UTAH GEOLOGICAL AND MINERAL SURVEY

REPORT OF INVESTIGATION

No. 213

Investigation of Potential Geologic Hazards near the Thistle Landslide, Utah County, Utah

by

Grant C. Willis

Utah Geological and Mineral Survey

February, 1987

Prepared by

UTAH GEOLOGICAL AND MINERAL SURVEY

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ABSTRACT

In the spring of 1983 an old landslide near Thistle, Utah reactivated and moved downslope, forming a dam 220 feet (67 m) high which blocked a major railroad, highway, and river. "Thistle Lake", which formed behind the landslide dam, reached a depth of 160 feet (50 m) before being drained by a diversion tunnel constructed that summer. One of several long-term proposals suggests that either the landslide be developed into a permanent dam and reservoir or that a dam and reservoir be constructed immediately upstream from the blockage. Irving J. Witkind, a geologist of the U.S. Geological Survey, expressed concern regarding two possible geologic hazards which he believed could exist in the area and could be of concern to a permanent dam and reservoir. The geologic structures he is concerned with are the Thistle Canyon fault, a feature mapped by earlier workers, and the Thistle Creek diapir, a feature which Witkind proposed. Because of poor surface expression and the lack of subsurface data, the existence and configuration of the Thistle Canyon fault and Thistle Creek diapir are controversial. This study indicates evidence supports the existence of the Thistle Canyon fault. It also indicates that the Thistle Creek diapir may be present but probably is a smaller structure and is deeper in the subsurface than proposed by Witkind, and thus presents a lesser concern than he suggests. Both structures are of concern, however, and should be investigated further through several approaches, primarily through the acquisition of subsurface data.

INTRODUCTION

In the spring of 1983 an old landslide near Thistle, Utah reactivated and began to move downslope. Within days it had blocked a major railroad line, a major highway, and the Spanish Fork River creating "Thistle Lake." The toe of the slide, modified by construction crews who attempted to stabilize and compact it, reached a heighth of 220 feet (67 m). Thistle Lake reached a depth of more than 160 feet (50 m) before being drained by a diversion tunnel constructed that summer (Kaliser and Fleming, 1986).

Since 1983 government officials have sponsored several studies to investigate the safety and possible uses of the landslide dam. Two of several alternatives considered are:

> -"Construct an entirely new earthfill dam immediately upstream, completely separate from the slide mass. This new structure would serve multipurpose functions of flood control, water supply, hydropower generation, and recreation as well as providing a solution to the public safety issue with a new emergency spillway and bypass tunnel providing full PMF (Probable Maximum Flood) hydraulic capacity. Included in this proposal is extension of the existing low-level drainage tunnel upstream to a new side-slope intake structure, construction of a powerhouse with 1.2 MWs of installed capacity, and construction of recreation facilities" (Kaliser and Fleming, 1986).

-"Complete studies on the existing landslide dam, undertake remedial measures, and make it into a full service multipurpose dam" (Kaliser and Fleming, 1986).

Upon learning that a permanent dam and reservoir may be constructed from or adjacent to the Thistle landslide, Irving J. Witkind of the United States Geological Survey reported his concerns on two possible geologic hazards (Witkind, 1986). Witkind had mapped in the Thistle area for several years as part of a larger study for the U. S. Geological Survey and coauthored a map covering the landslide area (Witkind, 1982; Witkind, 1983; and Witkind and Page, 1983). He recognized two geological features that he felt could be hazardous in dam construction or maintenance. These are "the Thistle Canyon fault" and "the Thistle Creek diapiric fold." The surface expression of both of these features is subtle and thus their true extent and significance is interpretive.

In May, 1986 the Utah Division of Water Rights requested that the Utah Geological and Mineral Survey to make an evaluation of Witkind's report. I was selected to make the evaluation because of my familiarity with Witkind's work on diapirism in central Utah. Witkind has delineated a large area of central Utah as possibly underlain by evaporite diapirs (Witkind, 1982). This includes the Salina area located about 60 miles (100 km) south of Thistle where I have been mapping the geology for the last 3 years (Willis, 1986; Willis, in press). I have accompanied Witkind on excursions to study possible diapir-related features in other areas and, in response to this request, in the Thistle area. This report of investigation will reflect my evaluation of Witkind's report on the Thistle area.

POTENTIAL HAZARDS

The reader is referred to Witkind (1986) for his discussion of the potential hazards and related geology of the proposed Thistle Creek diapir and Thistle Canyon fault. Only a brief summary is provided here. Locations described herein are referenced to Witkind's map (my figure 1; copies of figures from other reports that are discussed in this study are included herein for the convenience of the reader).

Thistle Canyon Fault

Baker (1976), Harris (1954), and Pinnell (1972) independently mapped a high-angle normal fault that trends N. 20° E. through the Thistle area. If present, the fault is located about 0.25 miles (0.4 km) east of the proposed damsite and under the proposed reservoir. The possible fault occurs between exposures of Jurassic rocks on the west side and Tertiary rocks on the east and is down to the east. It is poorly exposed and is mapped primarily on the basis of indirect evidence, primarily on separated outcrops of Tertiary Flagstaff Formation. On the west side of the fault isolated Flagstaff outcrops overlie the Jurassic rocks at an altitude of about 6500 feet (1950 m); to the east, across the proposed fault, similar rocks crop out at about 5300 feet (1590 m) (figure 2A).

Witkind does not believe the fault exists. He instead explains the offset Tertiary beds by the presence of an asymmetric anticline which was formed by a rising diapiric mass of Jurassic Arapien Shale (figure 2B). A question mark (?) is hereafter used in this report when referring to the Thistle Canyon fault to indicate its questionable existence.

Witkind is concerned with the possible effects of a body of water overlying this fault(?). I interpret his concerns to include the following: 1) the fault(?) might provide a conduit for ground water seepage , 2) seepage might lead to piping, subterraneous erosion or the development of springs in undesirable locations, and 3) the fault(?) might be reactivated through water seepage into the fault plane. Thus it is important to determine if the offset beds are caused by a fault or by an asymmetric fold.

Thistle Creek Diapir

Witkind believes that the proposed asymmetric anticline used to explain the offset Tertiary beds was caused by diapirism of underlying Jurassic evaporites (figure 2B). Geologically, a diapir is a mass of salt, gypsum, anhydrite, mudstone and/or other low-density material that rises slowly, penetrating through or bowing up overlying rock, similar to the way oil will rise through water and due to a lower relative density. Rate of movement can vary greatly. Witkind's main evidence stems from westward-tilted Tertiary beds on the west side of the anticlinal axis, eastward-tilted beds on the east side, possible thinning of the North Horn Formation through Green River Formation over the crest of the fold, and possible intruded evaporites that were exposed in the road cut in "Billies Mountain." If the diapir is present its axis would trend approximately under the proposed dam site. I interpret Witkind's concerns to include the following: 1) if the diapir is actively rising, it could disrupt dam fill over a period of time, 2) a change in ground-water characteristics caused by the reservoir might result in dissolution of evaporites and cause subsidence or collapse of the overlying rock and dam fill, 3) an overlying body of water might upset the isostatic balance and increase or renew diapirism, and 4) it raises doubt as to the stability of the rock foundation on which the dam might be built.

This Study

The primary purpose of this investigation is to determine if the surface evidence for the possible geologic hazards as advanced by Witkind is present; it is not to determine the extent or importance of such hazards. This investigation focuses on the geologic evidence supporting or refuting the presence of the features and suggests subsequent investigative steps to be taken.

INVESTIGATION

Thistle Canyon Fault

The fault(?)/asymmetric fold question is an offshoot of the larger diapiric anticline question. If the diapir is present the fault/fold feature is probably a fold, if the diapir is not present the feature is necessarily a fault. As is evident from a comparison of Witkind's cross sections (figures 2A and 2B), both a fault and asymmetric fold could produce similar surface features. This is particularly true since critical Tertiary rocks in the axial area have been removed by erosion. If the feature is a fault, it might not be a "single surface" but a complex fault with many surfaces and with drag that would produce a zone of shearing in incompetent rock and broken, rotated blocks in competent rock.

In general the surface expression of the fault(?) is obscured by surficial deposits. These deposits range from a few feet in places near Thistle Creek to possibly more than 100 feet (30 m) where the fault(?) crosses beneath the canyon floor. The fault(?) is well exposed in the recently exposed "Billies Mountain" road cut, however (figure 3). There Jurassic rocks are juxtaposed against Tertiary Flagstaff and Colton Formation. The Jurassic rocks dip about 45 degrees east while the Tertiary rocks are approximately horizontal (although locally deformed). The fault(?) plane closely follows the bedding plane of the Jurassic rocks and thus dips 45 degrees eastward also. The contact is a zone of intense shearing about 10 feet (3 m) wide and a larger zone about 100 feet (30 m) wide in which the Tertiary rocks are broken, brecciated, and rotated. The exposure in the roadcut reveals considerable displacement along the contact, indicating that the surface is a fault. However this does not resolve the question since it cannot be determined from surface exposures if the fault(?) is a deep-rooted normal fault or if it is the attenuated limb of an asymmetric anticline.

In considering the option that the fault(?) is the asymmetric limb of an anticline it is important to consider the mechanism Witkind proposes. He considers the fold to be formed by diapirism of underlying evaporite units and thus caused by vertical uplift with insignificant horizontal compression. This implies that the Flagstaff Formation must have been lengthened to span the greater curved distance and thus must have been attenuated. Since the fold is asymmetric it is most likely that attenuation would occur primarily in the steeper limb. This attenuation would produce shearing and broken blocks almost identical to a fault in the same location, thus a surface investigation would not be diagnostic. The significant difference would be in the subsurface.

I attempted to examine the fault(?) in other places along Thistle Creek. In the places I examined I found the critical contact to be too covered to aid in the interpretation. I do believe the contact could be exposed in some places by shallow trenching or stripping of surficial cover (figure 1). A critical place to attempt this would be just south of the last place Witkind mapped the fault in the southwest corner of his map. He stops the fault just before it cuts any of the Moroni Formation. Since the Moroni is the youngest bedrock unit in the area it would be valuable to know if the fault cuts the formation, is covered by it, or if the fault extends that far south. The fault does seem to decrease in offset toward the south. In the southwest part of Witkind's map, outcrops of the Flagstaff Formation on both sides of the fault trend could be projected so as to join without the need of a significant fault. Thus this trench alone would not be conclusive but it could be helpful. Other proposed trench sites are shown on figure 1.

One place I attempted to examine the fault was in the NE 1/4, sect. 7, T. 10 S., R. 4 E. Although the contact is covered, I was able to determine that deformation did occur in that area. I was able to recognize a sharp deflection of beds near the fault(?) surface. Of possible significance, a space problem exists with regards to the North Horn Formation in this locality. The North Horn has considerable thickness where exposed to the northeast, possibly a few hundred feet; however, in the locality I examined the Flagstaff Formation occurs within a few feet of the fault(?) surface. Thus the North Horn has been attenuated, faulted out, or depositionally thinned at this locality.

Thistle Creek Diapir

The Thistle Creek diapir is a much more complex feature than the fault and has little surface expression to aid in interpretation. Witkind's cross sections A-A' (figure 1) and B-B' (figure 2B) best illustrate his ideas. B-B' is most significant in that it is constructed through the dam site and reservoir area. Witkind proposes that large quantities of evaporites from the Arapien Shale have risen from a plate underlying the Charleston-Nebo thrust plate. The rising evaporites have bowed up the overlying rock, forming an asymmetric fold.

Surface evidences include: 1) a fold which has deformed Tertiary rocks as young as the Moroni Formation, 2) thinning of the Tertiary Formations, 3) small fingers of "intruded" Arapien Shale in the Twin Creek Limestone, 4) a possible intrusion cutting beds as young as the Colton Formation a few hundred feet to the east, and 5) regional relationships.

In examining outcrops in the field I found that there is evidence supporting Witkind's proposed diapir but that the evidence can be interpreted in more than one way. I made several independent assessments of bedding attitudes on both sides of the fold and agree with Witkind's measured bedding attitudes and mapping of this feature.

In addition to the fold itself, Witkind (page 13) describes "striking westward thinning of sedimentary strata toward the fold's axis" as evidence of diapiric uplift during the period of deposition of the sedimentary units. He sites figure 5 of Young, (1976) (my figure 4) as evidence. I question whether the thinning of Tertiary units is related to the fold as Witkind implies. Young's figure only extends as far westward as the east flank of the Thistle fold. The west flank is not shown. There is westward thinning as shown by Young, however Young shows that the thinning occurs continuously over six or more miles (10 km) which does not conform to the size of Witkind's suggested diapiric fold. Young's cross sections A-A' and B-B' (figure 5) suggest that the thinning is a regional phenomena related to the early Tertiary location of the basin margin. Local fluctuations appear to be related to erosionally resistant topographic highs.

If Witkind's interpretation is correct one would expect the Tertiary sedimentary units to thicken westward from the Thistle fold. This does not appear to be the case. Pinnell (1972, plate 4) (figure 6) constructed a fence diagram of stratigraphic sections which crosses the Thistle area. He does not show significant thinning of the Flagstaff Formation in the Thistle area. The North Horn does thin in that area, however, the most pronounced thinning occurs farther east (between Pinnell's columns 3 and 6 of plate 4), too far east to have been caused by the proposed fold. Metter (1955), who mapped from Thistle westward, did not measure the North Horn Formation but stated that, "the thickness of the Flagstaff Formation ranges from a few feet in the feather edges of the unit lapping against the southwestern slope of Loafer Mountain and the eastern slope of Dry Mountain to about 350 feet north of Crab Creek." Crab Creek is shown on Witkind's map and is located near Thistle. This would suggest that the Flagstaff Formation thickens toward the Thistle fold instead of thinning. Combining Metter, Young and Pinnell's work, there is a continued general thinning toward the west of all Tertiary units. Thus depositional thickness seems to be controlled by the regional basin configuration rather than local diapiric uplift.

In the eastern part of his cross section B-B' (my figure 2B) Witkind shows the Flagstaff as deposited directly on the Arapien Shale. This differs from his earlier map (Witkind and Page, 1983) and is based on an exposure near the east portal of the railroad tunnels in the SE 1/4, section 28 (I.J. Witkind, personal commun., 1986). There the Flagstaff is deposited on rock of questionable identity which Witkind believes may be Arapien. However I believe this rock is North Horn Formation as indicated on Witkind's earlier map and the map by Baker (1976) (figure 7) (Baker uses the term "Price River Formation" but indicates in his text that the upper part of the Price River may be equivalent to the North Horn Formation). This question could probably be resolved with a palynology study of the outcrop. If the Flagstaff was deposited directly on the Arapien Shale then the Arapien must have been high enough to protrude through the North Horn at the time of deposition of the Flagstaff. If the Arapien Shale protruded through the North Horn Formation at the time of deposition of the Flagstaff Formation, it likely did so because of diapirism since rock of the Arapien Shale is not resistant enough to remain high through all of North Horn time.

Witkind also sites fingers or wedges of Arapien Shale in the Twin Creek Limestone as evidence of his diapiric model. The best example of these is shown in a photograph in Witkind's report (figure 8A). The outcrop in the photograph was subsequently destroyed by highway construction. The exposure is only a short distance from the proper stratigraphic position of the Arapien Shale. The wedges of Arapien could have been forced into this position during Cretaceous thrusting or by later small-scale diapirism of the overlying mass. In another possibility, the wedge-shaped mass in the photograph may be from the Twin Creek itself rather than the Arapien. Thus I believe this evidence is inconclusive, not supporting any theory.

Near the Thistle Canyon fault(?) Witkind shows another possible diapiric mass of Arapien Shale (figure 8B). The outcrop was altered by subsequent widening of the roadcut since this photograph was taken but the principle features are still present. I do not believe this is a diapiric mass. The proposed intrusive mass occurs at the top of the Twin Creek Limestone and is either the uppermost member of the Twin Creek (Watton Canyon member) or the lower part of the Arapien Shale. The mass is not significantly deformed. The deformation that does occur can be explained by Cretaceous thrusting or by later movement from a fault that occurs in the right part of the photograph. In either case the mass is in its proper stratigraphic position and does not require diapirism or any other structural event to explain its presence.

Witkind shows on his map (figure 1) a diapiric feature located east of the "Billies Mountain" road cut which has its top exposed at the surface. Witkind (1986, p. 10) gives two interpretations of this feature: "(1) the mass of disturbed Arapien may be strata [from the underlying thrust plate] that punched up through Arapien beds that were part of the [Charleston-Nebo] plate, or (2) they may be integral elements of the Arapien within the [Charleston-Nebo] thrust plate that became mobile and then deformed the overlying strata." Witkind prefers the first interpretation, believing that it better fits his model. He connects the diapir with the larger proposed diapir in the subsurface (figure 2B). I prefer the second option since it only requires minor remobilization of immediately underlying strata instead of rock from several thousand feet below the surface. I have adapted and expanded Witkind's cross section to show my view (figure 9).

Although I question the larger Thistle Creek diapir, I believe a smaller diapir may be present a few hundred feet to the east where conditions are good for small-scale diapirism (figure 9). It involves outcrops of Arapien that are in their proper stratigraphic position and that are tilted to a high angle, such that diapiric material needed only to move a short vertical distance to intrude the overlying rock. The Arapien is internally deformed at this locality, supporting this theory. I do not believe this smaller diapir is connected at depth or related to the larger proposed diapir as suggested by Witkind (figure 2B). Importantly, it is located well east of the proposed dam site.

Thistle structures considered in light of the regional geology lend support for diapirism but again leave other interpretations open. Diapirism has been a controversial topic in central Utah since first proposed by Stokes (1952). Recent studies continue to reflect that controversy (Standlee, 1982; Willis, 1984; 1986). Witkind has been the leading proponent of diapirism (1982; 1983; 1986). The consensus among many workers in central Utah is that diapirism has been a structural agent in creating features observed today but many features are probably due to other causes (L.A. Standlee, personal commun., 1984; Lawton, 1985; D.A. Sprinkel, personal commun., 1986).

Witkind suggests the presence of the fold itself as a possible evidence of diapirism. It should be remembered that folds are common features in this part of the Wasatch area and many are probably not caused by diapirism. One other cause of folding is related to the Wasatch Fault which is located a few miles to the west. Since movement on the Wasatch fault is probably segmented and the fault is arcuate, the fault movement could produce numerous folds well to the east of the fault itself (Wheeler, 1984).

Mudstone versus Evaporites

Another important consideration is the composition of the possible diapiric material. One of Witkind's photographs is particularly significant (figure 8A). Although the outcrop shown is now destroyed, the intruded(?) material appears to be mudstone or limestone and not gypsum. In other places in central Utah the diapiric material is probably primarily mudstone while evaporites are a minor constituent of the mudstone. Witkind on the other hand believes that evaporites are the primariy diapiric unit and that mudstone only forms a passive sheath (Witkind, 1982). I believe this question would be of particular significance from an engineering standpoint.

Amplitude of the Fold

Witkind (p. 11) postulates an amplitude for the possible diapiric fold of about 1200 feet (365 m) (figure 2B). This is based on the elevation of the Flagstaff west of the fold (6500 feet, 1950 m) and a block of Flagstaff a few hundred feet long east of the fold axis near the east railroad portal (5300 feet, 1590 m). However the Flagstaff near the tunnel is dropped down from

Flagstaff located farther east. Less deformed Flagstaff a few hundred feet to the east occurs at an elevation of about 6000 feet (1800 m). If the fold is projected between the less deformed Flagstaff strata, it permits a fold with an amplitude of only about 500 feet (150 m) which is more symmetric. Figure 9 shows this interpretation. It is probable that the lower Flagstaff block is dropped down by a fault on the east as shown by Baker (1976) and/or by sag due to the Thistle Canyon fault(?) located just to the west. If the Thistle Canyon fault(?) is imbricate in the subsurface then sag would be a likely result. It may also be due to differential movement of the previously discussed smaller diapir. If the fold is more symmetric and has a smaller amplitude, as I propose, it would imply much less diapiric uplift than proposed by Witkind.

Charleston-Nebo Thrust

The position of the Charleston-Nebo thrust fault is important in the study of this issue. A comparison of Witkind's cross section A-A' (inset on figure 1) and Baker's cross section C-C' (figure 10), which is projected from about 9 miles (14 km) to the north, illustrates some significant differences. Witkind places the thrust fault in the subsurface at about 3000 feet (900 m) elevation (about 2000 feet, 600 m below the surface) with allochthonous Navajo Sandstone over autochthonous Arapien Shale.

Baker (1976) shows a significantly different interpretation (my figure 10). He places the thrust much deeper in the subsurface at an elevation of about 1000 feet (300 m) (on Baker's cross section Red Mountain is approximately on strike with Thistle, however, the Diamond Fork Anticline is not the same fold as that discussed by Witkind). Baker does not indicate what rocks underlie the thrust fault in the Thistle area.

I believe Baker's cross section is more correct in that the thrust fault occurs at an elevation of 0 to 1000 feet (0-300 m). I have adapted Witkind's cross section to indicate my view on the position of the thrust plate (figure 9).
Seismic and drill hole evidence suggests that the thrust is deeper than indicated by Witkind (D. A. Sprinkel, 1986, personal communication). The thrust fault is probably underlain by Arapien Shale as indicated by Witkind. If my interpretation is correct then any Arapien underlying the Navajo Sandstone is much deeper than indicated by Witkind in his cross section B-B' (figure 2B). Thus if the diapir is present, I believe it would also be much deeper.

Displaced Navajo Sandstone

In his cross section B-B' Witkind shows large amounts of Navajo Sandstone and Twin Creek Limestone to be displaced or replaced by Arapien Shale (figure 2B). I do not believe this is a likely relationship. At the surface the Navajo and Twin Creek are in their proper stratigraphic positions and, although fractured, they are not significantly deformed. Thus, if large amounts of these formations have been displaced in the subsurface, they must have been pushed out horizontally. I do not believe this is possible for diapirism which is controlled by gravity and is primarily a vertically directed force. Even if the Charleston-Nebo thrust fault is immediately below the line of his cross section it would still require the unlikely horizontal displacement of large masses of Navajo Sandstone. In addition, seismic and drill data suggest that the thrust is much deeper. Thus diapirism may have bowed up the overlying rock but not "forced rock out" horizontally (figure 9).

Differences in Cross Sections

A significant difference exists between Witkind's cross sections A-A' and B-B' although they occur along strike from each other and are only about 3 miles (5 km) apart (see figure 11). In A-A' he shows a large fold in the Navajo Sandstone so that bedding between the Navajo and the North Horn becomes parallel in the west part of the section. In B-B' he does not show a fold so that the Navajo and adjacent beds are truncated at a high angle by the North Horn Formation. I believe the surface evidence supports B-B'.

INTERPRETATIONS AND CONCLUSIONS

In general I found that the surface geology in the Thistle area is much the way Witkind described it. Diapirism is one explanation for the surface features but there are other possible explanations. I have attempted to point out alternatives to the model proposed by Witkind and alternative explanations for the evidence he presents.

Thistle Canyon Fault

Surface evidence, primarily the "Billies Mountain" roadcut, indicates that the Thistle Canyon fault(?) does exist. However, because of the possible connection to diapirism, the subsurface configuration of the fault cannot be determined from surface evidence. The fault may be the limb of an asymmetric diapiric fold that has attenuated to the point of developing some fault movement or it may be completely unrelated to diapirism. I believe a study of the subsurface geology will be necessary to determine the nature of the fault. The fault question is an appendage of the diapirism question and would probably be resolved by a study of the diapirism.

Thistle Creek Diapir

Although the Thistle Creek fold is definitely present, I question its relationship to diapirism. I believe that the base of the Charleston-Nebo plate is deeper in the subsurface than indicated by Witkind and that the diapir, if present, is a bulge beneath the thrust rather than an intrusive feature. I have indicated in the report other factors described by Witkind that I believe are open to interpretation. These include the presence and size of the fold itself, the thinning of Tertiary units, the amount of evaporite rocks in the Arapien Shale, and constraints on displaced Navajo Sandstone and related rocks in the subsurface. Thus I believe the diapir as proposed by Witkind is questionable and further study should be conducted; primarily of subsurface relationships.

I believe the diapir is much smaller and deeper in the subsurface than Wikind proposed and possibly may not be present at all. However I believe we must continue to be concerned about his proposed hazards until further information can be obtained. Emphasis should be placed on determining what lies in the subsurface beneath the Navajo Sandstone and the Twin Creek Limestone in the area that Witkind suggests contains diapiric material (see figure 2B). I believe there is a normal stratigraphic sequence beneath the

Navajo and Twin Creek with no diapiric material down to an elevation of 0 to 1000 feet (0-300 m), the probable elevation of the Charleston-Nebo thrust fault. If the diapir is that deep it is of much less concern. The best way to obtain conclusive information would be to drill several holes including one to a depth of at least 5000 feet (1500 m). This would be costly, so I first recommend other less expensive steps.

Summary of potential hazards

I interpret the geologic hazards postulated by Witkind, the Thistle Canyon fault(?) and the Thistle Creek diapir, to present the following concerns in designing and constructing the proposed dam at the Thistle site:

-the fault(?) might provide a conduit for subsurface seepage of an overlying body of water;

-seepage might lead to piping, subterraneous erosion, or development of springs in undesirable locations beneath and downstream from the dam;

-the fault(?) may be reactivated through water seepage into the fault plane;

-if the diapir as proposed by Witkind is actively rising, it could disrupt dam fill over a period of time;

-a change in ground-water characteristics caused by the reservoir might cause dissolution of the evaporites and result in subsidence or collapse of the overlying rock and dam fill;

-an overlying body of water might upset the isostatic balance and increase or renew diapirism;

-it raises doubt as to the stability of the rock foundation on which the dam might be built.

Recommendations

In order to evaluate the above concerns, the configuration and age of these geologic structures should be fully determined. A plan can then be developed to compensate for whatever influence, if any, these structures will have on the proposed dam and reservoir and an investigation made to determine if they present any concerns not listed here.

I recommend the following steps be taken in the order listed:

-Dig several "backhoe" trenches across the possible fault. Five localities are proposed here and are shown on figure 1. One trench would attempt to expose the fault in the Moroni Formation in the south end of the area; one would attempt to expose it in bedrock between the Flagstaff or North Horn Formation and the Navajo Sandstone; and three of the trenches would attempt to determine if the fault has cut any surficial deposits. If the fault is related to diapirism this could aid in determining if there has been any recent diapiric movement. It is realized that the trenches may prove unproductive because of the lack of stratified sediments, wrong interpretation of the fault location, water problems or other reasons.

-Attempt to obtain seismic information from petroleum companies who have run lines in the area.

-Run a shallow seismic refraction profile across the fold along the floor of the canyon.

-Conduct a gravity study across the fold along the floor of the canyon.

-Carefully measure the thickness of Tertiary rocks on both sides of the fold for several miles to determine if depositional thinning has occurred. This would probably require extensive field work since exposures are poor.

-The following two steps are less certain but may yield beneficial results.

> -attempt to measure the elevation of Lake Bonneville shorelines in the area to determine if they have been deformed;
>
> -make a careful study of joint patterns across the fold to aid in the determination of deformational forces. This would be done by a geologist who specializes in the interpretation of stress and strain through the study of structural joint patterns.

-If additional investigation is deemed necessary, I suggest drilling up to four deep holes in the bottom of the canyon through the Navajo Sandstone and Twin Creek Limestone. Recommended locations are shown on figure 1. Based on Witkind's cross section B-B' the holes would need to penetrate between 1000 and 2000 feet (300-600 m) of rock (figure 2B). However, if my cross section is more accurate then it would require drilling about 5000 feet (1500 m) (figure 9). The eastern-most hole would also aid in evaluating the subsurface configuration of the Thistle Canyon fault(?).

-Drill numerous shallow holes in the area of the dam site to determine suitability of the dam foundation. Most should be cored.

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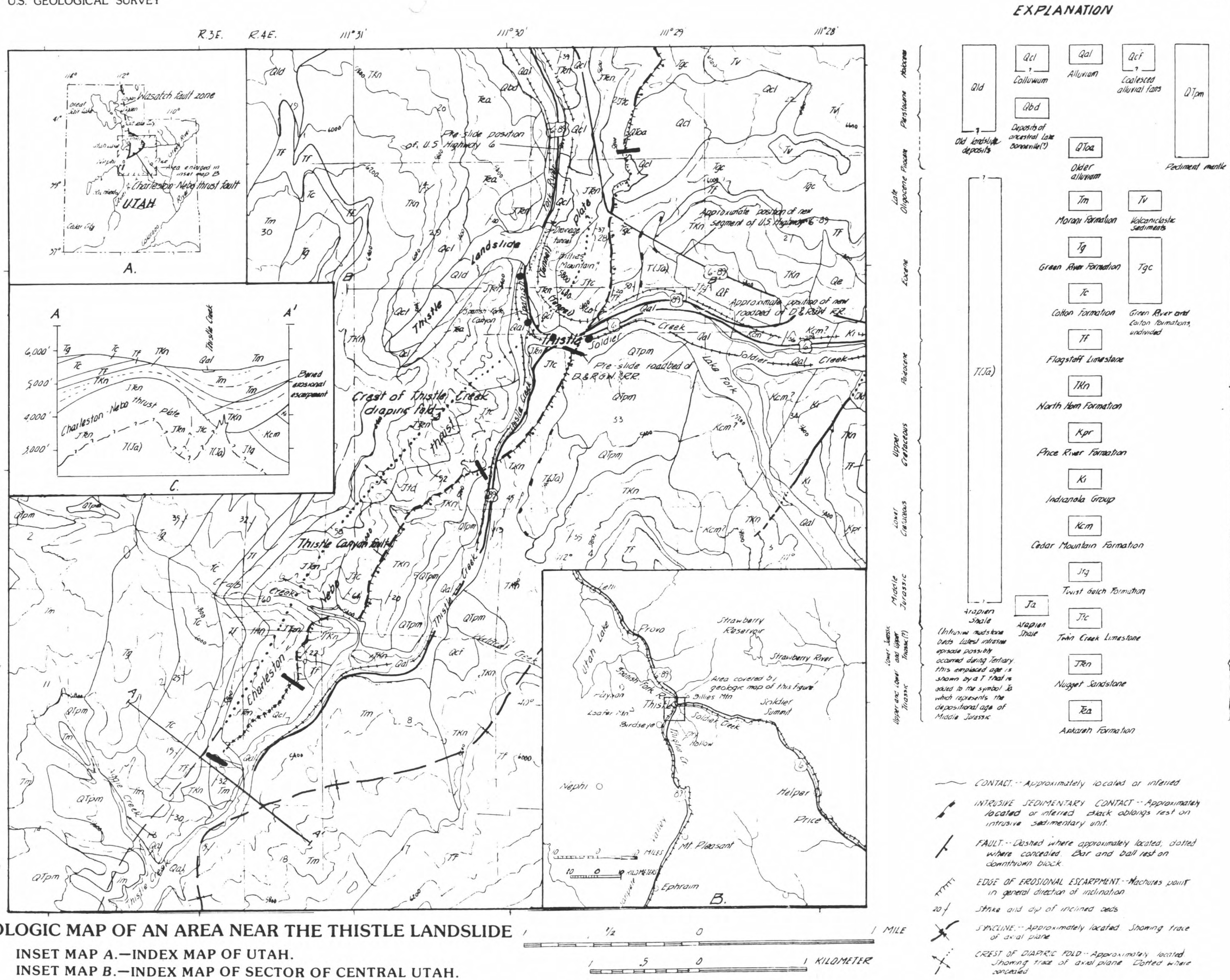
FIGURES



GEOLOGIC MAP OF AN AREA NEAR THE THISTLE LANDSLIDE

INSET MAP *A*.—INDEX MAP OF UTAH.
INSET MAP *B*.—INDEX MAP OF SECTOR OF CENTRAL UTAH.
INSET MAP *C*.—CROSS SECTION *A-A'*.

Figure 1. Witkind's (1986) Plate I with index map of the Thistle landslide area, geologic map, and cross section A-A'. I have added the proposed trench locations to explore the Thistle Canyon fault(?) and proposed drill holes to investigate the questioned Thistle Creek diapir.
- ● proposed investigative drill holes
- ▌ proposed investigative trenches

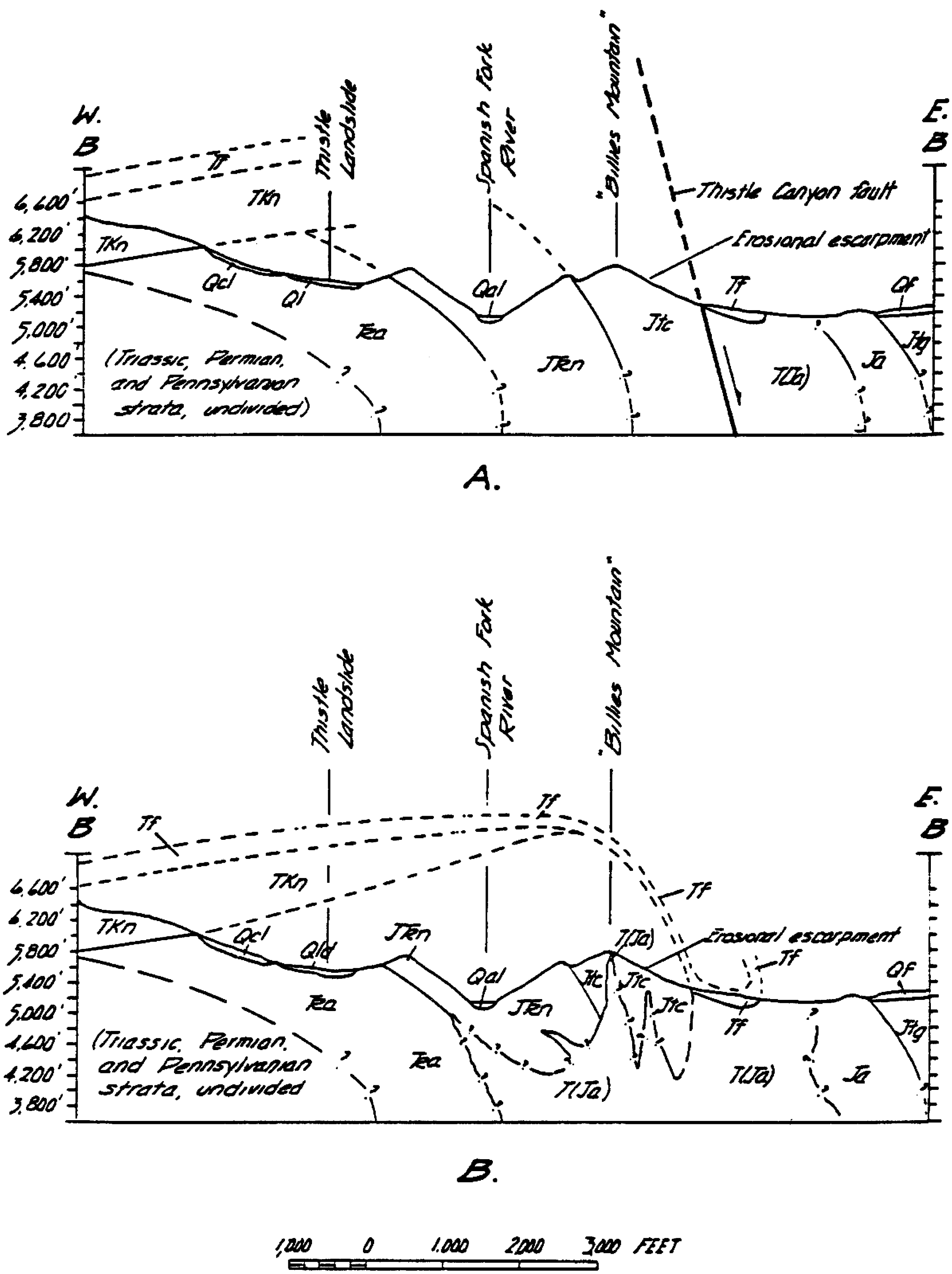


Figure 2. Witkind's (1986) figures 3A and 3B showing two possible interpretations of cross section B-B' shown on figure 1. Witkind prefers option B.

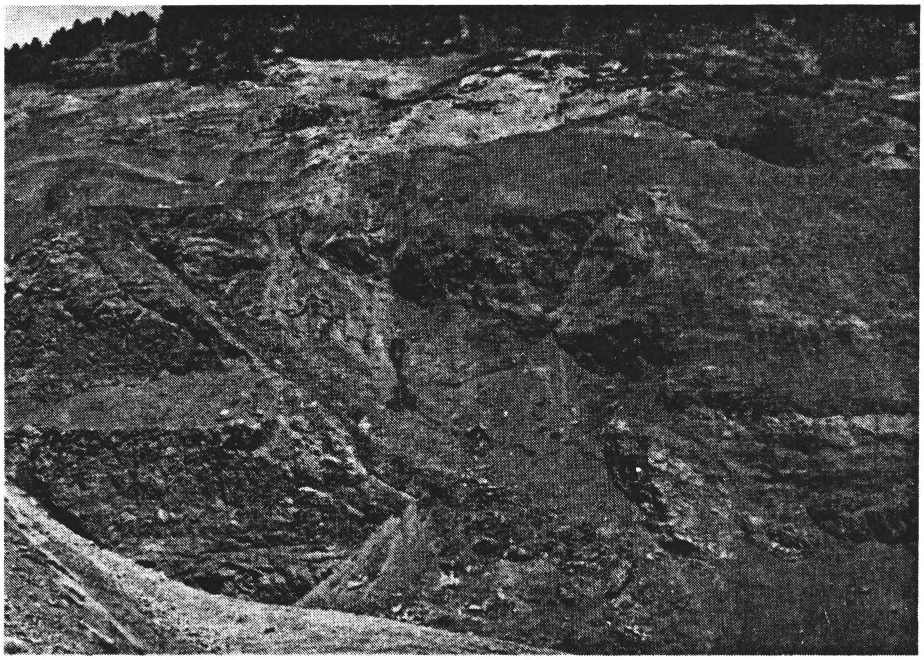


Figure 3. Photograph of the north side of U.S. highway 6, 89 roadcut through "Billies Mountain" showing the Thistle Canyon fault(?). The fault dips east about 40-45° and follows bedding of the Twin Creek Limestone exposed in the left half of photograph. The Colton Formation, exposed east of the fault, is generally horizontal but is intensely deformed and brecciated. Slickensides are common in the Tertiary rock. A zone about 5-10 feet (1.5-3 m) wide of intensely foliated clay occurs along the fault contact.

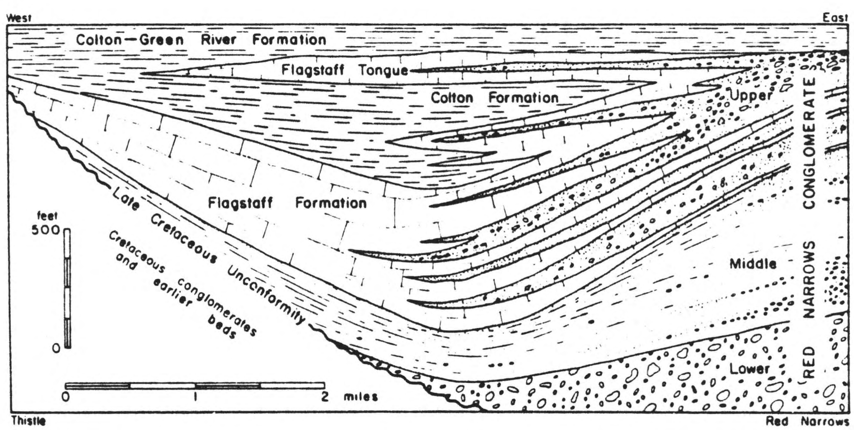


Figure 4. Figure 5 of Young (1976) showing a stratigraphic cross section extending east from the Thistle area. Thistle occurs along the left margin. Witkind (1986) cites this figure as evidence of depositional thinning over his proposed Thistle Canyon diapir. I believe the thinning is regional and not related to the questioned diapiric fold.

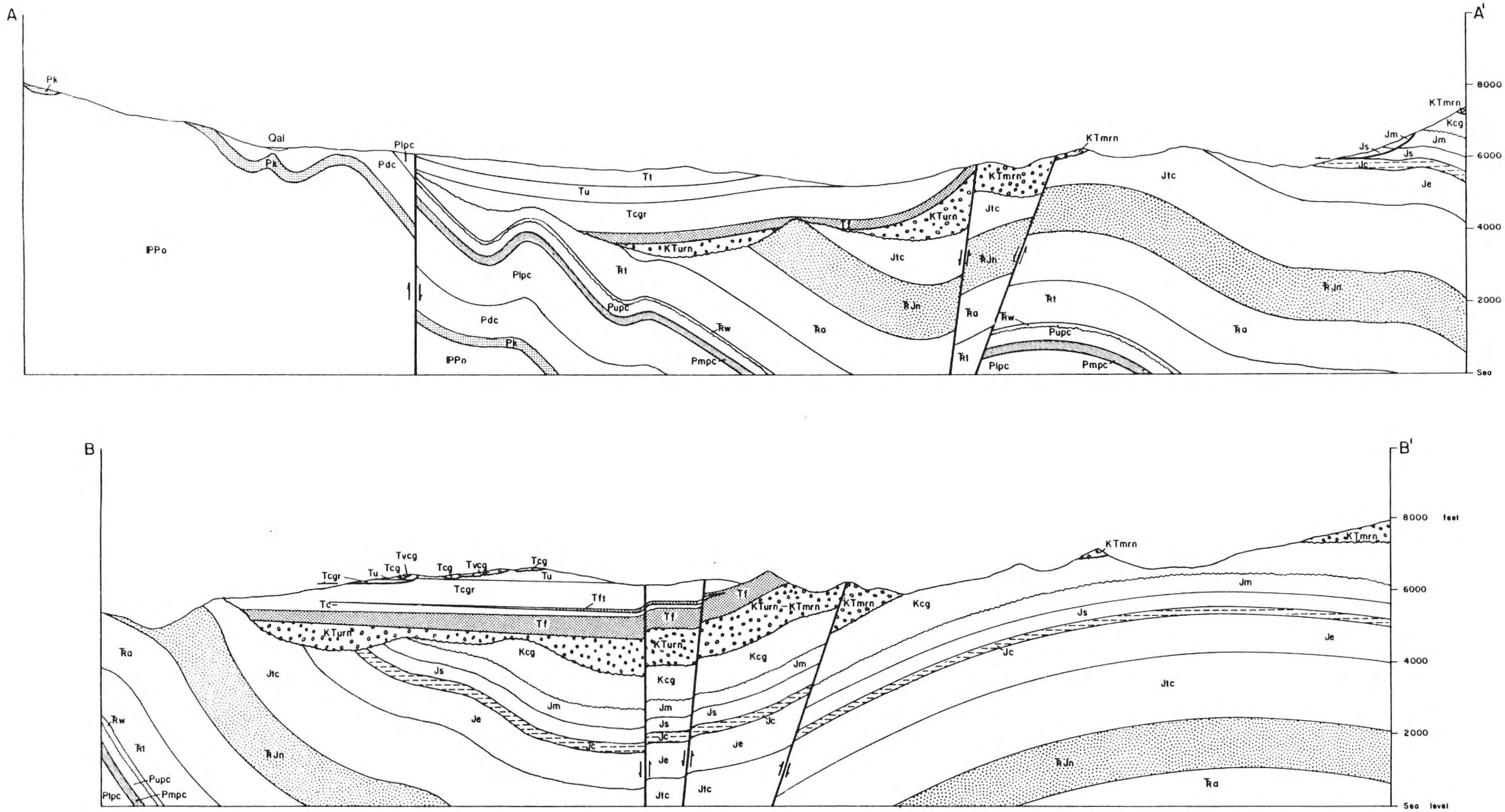


Figure 5. Cross sections A-A' and B-B' of Young (1976). The left margin of B-B', which is oriented east-west, is located about 1/2 mile (0.8 km) north of Thistle. A-A' is located farther north and is approximately parallel. Young's interpretation of depositional thinning over ancient erosionally resistant topographic highs is well illustrated. X marks the approximate position along strike of the Thistle site.

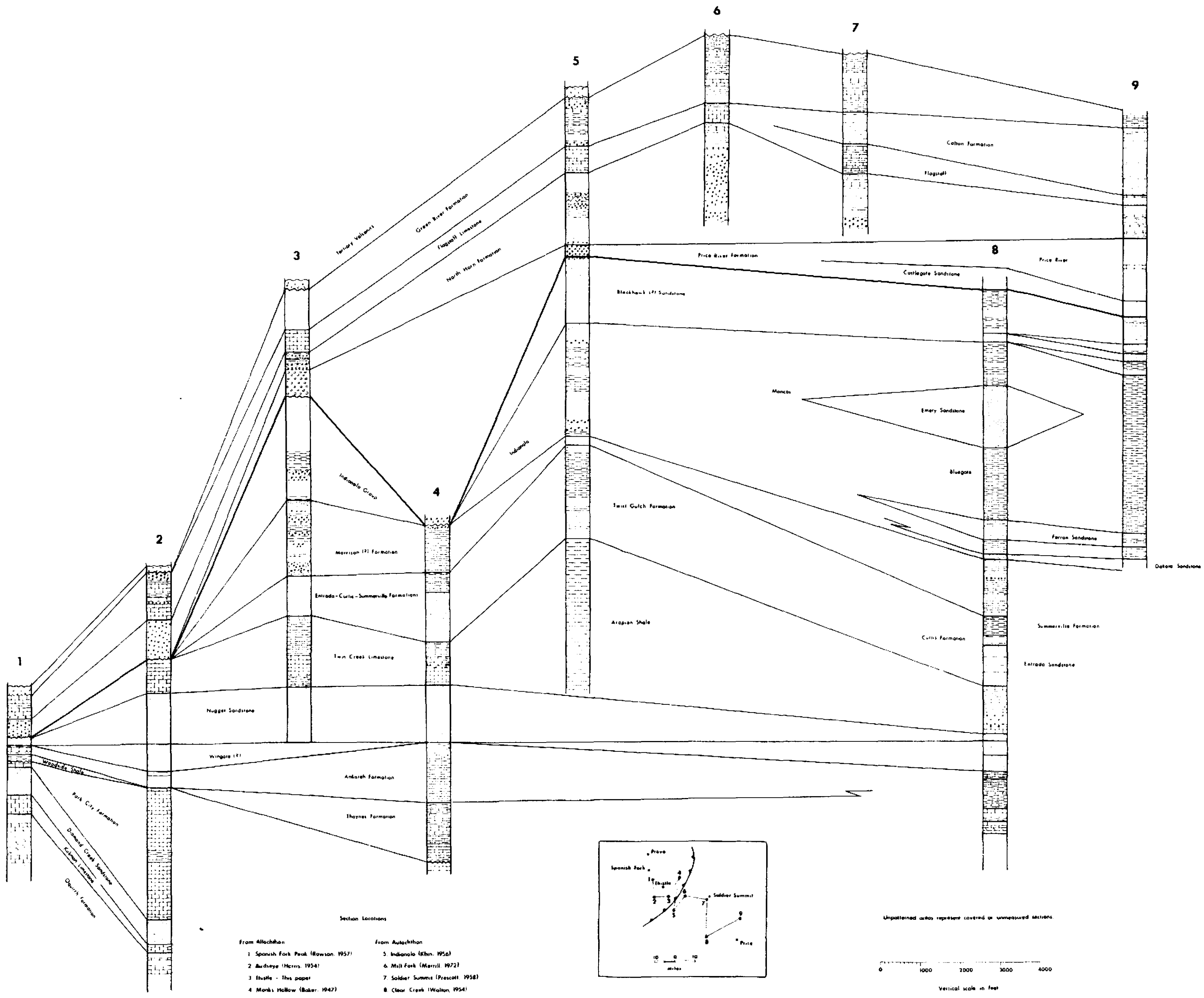


Figure 6. Pinnell's (1972) plate 4 of a fence diagram constructed across the Thistle area. The inset map in the lower part shows the location of Thistle relative to the diagram. Columns 2 and 3 are located closest to Thistle. Note the lack of any noticable thinning of the Flagstaff in the Thistle area, in fact it is thicker in the area of column 2. The North Horn shows some thinning but it is regional and does not appear to be related to the questioned diapir.

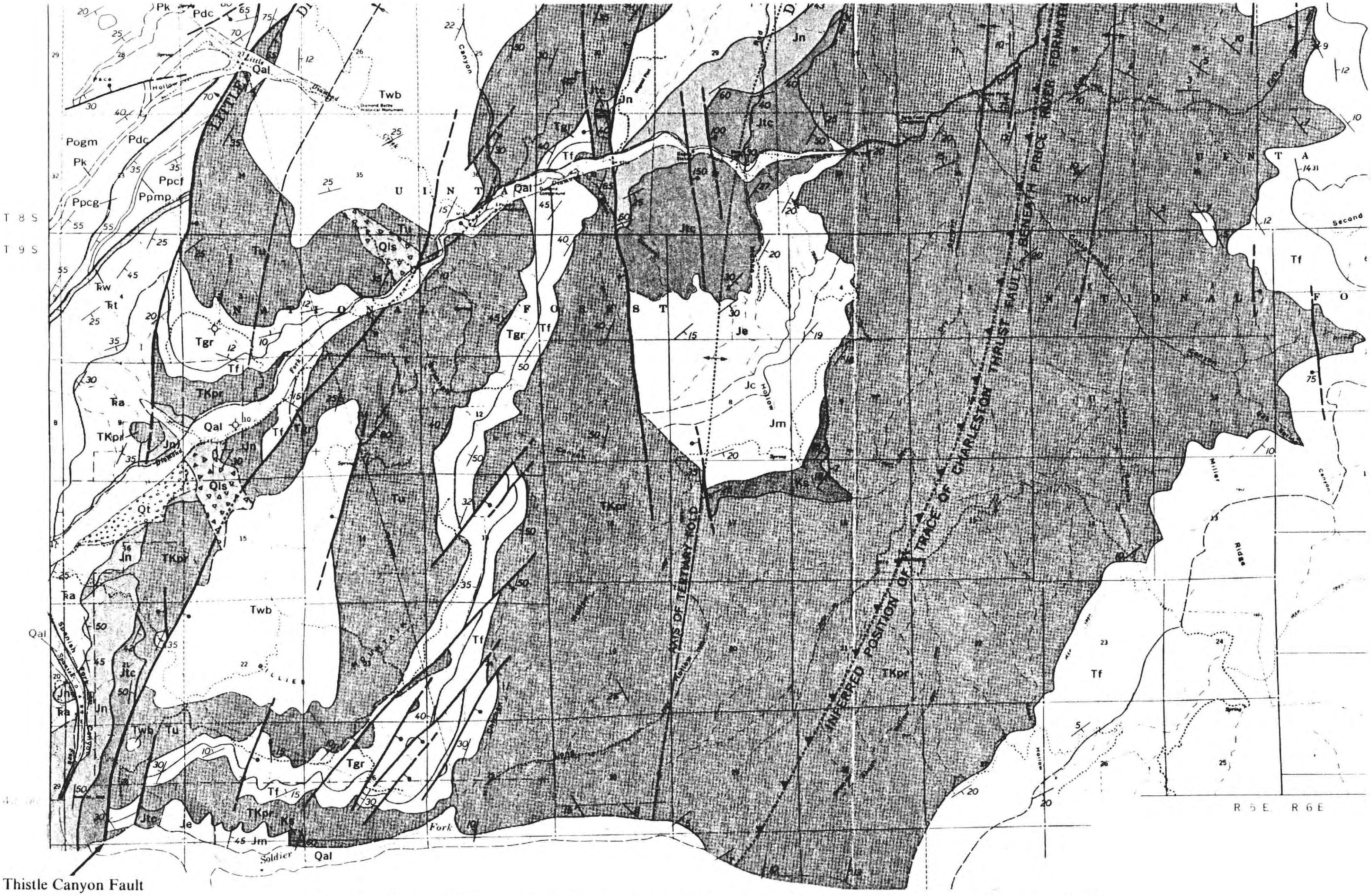
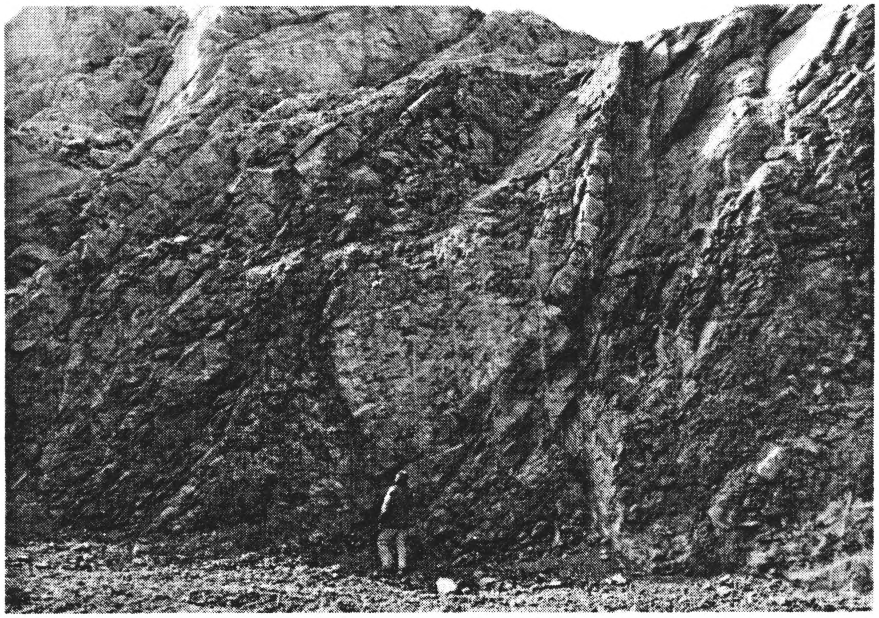
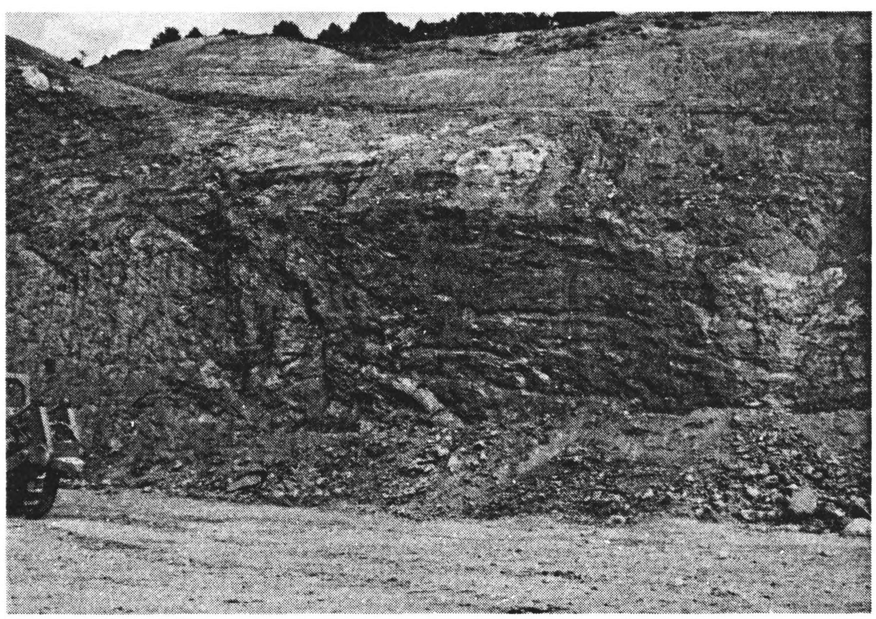


Figure 7. Part of the geologic map of the west half of the Strawberry Valley quadrangle by Baker (1976) which includes the northeast part of the Thistle area. Thistle is located just off the SW corner of the map. The northern part of the Thistle Canyon fault(?) is indicated by an arrow. Note the down-dropped block of Tertiary rock located between the Thistle Canyon fault(?) and an adjacent fault.



A



B

Figure 8. Witkind's (1986) figures 2C (A) and 2D (B) showing features he believes are diapiric. Note that the possible diapiric material appears to be limestone or mudstone in (A). I believe the feature in (B) is due to a fault and is not diapiric.

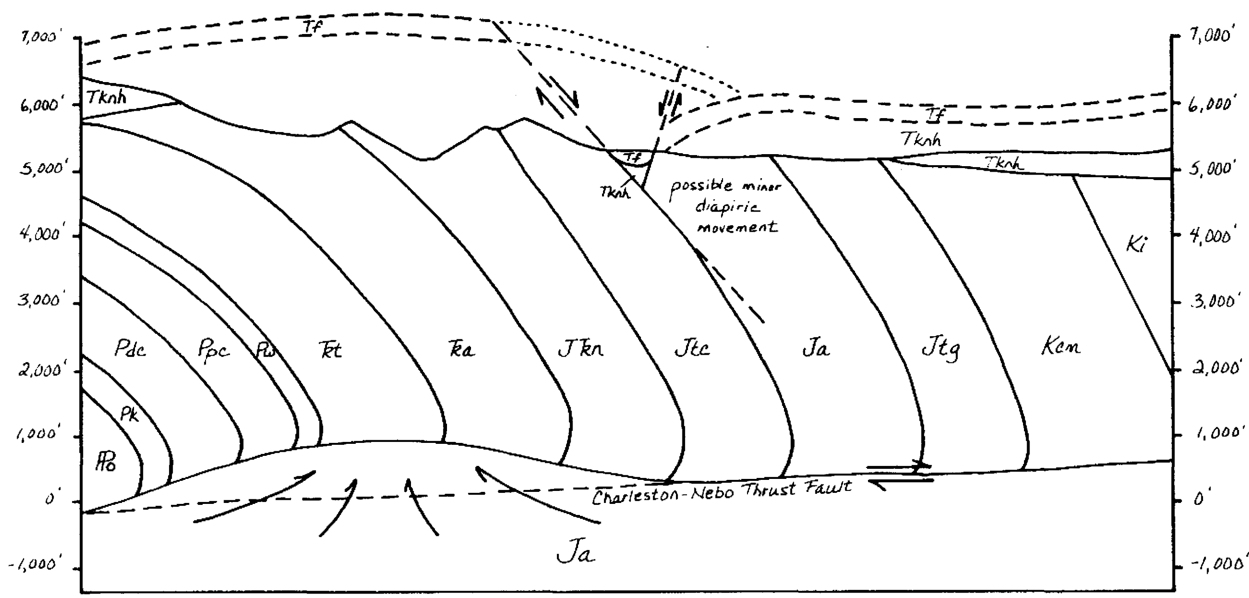


Figure 9. Cross section, expanded and adapted from Witkind's (1986) cross sections A-A'and B-B' (my figure 2), showing my interpretation of the structure through the Thistle area. Surficial deposits are not shown. Note the location of the Charleston-Nebo thrust near sea level, the faults used to explain the down-dropped Tertiary rock and the much smaller amplitude restored fold (projected through the air). If there is a diapir present in the subsurface I believe it would be a small feature that does not intrude overlying rock but rather bulges it up.

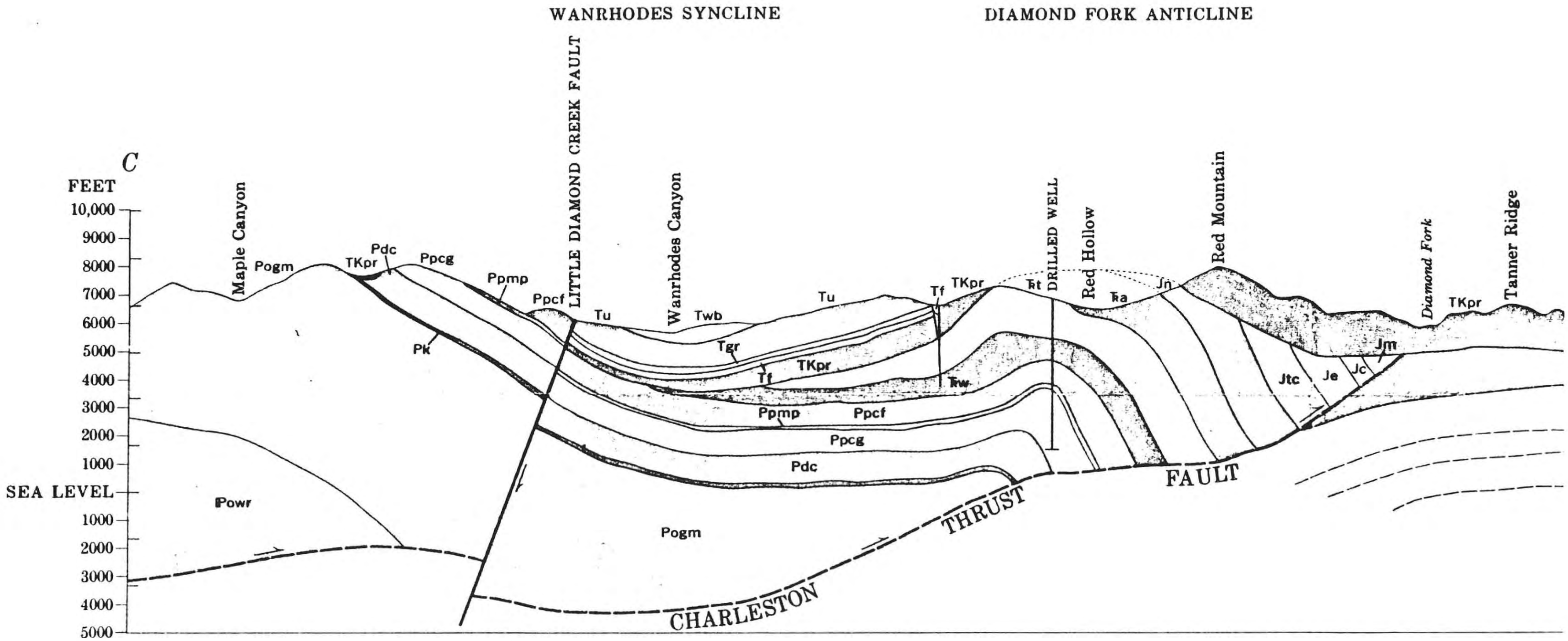


Figure 10. Part of Baker's (1976) cross section located about 9 miles (14 km) north of the Thistle area. The Mesozoic rocks near Red Mountain are approximately on strike with the Thistle area, however, the Diamond Fork anticline is not the same fold as the possible Thistle Creek diapir. Note the location of the Charleston-Nebo thrust in the subsurface. Compare with my interpretation (figure 9) and Witkind's interpretation (figure 2B).

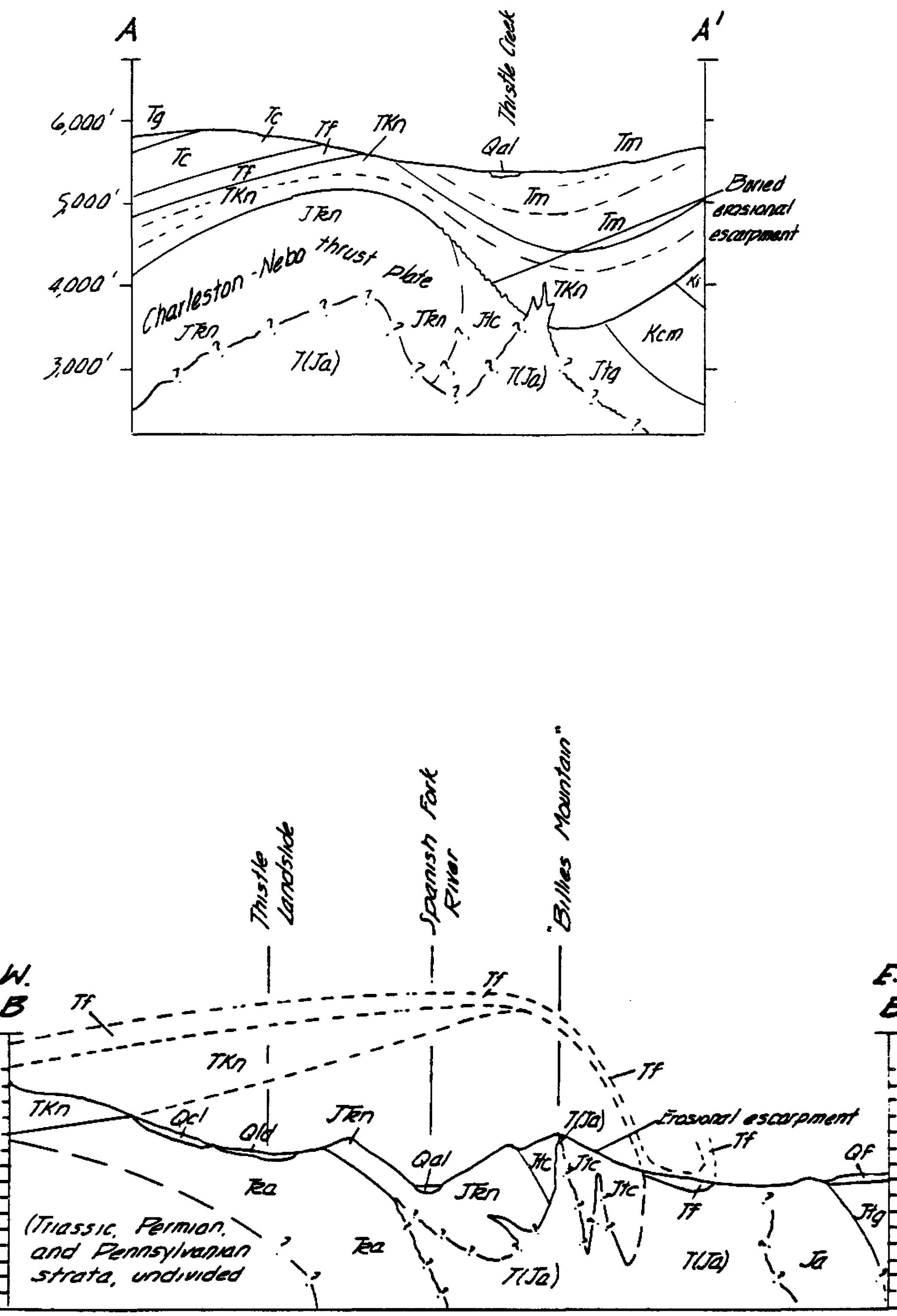


Figure 11. A repeat of parts of figures 1 and 2 in which copies of Witkind's cross section A-A' (from his plate I) and cross section B-B' (from his figure 3B) are shown together for comparison. Note the difference in the attitude of the Mesozoic rocks in the subsurface, particularly the Navajo Sandstone (JTrn).