive nature of the rocks, but mainly because the color is usually some shade of light gray, contrasting with the red and orange of the North Horn. The clasts are dominantly quartzite with some sandstones present. Paleozoic limestone clasts are conspicuously absent. In some places the Price River has been stained red with hematite from the overlying North Horn, but this coloration appears to be only surficial in nature. Except for Dry Creek, where Pinnell (1972) reports 75 m, the thickness is fairly constant. At Hjork Creek I measured about 300 m, and on Rock Creek the unit is 250–300 m thick.

Although Moussa (1965) strongly disagrees, Spieker (1946) claims that the two members of Price River defined in the Castlegate area grade imperceptibly into this coarse massive unit as it exists in the study quadrangle. These are what Spieker has termed "postorogenic conglomerates," and he attributes them to the first record and strongest pulse of the Middle to Late Montana Laramide orogeny. Thus, the Price River Formation, especially in the Indianola area, is believed to represent a whole new tectonic event, one which has a style significantly different from the previous Sevier orogeny.

The coarse western facies of the Price River is barren of any fossils, a fact not hard to understand when one views this high energy deposit with rounded quartzite clasts which commonly range from grit size to 46 cm in diameter. However, its stratigraphic position (as related to the orogeny), together with fossils reported by Spieker (1946) from the sandy facies in the Castlegate area, yields an age of Late Montana. An assumption can be made that this coarse westernmost facies is a bit younger, being in closer proximity to the orogeny, so a date of possible Middle and/or Late Montana is given. Spieker (1946, p. 131) places the Price River equivalent to the Fruitland and Kirtland formations of the San Juan region, Colorado.

CRETACEOUS-TERTIARY

North Horn Formation

The North Horn was first included by Spieker and Reeside (1925, p. 448) as the lower member of the Wasatch Formation. Later it was raised to formational rank (Spieker 1946, p. 132) because it was discovered to be not entirely Tertiary in age. After the unearthing of fossils that yielded a Lance age, Spieker (1946, p. 132) defined a new type locality on North Horn Mountain which is on the east side of the Wasatch Plateau opposite Manti, Utah. There he described four main units which are mostly variegated shale with sandstone, conglomerate, and some fresh-water limestone. This section is 500 m thick and in this part of the plateau represents an alternation of fluviatile and lacustrine conditions.

The rocks within the Indianola quadrangle are similar to the type section but do have some minor differences. At the Indianola district the North Horn is predominantly calcareous sand, algal units, conglomerate, and minor shale. Sand is the most abundant, conglomerate is common, shale and limestone are rare. The last two are usually thin and discontinuous over large areas. They are representatives of small disconnected lakes which encroached on the fluvial plains and were short lived if not ephemeral. The conglomerate normally contains abundant Paleozoic limestone clasts, which help to distinguish it from the Price River Formation in this area. They are thought to be channel systems that were deposited into an external drainage system (Hamblin pers. comm.). This conclusion comes not just from their channeled nature (fig. 8) but also from their being, in many cases, open-work conglomerates.

Other conglomerates that make the sedimentary units of this area unique (figs. 9, 10) are the massive deposits of "algal ball" calcareous sandstone and sandy limestone. What makes them unique is their size and recurrent distribution. They occur not only in the North Horn Formation but throughout Tertiary units like the Flagstaff, Green River, and even the volcanic conglomerates. However, the North Horn Formation seems to have them most abundantly spread throughout its limits and exclusively contains the gigantic forms which often range in diameter from 2.5 to 50 cm.

Malcolm Weiss (1969) studied the algal balls of the North Horn and Flagstaff formations in the central Utah region and concluded that they were formed in near-shore, warm, shallow, active waters, often near the mouths of streams. He even claims that several types are distinguishable as either autochthonous oncolites or allochthonous forms. The oncolites found in the Indianola vicinity do seem to fit his theory in that they are generally autochthonous. Some oolitic beds are also locally common near the top of the formation. I do not deny that these algal balls may have eventually reached the lake waters, and I concede that some may have even been generated completely within the lake boundaries, but I do not believe it to be true for the very large balls. These "giants" originated in streams of moderately high gradients. The climate was warm, and surface vegetation was a cacti type. The nucleus for the balls could be virtually anything as they generated and saltated downstream. They probably were maintained in the stream channel and grew most rapidly during flood stages of the fluvial systems. This simple hypothesis is shared with R. J. LeBlanc, Sr. (1975 pers. comm., Shell Research).

North Horn sediments range in color from bright red to cream white, but the dominant color is medium red-orange. Van Houten (1948, p. 2083) investigated the colors of various Cenozoic formations and came to the conclusion that variegated formations such as the North Horn were deposited in open country of savanna environments. In contrast to the gray Price River below and the whites and tans of the Flagstaff and Green River formations above, the consistent orange color of the North Horn is a reasonably reliable marker in the study area.

Stratigraphic relationships between the Price River and North Horn formations in the Indianola district are varied. As previously mentioned, there is a slight angular divergence between the two as demonstrated east of Rock Creek and East Lake Fork Canyon. It is due to renewed upward movement of a diapir and helps to date its recurrent movement. The upper contact northwest of West Lake Fork is conformable and clearly transitional with the Flagstaff, but nonconformable with the volcanics further southwest. On Brown's Peak, the crest is capped by a tongue of questionable Flagstaff (?) origin. But the Flagstaff (?) immediately east of the Blackhawk hogback seems to have a position attained by "strip thrusting" similar to the type Moussa (1965 p. 93) and Hardy (1952) describe in some of the Green River sediments of central Utah.

The age of the North Horn was first thought by Spieker to be Early Tertiary, but the discovery of reptilian bones near the base of the formation proved it to be in part Upper Cretaceous. Fossil bones of placental mammals found in the upper portion of the formation proved it to be in part Paleocene. Thus Spieker announced (1946, p. 135) that the passage from Cretaceous to Tertiary lies within the body of the formation. He also proceeded to correlate the North Horn with the Lance and Fort Union formations of Wyoming and Ojo, Alamo, Puerco, and Torrejon formations of the San Juan Basin. No physical or lithological basis for regional subdivision of the strata grouped in the North Horn Formation has been recognized, and as presently understood a boundary between Cretaceous and Paleocene cannot be mapped.

Reeside identified several fresh-water mollusks from North Horn rocks (Spieker 1946, p. 134). Their significance is regarded as uncertain because of the general reputation for long ranges of these fresh-water faunas. The type commonly found in the Indianola area which coincides with that noted by Spieker is *Goniobasis.* One form noted by La Rocque (1956, p. 140) and not by Spieker which I found in Indianola was *Hydrobia.* I also sampled several shales for pollen analysis and found no diagnostic forms. However, some of the organic debris in the samples did suggest a fresh-water environment.

TERTIARY

Flagstaff Formation

The "Flagstaff limestone member," formerly of the

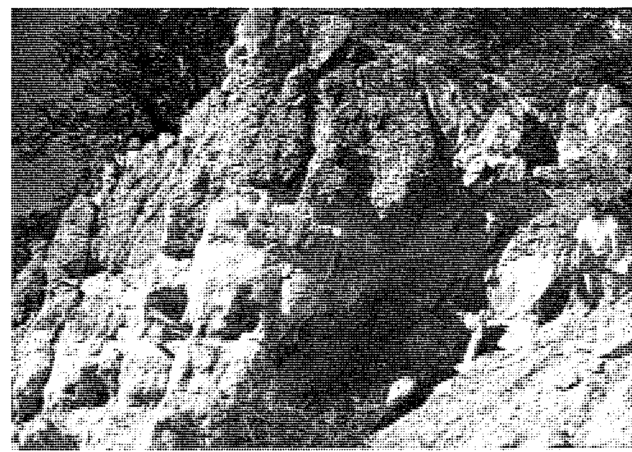


FIGURE 8.—Channel deposits in the North Horn Formation located on Blackhawk hogback.

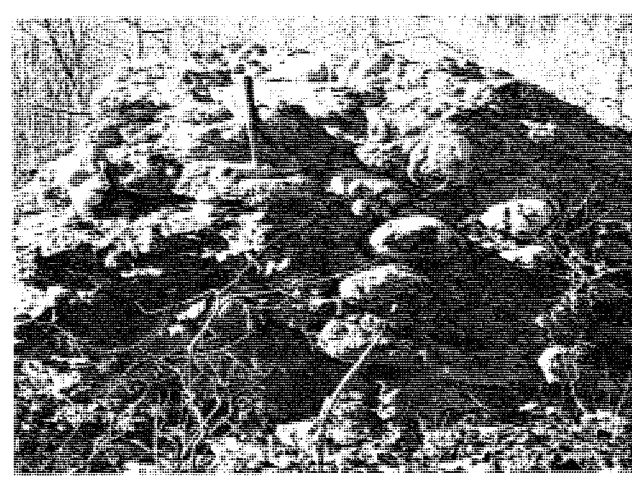


FIGURE 9.—"Giant" algal balls in the North Horn Formation on Jones Ridge. Note hammer for scale.

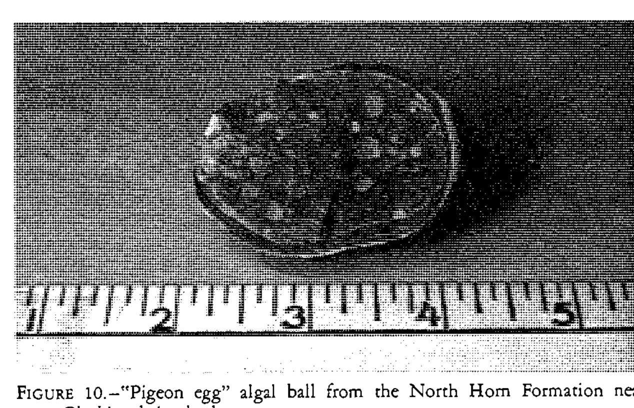


FIGURE 10.—"Pigeon egg" algal ball from the North Horn Formation near Blackhawk hogback.

Wasatch Formation, was defined by Spieker and Reeside (1925, p. 448) as a fresh-water, white limestone that appeared consistently between units previously called "upper and lower members of the Wasatch Formation." Later Spieker (1946, p. 135–36) raised the unit to formational rank and called it the Flagstaff Limestone. At the type section it is mostly composed of white to buff weathering lacustrine limestone with interbedded gray calcareous shales. Minor occurrences of sandstone, volcanic ash, oil shale, and carbonaceous beds are common. In other localities it is not uncommon to find a vastly different lithologic sequence occupying the same stratigraphic horizon. Gilliland (1949, p. 70) reports such a case in the Gunnison Plateau where it contains a considerable amount of sandstone and conglomerate. A similar lithology is reported by Stolle (1974 pers. comm.) on Long Ridge southwest of Levan, Utah. Gilliland found the term *limestone* inappropriate and substituted *formation.* McGookey (1960, p. 596) and La Rocque (1951, 1960) followed suit and also employed the term *formation* rather than its descriptive counterpart *limestone.* Thus Flagstaff Formation is the name applied to equivalent rocks exposed in the Indianola area.

Regionally, the upper contact of the Flagstaff is with either the Colton Formation or the Green River Formation. The Colton is a predominantly red sequence of sediments of fluvial origin that were initially considered the uppermost member of the Wasatch Formation. It is absent in the Indianola area as well as in the Thistle quadrangle (Pinnell 1972), thus connoting a high during Colton or pre-Flagstaff time in this region.

Three different exposures of Flagstaff occur within the Indianola quadrangle, each distinct from the other. Two of these are even questionable Flagstaff. The exposure in sections 12 and 14 northwest of Little Clear Creek is a southern continuation of the units exposed in Dipping Pen Creek in the Thistle quadrangle, a series of limestone, shale, and sand similar to the type section. However, one unique unit bears attention. It is an oolitic limestone that has been completely replaced by silica. It does not appear in outcrop, but it is locally prevalent as slope wash and therefore does not appear in the description of the measured section. I do not deny the occurrence of some siliceous limestones in other Flagstaff locations or the possibility of transportation of this material from another area, but the nature of fragmental angularity and local distribution suggests that it is very near its in situ position. Possibly it had collected as talus and was later modified by uplift and modern sedimentation such as colluvial deposits. In any event the point to be made is that the unique and total silicification of this "sedimentary" material may be due to a nearby volcanic vent. This possibility does not seem too far fetched since the Flagstaff here is covered by materials of a volcanic affinity. Admittedly, these are dominantly stream-transported deposits at this location, but the possibility of a concealed vent is not ruled out.

The Flagstaff (?) atop Brown's Peak is markedly distinct from the units just described. Here the rocks are dominantly clastic. Clean quartz sand, calcareous sand, algal balls, and thin laminar white limestone are present. Mase (1957) mapped this as Flagstaff and reported that Spieker had identified appropriate fauna. After studying regional characteristics and traveling extensively throughout central Utah to view the Flagstaff, as well as other stratigraphic units, I concluded that the rocks which cap Brown's Peak may be a tongue of the Flagstaff Formation. Its clastic nature suggests either a fluvial equivalent or a near-shore mud flat, as evidenced by shallow, lacustrine limestones which oftentimes display mud cracks healed with calcite.

The third exposure of Flagstaff, again questionable, is located between Indian Graves hogbacks east of the townsite of Indianola. The outcrop here is relatively small and does create some confusion. Spieker (1946) reported finding the Flagstaff in "dramatic" angular unconformity with the Arapien. Mase (1957) and Khin (1956) looked for this exposure and could not locate it, even with the benefit of Spieker's personal directions. I too spent considerable time seeking this unconformable surface and met with frustrating failure. However, the lower contact of the rocks that are here seems to be at a slight angular discordance with the North Horn. This may be due to postdepositional gravitational gliding similar to that reported by George Young (1975 pers. comm.) west of Thistle, Utah. The slippage occurred along either unconformable depositional planes or within incompetent shale beds. In any event the aftermath apparently demonstrates, on a small local scale, some form of sedimentary tectonism or structural failure from secondary diastrophism.

The lithology here too is mostly clastic and is not easily differentiated from the overlying Green River, with which it may indeed be confused. Surface samples yield a strong petroliferous odor when freshly broken, indicating that at some time these rocks may have been a hydrocarbon reservoir. This is entirely feasible since several kilometers to the north near Thistle, Utah, the Flagstaff Formation contains prolific tar sands.

The upper contact with Green River rocks is not clear; it seems to be faulted but may actually be transitional as pointed out in other areas by Spieker (1946, p. 136), White (1886) at Wales, Utah, and La Rocque (1960, p. 73).

Not only is the lithology of the Flagstaff in Indianola questionable, but its age is somewhat dubious. Spieker (1946, p. 136) dates it as probable Paleocene. Palynomorphs and organic debris seen in samples collected from the questionable Flagstaff indicate an age of Upper Paleocene and Lower Eocene, but these particular forms are not reliable for specific dates. However, one algal form, *Pediastrum,* does indicate a fresh-water environment. A suggested correlation from these results is beneath but near the Wasatch–Fort Union boundary in Wyoming which is considered to be a Paleocene–Eocene time division marker. (Schwab, Nieves, Elsik 1975 pers. comm.).

In summary it is only fair to mention that the Flagstaff lithology is very similar here to the Green River, and in reality a division of the two within the Indianola quadrangle may not be fair to either.

Green River Formation

The Green River Formation was named by Hayden (1869, p. 90) from exposures near Rock Springs, Wyoming. It was deposited into two basins separated by the Uinta Mountains. The famous oil shale deposits are contained in the northern basin, Goshiute Lake (King 1878, p. 446). The southern basin, Uinta Lake (Bradley 1930, p. 88), includes the study area and demonstrates lithologies of higher energy environments. They seem to be more clastic as a whole, and oil shales are rare if not absent. Spieker (1949, p. 35) recognized two distinct members in the Sevier County area. The lower is blue-gray to light blue shale, and the upper is cream to tan limestone. The Green River sediments within the Indianola quadrangle seem to differ greatly from these adjacent areas. The formation is characterized by numerous conglomerate units which reach 6–9 m in thickness. The clasts are predominantly pink and white quartzites with some dark limestones. The quartzites are from the Eo-Cambrian and Cambro-Ordovician Tintic and Eureka formations. The dense limestones bear Devonian and Mississippian marine fossils and often occur beneath units composed exclusively of quartzite, but this is not a strict rule. Mase (1957, p. 40) was correct when he gave credit to streams of great carrying capacity which drained highlands immediately adjacent to the basin. This stream action created eastward extending boulder fans which extended into the lake and is why shales sometime interfinger with the conglomerates. In my opinion, this section in the southern part of the Indianola quadrangle represents deltaic deposition of the classic Gilbert type. This theory is hard to demonstrate in the field because most of the Green River has been eroded from atop the Wasatch Plateau during the folding and faulting of the Wasatch monocline. However, the cuestas which are exposed here do remain true to form and exhibit a variety of lithologies and an unusual sequence of stratigraphy. There are some minor oil shales and ashy units present. Massive biostromal algal limestones are not uncommon, many of which have been silicified and are similar to those which McGookey (1960) describes several kilometers to the south. Some oolitic units are also present at Snail Hollow. It should be easy to recognize that Green River time provided a colorful sedimentary history in the limited area of these outcrops.

In areas adjacent to the Indianola townsite where the Green River Formation is present, its base is in contact with either the Colton or the Flagstaff Formation. These are gradational contacts and, in the case of the Colton, represent a change of environment from fluvial to lacustrine. At Indian Hollow, however, the Green River is faulted against questionable Flagstaff. Along the frontal scarp of the Wasatch Plateau the Green River has been faulted down against the North Horn. In the area north of Milburn a small series of cuestas has been interrupted structurally by a piercement diapir. It is evident from aerial photos that removal of the soluble contents of the diapir has taken place causing the cap rock of Green River to collapse creating breccia and a "caldera type" effect (fig. 4).

Pollen samples were taken near the Green River–North Horn fault contact and did yield some helpful but limited results (fig. 11). The age determined for this Lower Green River shale was Upper Paleocene–Lower Eocene. Determinations were based on the presence of *Aquilapollenites* sp. and the high percentages of *Pistillipollenites mcgregorii.* The latter is always, or nearly always, common of the Lower Eocene–Upper Paleocene contact. This is especially true in Wyoming where the greater concentration is near or at the Wasatch– Fort Union boundary.

Pistillipollenites mcgregorii becomes more scarce higher in the section, i.e., Upper Wasatch and Green River. The environment of deposition is continental with some fresh-water transport involved and/or a fresh-water lake. This conclusion is predicated on the presence or absence of the algae *Pediastrum* sp. It is worth noting that *Platycary* sp. was not found in these samples; otherwise an age of Lower Eocene could positively have been given. However, had it been found, it would also prove to be no older than Lower Eocene.

In most places of deposition into Uinta Lake, the Green River is thought to be Middle Eocene, but the accepted age is considered to be restricted only to the Eocene. The rocks exposed at Indian Hollow are believed to be an incomplete section of Lower Green River, and the pollen data suggest an age as old as uppermost Paleocene. A Paleocene age suggests the possibility of this belonging to the Flagstaff or at least being its equivalent, but no other diagnostic fossil or lithologic evidence supports this conclusion at this location. Therefore, I have elected to call these sediments Green River and Flagstaff (?), as indicated in figure 19.

Unnamed Volcanic Rocks

The suite of volcanic rocks north of the Indianola townsite represents a drastic change in the geologic history of Utah. Locally, large volumes of explosive volcanics were ushered in during the Oligocene. Centers developed at Bingham, Tintic, Crystal Peak, Marysvale, Little Cottonwood, and in the Needle Range. These are generally silicic and intermediate types (rhyolite-andesite-dacite) which were spewed out of the earth as ash falls, tuff, and latite flows (Hintze

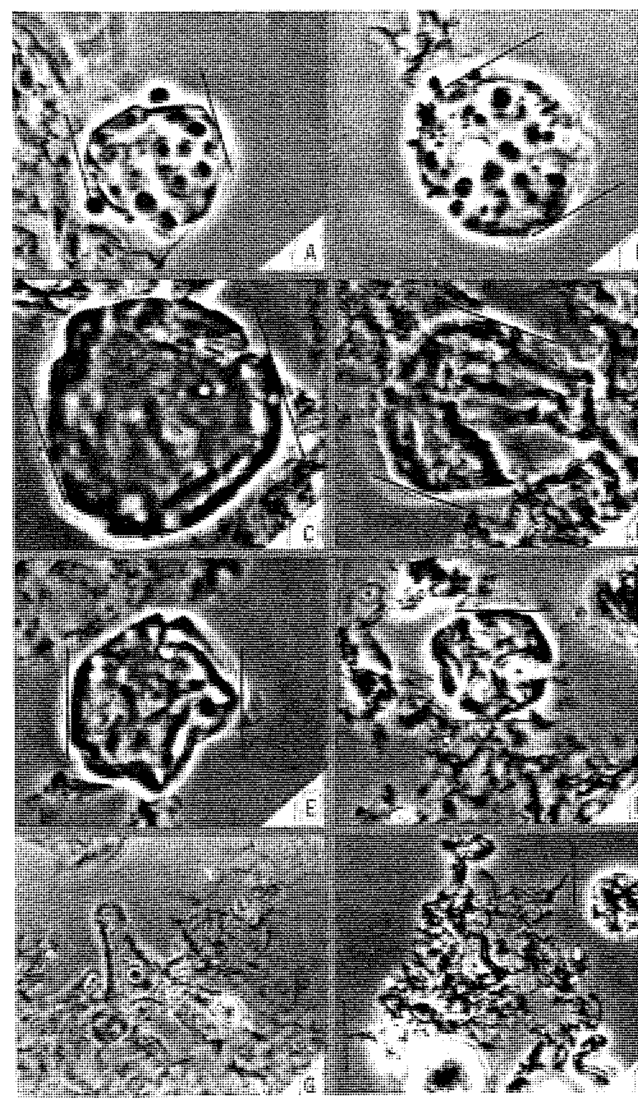


FIGURE 11.—Samples from Green River Formation, pollen photomicrographs. A.—*Pistillipollenites mcgregorii,* 22.4 microns. B.—*Pistillipollenites mcgregorii,* 24.0 microns. C.—*Carya* sp., 40.0 microns. D.—*Taxodium* sp., 32.0 microns. E.—*Alnus* sp., 27.0 microns. F.—Tricolporate pollen, 20.0 microns. G.—*Aquilapollenites* sp., no scale. H.—*Pediastrum* sp., 90.0 microns.

1973, p. 82). In most cases they seem to have filled the valleys and drainage systems of the Oligocene topography.

Such is the case with the rocks near Indianola. They are predominantly andesitic with common occurrences of both silicic and mafic types. In this case they definitely filled the existing drainage systems, but they are not occupying their original depositional sites. That is to say few if any of these rocks here are in their primary state. Rather they have been eroded and carried here by streams (fig. 12). For the most part they are at least crudely bedded and in some instances even cross-bedded. Many of the units are very coarse and contain clasts up to 40 cm in diameter. They are unconsolidated and commonly have algal balls mixed in with their nonsorted matrix.

Hintze (1973) considers these rocks a valuable reference horizon because they predate Basin and Range block faulting and postdate folding and thrusting of the Sevier and Laramide orogenies. In the Little Clear Creek area they also help to date recurrent movement on the adjacent diapir. They now stand atop some of the highest topography in that vicinity and form an impressive outcrop. Beneath them are disconformable and angular unconformable contacts with the Flagstaff, North Horn, and Indianola units.

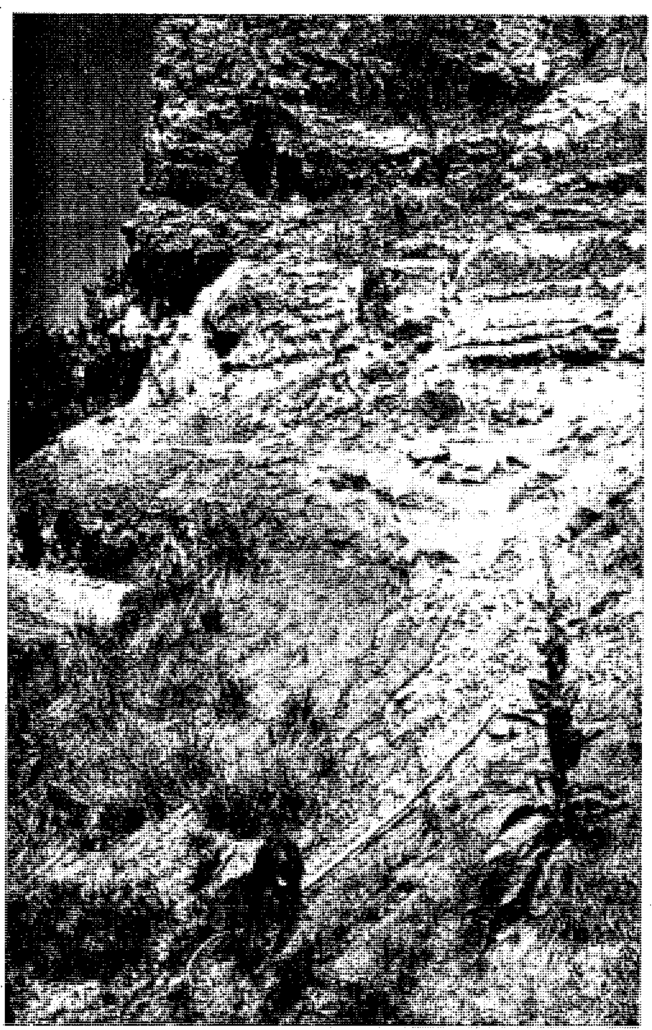


FIGURE 12.–Stream deposits of Tertiary volcanic conglomerates. Location is west of Little Clear Creek near the drainage divide.

The source area for these volcanics near Indianola is not accurately known. Morris (1957) and Hintze (1973, p. 83) suggest they may have come from the Tintic area. Schoff (1951), who reports oral communication with A. A. Baker and states that the volcanics of the Cedar Hills, adjacent to Indianola, may have come from vents in Strawberry Valley, goes on to rule this out on the basis of sedimentary texture and clast size. Khin (1956), who did some petrographic work on basalt clasts sampled near Little Clear Creek, speculates on a source area in the Park City district. All these source localities seem feasible and have merit, but recently discovered hot water vents northwest of Thistle, Utah, near Wanrhodes Canyon, shed new light on the subject. After finding one of these vents, George Young invited me into the field to inspect a newly unearthed fissure. Were it not for a very recent roadcut, this vent may possibly have been overlooked since at the surface it cuts the unconsolidated Tibble Formation which forms an indistinct topography. Also because of its topographical expression it is noted by George Young (1975 pers. comm.) that the entire Wanrhodes Canyon may be a collapse caldera.

Since the net effective transportation by the streams of the Oligocene was still east and south, and because this newly recognized area is in relatively close proximity to Indianola, I speculate that the "Wanrhodes Canyon Caldera" offers a good solution for this source enigma. It is also timely to note from my observation that since these vents are so easily concealed, it is not at all improbable that other vents could be buried near Little Clear Creek and possibly have supplied the necessary chemical ingredients for the "silicified oolitic limestone" found in the Flagstaff near there. Supporting this idea is the fact that the large volcanic boulders have not moved far and may be near their source.

Inasmuch as these rocks were deposited on an old erosional surface in topographic depressions of various types, their thickness varies from place to place. I estimate a thickness west of Little Clear Creek of 300–450 m. Pinnell (1972, p. 111) to the north of the study area estimated 45–125 m.

Age dates on these deposits range from Eocene to Miocene, but most workers seem to agree that Oligocene is the most likely age.

QUATERNARY

Unnamed

Valley fill, alluvial fans, floodplain materials, alluvium, landslide debris, and colluvium all contribute to the Recent sediments and the existing topography within the Indianola quadrangle. Occasional minor accumulations of stream terrace gravels occur in the low hills around Hjork Creek. Merrill (1972) reports such gravels in the Mill Fork area and attributes them to stream equilibrium during the prominence of Lake Bonneville. Pinnell (1972) offers an alternative explanation for the presence of similar gravels in the Thistle quadrangle, saying it is due to stream equilibrium recurrently interrupted by rejuvenation from active faults along the Wasatch front.

Alluvial fans and their subsequent erosional dissection record recent changes in Utah climatic conditions and continued uplift of the High Plateaus and Great Basin provinces. Landslides occur predominantly in canyons along the impressive front of the faulted Wasatch monocline although some do occur in conjunction with the salt collapse breccias at the foot of the plateau's frontal scarp. In any event, all debris areas were judged to be minor features and to pose no immediate threat to civilization or natural ecosystems. Actually surface creep seems to be the only presently active phenomenon. For this reason few debris areas were singled out andmapped except when they displayed a geologic or topographic significance of some sort.

Since the terrace gravels and volcanics at Bone Yard and Hill Top are higher than the valley floor, they are probably older. Schoff (1951, p. 636) suggests they may be assigned as Quaternary in age because there is a lack of any other evidence, but a Late Tertiary age for the higher-standing volcanic outwash should not be ruled out.

SEDIMENTARY TECTONICS

Diapiric tectonism is a phenomenon which seems uniquely capable of producing unusual and impressive structures. For example, it is well documented (Halbouty 1967) in the Gulf Coast region of the United States that subsurface domes have created tremendous hydrostatic pressures. These hyper pore-pressures play an important role in the structural rupture of stratigraphic systems. In Iran (Gera 1972, Kent 1958), where the climate is arid, salt spines have been known to propagate to the surface and create "salt glaciers" which produced soil "tills" while being powered by gravity. In the Paradox Basin salt overhangs have caused beds to overturn and form hydrocarbon traps in the subsurface. These are only a few examples of many which could be used to illustrate that diapirism, on a local scale, can create structural relationships and unconformities that can be confusing unless one clearly recognizes the mechanism with which he is dealing. Such is the case in the Indianola area where previous workers overlooked the express powers of salt. Within this small quadrangle, only 156 km², are three impressive piercement structures. As with most salt domes throughout the world, they are believed to have formed through a sequence of differential timing and pulsing rates of ascension which have created local inter- and intraformational unconformities, faulting, folding, and bed overturning. Collapse and cap-rock brecciation located atop these features have also played a key role in their evolution. This "roof caving" action was probably brought about as spines attached to the master domes encountered open-system, ground-water aquifers. The evaporites were taken into solution by the water and removed from the immediate area. This section of removal and collapsing, however, probably did not play an important role until the later stages of upwelling which has produced the present structure and topography (figs. 4, 13, 14, and 15).

Another point of interest associated with the removal of these evaporites is that during Recent times this area has comprised part of the Great Salt Lake drainage system. Many ideas have been promoted about the origin of evaporites for the lake, but I believe that the Jurassic salt from the Arapien Formation of central Utah provides a most credible explanation for a rich source of gypsum and halite.

The domes in the Indianola area fall under the classification of halokinesis as described by Halbouty (1967, p. 2). In general this means that the initiation of growth resulted from variations of overburden and isostatic physics which equalize the pressures between materials of two different spe-

FIGURE 13.–Low oblique aerial view from south of the collapsed N. San Pitch River diapir.

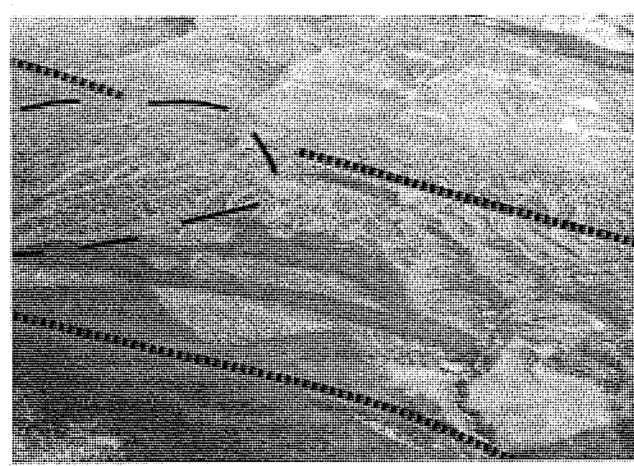


FIGURE 14.–Circular depression on left is the collapsed diapir. The diced pattern marks location of faults in N. San Pitch River Valley. In the background is the frontal scarp of the Wasatch Plateau.

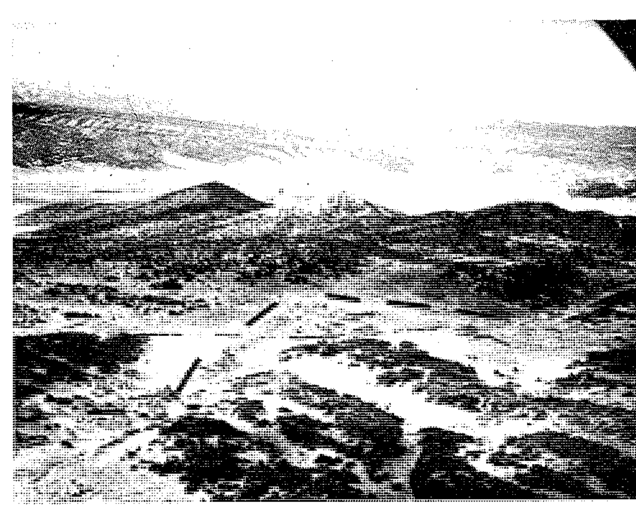


FIGURE 15.–Background is Wasatch Range and Cedar Hills. Middleground is Indianola townsite and cuestas of Green River–North Horn rocks. Foreground is western edge of the collapsed diapir.

cific gravities. In this case the Arapien is believed to be the mother salt. As in other areas along the Colorado Plateau (Stokes 1956b, p. 46), accumulations of salt were most likely amassed by tectonic folding, critical overburden, basement faulting, and/or locally increased geothermal gradients. Donald Kupfer (1975) notes that temperature is one of the most important factors involving salt dome movement. He also provides a good explanation of purification that results from ascension and crystal strain hardening, which aid in the mechanics of domal growth. These processes seem to be important since the Arapien is not known for its massive purity of evaporites. Whatever the mechanism for initiation of evaporite massing, it is a well-known fact that density differences alone are able to maintain an active state of diapir growth for a very long period of time.

Salt often forms valleys, both regionally, as those underlying the bolsons of West Texas, and locally, such as some of the entrenched river valleys in the Paradox Basin (Stokes 1956b, p. 44). This model holds true for the North San Pitch River Valley diapir north of Milburn in the study quadrangle, but not for Hjork Creek dome or Little Clear Creek piercement because these two are at the core of highs both structurally and topographically.

The Little Clear Creek diapir is similar to the ones in the Paradox Basin (Stokes 1956b, p. 46) in that it outcrops as a linear feature (fig. 19) instead of as a dome. This peculiarity is probably due to an obscure intimate relationship with the Little Clear Creek fault. The overturning of the Price River and South Flat on the east wall of the canyon is probably due, firstly, to the asymmetric ascension of the diapir and, secondly, to accentuation by subsequent collapse.

The Hjork Creek piercement is actually an elongated dome rather than a circular one and is illustrated on the formline contour map (fig. 7) as a plunging anticline. The exposed stratigraphy surrounding this immediate area clearly demonstrates numerous local angular unconformities which are the basis for explaining various episodes of upwelling.

All three of the diapirs in the study area are believed to be separate distinct master domes each acting independently of the others, thus revealing their evolutions and personalities as different topographic expressions. Their relations to and interactions with thick Rocky Mountain geosynclinal sediments, Laramide folds, Wasatch monocline, and Basin-Range faults are extremely complex and are best described by the sequence of cross-sections in figure 16.

An apparent problem with these diapirs is that they do not show up as strong negative anomalies on gravity maps compiled by the exploration efforts of an oil company. One explanation for this could be found in the concept of solution, removal of the low-density material, and collapse, which has previously been discussed. However, the most likely reason they did not show up strongly is that the gravity survey was too regional to indicate such small local anomalies. Thus it is felt that a proper scale of investigation relative to the size of the diapirs would show intense gravity lows.

STRUCTURE

Faults

Analysis of faulting was undertaken by standard methods using stream patterns (figure 17), field tracing of breccias, springs, and stratigraphy. Aerial photos, both conventional and low oblique late afternoon shadows, were also used. More sophisticated techniques, employing imagery analysis of Skylab III and ERTS photos and vibroseismic data, proved to be extremely interesting but were actually of limited help. By density slicing of the space photography, we attempted to produce a linear-trend overlay, making identification of faults, joints, and stratigraphy, but we were limited by nondescript geomorphology and vegetation. However, this method did demonstrate some interesting results and holds great potential for mapping and structural analysis from aerial photos, especially those from space, owing to their excellent bandwidth control.

Most of the faults in the study quadrangle fall in a normal-fault category. However, diapirism has allowed for some very unusual relationships and timing which is often difficult to pin down.

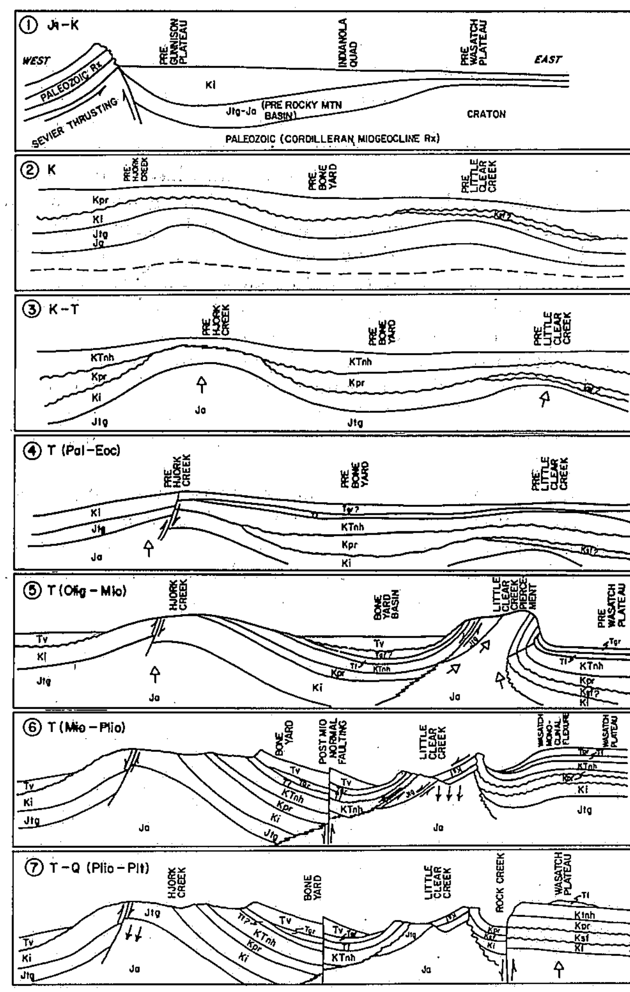


FIGURE 16.—Cross-sectional evolution of the Indianola area. Refer to figure 19 for stratigraphic abbreviations. (1) Section width (approximately 120.7 km) across the Rocky Mountain geosyncline. Deposition through Cretaceous times near the eastern center of the downbuckling geocline. (2) Cross-section width (approximately 9.7 km) across the Indianola quadrangle (figures 2-7). Folding and subsequent deposition of Price River conglomerates ending the Sevier orogeny and beginning the Laramide orogeny. Deposition through Price River times. (3) End of Laramide orogeny. Intermittent diapiric ascension. Deposition through North Horn times. (4) Diapiric growth and subsequent faulting. Deposition through Green River times. (5) Diapiric piercement at Little Clear Creek. Deposition through Tertiary volcanic times. (6) Collapse of diapir tops. Basin-Range faulting and subsequent overturning of South Flat and Price River rocks. (7) Uplift of Wasatch Plateau and present-day position of geology.

FIGURE 17.–Stream pattern analysis. Stippled areas denote areas of controlled drainage.

The NNE fault, which runs east of the Indianola townsite and divides the valley from the cuestas of Green River and North Horn rocks, is readily noticed as one studies a topographic map of the area. It has been speculated to be a Jurassic-age fault, a possible extension of the "ancient Ephraim Fault" (Moulton 1975). Jurassic age is only conjecture at this point because there is difficulty physically tracing the fault in the field. Had this problem not been suggested verbally to me, the age of faulting would be assigned to post-Oligocene, the beginning of the Basin-Range taphrogeny. Indeed, even if it were initiated in the Jurassic, it does seem to evidence significant Miocene movement. Although it is not connected on the attached map (fig. 19), this fault may continue to the NE up Little Clear Creek and ultimately control this faulted canyon at depth.

It is easy to envision that depositional control caused by a fault scarp in this position during the deposition of the Jurassic evaporites provided a plausible mechanism for the linear diapir which paralleled Little Clear Creek Canyon and subsequently overturned the Price River and South Flat strata. This is one of the criteria for suggesting a Jurassic rift basin.

The next oldest fault in the quadrangle is the curving N-S fault which parallels and controls the base of the Wasatch Plateau. It is thought to have been initiated during the Late Eocene at the inception of the Wasatch monoclinal flexure. Most likely this normal fault was a tensional fracture at the hinge of the fold and provided a zone of weakness for the greater displacement which began to occur during the Miocene. The fault is still active and is powered by the forces which are exhuming the Colorado Plateau. It, too, may have provided primary structural control for ascension of the circular North San Pitch River diapir.

The faulting directly associated with the piercements, especially the drag faults, are best explained by reference to the map and cross-sections (fig. 19, A-A', B-B'). The movement probably began in Cretaceous time and ranged to the present, with differential movement dependent on ascension and collapse of the diapirs.

The illustrated curved faults east of, and adjacent to, Blackhawk hogback are surface features produced by slumping and gravity sliding of the Flagstaff and Green River rocks on thin shale beds. Relative horizontal translation is at most a few hundred meters.

The only other major fault is the ENE-trending normal fault which runs through the Indianola townsite. I first discovered it while tracing the occurrence of numerous effluent warm springs. It also shows up on seismic section and proves to displace the basement by several thousand meters (fig. 19, C-C').

The rest of the small normal faults on the map are relief adjustments to the block-faulting patterns of the eastern Great Basin.

Joints

The only surface joints of any significance are the two pervasive sets that affect the Indianola?–Price River? rocks at the head of Hjork Creek. One set trends E-W and the other trends NNW-SSE. They were probably caused by the strain of standing these massive conglomerates on end during the final stages of ascension of the Hjork Creek diapir.

Folds

There are two significantly different types of folding within the study area: those associated with diapirism and the large monoclinal flexure which forms the structural and topographic front of the Wasatch Plateau.

Topographically the Wasatch monocline is one of the most impressive features of the central Utah area. It was probably formed during the Late Eocene (Eardley 1963), but its timing is difficult to pin down precisely. Spieker (1949b) reports that at one time the plateau was covered with Green River sediments and that they have since been stripped by erosion. I feel that the monocline was a positive feature during deposition of the (Oligo–Miocene?) volcanics which were deposited by streams parallel to the fold axis. The realization of these facts leads me to conclude that folding began in Late Eocene and continued into Early Oligocene times.

The series of two anticlines and two synclines which seems to align in a rough en echelon pattern and plunge to the SW, represents a complex interaction between the diapiric ascensions and possible folding during the Laramide epeirogeny. Therefore, their timing most likely ranges from latest Jurassic until Recent times with the strongest intermittent action in Late Cretaceous–Early Tertiary.

TECTONIC HISTORY

The tectonic evolution of this central Utah area (fig. 16) has been a complex interplay of the Cordilleran miogeosyncline, the Nevadan orogeny, the Sevier orogeny, the Rocky Mountain geocline, the Laramide orogeny, the Flagstaff and Green River lakes, Tertiary volcanic eruptions, the Wasatch monocline, Basin and Range taphrogeny, Recent regional uplift and dissection, and finally sporadic, intermittent ascension and collapse of diapirs.

This is a most impressive list of historic events, and it is certainly an understatement to mention that it is no wonder that the geology of the Indianola quadrangle has been misunderstood for a long period of time.

The following list is intended to be a concise, generalized chronologic outline of events which have directly affected the surficial geology.

1. Paleozoic deposition of Cordilleran miogeoclinal sediments. (Eo-Cambrian–Permian)
2. Nevadan orogeny (Jurassic), producing the arch of the Sevier geanticline and regional drainage shifts.
3. Sevier orogeny (Cretaceous) caused by strong compressive forces that produced a major thrust belt stretching from southern Nevada to Idaho.
4. Rocky Mountain geosyncline (M. Cretaceous–Paleocene), an asymmetric foredeep that collected a classic "inverted" stratigraphy shed from the frontal highlands of the disturbed belt. These extremely thick (4,500 m) sediments could have been the necessary critical overburden for initiation of diapirs.
5. Laramide epeirogeny (L. Cretaceous–Paleocene) caused by vertical uplifts that produced local gravity sliding. It produced the folding and unconformity that are represented at the base of the Price River conglomerates. This action may have aided the ascension of early diapiric movement.
6. Flagstaff Lake (Paleocene), really a unidirectional transition of the fluvial and lacustrine deposits of the North Horn formation. The fluvial clastics of the North Horn (Cretaceous–Paleocene) probably represent the dying phases of the Laramide orogeny. Lake

Flagstaff may not have been one large body of water but rather a series of intermountain lakes.

7. Green River Lake (Eocene), in this area the southern extension of ancient Uinta Lake. In this part of central Utah its nearness to highlands accounts for the abundance and coarseness of conglomeratic units.
8. Wasatch monocline (L. Eocene–E. Oligocene), a flexure that was post-Green River times and must have been a reaction between the evolving Great Basin and present "cratonal edge."
9. Tertiary volcanics (Oligocene–Miocene) ignimbrites, andesites, and basalts, in this area all reworked and deposited by streams.
10. Basin Range taphrogeny (Miocene–Recent), fault blocks being tilted and uplifted by regionally tensioned plate tectonic forces.
11. Recent regional uplift, a continuation of forces that created the Basin-Range features and entrenchment of the plateaus.
12. Diapiric action (Jurassic?–Recent), intermittent reactions caused by sediment overloads, faulting, folding, and regional uplifting. The final stages of development have been affected by collapse due to having their tops removed by ground-water solution. These solubles have probably been a source for at least some of the Great Salt Lake evaporites.

ECONOMIC GEOLOGY

The area within the study quadrangle offers significant economic potential in several categories. With the exception of gravel products, most of the resources could be developed without serious impact on the present surface uses of farming and ranching. Road gravel has already been stripped from some small foothills composed mostly of Tertiary alluvium. These deposits still offer limited quantities of gravel.

Noncommercial quantities of peat have been surface-mined by local farmers. Peat-supplying units lie adjacent to Parley's Canyon and other canyons east of the Milburn townsite and are contained in the Cretaceous North Horn Formation. Their extent has not been thoroughly investigated.

Bitter halines may be present in undetermined quantities near Hjork Creek and Little Clear Creek diapirs. The success of Croton's mine is not reported, but supposedly its inception was to retrieve sylvite.

When more is learned about the relative stability of salt domes, those within the study area could possibly be used for underground storage of hydrocarbons or even radioactive waste. This is a sensitive subject when one considers environmental and safety precautions. There are many unknown variables, but once these uncertainties are understood, the domes in this region could be considered for such storage facilities.

Perhaps the greatest economic potential within the area lies beneath the salt domes in structural oil and gas reservoirs. Walton (1974 pers. comm.) feels that the Clear Creek gas field may be a salt-controlled structure. Christiansen (1963) has for years recognized the powers of evaporite diapirs in this area of Utah. Also noncommercial shows from multipay zones have been reported from the Paleozoic rocks beneath the Wasatch Plateau several kilometers south of Indianola by Phillips Petroleum Company. Well-control data is extremely sparse in this region, but I believe that conditions for maturation and migration of commercial hydrocarbons are excellent. This is simply illustrated by figure 18, which demonstrates a model that reportedly can be seen in the Gulf Coast salt domes in Louisiana. The model has been proposed by Donald Kupfer (1975 pers. comm.) and was derived from his studies of salt mines and seismic data in that part of the country. The uplifted dome or anticline beneath the diapir is created by isostatic adjustment due to the rise of low density evaporites.

The subsurface stratigraphy beneath the Arapien in this part of central Utah consists of Paleozoic miogeosynclinal sediments of the Cordilleran and Mesozoic eolian and fluviatile deposits. These rocks provide a target for hydrocarbon source beds and reservoirs. Several formations could act as either, but the Jurassic Navajo should offer exceptional reservoir qualities. Also the close proximity of warm springs near the Indianola townsite suggests a good temperature regime for maturation and migration of hydrocarbons.

It is noteworthy to mention that in addition to isostatic uplift beneath the diapiric ascension, Laramide tectonics may have aided the formation of an amenable reservoir trap.

For these general reasons I suggest that the Indianola anticline is an excellent wildcat target.

OVERVIEW

The global plate tectonic model is far from perfect to date, but it is an excellent working hypothesis which functions well enough so that the burden of proof has been shed to the disbeliever. Its employment often generates new ideas, some good, some not so good, but it is important to promote and develop these ideas so that the model can be expanded and tested. I do not pretend that the small area of the study quadrangle will provide vast expansion of the model or even that the presented observations will make a good fit to the model, but some thoughts which surfaced during this project do seem worth discussion.

It was mentioned previously that the linear diapir that controls Little Clear Creek may have initially been a simple salt deposit against a fault scarp in a restricted basin. This is a common mode of origin which oftentimes accompanies rift basins. The Paradox Basin of southern Utah is an aborted rift basin, and speculation suggests that the age of control

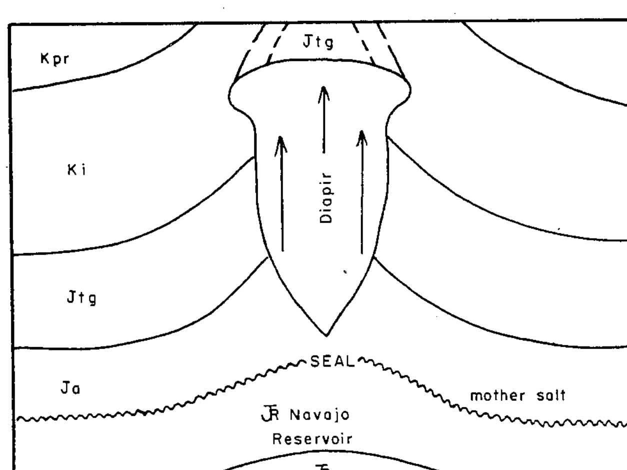


FIGURE 18.–Schematic diagram representing the ascension of Hjork Creek diapir. The structure beneath the diapir is created by isostatic rebound beneath the low-density evaporites. The Navajo Sandstone in this position makes an excellent target for a hydrocarbon reservoir.

possibly is related to the salt deposits of North Sanpete Valley. Is it too far afield to suggest that the restricted Jurassic sea which occupied the vicinity of central Utah was an ancient rift system? Could the present-day cratonal edge which underlies the Wasatch monocline (Schuey 1973, and Kenneth Cook 1973 pers. comm.) be related to such an ancient system, or is it more closely associated with the Great Basin rift which is presently developing?

The Laramide orogeny is another subject for speculation. Richard Wing (1975 pers. comm.) has recreated an interesting cross-section across the Rocky Mountain geosyncline that shows a sequence of half-grabens with the down-dropped edge to a central "downbuckling" axis. This shows orogenic clastics shed from upthrusts during the Laramide orogeny to have been deposited in a regional topographic low which may have been a plate attempt at subduction that failed for some reason. This topographic depression helps one to visualize the large basins necessary for North Horn, Flagstaff, and Uinta lake deposits.

The Sevier orogeny is one that supports an idea promoted by Hays and Pitman (1973) that the rapid worldwide spreading during the Cretaceous was accompanied by an elevation at the midocean spreading center which created a volumetric reduction of the ocean basin and forced the seas onto the continents. This event then forced the final marine invasion of central Utah. However, 90 million years is a long time without any marine transgressions. I think this is one indication that the continents are getting thicker and riding higher on their respective plates.

New questions now arise. Was the Sevier thrusting due to this rapid spreading rate? Was the Cretaceous volcanicity record of another aborted subduction attempt? Is it coincidence that the termination of salt diapirs and Wasatch monocline within Indianola area lie at a triple intersection of the Great Basin, the Colorado Plateau, and the Central Rockies (composed of the anomalously thick Oquirrh Basin sediments)? All these questions and others which will arise during the development of global geologic history present a tremendous challenge. I wish to express that this challenge and the stratigraphy, structure, and tectonic history of the Indianola quadrangle well represent classic geologic principles. It is an area that still demonstrates a promise of revelation for the future and one that has been an excellent proving ground for students of the earth.

APPENDIX

Arapien Formation

Section tape-measured in East Lake Fork, stream cut trending ESE in section 7, T. 11 S, R. 5 E.

Unit No.		Thickness Meters
	Price River Formation Fault Contact	
7	Mostly soil and vegetation covered. Sandstone, uniform, light brown, weakly bedded, minor shale streaks, gray-brown	45.1
6	Mostly soil covered. Shale, light green-gray, forms dark soil in places, hints of gypsum. Thin interbeds of buff silty limestone	15.2
5	Sandstone, golden-brown, limy, fair sorting, medium grained	.9
4	Mostly soil covered. Shale, gray	11.9
3	Sandstone, medium grained, red-brown with sparse, thin (2–15 cm) limy buff sands, oscillation ripple marks, and discontinuous shale lenses	7.9
2	Mostly covered. Shale, brown	22.8
1	Sandstone, very fine grained, white, light gray, quartz. Weathers to bulbous ledges	4.7
	Total	108.5
	Fault contact South Flat Formation	

Twist Gulch Formation

Section measured on traverse trending N55W in NW corner section 18, T. 11 S, R. 5 E. The outcrop is well exposed on stream cut and trends N 50 E 65 NW.

Unit No.		Thickness Meters
	North Horn Formation Alluvium–fault contact	
18	Sandstone, fine grained, fair to good sorting, mostly quartz with minor feldspars and traces of dark heavy minerals and chert, subangular-subrounded; strong hematite staining which yields a red hue; fracturing healed with calcite; thinly bedded wih minor weak cross-bedding; basal sand, interbedded with thin maroon, light green-gray silty shales and sands which occur as a distinct cyclic sequence	2.0
17	Sandstone similar to 18; cyclic sequence with bulbous weathering basal sand	11.9
16	Sandstone similar to 18 only cycles more even in thickness and spacing; gray silts and shales, highly calcareous; basal sand approx. 1.5 m thick demonstrating good graded bedding; white speckled appearance derived from imbricate aligned feldspars altered to kaolinite	8.7
15	Similar to unit 16; lensing of white speckled fragments (2.5–10 cm thick lenses) in the basal sand (fine–medium); shale thin, crinkled, dark red-brown	6.1
14	Sandstone, cyclic unit; white specks change to cross-bedded structures in the 2-m-thick basal sand; units above base fine upward thin and interbed with laminated shale and silts approx. 1–2 m thick	7.0
13	Similar to unit 14. Basal sand approx. 2.5 m thick and cross-bedded; color changed from maroon to red-orange; shales in upper part of unit weathered to a mottled appearance	10.4
12	Less distinctly cyclic although grain size and color similar to above; tight green-gray calcareous units abundant, interbedded with red shales; basal sand missing, given way to evenly bedded massive sands approx. .6–.9 m thick	10.4
11	Shale, green-gray to maroon, variegated with some bulbous ledge-forming interbedded sandy units approx. 1.2 m thick	30.9
10	Sandstone, massive bulbous, red-orange, quartzose	1.8
9	Shale, thin paper shales, light gray with minor fine sands approx. 5–10 cm thick, more prominent at the base of the section	29.0
8	Sandstone, very coarse to grit, immature, abundant calcite, some kaolinite; very colorful matrix approx. 50% of which is subangular quartz and abundant feldspars	.6
7	Shale, dark maroon, crinkled, with interbedded gray silty calcareous units approx. 2½ cm thick	20.7
6	Silt and fine sand, weathers fissile, red, evenly bedded, calcareous at base	12.1
5	Shale, red, some silt	14.5
4	Silt and fine sand, red, mottled, weathers in a chippy, fine slabby nature, interbedded red crinkled shales	22.6

3	Covered, soil	22.3
2	Cyclic sequence of dark red crinkled shale and silts with minor light red, fine-medium well-sorted sands; basal sand medium grained, red-orange approx. 46 cm thick	15.6
1	Shale, red	4.6
	Total	231.2

Fault
South Flat Formation

Indianola?–Price River Formation?

Section tape-measured on a traverse trending N40W in NW section corner, section 22, T. 11 S, R. 4 E.

Unit No.		Thickness Meters
	North Horn Formation Unconformable contact	
1	Conglomerate, massive, coarse, weathers to bulbous pinnacles; color dominantly gray to buff with minor red-orange surface staining; outcrop heavily fractured with two major joint sets, one trending N47W and the other N87E; clast composition (sizes up to .6 m dia.) dominantly quartzite with abundant sandstone clasts; most sandstone clasts have liesegang banding; matrix gritty and poorly sorted suggesting a possible source from the Twist Gulch Formation; outcrop with prominent channeling near the base of the section, some demonstrating a high degree of imbrication	237.5
	Total	237.5

Unconformity
Indianola Group

North Horn Formation

Section tape-measured in sections 29 and 30, T. 11 S, R. 5 E on a line trending N40W from the SW corner of section 29 to the SW corner of section 30.

Unit No.		Thickness Meters
	Flagstaff Formation?	
11	Sandstone, poorly exposed, medium to coarse grained, poor to fair sorting; occasional thin algal-ball beds, balls average 5–15 mm diameter, some clay galls incorporated; no fossils in algal balls; alternating red-orange to light buff on weathered surface	13.0
10	Mostly soil covered, sandstone slope wash	71.6
9	Similar to above, but slope wash orange and gritty; some minor interbedded red shales at base approx. 3 m thick	52.7
8	Sandstone, calcareous, very coarse, gritty, poorly sorted, light gray; small conglomerate lenses with limestone clasts; sandstones occasionally mottled, changing downward to sandy limestones with minor occurrence of algal balls	26.2
7	Mostly soil covered; sandstone, weathers bulbous, very calcareous, medium–coarse grained, orange to buff color	152.4
6	Sandstone, quartzose, light gray, fine–medium grained, good sorting with dark chert fragments and sparse limestone	7.5
5	Mostly soil, vegetation covered; sandstone, gritty, cross-bedded, lensing of fine conglomerate and clay gall beds, red-orange; top 9 m of section grading downward into fairly well-sorted calcareous sand, light gray with minor thin orange limy units; total section laterally variable, containing some unexposed interbedded red shales	52.4
4	Soil and vegetation cover	135.9
3	Poorly exposed; conglomerate, coarse, openwork with thick interbeds (approx. 6 m) of clay and algal balls; sandstone, buff, limy with occasional lensatic shales.	159.6
2	Mostly covered; sandstone, red-orange, medium to coarse grained with minor conglomerate (limestone clasts) lenses and algal ball units	60.2
1	Sandstone, red-orange, very calcareous, fair to poorly sorted; interbedded red silty shale approx. 4.5 m thick; iron banding common near contact of Price River rocks	26.7
	Total	758.2

Unconformity?
Price River Formation

Flagstaff Formation

Section tape-measured in section 6, T. 11 S, R. 5 E on a line trending NW–SE.

Unit No.		Thickness Meters
	Green River Formation	
7	Mostly covered; shale, dark gray with thin lenses of very light buff chippy weathering limestone	13.7
6	Limestone, light brown, medium density, thin lenses (15–45 cm); very dense siliceous fossiliferous limestone	8.6
5	Limestone, fossiliferous hash, gray, weathering chalky light gray-brown into small blocky chips	10.7
4	Shale, gray on weathered surface, dark gray brown on fresh broken surface;	6.1
3	Shale, gray brown, thinly even bedded, weathering chippy, interbedded with thin sandy limestone lenses	10.8
2	Limestone, white, chalky with some ash?, weathering fissile, medium density, containing fresh-water gastropods	3.3
1	Mostly soil covered; shale, gray	14.9
	Total	68.1

North Horn Formation

REFERENCES CITED

Armstrong, R. L., 1968, Sevier orogenic belt in Nevada and Utah: Geol. Soc. Amer. Bull., v. 79, p. 429–58.

Atwater, T., 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geol. Soc. Amer. Bull., v. 81, p. 3513–36.

Baer, J. L., 1969, Paleoecology of the cyclic sediments of the lower Green River Formation, central Utah: Brigham Young Univ. Geol. St., v. 16, pt. 1, p. 3–95.

Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., 1936, Correlation of the Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: U.S. Geol. Surv. Prof. Paper 183.

Bissell, H. J., 1952, Stratigraphy and structure of northeast Strawberry Valley quadrangle, Utah: Amer. Assoc. Petrol. Geol. Bull., v. 36, p. 575–634.

Bradley, W. H., 1930, The varves and climate of the Green River epoch: U.S. Geol. Surv. Prof. Paper 158, p. 87–110.

Burchfiel, B. C., and Davis, G. A., 1972, Structural framework and evolution of the southern part of the cordilleran orogen, western United States: Amer. Jour. Sci., v. 272, p. 97–118.

Burchfiel, B. C., and Hickcox, C. W., 1972, Structural development of central Utah: Utah Geol. Assoc. Publ. 2, p. 55–66.

Burger, J. A., 1963, The Cretaceous system of Utah: Utah Geol. and Mineralog. Surv., Bull. 54, p. 123–40.

Buss, W. R., 1963, The physiography of Utah: Utah Geol. and Mineralog. Surv., Bull. 54, p. 13–18.

Christiansen, F. W., 1963, Oil and gas possibilities of the transition zone in central Utah: Utah Geol. and Mineralog. Surv., Bull. 54, p. 237–338.

Clark, F. R., 1914, Coal near Wales, Sanpete County, Utah: U.S. Geol. Surv., Bull. 541, p. 478–89.

———, 1928, Economic geology of the Castlegate, Wellington, and Sunnyside quadrangles, Carbon County, Utah: U.S. Geol. Surv. Bull., no. 793, 165 p.
Crittenden, M. D., 1961, Magnitude of thrust faulting limits in northern Utah: U.S. Geol. Surv. Prof. Paper 316-E, p. 75–89.
Crosby, G. W., 1972, Dual origin of Basin and Range faults: Utah Geol. Assoc. Pub. 2, p. 67–74.
Dietz, R. S., 1972, Geosynclines, mountains, and continent-building: Scientific American, March, v. 226, p. 30–38.
Doelling, H. H., 1972a, Tertiary strata, Sevier-Sanpete region: Utah Geol. Assoc. Pub. 2, p. 41–54.
———, 1972b, Coal in the Sevier-Sanpete region: Utah Geol. Assoc. Pub. 2, p. 81–90.
Dutton, C. E., 1880, Geology of the high plateaus of Utah: U.S. Geog. and Geol. Surv., Rocky Mtn. Region Rept., 307 p.
Eardley, A. J., 1932, Stratigraphy of the southern Wasatch Mountains, Utah: Michigan Acad. Sci., Arts and Letters Papers, v. 18 (1933).
———, 1934, Structure and physiography of the southern Wasatch Mountains, Utah: Michigan Acad. Sci. Papers, v. 19, p. 377–400.
———, 1963, Structural evolution of Utah: Utah Geol. and Mineralog. Surv., Bull. 54, p. 19–29.
———, 1967, Idaho-Wyoming fold and thrust belt: Its divisions and an analysis of its origin: Intermountain Assoc. Petrol. Geol. Guidebook 15, p. 35–45.
Fenneman, N. M., 1931, Physiography of western United States: McGraw-Hill, New York, 534 p.
Gera, F., 1972, Review of salt tectonics in relation to disposal of radioactive waste in salt formations: Geol. Soc. Amer. Bull., v. 83, p. 3551–74.
Gilliland, W. N., 1949, Geology of the Gunnison quadrangle, Utah: Ph.D. dissertation, Ohio State Univ.
———, 1951, Geology of the Gunnison quadrangle, Utah: Univ. Nebraska St., no. 8.
———, 1963, Sanpete-Sevier valley anticline of central Utah: Geol. Soc. Amer. Bull., v. 74, no. 2, p. 115–24.
Gilluly, J., 1963, The tectonic evolution of the western U.S.: Geol. Soc. London Quart. Jour., v. 199, p. 133–74.
Halboury, M. T., 1967, Salt domes, Gulf region, United States and Mexico: Gulf Pub. Co., 425 p.
Hardy, C. T., 1952, Eastern Sevier Valley, Sevier and Sanpete counties, Utah: Utah Geol. Mineralog. Surv., Bull. 43, 98 p.
———, 1962, Mesozoic and cenozoic stratigraphy of north central Utah: Brigham Young Univ. Geol. St., v. 9, pt. 1, p. 50–64.
———, 1963, Tertiary stratigraphy of Utah: Utah Geol. and Mineralog. Surv., Bull. 54, p. 141–46.
Harris, H. D., 1953, Geology of the Birdseye area, Utah: Master's thesis, Brigham Young Univ., 146 p.
Hayden, F. V., 1869, U.S. Geol. and Geog. Surv., Terr. 3rd Ann. Rept., 155 p.
Hays, J. D., and Pitman, W. C., III, 1973, A model linking late Cretaceous extinctions and plate tectonics: (abstract), 85th Ann. Geol. Soc. Amer.
Hintze, L. F., 1962, Structure of the southern Wasatch Mountains and adjacent areas: Brigham Young Univ. Geol. St., v. 9, pt. 1, p. 70–79.
———, 1973, Geologic history of Utah: Brigham Young Univ. Geol. St., v. 20, pt. 3, 181 p.
Howell, E. E., 1875, U.S. Geog. and Geol. Surv., W. 100th Mer. Rept., v. 3, pt. 3, p. 231–301.
Hunt, R. E., 1954, South Flat formation, new upper Cretaceous formation of central Utah: Amer. Assoc. Petrol. Geol. Bull., v. 38, no. 1, p. 118–28.
Imlay, R. W., 1948, Marine Jurassic fossils of the western interior: U.S. Geol. Surv. Paper 214B.
———, 1967, Twin Creek Limestone (Jurassic) in western interior of the United States: U.S. Geol. Survey Prof. Paper 540, 105 p.
Kent, P. E., 1958, Recent studies of south Persian salt plugs: Amer. Assoc. Petrol. Geol. Bull., v. 42, p. 2951–72.
Khin, M., 1956, The geology of the district north of Indianola, Utah County, Utah: Master's thesis, Ohio State Univ., 214 p.
King, C., 1878, U.S. Geol. Expl. 40th Par. Rept., v. 1, 304 p.
Kupfer, D., 1975, Shear zones in the Gulf Coast salt delineate spines of movement: Lafayette Geol. Soc. Bull., v. 20, no. 3, p. 3–4.
La Rocque, Aurele, 1951, Molluscan fauna of the Flagstaff Formation, central Utah: (abstract), Geol. Soc. Amer. Bull., v. 62, p. 1457–58.
———, 1956, Tertiary mollusks of central Utah: Intermountain Assoc. Petrol. Geol. Guidebook 7, p. 140–46.
———, 1960, Molluscan fauna of the Flagstaff Formation of central Utah: Geol. Soc. Amer. Mem. 78, 160 p.
Mase, R. E., 1957, The geology of the Indianola embayment, Sanpete and Utah counties, Utah: Master's thesis, Ohio State Univ., 96 p.
McGookey, D. P., 1960, Early Tertiary stratigraphy of part of central Utah: Amer. Assoc. Petrol. Geol. Bull., v. 44, no. 5, p. 589–615.
McGookey, D. P., Haun, J. D., Hale, L. A., Goodell, H. G., McCubbin, D. G., Weimer, R. J., and Wulf, G. R., 1972, Cretaceous system: Geol. atlas of the Rocky Mtn. region: Rocky Mtn. Assoc. Geol, p. 190–228.
Merrill, R. C., 1972, Geology of the Mill Fork Area, Utah: Brigham Young Univ. Geol. St., v. 19, pt. 1, p. 65–88.
Morris, H. T., 1957, General geology of the East Tintic Mountains, Utah: Utah Geol. Soc. Guidebook, no. 12, p. 30–34.
Morris, H. T., and Lovering, T. D., 1961, Stratigraphy of the East Tintic Mountains, Utah: U.S. Geol. Surv. Prof. Paper 361, 145 p.
Moulton, F. C., 1975, Lower Mesozoic and Upper Paleozoic petroleum potential of the hingeline area, central Utah: Rocky Mtn. Assoc. Geol., 1975 Symposium, p. 87–97; see also Brigham Young Univ. Geology Studies, v. 24, pt. 1, p. 1–11.
Moussa, M. T., 1965, Geology of the Soldier Summit quadrangle, Utah: Ph.D. dissertation, Univ. of Utah, 191 p.
Nolan, T. B., 1935, The Gold Hill mining district, Utah: U.S. Geol. Surv. Prof. Paper 177.
———, 1943, The Basin and Range province in Utah, Nevada, and California: U.S. Geol. Surv. Prof. Paper 197, p. 141–96.
Pinnell, M. L., 1972, Geology of the Thistle quadrangle, Utah: Brigham Young Univ. Geol. St., v. 19, pt. 1, p. 89–130.
Richardson, G. B., 1907, Underground water in Sanpete and central Sevier valleys, Utah: U.S. Geol. Surv. Water Supply Paper 199.
Ritzma, H. R., 1972, Six Utah "hingeline" wells: Utah Geol. Assoc. Pub. 2, p. 75–80.
Schoff, S. L., 1951, Geology of the Cedar Hills, Utah: Geol. Soc. Amer. Bull., v. 62, p. 619–45.
Shuey, R. T., et al., 1973, Aeromagnetics and the transition between the Colorado Plateau and Basin Range provinces: Univ. Utah Geol. Dept. Pub., p. 107–10.
Spieker, E. M., 1936, Orogenic history of central Utah: Science, v. 83, no. 2142, p. 62–63.
———, 1946, Late Mesozoic and early Cenozoic history of central Utah: U.S. Geol. Surv. Prof. Paper 205-D, p. 117–61.
———, 1949a, Sedimentary facies and associated diastrophism in the upper Cretaceous of central and eastern Utah, in Longwell, C. R. (chm.), Sedimentary facies in geologic history (symposium): Geol. Soc. Amer. Mem. 39, p. 55–81.
———, 1949b, The transition between the Colorado plateaus and the Great Basin in central Utah: Guidebook to the Geology of Utah, no. 4, Utah Geol. Soc., 106 p.
Spieker, E. M., and Reeside, J. B., Jr., 1925, Cretaceous and Tertiary formations of the Wasatch Plateau, Utah: Geol. Soc. Amer. Bull., v. 36, p. 435–54.
Stokes, W. L., 1956a, Tectonics of the Wasatch Plateau and nearby areas (Utah) (abstr.): Amer. Assoc. Petrol. Geol. Bull., v. 40, no. 4, p. 790.
———, 1956b, Nature and origin of Paradox Basin salt structures: Intermountain Assoc. Petrol. Geol. Guidebook 7, p. 42–47.
———, 1963, Triassic and Jurassic periods in Utah: Utah Geol. and Mineralog. Surv., Bull. 54, p. 109–21.
Van Houten, F. B., 1948, Origin of red-banded early Cenozoic deposits in Rocky Mountain region: Amer. Assoc. Petrol. Geol. Bull., v. 32, no. 11, p. 2083–2126.
Walton, P. T., 1955, Wasatch Plateau gas field, Utah: Amer. Assoc. Petrol. Geol. Bull., v. 39, p. 385–421.
———, 1959, Structure of West Portal-Soldier Summit area, Wasatch, Carbon, and Duchesne counties, Utah: Intermountain Assoc. Petrol. Geol. 10th Ann. Field Conf. Guidebook, pl. 1.
Weiss, M. P., 1969, Oncolites, paleoecology, and Laramide tectonics, central Utah: Amer. Assoc. Petrol. Geol. Bull., v. 53/5, p. 1105–20.
White, C. A., 1886, On the relation of the Laramide molluscan fauna to that of the succeeding fresh-water Eocene and other groups: U.S. Geol. Surv., v. 34.
Wright, J. C., and Dickey, D. D., 1963, Block diagram of the San Rafael group and underlying strata in Utah and part of Colorado: U.S. Geol. Surv. Oil and Gas Investigation Chart OC-63.
Young, G. E., 1976, Geology of Billies Mountain quadrangle, Utah County, Utah: Brigham Young Univ. Geol. St., vol. 23, pt. 1, p. 205–80.