The Controversial Origin of Central Utah's Geologic Complexities

By Irving J. Witkind

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CONTENTS

FIGURES

TABLE

The Controversial Origin of Central Utah's Geologic Complexities

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Introduction

Geology, a somewhat inexact science, differs from the more precise sciences such as chemistry and physics. In geology, many complex rock exposures are not readily decipherable, and consequently lend themselves to differing interpretations. Geologists have a wry jest: one outcrop, two geologists, three interpretations! Regrettably, the enigmatic exposures in central Utah invite such unbridled speculation. Despite the hordes of geologists who have swarmed over central Utah during the past half century, no firm consensus has been reached concerning central Utah's tangled geologic history. Contending geologists, in hot debate, have commonly offered two dramatically different interpretations.

One interpretation, proposed more than half a century ago, suggests that mountain-building forces—commonly referred to as tectonic forces—coming from the west repeatedly deformed central Utah. This interpretation, here termed the multiple-tectonic concept, is favored by many geologists (DeCelles and others, 1995; Lawton, 1985; Standlee, 1982). A second interpretation, relatively new, proposes that the structural deformation in central Utah is best explained as the result of the repeated growth and collapse of large salt masses known as salt diapirs—the salt-diapiric concept (Witkind, 1983; 1987; 1994).

I contend that the contained salt in the Arapien Shale—expressed as salt diapirs—is the driving force that complexly deformed the rocks in central Utah. If valid, this view could have great economic significance. Elsewhere, throughout the United States and the world, large petroleum deposits are concentrated near salt diapirs comparable to those found in central Utah. One need look no farther than the Paradox Basin in southeastern Utah and southwestern Colorado to see a convincing relationship between salt diapirs and petroleum.

This article describes only the **rudimentary features** of the salt-diapiric concept. Additional **details** are available in U.S. Geological Survey Professional Paper 1528 (Witkind, 1994). Those readers interested in particulars of the multiple-tectonic concept should contact Douglas A. Sprinkel, Utah Geological Survey, P.O. Box 146100, Salt Lake City, Utah 84114-6100. Sprinkel's telephone number is: 801-537-3316; his e-mail address is: sprinkel@mail.vii.com.

The U.S. Geological Survey and the Utah Geological Survey, both sponsors of geologic studies in central Utah, take no official stance favoring either concept.

Central Utah's Structural Setting

Physiography

Figure 1 covers that part of central Utah wherein crop out many of the complex geologic features that have so intrigued geologists. I arbitrarily divide this sector into two parts: the huge mass of the Wasatch Plateau on the east (essentially that part of the area east of U.S. Highway 89), and the remainder of the area, to which I apply the well-established name "Sanpete–Sevier Valley area." Part of the region discussed here, chiefly the western sector, extends slightly beyond the normally accepted limits of the Sanpete–Sevier Valley area, but for ease of discussion I continue to use that name.

For ease of referring from text to figure 1, **locality names in the text are followed by a letter and numeral,** thus, Mayfield (G-3). The letter-numeral combination locates the feature via the grid overlaid on figure 1.

Wasatch Plateau

The Wasatch Plateau, the northernmost of the high plateaus of Utah, is a flat-topped mass about 80 miles long and some 40 miles wide that extends from Salina Creek Canyon on the south to the valleys of Soldier Creek and Price River on the north (all three localities are east of the area of figure 1). The plateau trends about N. 20º E., and maintains a constant altitude of about 10,000 feet. It separates Sanpete Valley (F-3) on the west from Castle Valley (east of the area of fig. 1) on the east. The plateau is underlain by near-horizontal Cretaceous and Tertiary strata, which flex down

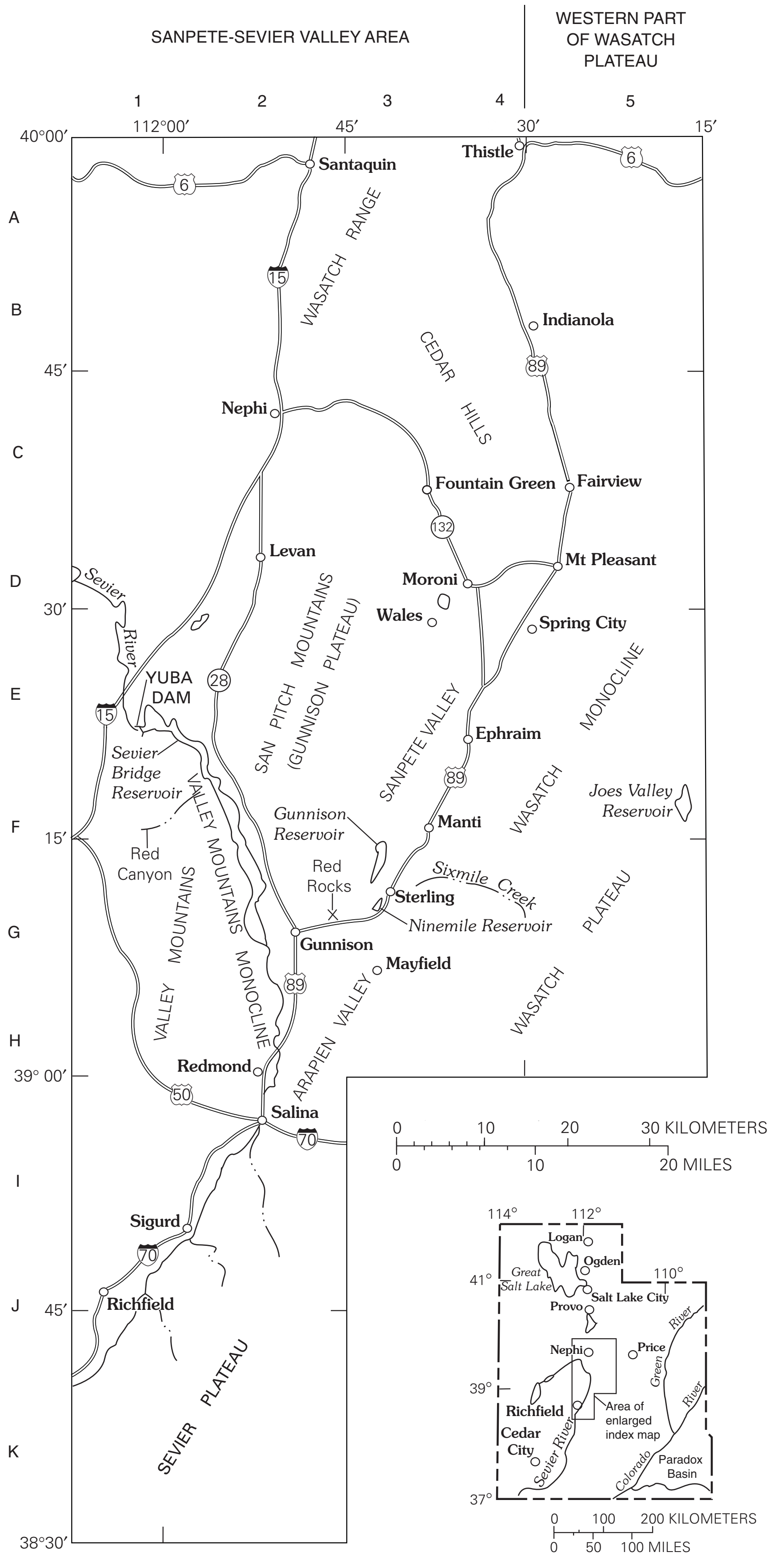


Figure 1. Index map of central Utah. A letter and numeral identify all localities mentioned in text, for example, Sterling (G-3). These letter-numeral combinations are keyed to this illustration.

along the west flank of the plateau to form the imposing Wasatch Monocline (F-4), some 62 miles long. High-angle normal faults, trending both north and about N. 20º E., break much of the plateau and the monocline. Locally these faults are paired to form grabens (elongate, narrow troughs bounded by near-parallel normal faults).

The Sanpete–Sevier Valley Area

The name, Sanpete–Sevier Valley area, used repeatedly in the geologic literature, encompasses an irregular area centered about the San Pitch Mountains, also known as the "Gunnison Plateau" (E-3). The Sanpete–Sevier Valley area is an arid lowland broken here and there by north-trending plateaus and low hills considerably lower than the adjacent Wasatch Plateau. Sedimentary, metamorphic, and volcanic rocks, more or less deformed, underlie most of these uplands. The very western part of the Sanpete–Sevier Valley area (as used here) includes the eastern reaches of the Basin and Range province.

Stratigraphy

Table 1 lists many (but not all) of the sedimentary units exposed in this sector of central Utah. Of all formations listed, the Arapien Shale of Middle Jurassic age, a unit rich in evaporites such as salt and gypsum, has played the greatest role in structurally deforming central Utah. I discuss the characteristics of the Arapien Shale later in this report.

The Diapiric Concept

In brief, the upward thrust of a rising salt diapir forces up the enveloping mudstones, and they, in turn, push up and locally overturn the overlying sedimentary strata to form a major upwarp—a salt-cored anticline, or diapiric fold, as these upwarps are sometimes called (fig. 2).

Although ample evidence of salt movement in the geologic past is widespread throughout central Utah, some tenuous evidence, in the form of recently tilted sedimentary deposits, supports the view that the salt is still moving today and still deforming the bedrock upon which humans have constructed many of their buildings. I can only conclude that the salt diapirs are contemporary geologic hazards.

The Arapien Shale

Vast amounts of salt and other evaporites, such as gypsum and anhydrite, are integral parts of the Arapien Shale, one of the most unusual formations in Utah. The Arapien, named for its excellent exposures in Arapien Valley (H-3) near Mayfield, Utah (G-3), has many appearances. Commonly it is a light-gray, almost white mudstone mottled here and there with pink blotches. This blotched appearance is distinctive and characterizes most Arapien exposures; it is best seen in the broad expanses between Salina (I-2) and Richfield (J-1), especially east of Sigurd (I-2). In places, however, the Arapien is red, bluish gray, and dark gray.

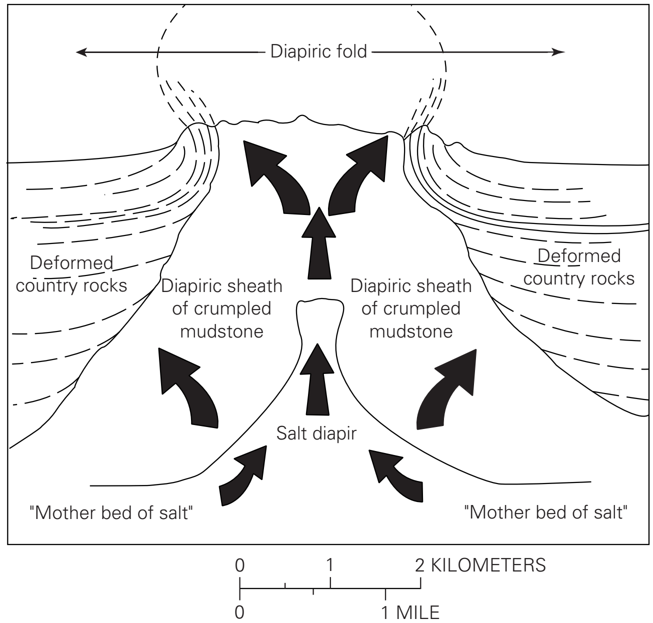


Figure 2. Cross section through a diapiric fold (salt-cored anticline). Arrows indicate general direction of movement of the mobile, plastic salt and mudstone. In places, upward vertical forces, stemming from the intrusive salt diapir, are translated laterally into horizontal compressive forces. Scale is approximate.

Salt

What makes the Arapien so unusual is its enormous content of evaporites, chiefly salt and gypsum. Salt is mined at Redmond (H-2), and gypsum near Sigurd (I-2), Salina (I-2), and Nephi (C-2). Both minerals contribute to the economic wealth of central Utah.

Salt is easily dissolved in the temperate climate that characterizes the Western Interior of the United States. No sooner does the salt reach the surface than it passes into solution. As a result it is seldom exposed. Thus, in the Paradox Basin, underlain by extensive deposits of salt, none is exposed at the surface. Central Utah, also underlain by much salt, displays only small amounts at the surface, chiefly near Salina (I-2) and Redmond (H-2).

Salt Diapirs

Salt is a remarkably mobile material. Deposited in horizontal beds, in many places it begins to move both laterally and vertically shortly after deposition. Why it starts moving

Table 1. Some stratigraphic units exposed in central Utah.
[Tu, Tku, and so on are symbols for combined units]

System	Series	Group and formation	Symbol	Thickness (feet)	Lithology	
Tertiary	Eocene	Green River Formation	Tg	1,200	Limestone underlain by shale unit	
		Colton Formation	Tc	450–600	Claystone and mudstone	Tu
	Paleocene	Flagstaff Limestone	Tf	50–1,800	Limestone with subordinate shale	
Cretaceous	Upper Cretaceous	North Horn Formation	Tkn	150–3,000	Mudstone, sandstone, conglomeratic sandstone	TKu
		Price River Formation	Kpr	20–2,000	Conglomerate, conglomeratic sandstone, siltstone	
		Indianola Group	Kl	3,000–7,000	Conglomerate, conglomeratic sandstone, sandstone	
	Lower Cretaceous	Cedar Mountain Formation	Kcm	300–2,000	Shaly siltstone and mudstone, some limestone	KJu
Jurassic	Middle Jurassic	Twist Gulch Formation	Jtg	3,000	Shaly siltstone and sandstone	
		Arapien Shale	Ja	4,000–13,000	Calcareous mudstone, much salt and other evaporites	
		Members of the Twin Creek Limestone	Jtc	320–450	Limestone, thin-bedded to massive	
	Lower Jurassic	Navajo Sandstone (Nugget Sandstone)	Jn	500–1,000	Sandstone, light-brown	
Triassic	Upper to Lower Triassic	Triassic strata, undivided	TRu	300–1,000	Chiefly shale, siltstone, some limestone	
Permian	Lower Permian	Permian strata, undivided	Pu	400–1,000	Limestone, cherty limestone	
Pennsylvanian	Upper to Lower Pennsylvanian	Pennsylvanian strata, undivided	IPu	11,500	Interbedded limestone and sandstone	

is unknown; several explanations have been proposed. One of the more reasonable suggestions attributes this initial movement to the reactivation of a nearby existing fault. In time, lateral migration leads to the development of large salt masses.

Because the specific gravity of salt is less than that of the surrounding sedimentary rocks, the buoyancy of the salt causes these large salt masses to rise. In their upward ascent, they push up and fold back the overlying strata, and then punch through them in a process called piercement. Piercement characterizes most diapirs, the name geologists apply to these rising salt masses.

Some of these diapirs are round, even as others are linear and ridgelike. Along the coastal plains of Texas, Louisiana, and Mississippi, many of the diapirs are rounded salt masses with near-vertical walls. Elsewhere, as, for example, in northern Germany, the diapirs are thin, narrow, ridgelike salt bodies that extend for miles.

Ridgelike diapirs characterize the Arapien Basin in central Utah as well as the Paradox Basin.

As the salt core of a ridgelike diapiric fold begins to dissolve in the subsurface, the crestal part of the fold either subsides between boundary faults or sinks into the newly formed voids (fig. 3*B*). Erosion quickly destroys the foundered remnants. The upturned limbs of the fold, lacking support, fail and sag to form paired, facing monoclines (fig. 3*C*).

Intermittently and repeatedly during the past 175 million years, the rising salt forced up the overlying, younger sedimentary strata to form these giant salt-cored upwarps that dominated the area. Each time, as the salt core dissolved, these upwarps collapsed. Erosion then reduced the remnants, leaving only steeply tilted or overturned beds here and there as evidence of their former presence. An outstanding example of such a remnant is the vertical ridge that defines much of the east flank of the Gunnison Plateau (San Pitch Mountains (E-3)). The ridge is readily examined near Wales (E-3).

Rate of Salt Movement

The salt moved at different rates as it rose toward the surface. For much of the time its rate of upward movement was almost imperceptible. Every now and then, however, it seems to have surged upward rapidly, almost spasmodically.

Slow, Upward Movement

Entire sequences of geologic formations—not just one or two formations—are both bowed up and anomalously thin near these salt-cored upwarps, implying that the implacable upward thrust of the rising salt forced these salt-cored anticlines upward slowly but continuously. Expectably, the rate of the rising salt determined the rate of the upward movement of the upwarp. These upwarps, thus, are best viewed as dynamic, moving masses, rather than static, stationary ones. If sediments were burying a static hill, several formations would thin, reflecting where those sediments were deposited against its flanks. Once the static hill was buried, younger formations would pass over it unchanged in thickness (sketches in *A*, fig. 4).

Rapid, Upward Surges

Brief but pronounced upward surges of the salt interrupted these lengthy episodes during which the salt rose slowly. Seemingly, at these times the salt surged upward in sudden spasmodic movements to form the enormous, linear diapiric folds. These salt-cored upwarps have been called anticlines, salt-cored anticlines, and diapiric folds. Figure 5 illustrates the difference between the terms, and why the term “anticline” may be misleading.

The descriptive term is important. If, as I contend, upward movement of Arapien salt is responsible for the development of the complex structures that characterize central Utah, **these structures should extend down to the base of the salt-bearing Arapien Shale, but no deeper**. Older formations below the Arapien may also be deformed, but if so, they were deformed by tectonic forces, not salt movement. In economic terms, then, two types of petroleum reservoirs may underlie central Utah—near-surface ones developed in the salt-generated structures, and deeper ones in the folded units concealed beneath the Arapien Shale.

Diapiric Structures in Central Utah

The diapiric structures found throughout central Utah include minor ones that are readily examined in the field, as well as major structures that extend for tens of miles and that are more difficult to perceive because of their great size and the extensive erosion they have undergone.

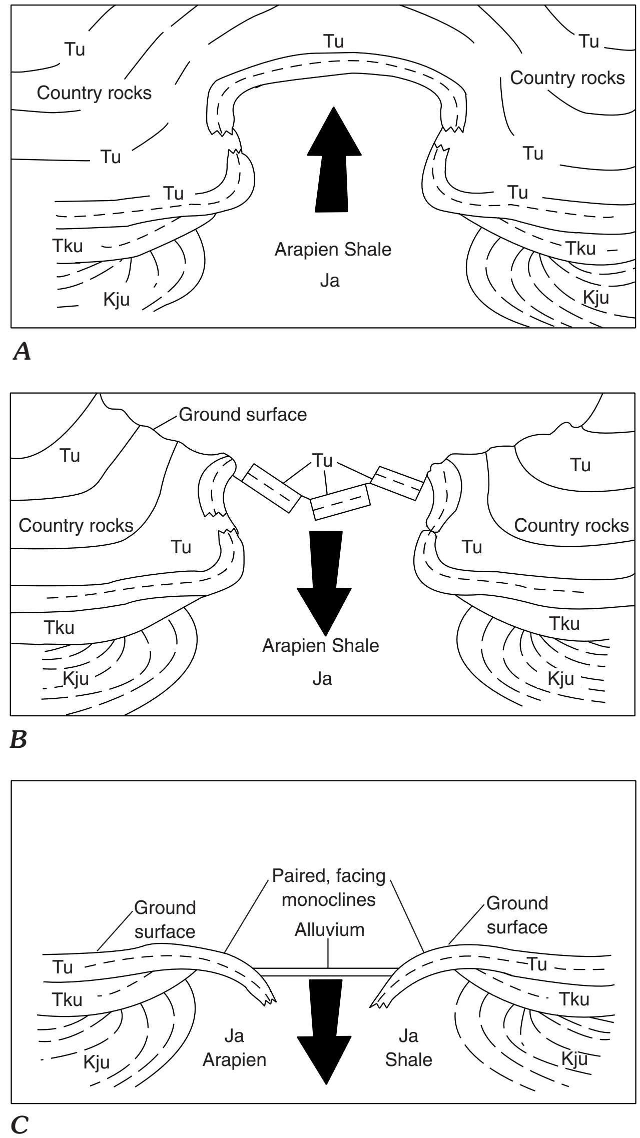


Figure 3. Several sketches suggesting how a diapiric fold may form and then fail. *A*, The rising salt diapir (not shown but within the Arapien Shale (Ja)) forces up the surrounding mudstones, which, in turn, push up and fold back the overlying country rocks. *B*, As the diapiric salt core gradually dissolves, support for the overlying strata is removed. The crest of the fold founders, breaking into large masses. Erosion attacks the failed fold. *C*, Erosion quickly destroys these fragmented blocks. Continued removal of salt from the salt core, and the resulting subsidence, culminates in downward flexing of both of the upwarp’s flanks to form paired, facing monoclines.

Minor Structures

I discuss here only two of the many minor salt-derived structures found in central Utah, one in the Thistle area (A-4), and another in the Sterling area (G-3).

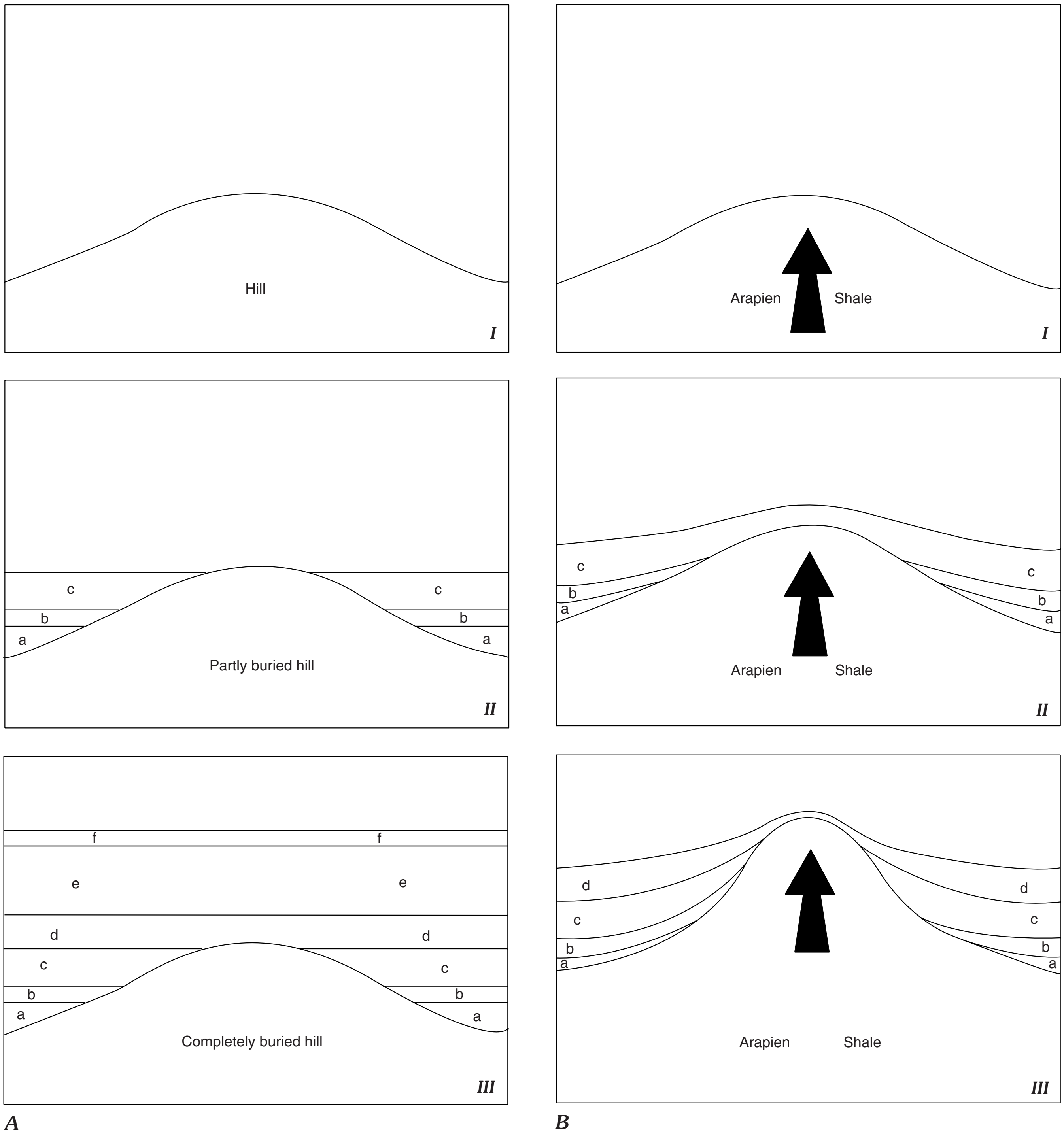


Figure 4. The critical difference between a static hill and a dynamic upwarp. *A*, Static hill. Sediments deposited against a static hill thin where they abut the flanks of the hill (units a, b, and c of sketch II). Once the hill has been buried they pass over it unchanged in thickness (units d, e, and f of sketch III). *B*, Dynamic upwarp. The dynamic upwarp (sketch I), driven by the rising salt (not shown), continues to rise as long as the salt maintains its upward movement (sketch II). Two characteristics mark this upward movement (sketches II and III): (1) The strata are warped up along the flanks of the rising mass; and (2) all strata along the upwarp's flanks thin anomalously.

Thistle Area (A-4)

Shortly after the disastrous Thistle Landslide of 1983, which effectively blocked the major highway (U.S. 6) connecting Price and Provo (small index map, fig. 1), construction crews cut a new highway through a ridge north of the landslide. The new roadcut exposes masses of Arapien Shale that intrude beds of the Twin Creek Limestone that form the ridge. Photographs of these exposures demonstrate not only the different aspects of the Arapien but also its intrusive nature (fig. 6).

Sterling Area (G-3)

The intrusive and deforming aspects of the Arapien Shale show well directly south of Sterling (G-3) near Ninemile Reservoir (G-3). In that area, the Green River Formation (the formation, incidentally, that furnished the limestone blocks used to construct the magnificent Mormon Temple at Manti (F-4)) forms a narrow, north-trending sag (syncline) followed by Arapien Valley (H-3). In detail, Green River strata east of Arapien Valley dip west as part of the Wasatch Monocline (F-4) (fig. 7). West of Arapien Valley (H-3), these same strata, exposed along the east flank of a small, unnamed knoll, are unexpectedly inclined to the east! Why the abrupt change in dip? The geologic relations displayed along the west flank of this unnamed knoll explain this surprising change. The exposures indicate that the Arapien Shale intruded and pushed up the overlying Green River beds and in so doing inclined them to the east.

Major Structures

The major, elongate, diapiric folds trend generally north or slightly east of north. At least 13 of these major diapiric folds, all deeply eroded, have shaped the landscape of central Utah.

Development of Major Diapiric Folds

Episodes

The salt diapirs surged upward at least three and possibly four times, and each time they warped the overlying strata into the elongate diapiric folds. The first episode likely began about 65 million years ago. A second probably started some 60 million years ago, and a third about 22 million years ago. Some evidence suggests that a fourth episode occurred about 25,000 years ago. The tilting of some modern sedimentary deposits implies that the salt is still active today. I am uncertain how long each of these episodes lasted.

Stages

Each diapiric episode logically divides into three stages—an **intrusive** stage, an **erosional** stage, and finally, a **depositional** stage. Figure 8 illustrates the interrelations of these three stages, and how they characterize each diapiric episode.

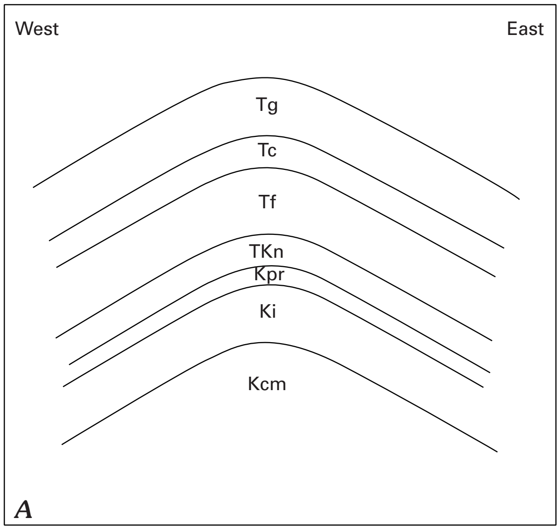
During the intrusive stage, the salt surges upward to form a salt-cored diapiric fold (III, fig. 8). Subsequently, as dissolution destroys the salt core, the fold collapses (IV, fig. 8), and the erosional stage begins, eventually forming a surface of low relief (V, fig. 8). Sediments deposited on this newly formed surface (VI, fig. 8) mark the beginning of the depositional stage. A renewed upward surge of the salt (VII, fig. 8)—the intrusive stage of the next diapiric episode—ends the depositional stage. These same three stages are repeated during each diapiric episode, and this repetition, time and time again, has determined the structural pattern of central Utah.

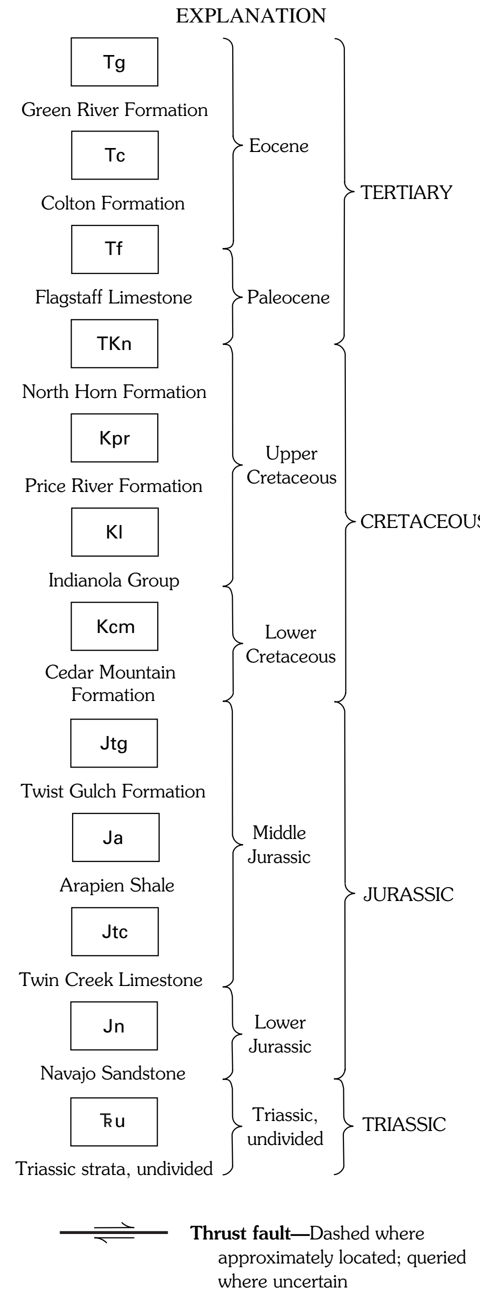
The geologic evidence suggests that each time the new diapiric folds formed they occupied the same sites and had the same trends as the previous, older diapiric folds. This implies that during the intrusive phase of each new episode, the remobilized salt surged up the same conduits previously followed by the earlier upward surges of the salt.

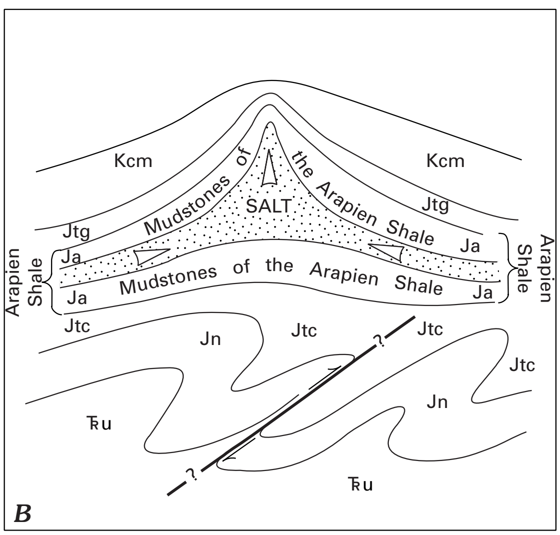
One possible explanation for this repeated use of the same conduits by the rising salt involves recurrent reactivation of the same major, ancient faults. Each time the faults moved, they triggered renewed movement of the salt. Expectably, the upward surge of the salt pushed up the surrounding mudstones, and these, following the established fault planes, forced up the overlying sedimentary rocks to form new diapiric folds whose trends coincided with the trends of former diapiric folds long since eroded and partly destroyed.

Monoclines

The paired, facing monoclines that formed when a diapiric fold failed (fig. 3*C*) are most unusual and not at all like those monoclines found elsewhere throughout the Colorado Plateau. Figure 9 illustrates the critical differences between the Colorado Plateau-type monoclines and those in central Utah. The east-facing Valley Mountains monocline (G-2)







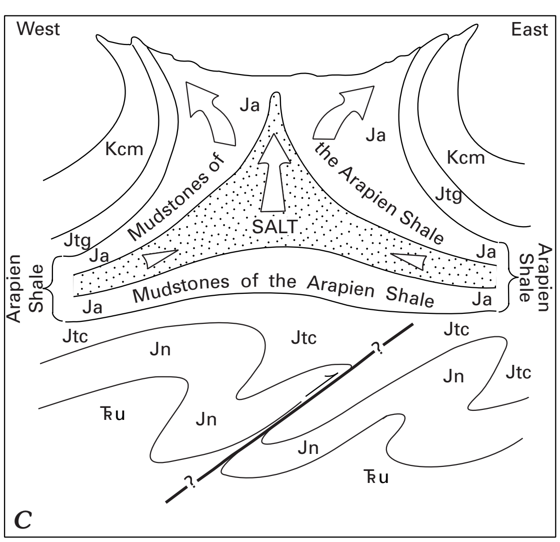


Figure 5. Sketches showing the fundamental difference between an anticline and a diapiric fold (salt-cored anticline). *A*, Section across a simple anticline. All strata are flexed into an upwarp. The units are much like the layers of an onion—the underlying formations conform closely to the overlying ones. *B*, Section across a diapiric fold (salt-cored anticline). The formations are divisible into two groups: an upper group consisting of the salt-bearing Arapien Shale (Ja) and the overlying younger units (units Jtg and Kcm in these sketches), and a lower group that underlies the Arapien Shale (Ja), (units Tru, Jn, and Jtc). *C*, The Arapien mudstones (Ja), forced upward by the rising salt, have warped the upper group of beds (units Jtg and Kcm) into a diapiric fold (salt-cored anticline). The lower group of strata (Tru, Jn, and Jtc) are deformed, but this deformation is unrelated to the movement of the salt and likely results from eastward-directed mountain-building forces.

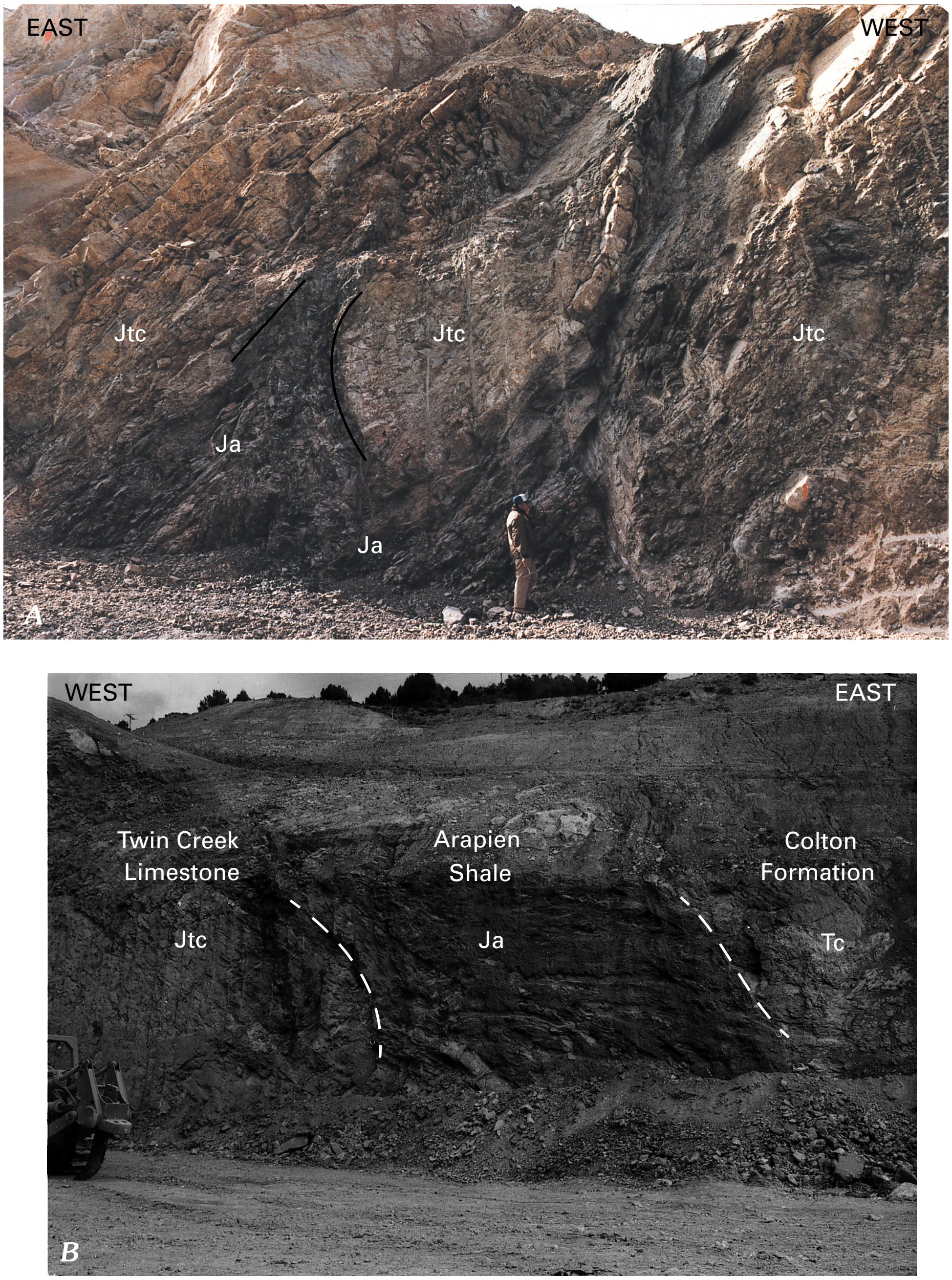


Figure 6. New U.S. Highway 6 through a ridge composed of Twin Creek Limestone beds (Jtc) of Middle Jurassic age. Exposures demonstrate that the salt-rich Arapien Shale (Ja) locally intrudes and deforms the country rocks. *A*, The Arapien Shale (Ja) intrudes and deforms tilted beds of the Twin Creek Limestone (Jtc). *B*, A dike-like, intrusive mass of the Arapien Shale (Ja) separates the Twin Creek Limestone (Jtc) and the Colton Formation (Tc) of Eocene age.

displays well the unusual structural relations that characterize the central Utah monoclines.

The Valley Mountains Monocline (G-2)

The Valley Mountains monocline (G-2) extends for about 28 miles along the east flank of the Valley Mountains (G-1). The monocline for the most part is undissected (much like fig. 9*B*). Only near its north end, near Yuba Dam (E-1), is the monocline breached for about 5 miles; the downwarped Flagstaff limestones that define the monoclinal slope (Tf, fig. 10, which is a diagrammatic sketch of the south wall of Red Canyon (F-1) in the Valley Mountains) have been eroded exposing the underlying strata (Kpr-TKn and KJu, fig. 10).

These strata, rather than conforming in attitude to the downwarped Flagstaff limestone beds (Tf) that form the surface units, are near-vertical and locally overturned. In addition, they are anomalously thin.

This structural pattern—upturned, anomalously thin older rocks (units KJu and Kpr-TKn, sketch I, fig. 10), overlain by downturned, anomalously thin younger ones (unit Tf)—has also been found near the mouth of Sixmile Canyon where Sixmile Creek (G-4) cuts through the Wasatch Monocline (F-4). Geophysicists have also recognized the same pattern in the subsurface of central Utah.

Such structural relations, I contend, are reasonably explained only by invoking multiple episodes of salt diapirism. Figure 10 demonstrates how a sequence of multiple diapiric events can result in upturned older beds overlain by downturned younger ones.

Conclusions

Right now, and with our current state of knowledge, no one can state with absolute certainty that any one concept explains central Utah's geologic complexity. It is my firm belief, however, that when we eventually resolve this vexatious dilemma, we will find that multiple episodes of salt diapirism played a major role in deforming the strata in central Utah.

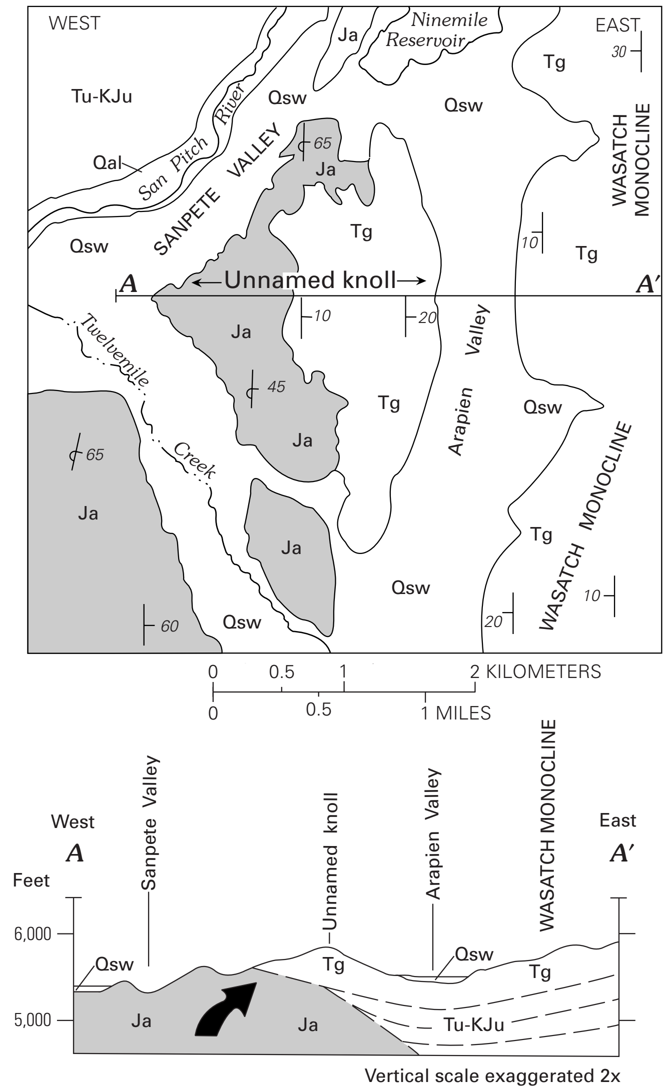


Figure 7 (above and following page). The Sterling area. Green River strata (Tg), inclined to the west as part of the Wasatch Monocline, pass below and are concealed beneath the floor of Arapien Valley (cross section *A*–*A*′). When they reappear (as part of a small unnamed knoll) along the west edge of the valley, they have reversed dip and are inclined eastward—a surprising change. What caused the unexpected reversal in dip? The west flank of the small, unnamed knoll contains the answer. The Arapien Shale (Ja), exposed there, pushed up the former westward-inclined Green River beds (Tg), forcing them into an eastward dip (cross section *A*–*A*′, arrow). Explanation on next page.

EXPLANATION

Sequence of deposition

Map unit	Description		Epoch	Period
Qal	Alluvium		Holocene and Pleistocene	QUATERNARY
Qsw	Slope wash and valley fill		Holocene and Pleistocene	QUATERNARY
Tg	Green River Formation		Eocene	TERTIARY
Tu-KJu	Older strata	Includes units of: Colton Formation (Eocene); Flagstaff Limestone (Paleocene–Eocene); North Horn Formation (Paleocene–Upper Cretaceous); Price River Formation (Upper Cretaceous); Indianola Group (Upper Cretaceous): and Cedar Mountain Formation (Lower Cretaceous)	Paleocene and Cretaceous	TERTIARY; CRETACEOUS AND JURASSIC
Ja	Arapien Shale		Middle Jurassic	CRETACEOUS AND JURASSIC

Contact—Approximately located or inferred

Attitude (strike and dip) of

20 **Inclined beds**

65 **Overturned beds**

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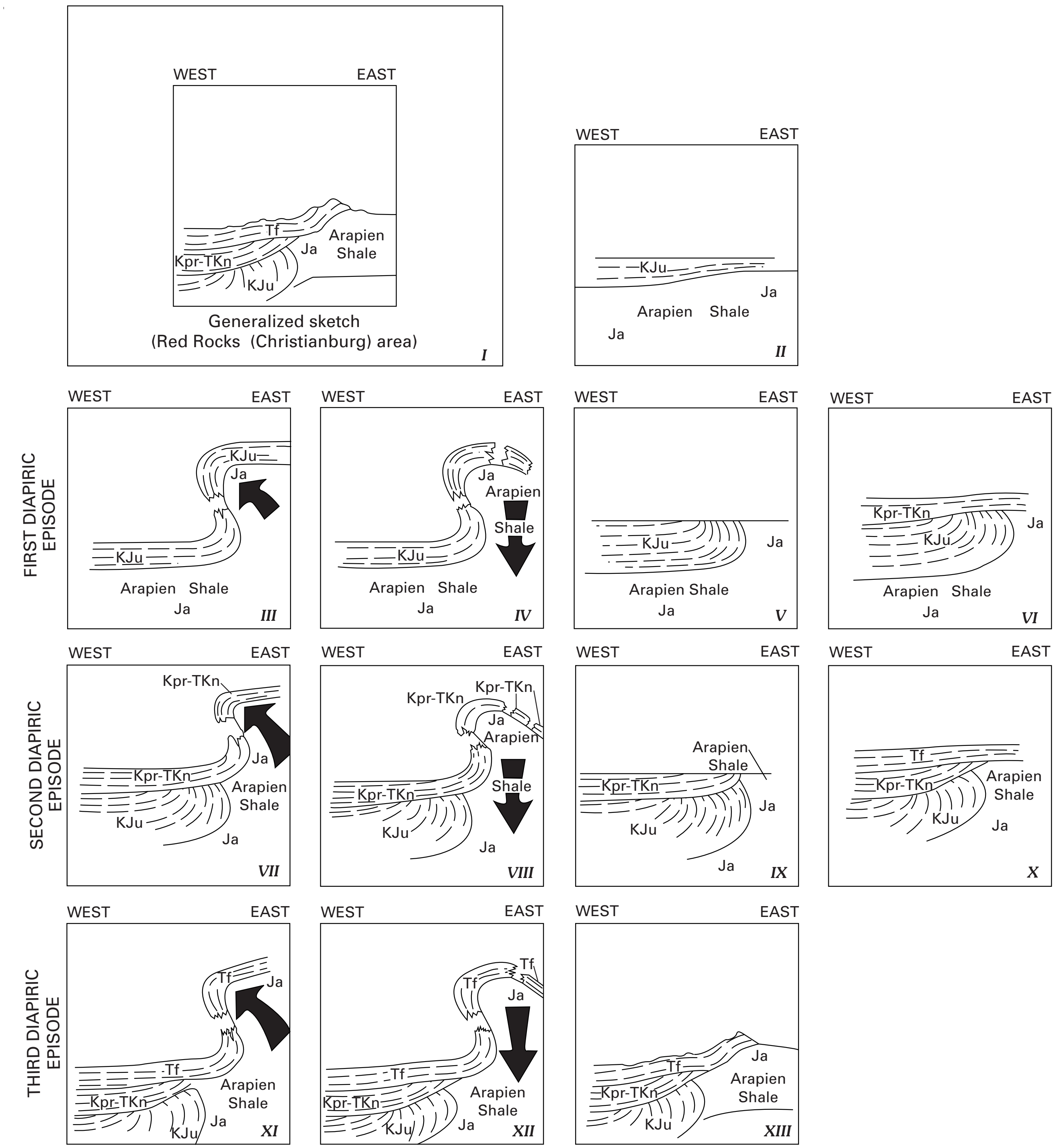

Figure 8 (above and following page). Diagrammatic sketches illustrating how the sequence of intrusion, erosion, and deposition, repeated during each of the three major diapiric episodes, complexly deformed the rocks exposed in the Red Rocks area (G-3). Explanation and continuation of caption are on page 13.

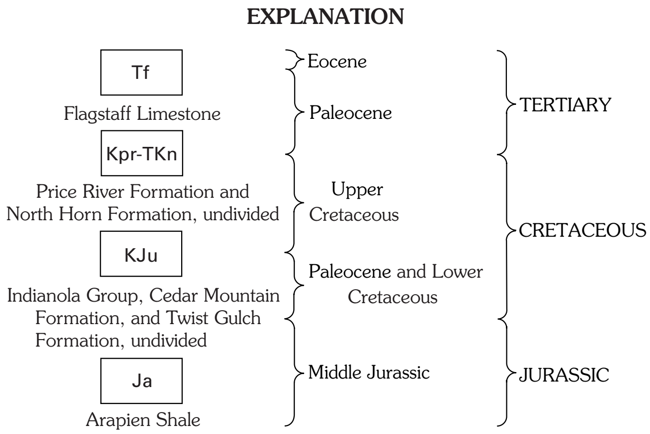

Figure 8—Continued. Red Rocks area.

All sketches show only the west limb of the diapiric folds. The diapiric salt cores and the east limbs of the developing folds are east (right) of these exposures but are omitted for clarity.

I. Generalized sketch of Red Rocks area (G-3). View is northward.

II. Sediments of the Twist Gulch Formation (Jurassic), Cedar Mountain Formation (Lower Cretaceous), and the Indianola Group (Upper Cretaceous), all grouped and represented here by the symbol KJu, are deposited on the Arapien Shale (Ja). These undivided Jurassic and Cretaceous strata thin laterally as a result of the slowly rising salt.

First diapiric episode.

III. Intrusive stage. An upward surge of the salt diapir pushes up the Arapien mudstones (Ja), and they, in turn, push up and fold back the overlying Jurassic and Cretaceous strata (KJu).

IV. Erosional stage. Partial dissolution of the salt core causes the fold's crest to collapse and founder.

V. Erosional stage—continued. Erosion of these fragmented remnants of the fold's crest eventually produces a surface of low relief.

VI. Depositional stage. Younger strata, the Price River Formation (Kpr) (Upper Cretaceous), and the North Horn Formation (TKn) (Paleocene and Upper Cretaceous), deposited across this eroded surface, are represented by the combined symbol Kpr-TKn. The slowly rising salt core causes these units to thin laterally.

Second diapiric episode.

VII. Intrusive stage. The second diapiric episode begins with a renewed upward surge of the salt core. The upthrust Arapien mudstones (Ja) deform the overlying Price River and North Horn strata (Kpr-TKn) into a new upwarp that occupies the same site and has the same trend as the previous diapiric fold.

VIII. Erosional stage. Again, removal of part of the salt core causes the fold's crest to founder.

IX. Erosional stage—continued. Erosion destroys these fold remnants, forming a new surface of low relief.

X. Depositional stage. Sediments of the Flagstaff Limestone (Tf) are deposited across this new surface. These sediments thin laterally reflecting the slow, upward movement of the salt.

Third diapiric episode.

XI. Intrusive stage. The salt diapir reactivates a third time to form a new upwarp that again occupies the same site and has the same trend as the previous two diapiric folds.

XII. Erosional stage. And again this new fold founders as part of the underlying salt core is removed.

XIII. Erosion stage—continued. Erosion attacks the fold's remnants and partly destroys them, but has not, as yet, completely reduced the area to a surface of low relief.

Compare sketch XIII with I, generalized sketch of Red Rocks area (G-3).

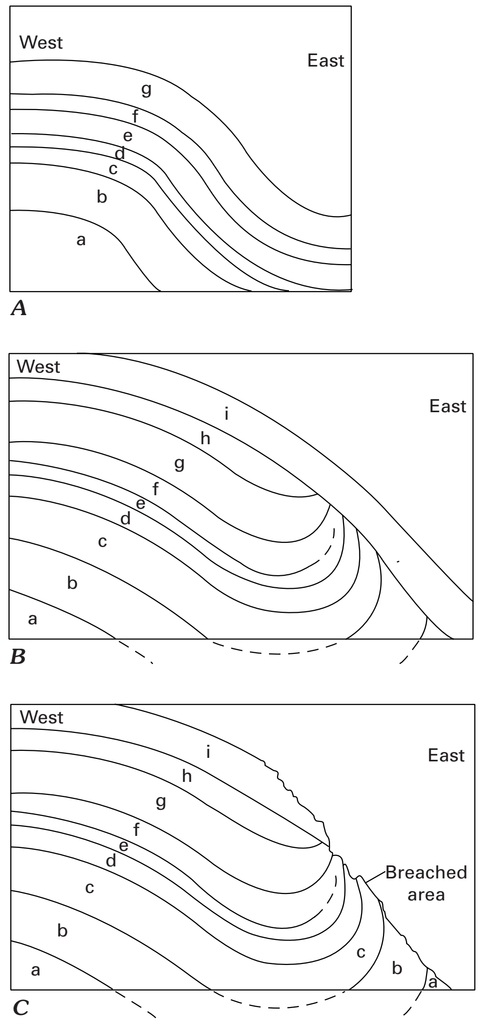

Figure 9. Cross sections showing fundamental differences between a typical Colorado Plateau-type monocline and a similar-appearing central Utah monocline. *A*, Colorado Plateau-type monocline. All units are conformable, and all maintain an even thickness. A section through this monocline is much like a section through an onion. *B*, Central Utah-type monocline. On the surface a central Utah-type monocline, prior to being breached, resembles the Colorado Plateau-type monocline—no hint is given of the underlying structural complexity. *C*, Central Utah-type monocline. After being breached, the monocline exposes complexly deformed underlying units that are considerably thinner than where these same units are exposed elsewhere.

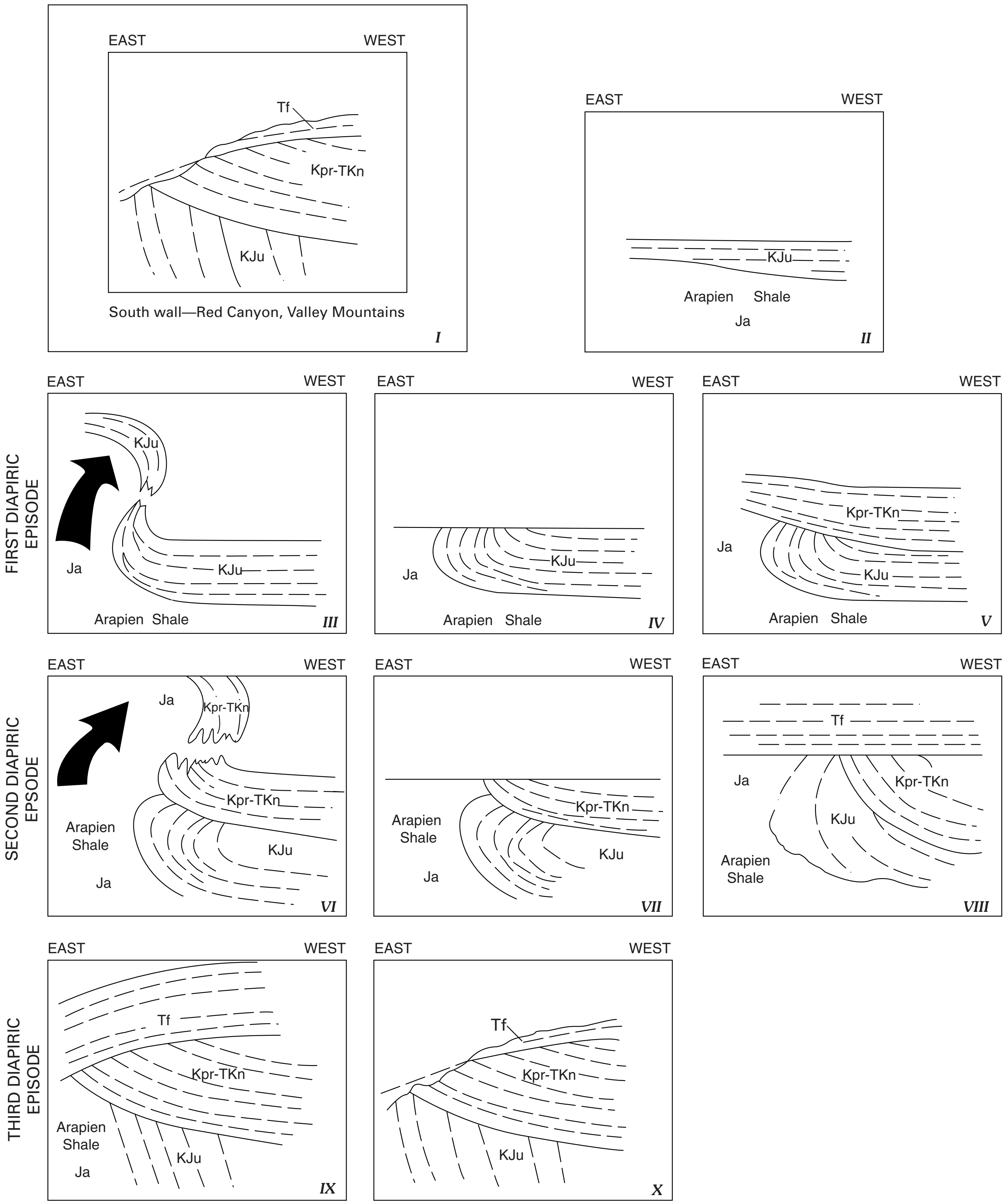

Figure 10 (above and following page). Red Canyon area, Valley Mountains. Explanation and continuation of caption are on page 16.

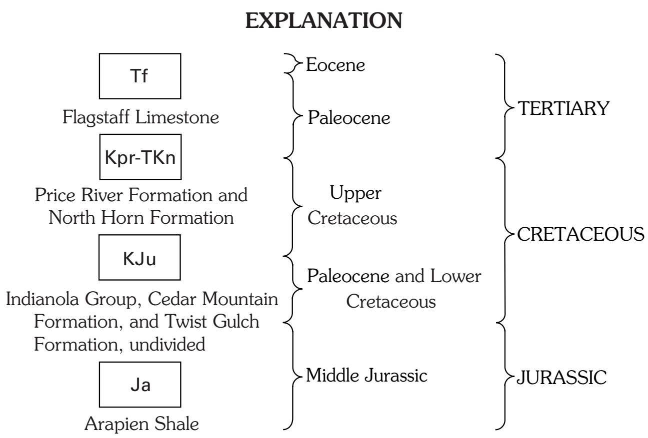

Figure 10—Continued. Red Canyon area, Valley Mountains.

I. Diagrammatic sketch of the south wall of Red Canyon in the Valley Mountains. View is southward. All sketches are of the west flanks of the diapiric folds. The causative salt diapir, east (left) of the area shown, is not exposed.

II. Sedimentary units of the Twist Gulch Formation (Jurassic), Cedar Mountain Formation (Lower Cretaceous), and the Indianola Group (Upper Cretaceous) are all here grouped under the symbol KJu. These units, deposited on the Arapien Shale, thin laterally eastward (left) reflecting the slow, upward movement of a salt diapir within the Arapien Shale.

First diapiric episode.

III. An upward surge of the salt diapir forces up the Arapien mudstones (Ja), and they, in turn, push up and deform the Jurassic and Cretaceous country rocks (KJu).

IV. Dissolution of part of the salt core causes the fold to founder, much as shown in figure 3*B*. Erosion removes the foundered blocks and cuts a surface of low relief across the upturned Jurassic and Cretaceous country rocks (KJu).

V. Younger sediments of the Price River Formation (Kpr) and the North Horn Formation (TKn), deposited across the erosional surface, thin eastward (left) in response to the slowly rising salt diapir.

Second diapiric episode.

VI. A renewed upward surge of the salt diapir forms a new diapiric fold.

VII. And again, dissolution of part of the salt core causes the fold to fail. Erosion removes the foundered blocks and then cuts a new surface of low relief across the Price River and North Horn (Kpr-TKn) country rocks.

VIII. Sediments of the Flagstaff Limestone (Tf) are deposited across this newly formed surface.

Third diapiric episode.

IX. What happened next is uncertain; two alternatives are possible. One alternative suggests that the salt surged upward once again to form a new diapiric fold. Subsequently, this fold failed and the flanks of the fold subsided to form paired, facing monoclines (much as shown in fig. 3*C*).

An alternative interpretation (shown here) is that the salt core remained quiescent; in essence, a new diapiric fold was not formed. Continued dissolution of the salt core removed support from the flanks of the fold, which then subsided to form paired, facing monoclines. Only the western monocline is shown here.

X. Erosion removed part of the downwarped Flagstaff Limestone (Tf), breaching the monocline and exposing the compexly deformed Price River (Kpr), North Horn (TKn), and the underlying Jurassic and Cretaceous units (KJu).

Compare sketch X with sketch I.

The end result is upturned older beds (units of Jurassic, Cretaceous, and Tertiary age (KJu and Kpr-TKn)), overlain by downturned younger ones (the Flagstaff Limestone (Tf))—in my view the fundamental structural pattern of central Utah.