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GEOLOGICAL SURVEY

Potential geologic hazards near the Thistle Landslide, Utah County, Utah

by

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Abstract

In mid-April, 1983, an old landslide near Thistle, Utah, began to move, and within days had blocked Spanish Fork Canyon. As the slide's movement continued, construction crews gradually converted the toe of the slide into an earth-filled dam--Thistle dam--that impounded northwest-flowing Spanish Fork River. The resultant reservoir, known as Thistle Lake, was subsequently drained because of uncertainty about the stability of the dam. Recently, officials of Utah County have explored various alternatives for a water-retention structure in the area, including utilization of Thistle dam. The Thistle Slide Committee, established by the State of Utah to evaluate the suitability of using Thistle dam, suggests that construction of a new dam upstream from the present one might be a more reasonable and cheaper solution than investigating the stability of the present dam. Two potential geologic hazards that could impact a dam site upstream from the Thistle dam, however, may be in the area: the Thistle Canyon fault and the Thistle Creek diapiric fold. Uncertainty shrouds the existence of both. The Thistle Canyon fault is a postulated high-angle normal fault that trends about N. 20° E. through Thistle. The fault, downthrown on the east, separates an erosional escarpment formed on the Charleston-Nebo thrust plate from younger overlying Cretaceous and Tertiary sedimentary rocks. The Thistle Creek diapiric fold theoretically trends about N. 30° E. through the area. Tenuous evidence suggests that the Arapien Shale, an evaporite-rich intrusive sedimentary unit that forms the core of the fold, was overridden by the upper plate of the Charleston-Nebo thrust fault. Since then, the Arapien has welled upward, arching both the thrust plate and the overlying younger sedimentary cover. Additional field investigations should be completed to determine the existence of these hazards prior to any final decision about a new dam. The presence of either or both of these hazards, however, does not necessarily preclude the construction of a safe and stable dam that would impound a multi-purpose reservoir.

Introduction

In mid-April 1983, near the small community of Thistle, Utah, an old landslide that had moved repeatedly in the past began to move once again. In recent years, movements had been localized and of limited extent, but sufficient, nevertheless, to displace repeatedly the nearby tracks of the Denver and Rio Grande Western Railroad. Realigning the tracks, in fact, had become almost an annual chore. By April of 1983 the old slide had been thoroughly soaked by record-breaking amounts of water from melting snow and from torrential rains. This time the slide rapidly overwhelmed the drainage of nearby Spanish Fork Canyon just below the confluence of Soldier and Thistle Creeks (pl. 1). Within days the slide had blocked the canyon, dammed the northwest-flowing Spanish Fork River, buried the railroad tracks and a segment of U.S. Highway 6 and 89, halted all rail and road traffic through the canyon between Price in eastern Utah and Provo in central Utah, and gradually forced the inhabitants of Thistle to abandon their homes.

Almost from the moment the slide began to move, efforts were made to keep the railroad tracks clear. When it became evident that such efforts would fail--the slide was moving much too rapidly--construction crews began to plane off the top of the slide and use the debris to construct a crude dam to keep the rapidly rising water from overtopping the toe of the slide. A small pond formed at first, but soon a sizeable lake began to innundate the nearby countryside. As the water rose, additional construction crews were brought in, and by the middle of the summer of 1983, the toe of the landslide had been converted by earth-moving equipment into an earth-filled dam some 200 meters (660 ft) long, and 60 meters (200 ft) high. The small pond had grown into a large lake, known as Thistle Lake, whose arms extended eastward and southeastward into the valleys of Soldier Creek and Lake Fork, respectively, and southward into the valley of Thistle Creek.

The economic impact on central Utah was severe, and, although new rail and road routes have now been constructed around the landslide, certain sectors of central Utah, notably the Sanpete Valley area (inset map B, pl. 1), are still not served by rail.

By the end of summer, the residents of Utah County had mixed feelings about the completed dam. Some, impressed by Thistle Lake, which was in a striking mountain setting, favored retention of the dam--not only because the lake seemed ideally sited as a new recreational feature that was bound to attract tourists but also because the dam could be used for flood control. Other residents viewed the dam as being inherently unstable and unsafe and noted that collapse of the dam would likely cause loss of life and great damage to property. Caution prevailed, and during the fall of 1983 Thistle Lake was gradually drained.

At the present time, Thistle Dam is an isolated structure that blocks Spanish Fork Canyon but impounds no water. The Spanish Fork River passes around the dam through a low-level drainage tunnel that was originally used to drain the lake.

Thistle Slide Committee

Drainage of the lake was not greeted happily by all concerned. Many nearby residents and some officials of Utah County wanted the dam used once again to impound waters and form a new lake.

In an attempt to determine whether Thistle dam was a stable structure suitable for impoundment of a multi-purpose reservoir, Dee C. Hansen, State Engineer of Utah, established a three-man Thistle Slide Committee_/ to evaluate the integrity of the dam. The Committee, after much work, submitted its report on November 8, 1985. I cite below a statement from the report (Duncan, Fleming, and Patton, 1985, p. 61) that summarizes its conclusions (underlining mine).

> It is the Committee's opinion that the landslide can safely be used as a flood control dam, storing water up to El. 5055 for periods of 3 months or so. The Committee believes it would be unsafe to store water to higher elevations, unless very extensive further exploration of the landslide was undertaken to assess its stability. The Committee further believes that there is a very significant possibility that further exploration might prove inconclusive no matter how extensive the program, or that it might reveal deficiencies that could not be remedied at any reasonable cost. It seems likely that a multiple-use reservoir can be developed at lower cost, and with much greater reliability, by constructing a dam upstream from the landslide blockage rather than modifying the blockage so that it can be used as a dam.

The use of the term "blockage" in the report reflects the Committee's unwillingness to use the term "earth-filled dam" for the modified landslide.

The report implies, thus, that a new dam, upstream and south of the present dam (pl. 1), might be a more feasible and reliable solution than re-use of the present dam. The Committee's statement implies that although it is almost impossible to investigate and determine whether the landslide could be used as a safe dam, such needed investigations could be made at a selected upstream site. It is clear from the general tenor of the report that the Committee sees inherent problems in any such site upstream from the landslide, but despite these problems, the Committee thinks that an upsteam site is still a better location for a safe dam than the landslide. The topography of the area dictates that this new dam would have to be less than 0.6 km (0.4 mi) south of the upstream side of the present dam, entirely within the narrow confines of Spanish Fork Canyon.

_/ The Committee, listed alphabetically, consisted of: (1) J.M. Duncan, W. Thomas Rice Professor, Department of Civil Engineering, Virginia Polytechnic Institute and State University, 104 Patton Hall, Blacksburg, Virginia, 24061; (2) R.W. Fleming, Geologist, Branch of Engineering Geology and Tectonics, U.S. Geological Survey, Box 25046, Federal Center, Denver, Colorado, 80225; and (3) F.D. Patton, President, F.D. Patton Consulting Geologists and Geotechnical Engineers, 507 East 3d Street, North Vancouver, British Columbia, Canada, V7L 1G4.

The possibility of constructing a new dam near the present one is now under consideration. In fact, Utah County had retained a consulting firm in the fall of 1985, to determine the feasibility of constructing such a dam. In view of this action, all concerned officials ought to become knowledgeable about the complex geologic setting of the immediate area and the effect geology might have on the siting and construction of the proposed dam. In this article I discuss first the geologic framework of the area surrounding the Thistle Landslide, and then offer my interpretation of the geologic setting. My knowledge of the area stems chiefly from work I completed in 1981 during which I became convinced that the area had been diapirically deformed (Witkind, 1983, p. 55).

Previous work

During the Spring of 1983, even as the toe of the Thistle Slide was being converted to an earth-filled dam, my colleague W.R. Page and I prepared a geologic map of the area surrounding the slide (Witkind and Page, 1983). The map is essentially a factual statement; it omits any interpretation of the geologic features shown. This article attempts to remedy that omission. A part of that map is reproduced in this article as plate 1.

In preparing our map we drew upon published geologic maps by Baker (1972, 1976), who studied an area north and northeast of Thistle; by Harris (1954), who studied the Birdseye area (an area essentially south of Thistle); by Pinnell (1972), who mapped the Thistle quadrangle (an area south and southeast of Thistle); and by Young (1976), who mapped the area north and northeast of Thistle (essentially in and around Billies Mountain).

Geologic setting

Two major elements dominate the geologic framework of the Thistle area: the eroded east margin of the major Charleston-Nebo thrust plate, and a sequence of younger Cretaceous and Tertiary sedimentary and volcanic rocks that unconformably overlies and partly buries the thrust plate (pl. 1).

Charleston-Nebo thrust plate

The Charleston-Nebo thrust plate, floored by the Charleston-Nebo thrust fault, forms the southern part of the Wasatch Range. The thrust plate extends across central Utah, reaching from near Salt Lake City to Nephi (pl. 1, inset map A). On the basis of folds, the plate was thrust eastward and southeastward, but how far it moved is unknown. Various lines of evidence suggest a displacement of about 65 km (40 mi) (Crittenden, 1961, p. D129). Seemingly, the plate has not moved since it was emplaced during the Late Cretaceous, some 65 million years ago.

In the Thistle area, the easternmost exposed rocks of the Charleston-Nebo thrust plate form a high ridge that trends slightly east of north (pl. 1). It is unclear whether this ridge is at the distal margin of the thrust plate (fig. 1, A) or whether the distal margin is farther east buried beneath younger strata (fig. 1, B). If the latter, the plate margin in the Thistle area is an erosional escarpment cut on the thrust plate (sketch B). Because of uncertainty as to which of these two alternatives is correct, I refer to this east margin of the thrust plate as an "erosional escarpment", and

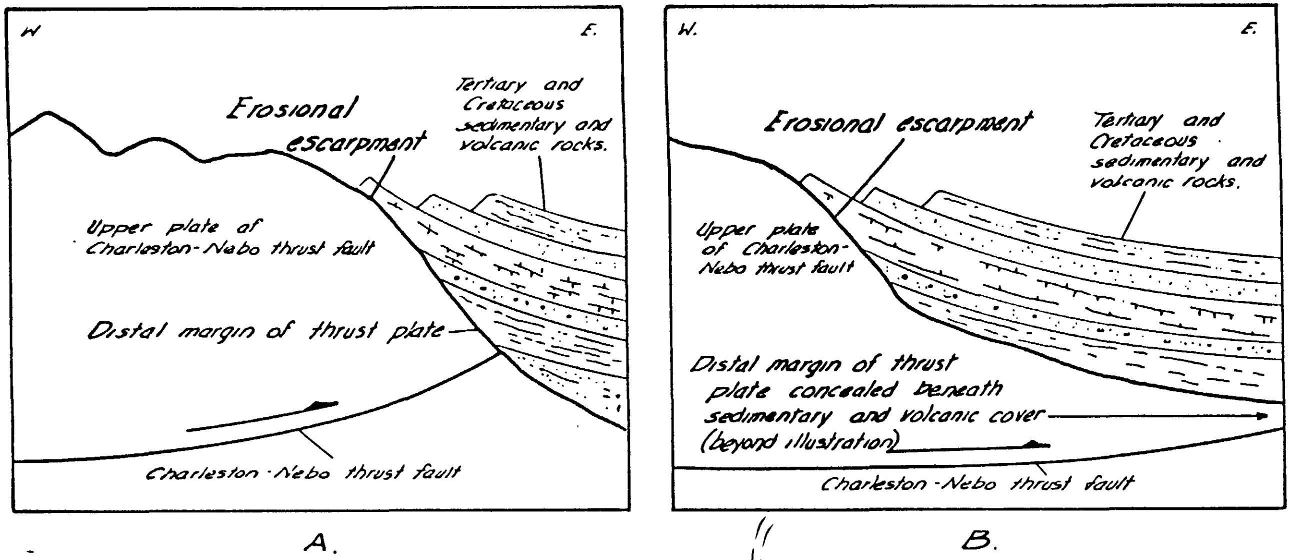


Figure 1.--Diagrammatic cross sections illustrating possible relations between an easterly facing erosional escarpment formed on the Charleston-Nebo thrust plate and a partial cover of Cretaceous and Tertiary rocks.

A.--Erosional escarpment is at the distal margin of the eroded thrust plate.

B.--Erosional escarpment is along the east flank of the eroded thrust plate but not at the distal margin, which is farther to the east concealed beneath the Cretaceous-Tertiary cover.

delineate it on plate 1 by hachures.

Spanish Fork River and its tributaries, west-flowing Soldier Creek and north-flowing Thistle Creek, have cut a deep canyon, shaped somewhat like a T on its side, through the ridge (pl. 1). That part of the ridge north of the confluence of Soldier and Thistle Creeks is unnamed; in the past, crews involved in the construction of Thistle dam and the new segment of U.S. Highway 6 and 89, incorrectly called it "Billies Mountain", but in fact, Billies Mountain is some 3 km (2 mi) to the northeast (inset map B, pl. 1). Continued incorrect usage, however, has transferred the name Billies Mountain to the north part of the ridge, and in this article I follow that custom but alert the reader to this misusage by placing the name in quotes, thus, "Billies Mountain".

In the Thistle area, the rocks in the thrust plate range in age from Permian-Pennsylvanian to Jurassic (table 1). Most of them dip eastward at moderate to high angles; in the ridge, at the east margin of the thrust plate, Nugget (JTrn on the map) and Twin Creek (Jtc) strata dip eastward at about 60°. Farther westward, toward the main mass of the thrust plate, successively older strata dip eastward at about 40° (pl. 1).

Sedimentary sequence of younger rocks

The deeply eroded plate is partly buried by younger sedimentary rocks of Late Cretaceous to Eocene age (table 1). Locally, these rocks are mantled by pyroclastic volcanic rocks of the late Oligocene(?) Moroni Formation. East of the erosional escarpment (which is shown on pl. 1 by hachures), the younger sedimentary and volcanic rocks, dip eastward at low to moderate angles (10° to 30°). By contrast, the same strata west of the escarpment dip westward at low angles (fig. 2, A). Wherever exposed, these younger sedimentary and volcanic rocks unconformably overlie the eastward-dipping rocks of the thrust plate.

Strata north of Spanish Fork Canyon

("Billies Mountain" area)

Most of these younger Cretaceous and Tertiary strata are well exposed where they mantle the thrust plate south and west of Spanish Fork Canyon, but they have largely been eroded from much of the thrust plate north and east of the canyon. Some units do crop out north of the canyon as a series of eastward-dipping strata that lap onto the east margin of the plate. This general pattern of eastward-dipping strata is interrupted, however, north of Soldier Creek directly east of "Billies Mountain". There, the Flagstaff Limestone (Tf) abuts the east flank of "Billies Mountain" at an eastward dip of about 20° (pl. 1). About 150 m (500 ft) east of the ridge, the Flagstaff gradually flattens, and then reverses and dips moderately to steeply westward; locally these strata are almost vertical (fig. 2, B). Although the Flagstaff Limestone is underlain by the North Horn Formation throughout most of central Utah (table 1), in this specific locality the near-vertical beds of the Flagstaff are underlain by the Arapien Shale (T(Ja)) of Middle Jurassic (Callovian) age. These Arapien strata, chiefly calcareous mudstones, are severely contorted and broken. Under intense compression, the Arapien apparently has raised and tilted back the Flagstaff Limestone (Tf). Comparable relations between the Arapien and other sedimentary rocks elsewhere

SYSTEM	SERIES	UNIT		Approximate Thickness		LITHOLOGY
				Meters	Feet	
Tertiary	Oligocene?	Moroni Formation		610?	2,000?	Light-gray to gray, thick-bedded pyroclastic rocks
	Eocene	Green River Formation		30+	100+	Light-green fissile shale and light-brown even-bedded limestone
		Colton Formation		120	400	Mottled red and gray mudstone
	Paleocene	Flagstaff Limestone		30 to 185	100 to 600	Light-gray, thin- to thick-bedded, even-bedded fine-grained limestone.
Cretaceous	Upper Cretaceous	North Horn Formation		15 to 1,065	50 to 3,500	Reddish-brown, thin- to thick-bedded mudstone, sandstone, conglomeratic sandstone, and limestone.
		Price River Formation		6 to 600	20 to 2000	Light-gray to gray, thin- to thick-bedded conglomerate, conglomeratic sandstone, and sandstone.
		West of Sanpete Valley	East of Sanpete Valley	915 to 2130	3,000 to 7,000	Red to reddish-brown, thick-bedded to massive, well-cemented conglomerate.
		** Indianola Group, undivided	Sixmile Canyon Formation	830	2,725	Brown sandstone, conglomeratic sandstone, carbonaceous shale, and some coal.
			Funk Valley Formation	685	2250	Light-brown sandstone and interbedded shale.
			Allen Valley Shale	182 to 245	600 to 800	Dark-gray to black, thin- and even-bedded shale
			Sanpete Formation	410	1,350	Brown, thin- to medium-bedded sandstone and conglomeratic sandstone.
	Lower Cretaceous	** Cedar Mountain Formation		300 to 550	1,000 to 1,800	Reddish-brown shaly siltstone and mudstone
Jurassic	Middle Jurassic	** Twist Gulch Formation		460	1,500	Reddish-brown, thin- and even-bedded shaly siltstone and sandstone
		** Arapien Shale		1220 to 3,960	4,000 to 13,000	Variegated red and gray calcareous mudstone, shaly siltstone and much salt and other evaporites
		* Units of the Twin Creek Limestone		180 to 250	600 to 800	Dominantly light-gray thin-bedded limestones; includes reddish siltstone and sandstone
Triassic	Lower Jurassic and Upper Triassic	* Nugget Sandstone (Navajo Sandstone)		425 to 460	1,400 to 1,500	Light-brown, medium to thick-bedded, fine- to medium-grained quartzose sandstone.
	Upper to Lower Triassic	* Ankareh Formation		425	1,400	Reddish-brown shaly siltstone and cross-bedded sandstone
	Lower Triassic	* Thaynes Limestone		380	1,250	Chiefly grayish-red limestone with some reddish-brown shaly siltstone and sandstone beds.
		* Woodside Formation		60	200	Reddish-brown shaly siltstone and cross-bedded fine- to medium-grained sandstone.
Permian	Lower Permian	* Park City Formation		215	700	Chiefly gray to pale-red, thin- to thick-bedded limestone; some brownish cherty limestone
		* Diamond Creek Sandstone		280	900	Reddish-brown to light-brown cross-bedded sandstone
		* Kirkman Limestone		90	300	Light-gray to medium-gray, thin- to thick-bedded limestone; contains chert
Pennsylvanian	Upper to Lower Pennsylvanian	* Oquirrh Formation		305	1,000	Gray to brownish-gray, thin- to thick-bedded limestone and interbedded light-brown sandstone.

* Integral units of the Charleston-Nebo thrust plate

** Units that are likely parts of the Charleston-Nebo thrust plate

Table 1.--Some stratigraphic units exposed in the Thistle area, Utah.

throughout central Utah have lead me to conclude that the Arapien is an "intrusive sedimentary unit" (Witkind, 1982). Indeed, during excavation for the new stretch of U.S. Highway 6 and 89 through "Billies Mountain", the earth-moving equipment time and again exposed wedge-like masses of Arapien Shale that intrude and deform the steeply tilted beds of Twin Creek in the thrust plate (fig. 2, C). At the eastern edge of "Billies Mountain" a dike-like mass of the Arapien (T(Ja)) separates Twin Creek (Jtc) strata of the thrust plate from the tilted units of the Colton Formation (Tc) that lap onto the erosional escarpment of the plate (fig. 2, D).

East of "Billies Mountain", where the steeply tilted Flagstaff Limestone beds are underlain by the intensely contorted Arapien strata (fig. 2, B), the deformed Arapien beds pass eastward into non-contorted but nearly vertical Arapien strata. These beds are right-side-up and lack the crumpled and contorted aspect of the profoundly disturbed Arapien beds. As these steeply dipping Arapien strata are traced eastward, they seem to underlie conformably the Twist Gulch Formation (Jtg), which in turn, underlies the Cedar Mountain Formation (Kcm). The unbroken progression of beds, in normal stratigraphic sequence east from the disturbed mass of Arapien, implies that the thrust plate extends eastward beyond the erosional escarpment. Two alternatives are possible: (1) the mass of disturbed Arapien may be strata that punched up through Arapien beds that were part of the plate, or (2) they may be integral elements of the Arapien within the thrust plate that became mobile and then deformed the overlying strata. Of the two interpretations, I prefer the former: I believe that an underlying, overridden mass of Arapien Shale deformed the thrust plate (pl. 1, inset map C, cross section A-A′), and that intrusive fingers of the Arapien punched up through both the plate and the adjacent younger strata. In this interpretation, the contorted Arapien strata and the less deformed Arapien beds of the thrust plate are fortuitously juxtaposed.

Other examples of Arapien deformation are exposed elsewhere in the general area. So, for example, a small mass of Arapien Shale (labeled T(Ja) on pl. 1) crops out along the east valley wall of Thistle Creek about 0.8 km (1/2 mi) south of the confluence of Soldier and Thistle Creeks. West of that outcrop, North Horn (TKn) beds dipping eastward off the erosional escarpment cut on the thrust plate flatten, and then reverse to assume a steep westerly dip directly adjacent to the west flank of the Arapien exposure. East of the Arapien mass, the North Horn beds dip eastward. These opposing dips in North Horn strata that flank the Arapien lead to the inference that consolidated North Horn strata have been arched by an intrusive mass of Arapien Shale.

Strata south and west of Spanish Fork Canyon

Younger sedimentary and volcanic rocks mantle parts of the thrust plate exposed south and west of Spanish Fork Canyon. Indeed, detritus from these younger rocks, chiefly the North Horn Formation, forms the bulk of the Thistle Landslide. Directly east of the escarpment cut on the thrust plate, these younger sedimentary and volcanic rocks dip eastward; the same units exposed west of the escarpment dip westward (fig. 2, A). Relations between the thrust plate and these overlying sedimentary rocks are well exposed along the west valley wall of Thistle Creek some 6 km (3.5 mi) north of the small community of Birdseye (pl. 1, inset map B). One of the best exposures occupies parts of secs. 5, 6, and 7, T. 10 S., R. 4 E., near the junction of Crab and Thistle

Figure 2.--Photographs showing intrusive aspects of the Arapien Shale near Thistle, Utah.

A.--View looking northward at westward-dipping mantle of Cretaceous and Tertiary rocks that unconformably overlie the Charleston-Nebo thrust plate, of which the Nugget Sandstone (JTrn), dipping eastward at about 50°, is a part. Lines indicate approximate attitude of the Nugget Sandstone.

B.--View looking eastward at beds of the Flagstaff Limestone (Tf) that dip steeply westward. Light-gray Flagstaff beds, commonly underlain by the North Horn Formation (TKn), are underlain, in this specific locality, by reddish-brown contorted and crumpled beds of the Arapien Shale (T(Ja)).

C.--View looking southward in roadcut where the relocated segment of U.S. Highway 6 and 89 crosses the crest of "Billies Mountain". Wedge-like masses of the Arapien Shale (T(Ja)) intrude and deform eastward-dipping beds of the Twin Creek Limestone (Jtc). Since this photo was taken (in October, 1983) the roadcut has been widened and the exposure destroyed.

D.--View looking northward in roadcut where the relocated segment of U.S. Highway 6 and 89 crosses the crest of "Billies Mountain". A dike-like mass of Arapien Shale (T(Ja)) is intruded between the Twin Creek Limestone (Jtc) (which here forms part of the erosional escarpment cut on the Charleston-Nebo thrust plate) and the Colton Formation (Tc), one unit in a mantle of younger Cretaceous and Tertiary rocks that partly overlies the thrust plate.


W.
E.
Spanish Fork Peak
Tf
Tkn
Tkn


Tf
T(Ta)
B.


E.
W.
Jtc
Jtc
Jtc
T(Ta)
C.


W.
E.
Jtc
T(Ta)
Tc
D.

Creeks (pl. 1). There the thrust plate is represented by beds of Nugget Sandstone (JTrn) and Twin Creek Limestone (Jtc) that dip eastward about 60°. These beds are unconformably overlain to the east by the North Horn Formation (TKn), which also dips eastward, but between 20° and 22°. A small wedge of eastward-dipping Flagstaff Limestone (Tf) (in the NE 1/4, sec. 7, T. 10 S., R. 4 E.) conformably overlies the North Horn.

Farther south, near the junction of Aggie and Thistle Creeks, pyroclastic rocks, part of the Moroni Formation, unconformably overlie the North Horn strata; the Moroni also dips eastward at this point but at about 30°. Westward from this exposure, as shown on cross section A-A′ (pl. 1, inset map C), the North Horn (TKn) passes over and conceals the thrust plate, and then dips westward. The North Horn is overlain conformably by the Flagstaff Limestone (Tf), which passes westward beneath ever younger sedimentary beds that also dip westward. This sedimentary sequence is overlain to the west, beyond the area shown in the cross section, by westward-dipping pyroclastic rocks of the Moroni Formation. It seems clear that the sedimentary rocks were originally overlain by an unbroken blanket of volcanic rocks, now much eroded.

Structurally, then, the sedimentary and volcanic rocks appear to have been warped into a north-trending asymmetric anticline marked by a steep east flank and a gentle west one. After the beds were arched, erosion removed many of them and in the process exhumed part of the buried thrust plate.

As the eastward-dipping sedimentary and volcanic rocks that lap onto the thrust plate pass eastward across Thistle Creek, they gradually flatten, become horizontal, and then reverse dip to form an ill-defined syncline that trends generally northeast (pl. 1).

Discussion of alternative interpretations

Faulted terrain

Although all workers in the area agree that the basic structural pattern involves an eroded thrust plate partly buried beneath younger sedimentary rocks, some disagreement exists as to a suitable explanation for the tilted strata. Baker (1976), Harris (1954), and Pinnell (1972) independently concluded that a high-angle normal fault, downthrown to the east and named the Thistle Canyon fault by Harris (1954), separates the younger Cretaceous and Tertiary rocks from the thrust plate (fig. 3, alternative A). Presumably, the eastward-tilted younger rocks, east of and juxtaposed against the erosional escarpment, are the result of drag as the east block dropped along the fault. Downthrow to the east is also suggested by the difference in altitude between Flagstaff (Tf) strata astride the thrust plate west of the escarpment, and those Flagstaff strata east of the escarpment. West of the escarpment the Flagstaff (Tf) beds are at an altitude of about 6,500 ft; east of the escarpment--about 2.5 km (1 1/2 mi) away--they are at an altitude of about 5,300 ft, some 365 m (1,200 ft) lower.

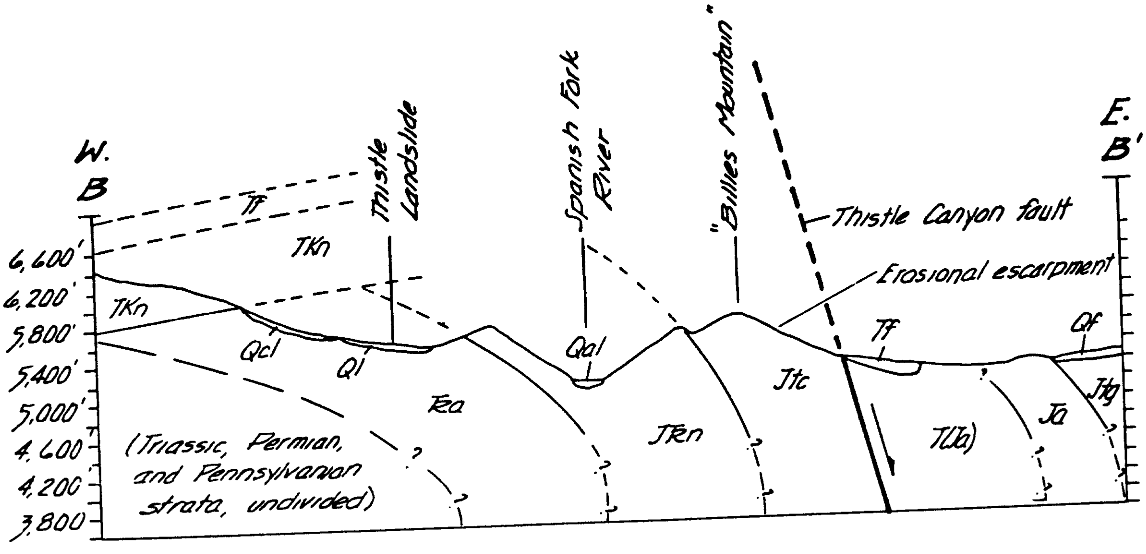
To the best of my knowledge no worker has offered any explanation for the westward tilt of those strata that overlie and are west of the erosional escarpment (fig. 2, A). A possible hypothesis calls for westward tilting of a discrete fault block as a result of downthrow along a north-trending normal fault, as yet unrecognized, that may extend along the east flank of Loafer

Figure 3.--Two alternative interpretations of the geologic relations in the Thistle area. Cross section B-B′ crosses Spanish Fork River near a possible site for a new dam that would be upstream and south of the present Thistle dam, which was constructed on the toe of the Thistle Landslide.

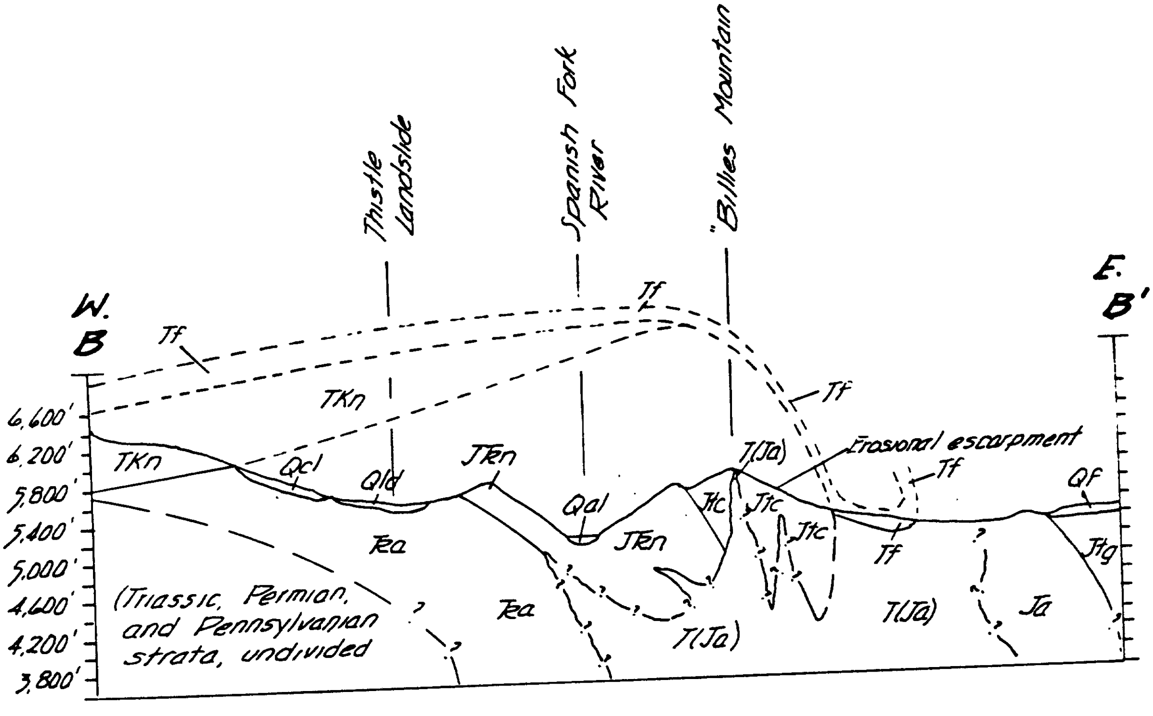
Alternative A.--A high-angle normal fault--the Thistle Canyon fault--downthrown to the east separates the younger Cretaceous and Tertiary sedimentary rocks, here represented by the Flagstaff Limestone (Tf), from the Charleston-Nebo thrust plate, here represented by beds of the Twin Creek (Jtc), Nugget (JTrn), and Ankareh (Tra) Formations.

Alternative B.--A mass of Arapien Shale (T(Ja)) intrudes and raises part of the Charleston-Nebo thrust plate, and in so doing arches the overlying younger Cretaceous and Tertiry sedimentary and volcanic rocks into an asymmetric fold. The eastward-dipping Flagstaff (Tf) strata, directly east of the erosional escarpment, are part of the fold′s east flank. The westward-dipping strata (TKn), west of the escarpment, are part of the fold′s west flank.

The thinning of all younger sedimentary units (here represented by the North Horn (TKn) and Flagstaff (Tf) Formations), toward the axis of the fold suggests that a diapiric fold, concealed beneath the thrust plate, has been growing at a slow, almost imperceptible rate impeding sedimentary deposition.


W.
B
E.
B'
Thistle Landslide
Spanish Fork River
"Billies Mountain"
Thistle Canyon fault
Erosional escarpment
Tf
TKn
TKn
Qcl
Ql
Qal
Tf
Qf
Ҟa
JҞn
Jtc
T(Ja)
Ja
Jtg
(Triassic, Permian, and Pennsylvanian strata, undivided)
6,600'
6,200'
5,800'
5,400'
5,000'
4,600'
4,200'
3,800'

A.


W.
B
E.
B'
Thistle Landslide
Spanish Fork River
"Billies Mountain
Tf
Tf
Tf
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Jtc
Erosional escarpment
Tf
Tf
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T(Ja)
T(Ja)
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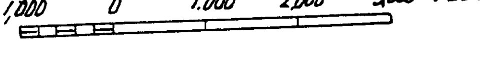
Jtg
(Triassic, Permian, and Pennsylvanian strata, undivided
6,600'
6,200'
5,800'
5,400'
5,000'
4,600'
4,200'
3,800'

B.


1,000
0
1,000
2,000
3,000 FEET

Mountain (about 1.6 km (1 mi) west of area shown on pl. 1). Nor have any previous workers offered any explanations for the many localized structural complexities that seem related to intrusive masses of the Arapien Shale. These complexities seem to be products of plastic intrusion.

Diapiric deformation

I view most of the structural complexity in the Thistle area as a direct result of diapiric deformation after emplacement of the Charleston-Nebo thrust plate. The localized upwarp of those Flagstaff Limestone beds north of Spanish Fork River, the arching of the strata, both on a small and a large scale, seem reasonably explained only by assuming that masses of the Arapien Shale deformed the country rocks long after these rocks were emplaced and consolidated. In its most elementary aspect, the diapiric concept suggests that masses of the Arapien Shale were forced upward, and as a result bowed up the overlying units (Witkind, 1982).

The Arapien Shale, one of the most unusual sedimentary formations in central Utah, consists chiefly of calcareous mudstone that, in places, contains very large amounts of evaporites, chiefly salt, gypsum, anhydrite, and calcite. As seen in most exposures, the Arapien appears as complexly deformed light-gray masses that are mottled with patches of pale red. Locally, it is drab gray, elsewhere it appears as amorphous, earthy, reddish-brown masses. Fresh rock, as in road cuts, is dark gray, and has a waxy appearance (fig. 2, C and D). Commonly it is intensely contorted; overturned beds are common, and small crumpled folds are impressed on still larger ones. Spieker (1946, 1949), Hardy (1949, 1952), and Picard (1980), among others, have described various aspects of the Arapien.

I believe that the salt contained within the Arapien is the motive force responsible for the upward movement of the Arapien, and propose that the salt has been moving continuously almost since it was deposited. Some of this movement has been a slow, almost imperceptible upwelling, recognizable chiefly by the thinning or pinchout of beds toward the axes of the resultant upwarps. But some of the movement, I suspect, has been rapid, as measured in terms of geologic time. The salt seems to have welled upward forcefully, and in so doing formed a series of fan-shaped, salt-cored anticlines, which I term "diapiric folds" rather than anticlines, to emphasize the concept that the deformation is a result of salt movement. These diapiric folds are elongate, faintly sinuous structures that extend for very long distances, some as much as 100 kilometers (65 mi). Most trend slightly east of north (fig. 4). The salt has surged upward repeatedly since it was deposited; because of these recurrent movements, I use the symbol "T(Ja)" on plate 1 and other figures in this article to identify the Arapien; the "T" represents the latest emplacement age of the beds (Tertiary), the "J" represents the depositional age (Jurassic), and the "a" represents the formation name (Arapien Shale).

Commonly, the folds are deeply eroded, and the remnants of their flanks form elongate, narrow, localized structural zones that, in places, are adjacent to cores of Arapien Shale. Most of these zones are marked by vertical to overturned beds unconformably overlain by right-side-up North Horn or younger rocks.

In the Thistle area, such a diapiric fold (No. 10 of fig. 4) is exposed

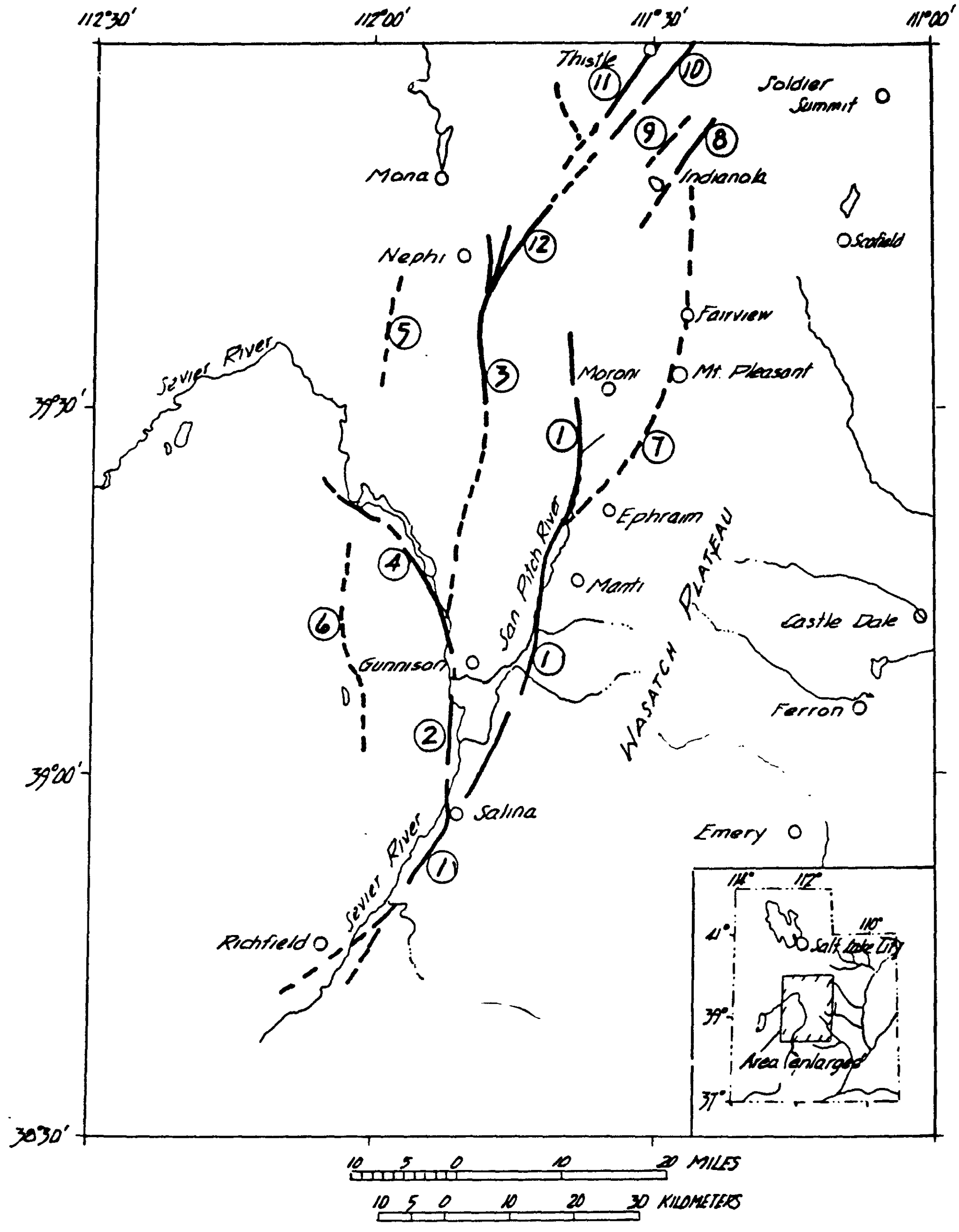


Figure 4.--General pattern of diapiric folds that I recognize in central Utah. Encircled numbers identify folds: (1).--Sanpete-Sevier Valley, (2).--Redmond, (3).--Levan, (4).--Sevier Bridge Reservoir, (5).--West Hills, (6).--Valley Mountains, (7).--Fairview, (8).--Little Clear Creek, (9).--Hjorth Canyon, (10).--Dry Hollow, (11).--Thistle Creek, (12).--Pole Creek. Solid lines designate folds whose trends are delineated by discrete geologic outcrops; dashed lines indicate folds whose trends are postulated on the basis of tenuous evidence.

in Dry Hollow (shown on inset map B, pl. 1), some 3 km (2 mi) southeast of Thistle Creek, where vertical and overturned beds of the Indianola Group that strike northeast are unconformably overlain by beds of the North Horn Formation that dip gently southeastward. Another fold, not as easily recognizable, trends northeasterly through Thistle, and I believe this specific fold, known as the Thistle Creek fold (No. 11 of fig. 4), is responsible for much of the deformation in the Thistle area. The north-trending asymmetric upwarp described on page 11 is part of the Thistle fold. On plate 1, the concealed crest of the Thistle diapiric fold--the trace of the axial plane--is shown by a line of thick dots.

Thistle Creek fold

Many of the diapiric folds in central Utah are readily recognizable by the juxtaposition of contorted Arapien Shale masses against vertical to overturned beds, commonly of the Indianola Group. In the Thistle area, by contrast, a diapiric fold is indicated by strata arched asymmetrically over the escarpment cut on the Charleston-Nebo thrust plate. The eastward-dipping North Horn (TKn), Flagstaff (Tf), and Moroni (Tm) strata east of the erosional escarpment are in the east flank of the fold; the same strata west of the escarpment are in the west-dipping flank. Although a postulated high-angle Thistle Canyon fault may separate the thrust plate from the younger strata, I found no conclusive evidence of its presence and I am not convinced that it exists. I suggest that the opposing dips of the strata and the difference in altitude between Flagstaff strata west and east of the escarpment merely reflect the configuration and asymmetry of the fold draped across the escarpment (fig. 3, alternative B).

Evolution of geologic pattern

The Charleston-Nebo thrust plate was emplaced after deposition of the Twin Creek Limestone (of Middle Jurassic (Callovian) age), but before deposition of the North Horn Formation (of Late Cretaceous (Maestrichtian) and Paleocene age). Erosion began to dissect the thrust plate even as the plate was being transported eastward, and dissection must have continued after the plate ground to a halt. Thus, when the North Horn began to accumulate it must have lapped onto a well-dissected mass and and eventually buried it. In time, still younger sediments accumulated; the youngest sedimentary rocks that remain on the plate are part of the Green River Formation (Eocene). During late Oligocene(?) time, pyroclastic rocks of the Moroni Formation mantled the sedimentary sequence.

Even as these younger sediments accumulated, a diapiric fold began to move upward beneath the thrust plate. This movement is suggested by the striking westward thinning of the sedimentary strata (Young, 1976, fig. 5) toward the fold's axis. Young's diagram shows that all units from the North Horn to the Green River Formation thin westward toward Thistle. A long-lived paleo-topographic high, therefore, continued to rise at a slow almost imperceptible rate, impeding sedimentary deposition throughout much of the late Cretaceous and early Tertiary. The fact that the Moroni Formation is involved in the arching indicates that upwelling continued at least through late Oligocene(?) time.

As the fold grew, the Arapien Shale intruded, raised, and arched both the thrust plate and the overlying sedimentary and volcanic rocks (fig. 3, alternative B). Fingers of Arapien that intruded the plate remain as wedge-shaped masses of Arapien in the Twin Creek strata (p. 9, and fig. 2, C). Other fingers, concomittently deforming the sedimentary and volcanic rocks that overlay or abutted the plate, tilted the Flagstaff (Tf) and North Horn (TKn) Formations up on edge (p. 9, and fig. 2, B).

The end result of the growth of the diapiric fold was an elongate, northeasterly trending upwarp containing: (1) a thin skin of the younger sedimentary and volcanic rocks, underlain by (2) the arched thrust plate which, in turn, was underlain by (3) the Arapien (T(Ja)) core (pl. 1, cross section A-A′). Erosion has since removed much of the upwarped sedimentary and volcanic cover and exhumed part of the plate, preserved as the steeply dipping Nugget (JTrn) and Twin Creek (Jtc) beds. The sedimentary and volcanic remnants on both flanks of the fold reflect the general asymmetric shape of the arch.

Implications and conclusions

Two potential geologic hazards may be in the area: the Thistle Canyon fault, and the Thistle Creek diapiric fold. A new dam upstream from the present dam in Spanish Fork Canyon would be closer to both geologic features, and the reservoir would cross both. Additional field investigations should be planned to evaluate the extent of the hazards. Although I question the existence of the Thistle Canyon fault, previous workers have postulated and mapped it. Further, the dike-like mass of Arapien that separates the thrust plate from the overlying Colton Formation (p. 9, and fig. 2, D) hints that a fault plane guided its intrusion. Investigations should determine if the fault does exist, and if so, its characteristics. If the fault exists, is it active, and does it threaten any man-made structure in the area? One locality that might indicate whether such a fault does offset the rocks is along the east flank of "Billies Mountain" directly north of the east portal of the railroad tunnel. In that area the critical relations between the thrust plate and the younger strata are masked by a small mass of detritus that could easily be removed by earth-moving equipment.

Testing for the presence of the Thistle Creek diapiric fold is more difficult. Elsewhere in central Utah, beds as young as Pleistocene(?) have been bowed up vertically apparently by diapiric intrusion (Witkind, 1981, fig. 2). The salt responsible for the development of diapiric deformation, therefore, may still be moving. The existence of salt-generated structures in the Thistle area should be evaluated early in the planning stage before any construction work on a new dam. If a diapiric fold passes through the Thistle area, as shown in cross section A-A′, plate 1, the Arapien Shale (T(Ja)) must underlie the thrust plate. Geophysical studies may indicate the depth and shape of the Arapien, and whether or not it has deformed the thrust plate and its overlying mantle of sedimentary and volcanic rocks. I believe that much of the area has recently been traversed repeatedly by seismic crews. Although the seismic reflection data gathered are proprietary, possibly some information might be made available either to Federal, State, or County officials.

The presence of either or both of these hazards, however, does not necessarily preclude the construction of a safe and stable dam in the area.

The Crystal Springs earth-filled, causeway dam in California, constructed across the Stevens Creek fault (subsequently re-named the San Andreas fault), retained its integrity after being offset about two meters (6 ft) when the fault reactivated in 1906 (Taber, 1906, p. 308-309 and fig. 7; Lawson, 1908, v. 1, p. 102 and fig. 40).

Officials who will make the final decision as to whether or not a new earth-filled dam is constructed in Spanish Fork Canyon, near Thistle, should be knowledgeable about both the favorable and unfavorable geologic characteristics of the area. Geologic relations suggest that a much larger area must be evaluated than just the dam site.

References cited

Baker, A. A., 1972, Geologic map of NE part of Spanish Fork Peak quadrangle, Utah: U.S. Geological Survey Open-File series. Scale 1:24,000.

________, 1976, Geologic map of the west half of the Strawberry Valley quadrangle, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-931. Scale 1:63,360

Crittenden, M. D., Jr., 1961, Magnitude of thrust faulting limits in northern Utah: United States Geological Survey Professional Paper 424-D, p. D128-D131.

Duncan, J. M., Fleming, R. W., and Patton, F. D., 1985, Report of the Thistle Slide Committee to State of Utah, Department of Natural Resources, Division of Water Rights: Administrative Report issued by Robert L. Morgan, State Engineer, Division of Water Rights, Department of Natural Resources, 1636 West North Temple, Salt Lake City, Utah, 84116. 62 p. plus appendices.

Hardy, C. T., 1949, Stratigraphy and structure of the Arapien Shale and the Twist Gulch Formation in Sevier Valley, Utah: Columbus, Ohio, Ohio State University unpublished Ph.D. thesis, 85 p.

________ 1952, Eastern Sevier Valley, Sevier and Sanpete Counties, Utah--with reference to formations of Jurassic age: Utah Geological and Mineralogical Survey Bulletin 43, 98 p.

Harris, H. D., 1954, Geology of the Birdseye area, Thistle Creek Canyon, Utah: The Compass, v. 31, no. 3, p. 189-208.

Lawson, A. C., Chairman, 1908, The California earthquake of April 18, 1906: Report of the State Earthquake Investigation Commission: vol. 1, 451 p., vol. 2, 192 p. Carnegie Institution of Washington, reprinted in 1969.

Picard, M. D., 1980, Stratigraphy, petrography, and origin of evaporites in Jurassic Arapien Shale, central Utah, in Picard, M. D., ed., Henry Mountains symposium: Utah Geological Association Publication 8, p. 129-150.

Pinnell, M. L., 1972, Geology of the Thistle quadrangle, Utah: Brigham Young University Geology Studies, v. 19, Pt. 1, p. 89-130.

Spieker, E.M., 1946, Late Mesozoic and early Cenozoic history of central Utah: U.S. Geological Survey Professional Paper 205-D, p. 117-160.

________ 1949, The transition zone between the Colorado Plateaus and the Great Basin in central Utah: Utah Geological Society Guidebook to the Geology of Utah, no. 4, 106 p.

Taber, Stephen, 1906, Some local effects of the San Francisco earthquake: Journal of Geology, v. 14, no. 4, p. 303-315.

Witkind, I. J., 1981, Reconnaissance geologic map of the Redmond quadrangle, Sanpete and Sevier Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1304-A. Scale 1:24,000.

________ 1982, Salt diapirism in central Utah, in Nielsen, D.L., ed., Overthrust belt of Utah symposium: Utah Geological Association Publication 10, p. 13-30.

________, 1983, Overthrusts and salt diapirs, central Utah, in Miller, D. M., Todd, V. R., and Howard, K. A., eds., Tectonic and stratigraphic studies in the eastern Great Basin region: Geological Society of America Memoir 157, p. 45-60.

Witkind, I. J., and Page, W. R., 1983, Geologic map of the Thistle area, Utah County, Utah: Utah Geological and Mineral Survey Miscellaneous Series Map 69. Scale 1:24,000.

Young, G. E., 1976, Geology of Billies Mountain quadrangle, Utah County, Utah: Brigham Young University Geology Studies, v. 23, Pt. 1, p. 205-280.