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# Cenozoic structural history of selected areas in the eastern Great Basin, Nevada-Utah

by

R. Ernest Anderson

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CONTENTS

## ABSTRACT

The Confusion Range structural trough (CRST) of west-central Utah predates the Oligocene rocks that are exposed along it. The northern part of the axial region of the CRST is complicated by structures that include reverse faults and associated folds, a large-amplitude mushroom fold, and belts of sharply flexed to overturned strata some of which are fault bounded. These structures, which also predate the Oligocene rocks, formed in a compressional regime that has been interpreted as resulting from thin-skinned gravitational gliding toward the axis of the CRST.

Study of the sparse Tertiary rocks that are scattered along the axial region of the CRST reveals abundant evidence of Oligocene and younger deformation. The chief evidence includes (1) widespread Oligocene and Miocene coarse clastic rocks, many of which are conglomerates, that attest to local and distant tectonism, (2) faults that range from high-angle structures generally with less than 100 m of normal displacement to low-angle attenuation faults some of which may have large displacements, and (3) open asymmetric folds. Together with the distribution of sheet-form bodies of ash-flow tuffs, the Oligocene stratigraphic record allows for paleogeographic reconstruction of a lacustrine basin across what is now the northern Confusion Range and one or more basins in the southern part of the CRST. The basins are inferred to have been fault controlled by reactivation of previously formed faults or steep fold flanks. They may have been localized by differential vertical movements similar to those that produced the older systems of folds and faults. Parts of early formed basins were cannibalized as local syndepositional deformation took place in the axial region of the CRST.

Both limbs of the CRST have been modified by folds that involve Oligocene rocks. Some of these folds appear to be genetically related to displacements on faults that bound them. They may record thin-skinned Neogene tectonic displacements toward the axis of the CRST.

The most intensely faulted and tilted rocks along the axis of the CRST are located in the Tunnel Spring Mountains where Miocene(?) extension on closely spaced listric faults produced as much as 70 percent extension locally. Three episodes of Oligocene-Miocene deformation, all interpreted to have formed in an extensional environment, are recognized in the Tunnel Spring Mountains. The nearby Burbank Hills area may have been involved in the same deformational episodes, though there the relationships are not as clear-cut nor does evidence occur of extreme extension. Tight asymmetric folds in the Burbank Hills are interpreted as drape structures formed over buried normal faults. Other structures along the southern CRST have fold-like forms, but they result from cross-strike alternations in fault-related tilt directions, and they formed in an extensional stress regime. Least-principal stress directions inferred from orientations of extensional structures vary from ENE-WSW in the southern Tunnel Spring Mountains to approximately E-W in the Disappointment Hills and NW-SE in selected areas east of the axis of the CRST. The size, geographic distribution, and new data on the age of areas of major extensional faulting preclude previously published interpretations that the extension is related to major east-directed overthrusting of the Sevier orogeny in areas east of the hinterland of west-central Utah.

Cenozoic extensional deformation in broad areas to the east and west of the CRST is apparently characterized by major displacement of hanging-wall blocks toward the axis of the CRST. Two major structures (the Snake Range decollement and the Sevier Desert detachment fault) face toward the axis and accomodated major Cenozoic extension above them. Neogene displacement on common steep- to moderate-dipping normal faults along the axis of the CRST and on a system of low-angle younger-on-older faults in the Confusion and Conger Ranges record important extensional deformation that may be coeval with and structurally above the extension on the axially vergent, but deeper, Snake Range and Sevier Desert faults. Although Neogene stratal tilting is mild to moderate, the magnitude of extensional deformation in the Conger-Confusion Range area may be as great or greater than that in the highly fault rotated parts of the Tunnel Spring Mountains. This possibility stems from the fact that large but indeterminate displacements may have taken place on faults that cut bedding at low angles.

## INTRODUCTION

A 6,500 $km^2$ area in west-central Utah and adjacent Nevada lacks evidence of late Quaternary faulting such as is found in adjacent areas (Bucknam and others, 1980; Thenhaus and Wentworth, 1982). The area is embedded in a larger area within which there is insignificant earthquake activity in the magnitude range greater than $M_s$ 4 (Arabasz and others, 1980; T. Algermissen and B. Askew, written commun., 1982). Many published geologic maps and cross sections (scales ranging from 1:24:,000 to 1:250,000) of these areas indicate very little evidence of deformation in the past 30 million years or so (Anderson, 1980b). This appearance of long-term structural stability contrasts sharply with that indicated on geologic maps of the surrounding areas. Because of its potential importance to understanding the distribution of young earthquake activity in terms of patterns of older structural history, the evidence for long-term structural stability was evaluated by systematic photogeologic and field geologic studies. Surprisingly, much of the evidence for the long-term structural stability vanished under close scrutiny. Thus, the study succeeded in eliminating the object under study. In its place emerged a fragmentary understanding of the late Cenozoic geologic history of all or parts of the Tunnel Spring Mountains, Burbank Hills, and Conger-Confusion Ranges, Utah, and some minor but potentially important modifications to our understanding of parts of the Schell Creek Range, Nevada, and parts of the House Range and Spor Mountain-Drum Mountains areas, Utah (fig. 1). This report presents the results of those studies. The understanding is fragmentary because (1) exposures of Tertiary rocks are few and far between and, thus, the Tertiary geologic record is fragmentary, and (2) limited time did not allow for detailed studies of many potentially important localities.

Little of value resulted from photogeologic studies because Tertiary rocks in the region are found in widely scattered small areas mainly on the flanks of ranges where exposures are poor. These areas are not well-suited for photogeologic interpretation. They are not ideal for geologic mapping either; but at many localities they display critical evidence pertaining to (1) whether the contact between Tertiary and older rocks (the critical contact) is depositional or faulted, (2) how much, if any, local deformation predates the critical contact, (3) whether clast assemblages in clastic strata

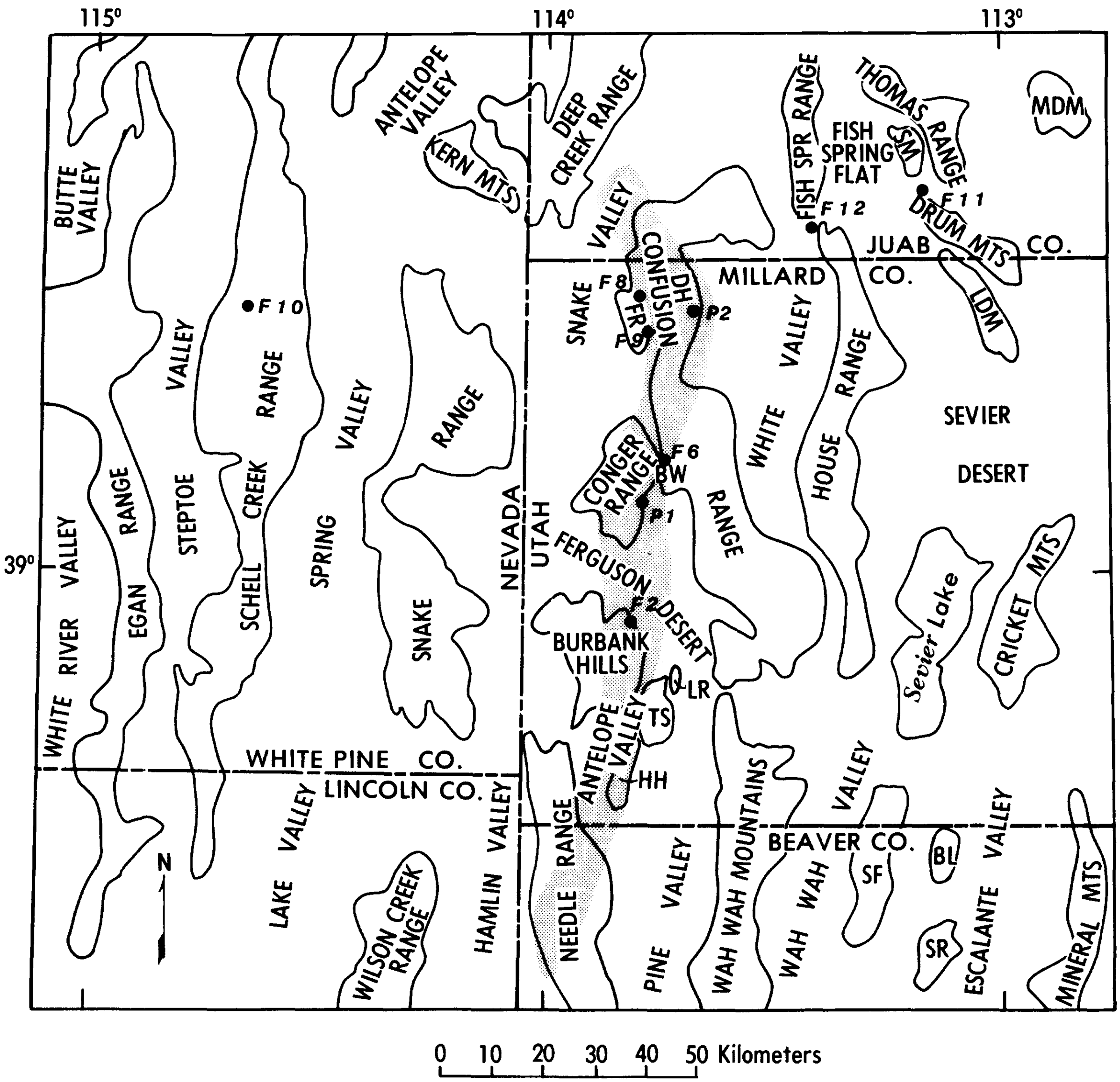



Figure 1.--Index map of west-central Utah and east-central Nevada showing location of major physiographic features, the trace of the Confusion Range structural trough (patterned), and the approximate location of figures and plates (indicated by labeled dots). SM, Spor Mountain; MDM, McDowell Mountains; LDM, Little Drum Mountains; FR, Foote Range; DH, Disappointment Hills; BW, Browns Wash; LR, Little Rough Range; TS, Tunnel Spring Mountains; HH, Halfway Hills; SF, San Francisco Mountains; BL, Beaver Lake Mountains; and SR, Star Range.

are derived from existing or previously destroyed adjacent highlands or from distant sources, and (4) whether the rocks represent geographically restricted or widespread sheet-form deposits. Such evidence is needed to piece together a regional picture from fragmentary data. In general, the evidence points to an eventful late Cenozoic structural history that locally includes several episodes of major structural disturbance.

Throughout much of the House Range and most of the southeastern Confusion Range and northern Wah Wah Mountains (fig. 1) exposed mid Tertiary rocks are undeformed or only slightly tilted and faulted. Paleozoic rocks in large parts of those areas show evidence of gentle tilting and erosional beveling prior to deposition of the oldest Tertiary strata (Hintze, 1974a, b, c, d, 1980a). The pre-Tertiary paleotopography was mostly gentle, but severe paleotopography is well known from localities such as Crystal Peak in the Wah Wah Mountains, Ibex in the southernmost House Range, Kings Canyon in the central House Range and Mount Laird in the Drum Mountains. The present report is concerned mainly with areas where evidence for Cenozoic faulting and folding can be documented.

I am grateful to J. T. Abbott and Bud Walker for guiding me to exposures in the Sand Pass area, to Lehi Hintze for guiding me to critical exposures in the southernmost Confusion Range, to Tom Fouch for assistance in interpreting the significance of structures and textures in lacustrine limestones from the Toms Knoll and Browns Wash localities, and especially to Bob Bohannon for providing fission-track age data. I received some assistance in the field from my wife, Mary, and brother-in-law Clemont Neilson. The report was improved significantly as a result of reviews provided by Joe Ziony and Dick Hose.

## TUNNEL SPRING MOUNTAINS AND ADJACENT AREAS

A report describing the Cenozoic stuctural history of the Tunnel Spring Mountains including geologic maps and cross sections has been published (Anderson, 1980a), and only a brief summary of the history is included herein. The area was the site of several episodes of deformation since early Oligocene time. Whatever local deformation occurred prior to that time left no obvious record either of strong topographic or structural relief, or of significant stratal rotation. Four episodes of deformation, some of which may overlap, are recognized. They are summarized in order of decreasing age.

1. During early Oligocene time, coarse clastic strata together with volcanic strata of the Tunnel Spring Tuff (age dated at about 33-34 m.y.) accumulated in a basin that was probably fault-bounded. This event was followed during later Oligocene time by emplacement into the basin of ash-flow tuffs of the Needles Range Formation (age averaged at about 29 m.y.). The total thickness of volcanic and clastic strata may have reached a few hundred meters. Hypabyssal masses of porphyritic rhyolite and quartz latite (discordantly age dated at about 34 and 28 m.y.) were intruded passively.

2. During Miocene(?) time deformation that probably involved strong vertical displacement on faults produced highlands that shed coarse clastic debris and landslide sheets into the Oligocene basinal area now

occupied by the Tunnel Spring Mountains. The part of the Oligocene basin situated in the area that is now west of the northern Tunnel Spring Mountains was elevated and exposed to erosion prior to or during the early stage of this episode of deformation. Clastic deposits accumulated throughout the Tunnel Spring Mountains area to thicknesses of several hundred meters. In some areas they rest conformably on subjacent Tertiary rocks and in other areas unconformably. The age of accumulation of these coarse clastic strata is poorly constrained by a fission-track determination of about 15 m.y. on one of several tuff beds interstratified with conglomerate interpreted to be near the base of an unconformable stratal succession. In general, the highlands and fault fronts from which these large volumes of materials were shed are no longer exposed. Presumably they were destroyed by erosion or by structural downfaulting (or by both processes) before or during the subsequent episode of deformation.

3. Possibly beginning during episode 2 and extending into later Miocene time, the Tunnel Spring Mountains area was involved in a major episode of extensional deformation that produced displacements and stratal rotations of all strata, including the newly deposited thick clastic units of episode 2. Large displacements on listric NNW- to NS-trending normal faults probably did not produce significant amounts of structural or topographic relief across the area; they did, however, account for most of the Cenozoic extensional tectonics of the area. The amount of extension varies widely. It is nominal in small areas of flat-lying to gently dipping strata, but is about 70 percent (2.2 km across a 5.4 km distance) locally. Cross-strike differences in direction of fault-related tilting has formed fold-like structures. Two domains of contrasting structural fabric developed. Most of the range consists of a domain of down-to-west faulting and easterly stratal rotations, but in the southern part there is a domain of down-to-east-northeast faulting and west-southwest rotations. The two domains are separated by a major fault that compensates for the contrasting fault kinematics.

4. An unknown amount of the current physiographic expression of the Tunnel Spring Mountains is probably related to uplift and gentle east tilting of the main range block. A broadly arcuate fault whose trace follows the precipitous west base of the range probably continued to be active after the main episode of extension on closely spaced listric faults (episode 3). The age of the young block uplift is not known. An unknown but significant amount of the physiographic expression of the Tunnel Spring Mountains results from preferential erosional planation of flanking Tertiary rocks that are weak relative to the resistant core of Paleozoic rocks. Threet (1960) noted a generally poor spatial coincidence between normal faults and range-front topography in other parts of the central Great Basin, and suggested that much of the physiography is controlled by contrasts in resistance to erosion. More recently Dohrenwend (1982) noted similar relationships in the western Great Basin.

The episode of severe extensional deformation recorded in the Tunnel Spring Mountains did not affect the northern Wah Wah Mountains to the southeast or the southernmost Confusion and House Ranges to the northeast (fig. 1).

Paleozoic rocks in those areas were gently tilted, erosionally beveled, and locally incised by canyons prior to deposition of the oldest Oligocene volcanic rocks and coarse clastic strata (Hintze, 1974a, b, c, d). Sparse widely scattered Oligocene rocks are cut and gently tilted by faults that are moderately to widely spaced and trend northerly to northwesterly (unpublished mapping by author). These faults have inferred steep dips and normal displacement of small magnitude, and therefore could not account for much extension.

The Burbank Hills are located northwest of the Tunnel Spring Mountains (fig. 1) and consist of a series of northeast-trending hills and ridges. They are composed mostly of Upper Paleozoic rocks that are folded on NE trends and faulted on NE and NW trends (Hintze, 1960). Sparse exposures of Tertiary strata are found in the Jensen Wash area on the north flank of the Burbank Hills (fig. 2). These strata consist mostly of conglomeratic sediments interstratified with tuffs that are interpreted to correlate with the Oligocene Tunnel Spring Tuff and Needles Range Formation of the adjacent Tunnel Spring Mountains (Bushman, 1973). If the conglomerate that overlies the Needles Range Formation (fig. 2) correlates with similar conglomerate in the Tunnel Spring Mountains, it may be of Miocene age. The total thickness of these Tertiary clastic and volcanic strata may exceed 1 km. Their predominantly coarse clastic lithology constitutes evidence for deformation analogous to that summarized in episodes 1 and 2 for the Tunnel Spring Mountains. Dips in the Tertiary strata average about 20$^{\circ}$. Their attitudes suggest a faulted open NNE-plunging syncline, and their gentle dips preclude large-magnitude extension such as that seen in the Tunnel Spring Mountains. However, indirect evidence summarized in the following paragraphs suggests that much of the structure mapped by Hintze (1960) in the upper Paleozoic rocks of the Burbank Hills may have formed during an episode of mild Tertiary extension.

Attitudes in the west limb of the Tertiary syncline are discordant to those in the on-strike Paleozoic rocks to the southwest (fig. 2). Although this discordancy could be taken to indicate that the Paleozoic rocks were tilted prior to deposition of the Tertiary strata, the contact between Tertiary and Paleozoic strata does not appear to be depositional. My attempt to locate that contact as accurately as possible shows it to have a conspicuous sawtooth trace that is difficult to interpret as a depositional contact. Also, at localities A through E (fig. 2), relationships seen in shallow hand-dug excavations suggest that the contact is steep and marked by clay-rich decomposed rock that looks more like fault gouge than a paleosoil. The contact is interpreted to be faulted throughout that area. A similar on-strike discordancy involving only Paleozoic rocks is mapped on the southwest flank of the Burbank Hills (Hintze, 1960), suggesting that such discordancies are of structural rather than depositional origin. If this interpretation is correct, much of the structure seen in the Paleozoic rocks could be of Tertiary age.

The core of the Burbank Hills consists of a broad synclinal warp on which sharp asymmetric flexures are superposed (Hintze, 1960). The sharp asymmetric flexures are herein interpreted as drape folds that formed above buried normal faults that break subjacent rocks of higher strength than those exposed at the surface (fig. 3A). Those on the west flank of the broad warp displace beds down to the west and the one on the east flank displaces beds down to the east. The combined effect is to extend the broad warp normal to its axis.

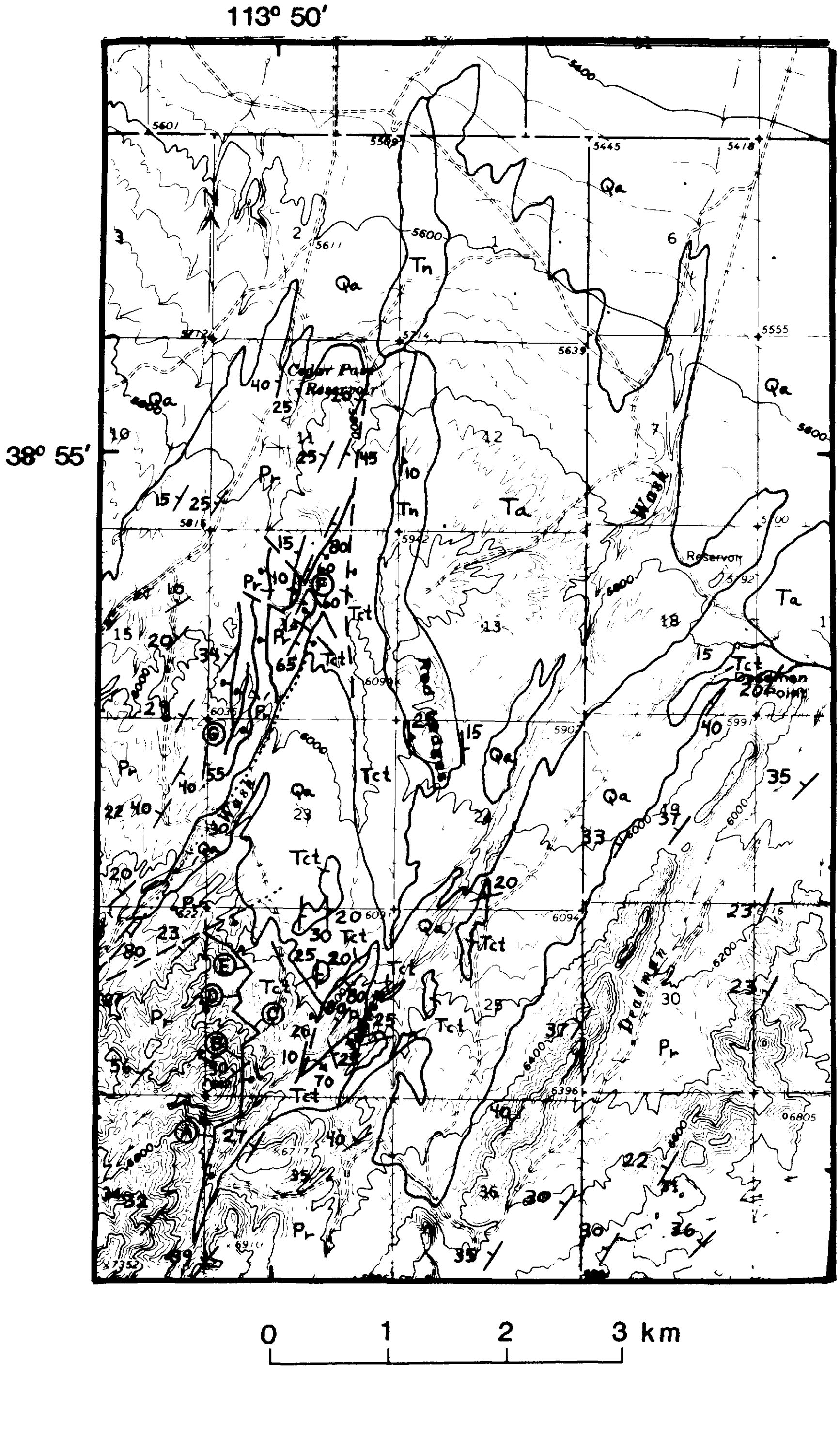



Figure 2.--Geologic map of the Jensen Wash area, Burbank Hills 15' quadrangle, Millard County, Utah.

## EXPLANATION FOR FIGURE 2

Qa

Quaternary alluvium

TERTIARY

Ta

Alluvium

Tn

Needles Range Formation, ash-flow tuff

Tct

Conglomerate and tuff, mostly conglomerate,
tuff probably correlative with Tunnel Spring Tuff

Pr

Paleozoic rocks; mostly Mississippian and Pennsylvanian

Contact

Fault, dashed where approximate, dotted where buried, bar and ball on downthrown side.

27

Strike and dip of bedding

10

Strike and dip of foliation

Ⓐ

Locality discussed in text

The amount of postulated extension is small--probably 10-20 percent. That the sharp flexures formed in an extensional rather than compressional environment is suggested by the manner in which one of them that projects into the Jensen Wash area is faulted. In the vicinity of locality F (fig. 2), upper Paleozoic strata in the east limb of a sharp flexure are cut by several gently west dipping normal faults that form an approximate 90° angle with bedding, and serve to extend the fold limb normal to its axis (fig. 3B). At locality G (fig. 2), Paleozoic rocks in the east limb are intensely shattered over a broad area. The shattered aspect is related to lateral spreading and brittle attenuation of the steep east limb between sets of gently west-dipping normal faults similar to those at locality F. The low-angle normal faults and shattered rocks are spatially restricted to the steep east limb, suggesting that they are genetically related to the flexure process. If so, the flexuring resulted from extensional rather than compressional forces. This is consistent with the drape-fold interpretation shown in cross section (fig. 3A). Because of their apparent relationship to extension, the flexures are interpreted to be of Tertiary age.

## CONFUSION RANGE AND CONGER RANGE

The Confusion Range contains about 7 km of exposed Upper Cambrian to Lower Triassic miogeosynclinal strata (Hose, 1977). It is structurally different from adjacent ranges in that an elongate, curved structural trough or synclinorium is formed in those strata (fig. 1). Hose (1966) named the feature the Confusion Range structural trough(CRST) and estimated its age as late Mesozoic to early Cenozoic (Hose, 1977). The Conger Range is a stubby topographic appendage that extends south-southwest from the west flank of the much larger Confusion Range which trends north-northwest. Structurally the Conger Range is part of the Confusion Range because the axis of the CRST extends through it (figs. 1, 4).

Cenozoic strata are exposed only over an estimated 2 percent of the Confusion Range-Conger Range region. Most of the region is covered by 1:24,000-scale geologic maps (see index of coverage in Hose, 1977, pl. 1). Important data pertaining to the Cenozoic structural history are found in four areas: (1) Toms Knoll, (2) Browns Wash, (3) Disappointment Hills, and (4) the area between the Confusion Range and Foote Range (fig. 1). My geologic mapping of these areas differs somewhat from the published mapping. To allow for critical evaluation of the differences, chips from the published maps form a screened base on which the new data and selected published data are compiled (pls. 1, 2; figs. 6, 8, 9). Because this report is focused on the Cenozoic history, each map only includes a partial explanation that covers the mapped Cenozoic stratigraphic units. Reference should be made to the published maps for a complete explanation. Important stratigraphic and structural observations from the four areas are described and summarized in the paragraphs that follow.

### Toms Knoll

Scattered exposures of Tertiary strata that straddle the axis of the CRST in the Conger Range form the most extensive area of such strata in the region (Hose, 1977). Because they are relatively extensive, their stratigraphy and

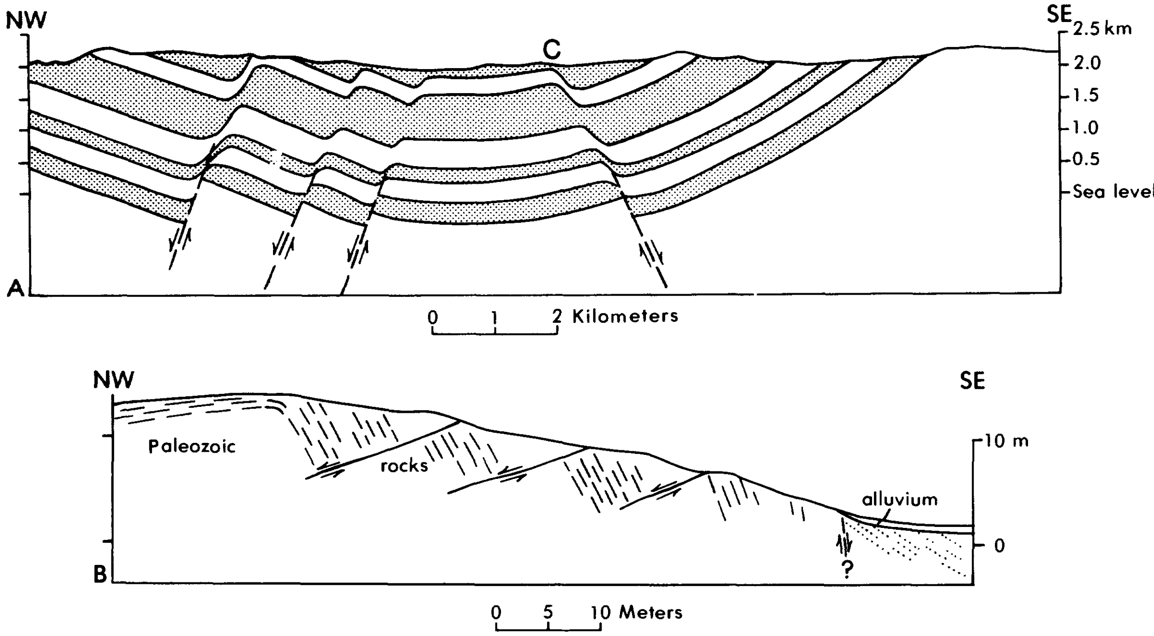



Figure 3.--Northwest-southeast, cross-strike, cross-sectional sketches of structures in the Burbank Hills. A shows a major synclinal warp in upper Paleozoic rocks (banded units) in the core area of the Burbank Hills. Superposed on the warp are sharp flexures that are interpreted as drape folds that formed over in - ferred buried normal faults (shown as dashed lines with arrows indicating direction of movement). B shows low-angle normal faults (heavy lines with arrows) that cut upper Paleozoic rocks in the east limb of a sharp flexure near locality marked F in figure 2. The faults are interpreted to be genetically related to the flexures and, as such, suggest flexing in an extensional environment. The locality lies along the northeasterly projection of one of the sharp flexures shown in A (labled C in sketch A). Patterned area beneath alluvium in southeastern part of area of sketch is Oligocene conglomerate.

structure are described in considerable detail. All localities and stratigraphic unit designations referred to in the text for the Toms Knoll area are found in plate 1.

## Stratigraphy

Plate 1 covers part of the Conger Range NE quadrangle mapped by Hose (1965a). On Hose's map, Tertiary sedimentary and volcanic rocks are divided into four units as shown on plate 1. The new mapping incorporates three stratigraphic changes (1) Tuff breccia mapped by Hose (1965a) is not recognized because at several localities visited it is either a tectonic breccia related to faulting or a conglomerate. (2) Rhyolitic tuffs that are found in low and high stratigraphic positions in the Tertiary sequence were mapped as a single unit by Hose (1965a, 1965b). These rocks are divided into two separate map units in plate 1. (3) Limestone and interbedded conglomerate and montmorillonitic tuff that were mapped separately by Hose (1965a) are mapped as sedimentary rocks.

The strata in the Toms Knoll area are described in ascending order. The lower of the two units of tuff consists of two cooling units of rhyolitic ash-flow tuff containing 5 to 25 percent phenocrysts of alkali feldspar, quartz, plagioclase, and biotite. Exposures of these tuffs are found mainly along the east side of the Toms Knoll syncline. However, similar tuff is exposed in a small fault sliver near locality I, and fault gouge excavated at locality B contains quartz grains assumed to have been derived from those rhyolitic tuffs as they were eliminated from the contact by faulting. Occurrence of these tuffs at these two localities suggests that they were spread across this part of the Conger Range prior to faulting and that their absence at most faulted contacts results from structural processes including attenuation faulting. Zircon extracted from the upper cooling unit at locality V yielded a fission-track age of 31.7 $\pm$ 1.0 m.y. (table 1).

Sedimentary rocks consist of interstratified conglomerate and lacustrine limestone. Limestone beds are resistant and generally well exposed compared to the easily disintegrated conglomerate beds which are generally concealed beneath a mantle of lag debris that greatly limits determination of sedimentary structures within them.

Near Toms Knoll Pass NNW of locality P, the lowermost Tertiary sedimentary strata consist of coarse conglomerate that contains angular to rounded clasts of limestone, dark dolomite, and quartzite ranging to 2 m in diameter. Though the contact with pre-Tertiary rocks is not exposed, the large angular blocks in the conglomerate are probably locally derived and suggest nearby tectonic activity. Overlying Tertiary strata consist of about 60 percent conglomerate interbedded with about 40 percent limestone in beds several meters to several tens of meters thick. The proportion of conglomerate to limestone decreases westward. These stratigraphic relationships suggest active local tectonism during basin sedimentation.

Limestones are generally flat-, thin-, and parallel- to wavy-bedded and locally stromatolitic. They range from lithographic to coarsely crystalline. At locality T, thin-bedded limestone is crumpled into chevron and mushroom

Table 1.--Fission-Track Age Determinations
[analyst: R. G. Bohannon]

| Sample (field station) | Material (area) | Quadrangle (lat N., long W.) | Total fossil tracks | Total induced tracks | Track densities ($T/cm^2$) $\rho_s$(fossil) X$10^6$ | $\rho_i$(induced) X$10^6$ | Total No. grains counted | r | U(ppm) | Age (m.y.) | Range (m.y.) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DF-3221 (D1479-32) | Zircon (Toms Knoll) | Conger Range NE (39°09'06",113°47'17") | 514 | 884 | 3.53 | 6.06 | 6 | 0.9455 | 191 | 31.7 | 1.0 |
| DF-3220 (D1215-1) | Zircon (Disappointment Hills) | Cowboy Pass NW (39°24'45",113°40'08") | 499 | 950 | 3.42 | 6.52 | 6 | 0.6122 | 205 | 28.7 | 2.6 |
| DF-3218 (15919-3) | Zircon (Duck Creek) | Ely, 1°x2° (39°31'50",114°40'00") | 740 | 1,280 | 3.68 | 6.36 | 8 | 0.9492 | 201 | 31.6 | 1.5 |
| DF-3219 (15919-1) | Zircon (Duck Creek) | Ely, 1°x2° (39°31'35",114°40'45") | 637 | 1,268 | 3.60 | 7.17 | 7 | 0.9533 | 226 | 27.4 | 1.3 |
| DF-2268 (D979-2) | Apatite (Sand Pass) | Sand Pass (39°35'15",113°23'12") | 713 | 1,393 | 0.211 | 0.413 | 100 | 0.0613 | 11.9 | 30.6 | 3.75 |

Thermal neutron flux (in neutrons $cm^{-2}$) = 9.14 $e^{14}$; error on flux = $\sigma\phi$ = 0.02

Constants used: $\lambda_f$ = Fission decay constant = 7.03 $e^{-17} yr^{-1}$; $\lambda_d$ = Total decay constant = 1.551 $e^{-10} yr^{-1}$; I = $^{235}U/^{238}U$; correction factor = 7.252 $e^{-3}$; thermal neutron fission cross section = $\sigma$ 580 $e^{-24} cm^2$

folds that involve bed sets several meters thick. Though large in size, these structures resemble folds formed penecontemporaneous with deposition as a result of soft-sediment slumpage. At locality F, relatively undisturbed limestone that overlies conglomerate can be traced laterally into strongly folded and broken beds that appear to bend downward and truncate the underlying conglomerate. The relationships are suggestive of slumpage into sinkholes. Despite these indications of non-tectonic deformation, conglomerate beds in addition to those described in the previous paragraph suggest tectonic disturbances internal to the basin. Though exposures are limited and of poor quality, studies of lag debris that mantles conglomerate indicate the common presence of angular boulders and blocks of yellowish-gray lacustrine limestone of probable Tertiary age in the Tertiary conglomerate. These clasts commonly are internally deformed and the structures they display could be nontectonic. However, their angular borders cut across internal structures, suggesting that they are bona fide clasts contributed to the conglomerate from nearby parts of the basin that were being uplifted and eroded. Similar relationships are seen in the Tunnel Spring Mountains (Anderson, 1980a) suggesting widespread syndepositional tectonism and cannibalistic sedimentation.

Some conglomerate contains rounded clasts of pre-Tertiary quartzite and dark- and light-gray limestone and dolomite as much as 2 m in diameter. These appear to be derived from distant sources because they do not match local bedrock lithologies and are rounded. Thus, lithologic evidence exists for local and distant tectonism of strong magnitude contemporaneous with basin sedimentation.

The upper of the two tuff units includes some rhyolitic tuff in its lower part, but its upper part, which forms most of the exposures, consists mostly of quartz latite tuff that is probably correlative with rocks mapped in more southerly areas of western Utah as Needles Range formation. (Best and others, 1973; Anderson, 1980a, Anderson and Rowley, 1975). On the basis of K-Ar age determinations the best estimate of the age of the Needles Range formation is 28.9 ± 1.2 m.y. (Fleck and others, 1975). The Tertiary strata are, according to these data and the 31.7 m.y.-age yielded by the lower tuff unit, Oligocene in age.

## Structure

The structure of the part of the Conger Range near Toms Knoll was produced by multiple deformation and is complex. It is dominated by 1) the north-trending CRST, 2) a narrow zone of strong uplift on faults and folds that parallel, and are approximately coincident with, the axis of the CRST, 3) a major arcuate fault zone that Hose (1977) named the Conger Range fault, 4) an important sigmoidal fault herein named the No-Road fault, 5) an east-dipping low-angle fault herein named the Buckskin Hills fault, and 6) two north-northwest-trending open folds, one of which is herein named the Toms Knoll syncline (fig. 4). Other mapped structures that complicate the CRST include numerous high-angle strike and transverse faults and short-wavelength folds (pl. 1, and Hose, 1965a). The strongly uplifted zone in the axial region of the CRST is, in itself, a complex feature. South of Toms Knoll, it is a highly faulted 2-km-wide mushroom fold with estimated structural relief of 2 km (Hose, 1965a, 1977). New data discussed below indicate that directly south of

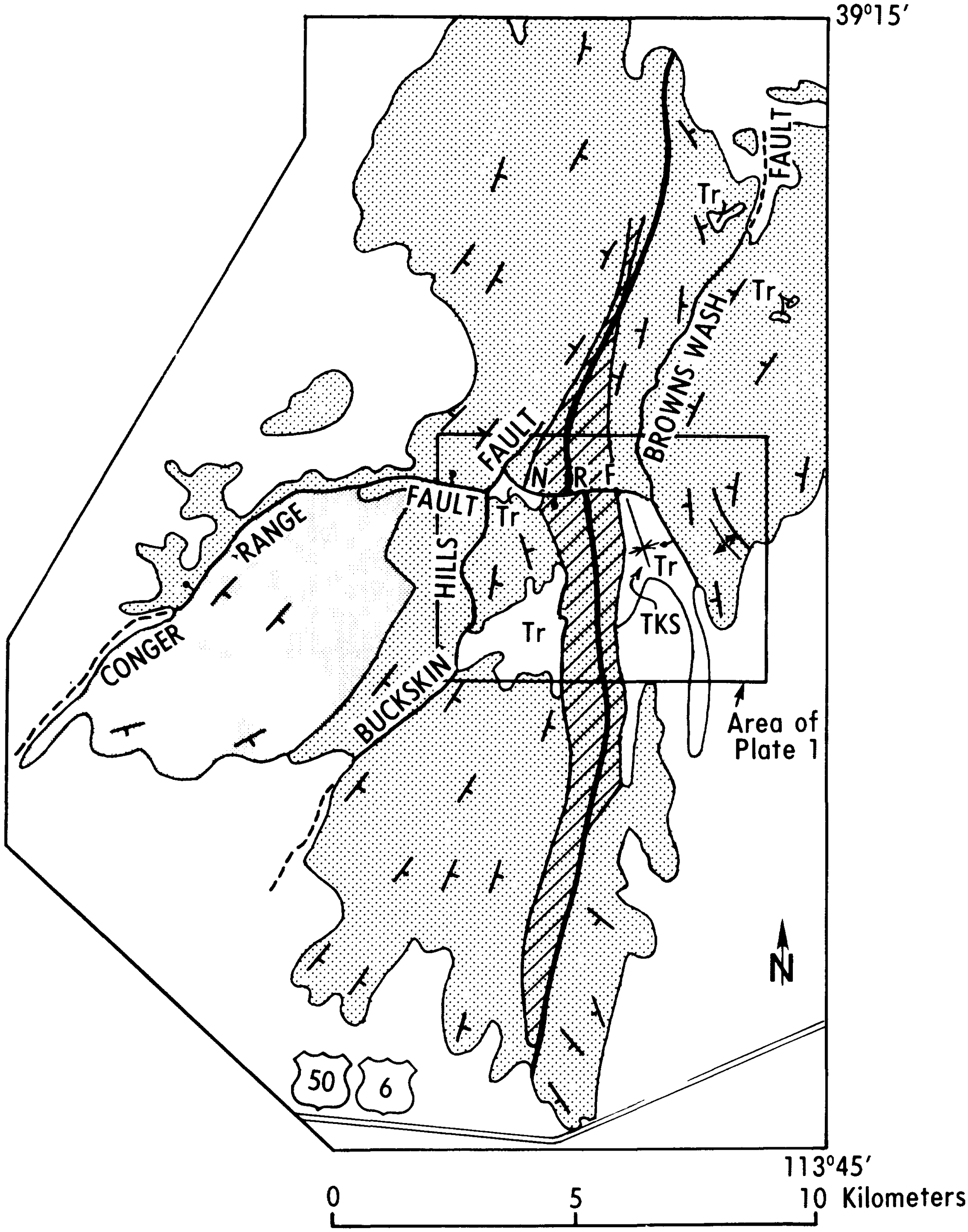



Figure 4.--Highly generalized geologic map of the Conger Range showing some major structural features including the axis of the Confusion Range structural trough (heavy line), major north-trending zone of east-dipping overturned rocks (ruled area), some average dip directions, and selected faults and folds. Tr, Tertiary rocks; shaded area, Devonian and older rocks; stippled area, Devonian and younger Paleozoic rocks; TKS, Toms Knoll syncline, NRF, No Road Fault.

the No-Road fault it is a major 1.5-km-wide zone of east-dipping overturned beds bounded on the east by a major fault, whereas a few kilometers north of the No-Road fault major uplift is associated with a single high-angle fault (herein named the Browns Wash fault). In that area overturned beds are restricted to a narrow 500-m-wide zone within the west-tilted block west of the Browns Wash fault (fig. 4).

Tertiary rocks around Toms Knoll are restricted to the area south of the No-Road transverse fault and east of the Buckskin Hills strike fault. Both faults cut Tertiary rocks. Faults that trend parallel and transverse to the strike of the beds form most of the contacts between Tertiary and pre-Tertiary rocks, and many are found internal to areas of Tertiary rock where their spacing and stratigraphic separation are about equal to the average spacing and separation of faults in surrounding areas of pre-Tertiary rock (pl. 1). Also, several faults of each type that cut Tertiary rock are coextensive with faults mapped in adjacent pre-Tertiary rocks by Hose (1965a, b), but on those maps, Hose showed no faults at the boundaries of or within the areas of Tertiary rock.

The best exposures of faults that cut Tertiary rocks are found at localities where the dip of the fault is indicated on the geologic map and at localities marked by a solid triangle (pl. 1). At localities A and B, however, the Buckskin Hills fault had to be excavated for viewing. Only at locality U were slip lines in the form of grooves and slickensides seen on a fault surface. Several of the faults that are not exposed are inferred on the basis of zones of brecciated rock or rotated bedding, or on the basis of stratal repetition or along-strike structural juxtapositioning of contrasting strata.

Some faults are marked by sharp breaks (localities L, M, N, U), some by gouge zones a meter or so wide (localities A, B), and some by zones of breccia, contorted bedding, and structural intermixing (localities C, D, G, J). Though no systematic mapping was done in areas of pre-Tertiary rock, a few faults that were investigated show a range of complexity similar to faults that cut Tertiary rock. Of special significance are some broad zones of highly fractured pre-Tertiary rock within which there is no single plane of major dislocation but across which there is appreciable stratigraphic offset or attenuation as in the vicinity of locality K. At localities D and J, this type of structural complexity is found on both sides of the faulted Tertiary pre-Tertiary contact, suggesting a Tertiary age for the deformation. The style of this brittle attenuation is similar to that found in the Burbank Hills described above (locality G, fig. 2) where it is related to extensional tectonism.

Rotations of Tertiary strata cannot be resolved into a simple fault-related pattern. For some strike faults such as those in the vicinity of localities L, M, and N, there is a strong tendency for beds to be tilted toward the fault, suggesting fault-related tilting. Along other strike faults, such as those that bound the Toms Knoll syncline and the Buckskin Hills fault in the vicinity of locality A, strata dip away from or tend to be dragged into parallelism with the faults. Some transverse faults sharply truncate Tertiary strata as near locality P, whereas along others, such as south of locality N, strata appear to be dragged along the fault. Similar complex patterns of stratal rotation are seen along faults that cut the pre-Tertiary rocks as mapped by Hose (1965a, b).

The No-Road fault may have been active during deposition of the Oligocene sediments as indicated by the abundance of coarse clastic deposits along it. The normal component of Tertiary displacement is down to the south and appears to be at least 350 m on the basis of projection of bedding in Tertiary rocks in the east limb of the Toms Knoll syncline into the fault. Hose (1965) showed displacement on the No-Road fault to be down to the north instead of down to the south on the basis of offset contacts in overturned pre-Tertiary rocks. That sense of displacement, if it exists, must predate the Tertiary rocks in the area. Alternatively, Tertiary movement on the fault may have included a major component of left slip consistent with the offset contacts in overturned pre-Tertiary rocks. If so, the No-Road fault is left oblique, south-side down with an estimated displacement of 700 m. It need not have had two contrasting displacement histories.

The left-oblique (?) south-down No-Road fault is not the easterly extension of the Conger Range fault that displaces rocks down to the north. Both faults appear to be restricted to opposite sides of the Buckskin Hills fault--the Conger Range fault to the footwall and the No-Road fault to the hanging wall. Tertiary displacement on the Conger Range fault has not been documented. The Buckskin Hills and No-Road faults could be closely related genetically to east-west extension of Tertiary age. This interpretation differs greatly from that of Hose (1977), who concluded that the Buckskin Hills fault is offset a large amount by the Conger Range fault, and that both predate the Tertiary rocks in the area.

Cross sections constructed by Hose (1965a, 1977) across the Buckskin Hills fault and other low-angle, east-dipping "decollement" faults in the region show numerous high-angle faults in the hanging-wall block to be truncated by, and therefore to be older than, the low-angle fault. Because the Buckskin Hills fault is now known to be of Tertiary age, as are many of the high-angle faults in its hanging-wall block, the high-angle and low-angle faults are interpreted as contemporary and genetically related structures of Tertiary age.

Hand-dug excavations and shallow machine augering along the trace of the Buckskin Hills fault at localities A and B revealed moderate to gentle east dips of the fault zone as well as pulverized Tertiary rocks in the zone. Mapping reveals that the fault bears a complex relationship to adjacent strata. Near locality A it approximately parallels bedding in Mississippian rocks of the footwall and Tertiary rocks of the hanging wall. As it is traced northward it displays moderate-angle truncation of bedding in Paleozoic and Tertiary rocks of the hanging wall. Thin-bedded Tertiary limestones dip $20^{\circ}$ to $45^{\circ}$ into the fault and are therefore offset by it. The fault extends northeast from locality C into the Buckskin Hills where it separates a southeastern area of overturned upper Paleozoic Ely Limestone from a northwestern area of normally northeast dipping Ely Limestone, thus indicating a potentially large component of displacement. Hose (1977) does not show the fault extending into the Buckskin Hills, probably because he did not recognize that it forms the boundary between Tertiary and Paleozoic rocks between localities B and C.

The only well-developed fold in Tertiary rocks large enough to be mapped is north of Toms Knoll, and it is herein named the Toms Knoll syncline. It is a south-southeast-plunging open asymmetric syncline formed in Tertiary rocks with dips as much as $70^{\circ}$. The northern part of the syncline is well exposed, but to the south it plunges beneath a cover of younger deposits. In its well-exposed northern part the syncline is fault bounded, and beds with the steepest dips are found along the boundary faults, suggesting a component of drag associated with faulting. The syncline is not expressed in pre-Tertiary rocks to the west which are overturned and have stratigraphic top directions that are opposed to those of the west limb of the syncline. Neither is it expressed to the north of the No-road fault (pl. 1). The Toms Knoll syncline is limited by and probably genetically related to its bounding faults. Deposition within it was probably partly coincident with its formation because the coarsest clastic rocks as well as the most highly deformed rocks are found near its faulted boundaries. A critical exposure of pre-Tertiary limestone and limestone-pebble conglomerate in which well-developed cross bedding indicates $45^{\circ}$ east dip (not overturned) is located where the west-bounding fault joints the No-Road fault at locality Q. Bedding in this exposure of right-side-up rock is concordant with nearby exposures of Tertiary rock--a condition that is also seen along the east-bounding fault. No need exists to infer a major subsurface discordance between Tertiary rocks in the Toms Knoll syncline and underlying Paleozoic rocks as depicted in a cross-strike structure section drawn by Hose (1965a, section C-C'). The Tertiary and underlying Paleozoic rocks of the Toms Knoll syncline were folded in approximate concordance (fig. 5).

The west-bounding fault of the Tertiary Toms Knoll syncline also forms the eastern boundary of the major overturned syncline that occupies the axial portion of the CRST. Thus, that fault separates folds with dramatic tilting and opposed vergence as shown in figure 5. This relationship is most easily explained by juxtapositioning of folds that formed separately--either in separate plates that have been juxtaposed vertically or in separate areas that have been juxtaposed horizontally.

A north-northwest-plunging anticline formed in Paleozoic rocks is well exposed in the area east of the Toms Knoll syncline (indicated by form lines in pl. 1). The anticline is similar in size, axial trend, and asymmetric form to the Toms Knoll syncline. Its steep east limb is bounded by a fault in a fashion similar to that of the steep west limb of the Toms Knoll syncline. The anticline is known only to be post Mississippian in age, but on the basis of its strong similarity to the nearby Toms Knoll syncline, it can be inferred to be either of Tertiary age or it and its Tertiary neighbor formed at separate times but under similar stress conditions.

## Browns Wash Area

Stratigraphic and structural relationships that are critical to evaluating the Cenozoic structural history of the Conger Range are exposed at localities along Browns Wash in the northeastern part of the Conger Range NE quad

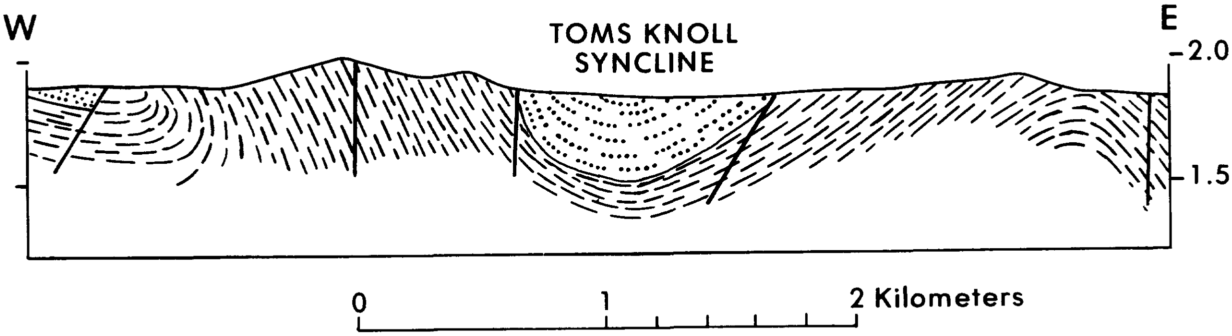


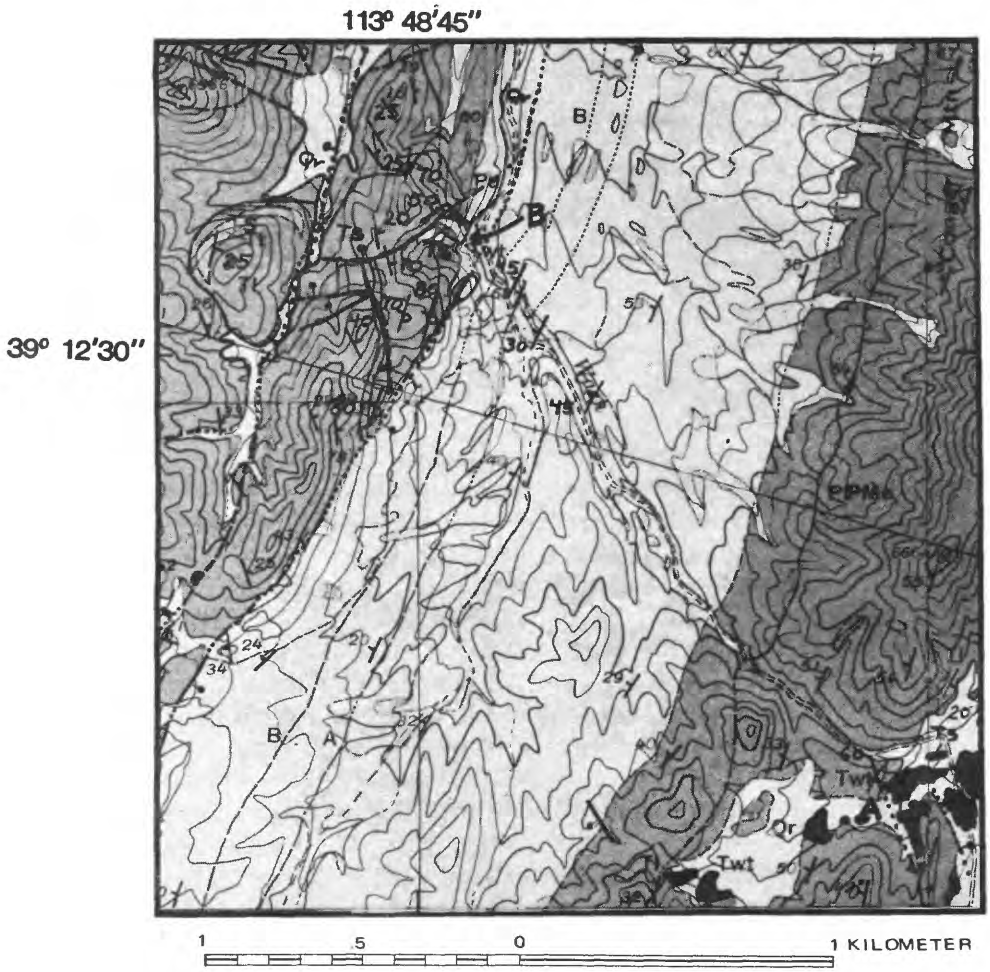

Figure 5.--Sketch of west-east cross-sectional relationships across the Toms Knoll syncline showing concordance of dip components in Tertiary rocks (dot pattern) and underlying Paleozoic rocks (dash pattern) and the sharp discordance of dip components across the fault that bounds the Toms Knoll syncline on the west (Paleozoic rocks to west of that fault are overturned and to east are right-side-up). Heavy lines are faults.

rangle (marked A and B in fig. 6). Modifications and additions to the published geologic map (Hose, 1965) are trivial.

At locality A, a well-exposed unconformity occurs between Paleozoic rocks that dip $50^{o}$ WNW and overlying Tertiary limestone that dips $30^{o}$-$40^{o}$ SE. The limestone is overlain concordantly by an ash-flow tuff that is lithologically similar to a tuff from the Disappointment Hills that yielded a fission-track age on zircon of $28.7 \pm 2.6$ m.y. (table 1). The Paleozoic rocks can be restored to vertical dips by removing the dip of the Tertiary rocks. However, nearby Tertiary rocks are subhorizontal suggesting that the $30^{o}$-$40^{o}$ dips at the unconformity are local and should not be applied uniformly to palinspastic reconstruction of a large area. The distribution of unconformable Tertiary rocks does provide proof of $30^{o}$-$50^{o}$ pre lower Oligocene WNW rotation of part of the east flank of the CRST.

At locality B Tertiary strata exposed in the east-facing wall of Browns Wash suggest faulting both contemporaneous with and following deposition. The lowest exposed beds consist of about 15 m of clast-supported conglomerate containing moderately- to well-rounded pebbles, cobbles, and boulders as much as 1 m in diameter. The clasts consist of light-gray limestone, cherty limestone, chert, and pale reddish quartzite, all presumed to be of Paleozoic age, contained in a sandy matrix rich in quartz and biotite sand grains derived from volcanic rock. The occurrence of volcanic clasts in the matrix suggests an Oligocene age for the conglomerate. The basal contact of the conglomerate is not exposed. The conglomerate is overlain by a few meters of friable, gray vitric ash-flow(?) tuff that is lithologically and petrographically similar to the tuff from the Toms Knoll area dated at 31.7 m.y. (table 1). Above the tuff is a zone several meters thick containing cobbles, boulders, and large angular blocks as much as 4 m in diameter of assorted Paleozoic rocks in a matrix of stromatolitic limestone that ranges from thinly laminated micrite to coarsely layered and coarsely recrystallized rock. Though the exposures are not good enough to determine the gross bedding features in this zone, some of the small-scale features are exposed. In particular, the morphology of bedding surfaces is dominated by close-packed dome-like forms (fig. 7). Cross sections through these features show that the laminations in micritic rocks and the layering in coarsely recrystallized rocks parallel the surface morphology and are therefore concentric within each dome-like structure. Downward-pointing chevron patterns are formed where domes intersect with one another. In a few exposures, it is clear that the concentric pattern was initiated as a coating on a cobble or boulder and progressed outward and upward forming a dome-like stromatolite. Similar rocks are found in the Toms Knoll area. They are especially common near locality S (pl. 1), which is also situated along the Browns Wash fault. These interesting deposits are interpreted as fault-front colluvium that was fed to an Oligocene lake within which carbonate was precipitated biogenetically. They indicate that the Browns Wash Fault was active during Oligocene time. At locality B (fig. 6) the deposit is in fault contact with overlying lacustrine limestone that is at least 50 m thick. Though the limestone is rotated to a $50^{o}$ NW dip at the NE-trending fault, most of it dips less than $25^{o}$NW.

Contacts of the colluvium and overlying tuff with adjacent Paleozoic rocks are faulted forming a narrow WNW-trending graben. The graben cuts




EXPLANATION FOR FIGURE 6

(See geologic map of the Conger Range NE quadrangle (Hose, 1965) for explanations of stratigraphic units and map symbols not explained below)

| | |
|---|---|
| Qr | Unconsolidated alluvium and colluvium of diverse origin and Quaternary age |
| Ts | Sedimentary and volcanic rocks of Tertiary age, mostly lacustrine limestone with minor conglomerate and ash-flow tuff |
| A | Locality referred to in text |

Figure 6.--Geologic map of an area along Browns Wash in the Conger Range NE quadrangle, Utah.

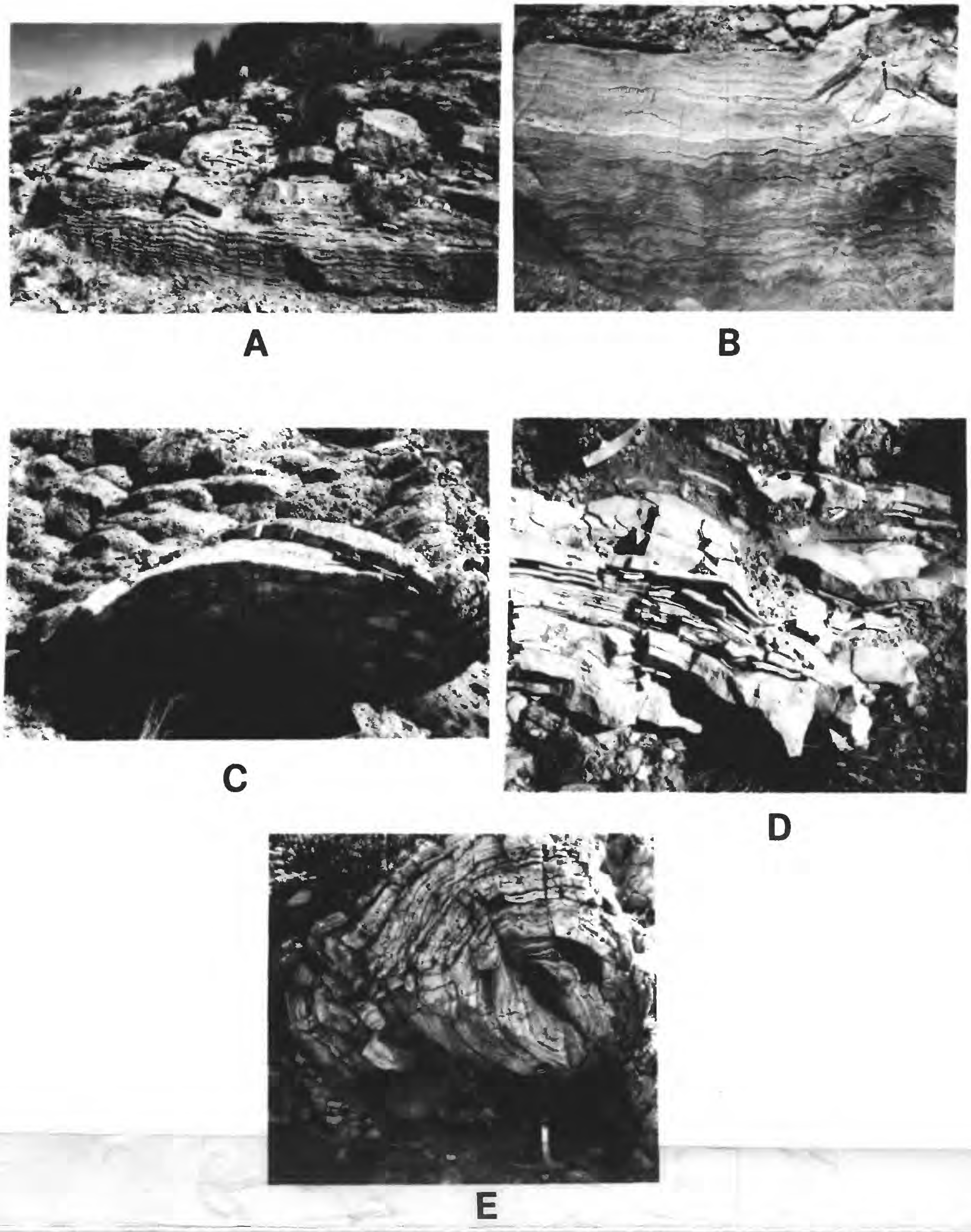



Figure 7.--Photographs of bedforms and a biscuit-shaped stromatolite in Oligocene lacustrine algal limestones from the Confusion Range. _A_ and _B_ show small-scale wavyness in recrystallized parallel-bedded rock; _C_ and _D_ show cross sections of coarsely recrystallized (C) and micritic (D) limestones that have a well-developed botrioidal aspect to their bedding surfaces. _E_ shows the internal structure of an algal biscuit that apparently nucleated on a rounded clast (above hammer handle).

across, and is therefore younger than, a northerly trending overturned fold limb formed in upper Paleozoic rock. The colluvium is interpreted as a graben-fill deposit formed during and after downfaulting. The gently dipping overlying limestone is locally in depositional contact with steeply dipping Paleozoic rocks. It does not appear to have been involved in the graben-forming faulting but was faulted later on NE and NNE trends.

The Browns Wash fault is apparently a complex structure characterized by dramatic variation in form along its strike--somewhat analagous to the dramatic along-strike variation in the form of the narrow zone of strong uplift and overturning described under the Toms Knoll heading. In the area included in figure 6, Hose (1965) showed it as a major, broadly arcuate, northerly trending, steep reverse fault with as much as 1.1 km of vertical stratigraphic separation. An overturned fold in the hanging-wall block west of the trace of the fault predates the Tertiary rocks in the area and is presumably related to reverse movement on the major fault. The overturned fold in the hanging-wall block is a local feature. Published mapping shows that it is absent to the north of the area of figure 6 (cross section A-A', Hose, 1965) and along a 3.4-km segment of the fault to the south-southwest of locality C, figure 6. In those segments, the fault could be high-angle normal as shown by Hose (cross section A-A', Hose, 1965). Farther south, in the 2-km-long segment north of the Toms Knoll syncline, the fault has an irregular surface trace suggestive of a moderate to gentle east dip. Rocks in the hanging-wall block are crumpled into folds that parallel the Browns Wash fault and have wavelengths of only about 100 m, suggesting that they do not penetrate deep. Perhaps these folds, which are seen in other parts of the Conger Range (Hose, 1965, 1965a), represent crumpling of mechanically weak rocks in the structurally thin parts of hanging-wall blocks above gently dipping normal faults.

In summary, the following events are indicated: 1. Formation of the CRST and associated (?) reverse faulting and locallized stratal overturning. 2. Erosional beveling of pre-Tertiary rocks. 3. Formation of structural and topographic relief during Oligocene (?) time and sedimentation in what is interpreted to be a combined basin and fault-front environment. This event included local graben-forming faulting on a WNW trend. 4. Faulting on NE and NNE trends. On the basis of this structural history, most, if not all, of the high-angle normal faults with WNW and northerly trends mapped by Hose (1965) in the northern part of the Conger Range are inferred to be of Tertiary age.

### Disappointment Hills

Tertiary strata in the Disappointment Hills, which are located on the east flank of the Confusion Range, consist of conglomerate, tuff, tuffaceous sandstone, and welded tuff. Hose and Repenning (1963) inferred that the conglomerate overlies the tuffs, and later mapping by Hose (1974) in the northern part of the Disappointment Hills indicates that the various tuffaceous rocks are of Oligocene age and the conglomerate is of Pliocene(?) age. New data indicate that much of the conglomerate is of Oligocene age.

At locality A, in the southeastern part of the area covered by plate 2, an ash-flow tuff of unknown but probable Oligocene age is sandwiched between alluvial conglomerate. To the west, at locality B, an ash-flow tuff that differs petrographically from the one at locality A, but is probably also of Oligocene age, is down dropped to the west against alluvial gravels on a fault that dips about 65°W and on which striae indicate normal slip. In the southernmost Disappointment Hills, about 4 km south of the area included in plate 2, a sample of ash-flow tuff yielded an age of 28.7 ± 2.6 m.y. by the fission-track method (table 1). The age falls within the age range of four K-Ar determinations reported by Fleck and others (1975) on the Needles Range Formation from the Cowboy Pass area 10 km to the south. The tuff is sandwiched between weakly consolidated sand and matrix-supported gravel. The gravel consists of angular to slightly rounded pebbles and cobbles of pre-Tertiary rocks in a sand matrix containing sparce grains of quartz and mafic silicates derived from volcanic rocks. These relationships demonstrate that the tuffs are interstratified with coarse clastic strata some of which are of Oligocene or older age. At locality C (pl. 2), a thick section of tilted and beveled alluvial conglomerate rests on tuff of presumed Oligocene age. The conglomerate is well exposed beneath Quaternary pediment gravels along an unnamed east-draining wash east of locality C. It consists almost entirely of angular to rounded, boulder-bearing detritus of Paleozoic rocks. Beds that contain volcanic clasts are found only near the base of the unit. Conglomerate in the pod-shaped area of Cenozoic rocks southeast of locality D is poorly exposed. It rests on tuff and contains more volcanic detritus than the conglomerate in the area east of locality C. Clasts of distinctive, dark, resistant andesite are found in the conglomerate in both areas, suggesting they may be correlative.

Ash-flow tuff at localities B and C correlates megascopically with the tuff dated at 28.7 ± 2.6 m.y. from about 4 km south of the area of plate 2. These tuffs appear to be quartz latitic to rhyodacitic in composition and are tentatively correlated with the Needles Range Formation. Ash-flow tuff at locality A correlates megascopically and petrographically with tuff in the vicinity of locality D. Although compositionally similar to the Needles Range Formation, these tuffs contain conspicuously fewer phenocrysts (about 10 percent). Their age relative to the Needles Range Formation is not known but they are inferred to be of Oligocene age.

The poor quality of most exposures limits ability to estimate thicknesses. The tuffs are probably only a few meters to a few tens of meters thick. The conglomerates are probably thicker--especially east of locality C and south-southeast of locality D where, although beds are repeated by a few faults of small displacement, they are probably as much as 400 m and 200 m thick, respectively.

Tuffs in the Disappointment Hills are all inferred to be of Oligocene age because of their similarity to tuffs dated radiometrically from other areas in and near the Confusion Range (table 1; Hose, 1977). Conglomeratic sediments beneath the tuffs contain volcanic clasts, indicating that they were deposited after volcanism began in the region. They are inferred to be of early Oligocene age. The conglomeratic strata above the tuffs is Oligocene or younger.

Structure

Bedding and foliation attitudes reported by Hose and Repenning (1963) and additional attitudes measured by me (pl. 2) shows that the Cenozoic, Mesozoic and Paleozoic rocks in the Disappointment Hills dip homoclinally east and northeast. Dips as mucht as 42° are reported in the Cenozoic rocks (Hose and Repenning, 1963). The area is situated in the east limb of the CRST (Hose, 1977) where pre-Tertiary rocks would be expected to dip westward, not eastward. This highly anomalous structural relationship deserves special attention.

In the vicnity of locality D, a distinctive light-colored ash-flow tuff is overlain by dark-colored rubble of dacite and andesite flows. The contact between the two rocks dips gently east-northeast discordantly towards Paleozoic rocks and is repeated at least three times, suggesting westward downdropping on faults (pl. 2). To the south-southeast, conglomeratic strata that may be as much as 200 m thick dip homoclinally easterly, are para-conformable to underlying east-dipping Mesozoic and Paleozoic rocks on the west, and are in fault contact with an east-dipping block of Paleozoic rocks on the east. At one locality the fault is marked by a resistant rib of dark-reddish-brown fault breccia that dips 50°W. A cross section constructed across the area of Cenozoic rocks by Hose and Repenning (1963, section A-A') shows the Tertiary rocks as an unfaulted thin veneer beneath which the Paleozoic and Mesozoic rocks are faulted. Instead, the new data show that the Tertiary strata are involved in the full range of fault offset and eastward stratal rotation to which the older rocks have been subjected in this area.

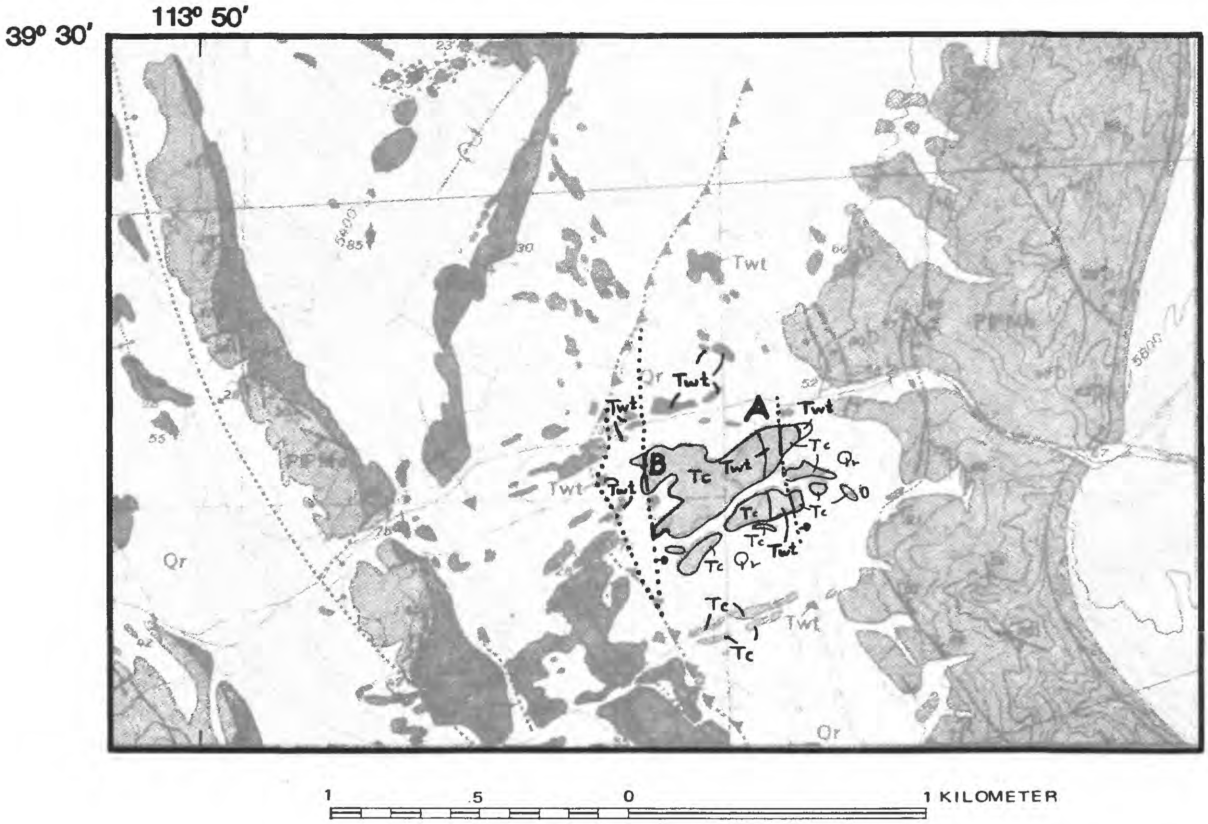
Attitudes measured at locality C and to the east of there along the unnamed east-draining wash show consistent easterly dip, the magnitude of which decreases eastward from 20° to 5°. The steeper of the attitudes are essentially concordant with those of underlying Paleozoic rocks to the west. The Tertiary and pre-Tertiary rocks are cut by several faults of small displacement. Faults in the Tertiary gravels (only one is shown in pl. 2) form an angle of about 90° with bedding and drop strata down toward the Disappointment Hills (west). Stratal attitudes in the Paleozoic and Tertiary rocks appear to be fault-related, and overall stratal concordance suggests that the rocks were deformed together.

A very important modification is made to the geologic map of Hose and Repenning (1963) in the area west-southwest of locality B. Their map shows scattered exposures of Tertiary tuff and conglomerate at low elevations along the unnamed transverse drainage in that area. A search for those exposures revealed only Quaternary alluvial deposits. Also, new data show that the Tertiary rocks near locality B are inset into the range flank by displacements on normal and transverse faults and have attitudes similar to adjacent Paleozoic rocks instead of having been deposited unconformably across faulted and tilted Paleozoic rocks as depicted by Hose and Repenning (1963). The importance of the new data can not be over emphasized. The early mapping requires that a paleotopographic predecessor of the Disappointment Hills complete with its internal fault structure and a transverse drainage existed during Oligocene time and that the modern topography is, to some extent, an exhumed replica of the Oligocene paleotopography. The new data require no such interpretation. Instead, they suggest that most of the faulting and stratal tilting is of Cenozoic age and that the exposed rocks were little faulted or possibly unfaulted prior to that. The same interpretation is valid for the southernmost Disappointment Hills south of the area covered by plate 2. In that area Tertiary conglomerate and age-dated interbedded ash-flow tuff dip 30° to 40° southeast essentially concordant with underlying Mesozoic strata. Easterly dips in Tertiary rocks of 29°, 30°, and 41° were reported by Hose and Repenning (1963) from that area and easterly dips of 27° and 20° were recorded from the vicinity of localities A and C. However, the structural significance of all these attitudes was neglected in their construction of two cross-strike structure sections (B-B', C-C', Hose and Repenning, 1963) which depict the Tertiary rocks as a thin veneer deposited unconformably on tilted, faulted, and beveled Paleozoic and Mesozoic rocks.

In summary, Oligocene conglomerates in the area document strong deformation of that age. Despite this documentation, Oligocene strata were deposited on pre-Tertiary rocks that show no evidence of having been strongly deformed. The highly anomalous easterly dips in the east limb of the CRST in the Disappointment Hills were produced by an episode of extensional faulting that postdates Oligocene rocks. These dips totally mask early westerly dips associated with the trough. That a trough existed in the area prior to deposition of the Tertiary strata is suggested by the fact that Tertiary strata rest on Mesozoic rocks near the axis and on Upper Paleozoic rocks away from the axis (Hose, 1977).

## Area Between Confusion Range and Foote Range

Brief field investigations in two separate parts of the area between the Confusion and Foote Ranges (figs. 8, 9) resulted in trivial modifications of the published geologic map of the Hose and Ziony (1963). The maps are presented mainly to show the location of sites where critical stratigraphic, lithologic, and structural observations were made. Tertiary rocks in the area consist of conglomerate, tuff, tuffaceous sedimentary rocks, limestone, sandstone and gravel (Hose and Ziony, 1963). In general, the Tertiary rocks differ from the Tertiary rocks in the Disappointment Hills to the east in containing significant beds of lacustrine limestone and tuffaceous limestone. However, some rocks are remarkably similar in the two areas. In particular, light-colored, friable ash-flow tuff and overlying dark-colored conglomerate near locality A (fig. 8) correlate directly with similar rocks exposed in the Disappointment Hills at localities D and A in plate 2. Diagnostic features of the tuff include the low content of phenocrysts (8-10 percent), their small size (average about 0.5 mm), and their fragmented habit. They consist of 55-73 percent plagiocluse and essential biotite and hornblende and include accessory quartz, sanidine, pyroxene, opague oxides, apatite, and zircon. The grains are set in a turbid shard-rich matrix containing pumice. The conglomerate is distinctive in its content of clasts of dark dacite and andesite. The direct correlation across the Confusion Range of a conglomerate that contains clasts of volcanic rocks that are nowhere exposed as bedrock in the range has important paleotopographic implications. It suggests that the range block did not exist as a positive topographic feature composed of upper Paleozoic rocks during Oligocene time when the conglomerate was deposited. Also, the tuff was probably erupted onto a surface of low relief prior to develop




EXPLANATION FOR FIGURES 8 AND 9

(See geologic map of the Gandy NE quadrangle by Hose and Ziony (1963) for explanation of pre-Tertiary units and map symbols)

Qr — Alluvial and colluvial material of Quaternary age derived from local sources

Tc / Twt / Ttl — Sedimentary and volcanic rocks of Tertiary age

Tc, poorly consolidated conglomerate with calcareous or calcareous-tuffaceous matrix
Twt, welded tuff
Ttl, sedimentary tuff, tuffaceous limestone, sandstone and gravel

20 — Strike and dip of beds

40 — Fault showing dip, dotted where concealed

Concealed axis of syncline

A — Locality referred to in text

Figure 8.--Geologic map of a part of the Gandy NE quadrangle between the Foote and Confusion Ranges, Utah.

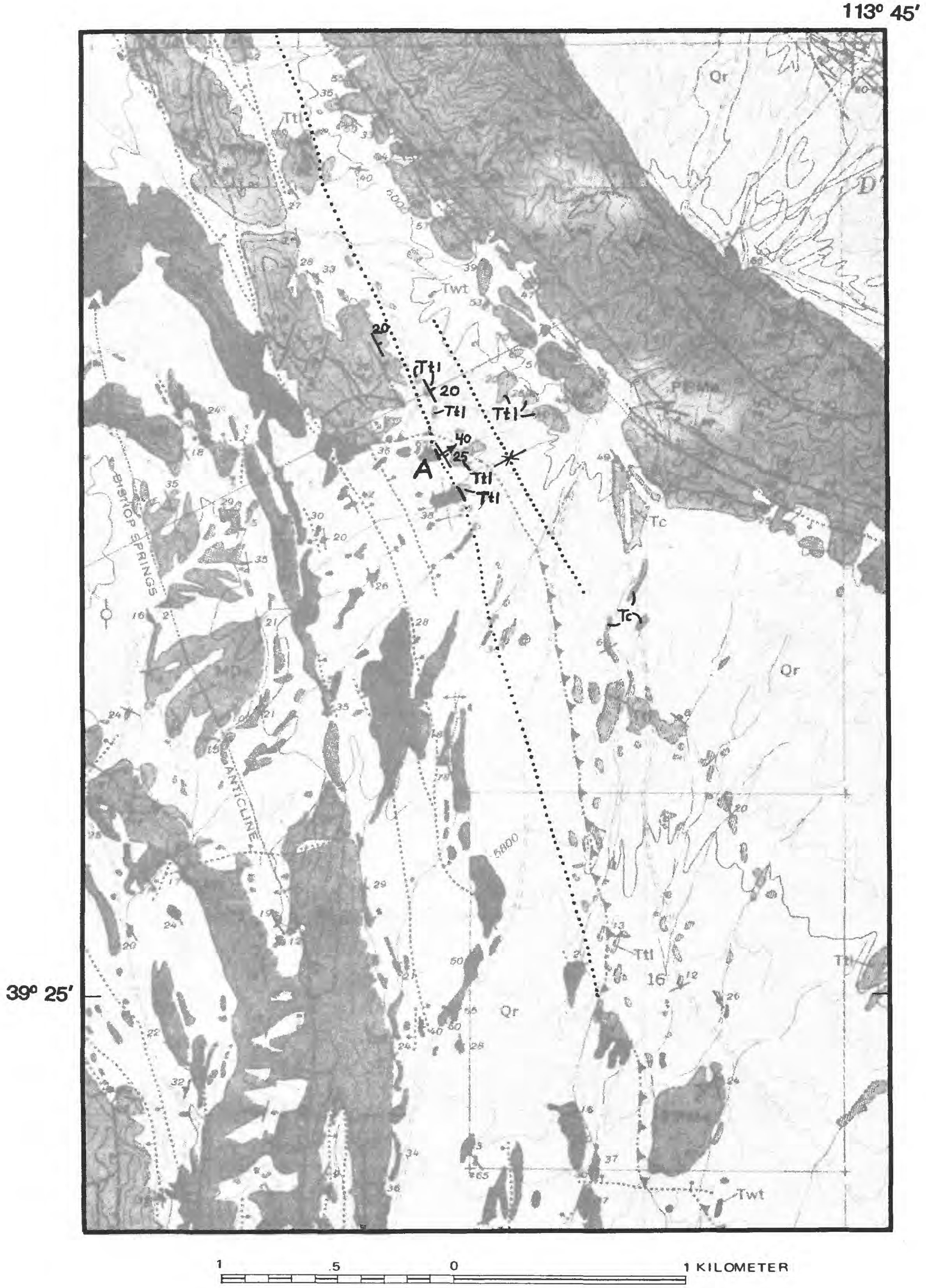



Figure 9.--Geologic map of part of the Gandy NE quadrangle, Utah. See figure 8 for explanation.

ment of the Confusion Range. These paleotopographic inferences are completely consistent with those based on remapping and structural relationships in the Disappointment Hills as noted above.

### Structure

Limited new structural data collected from the area between the Foote Range and Chevron Ridge of the Confusion Range indicate that the Tertiary rocks there were involved in at least part of the deformational history of the area. In the vicinity of locality A (fig. 8), tuff and overlying sedimentary debris are displaced by faults with apparent easterly downthrow toward the axis of the Confusion Range. Tertiary rocks are probably offset in a similar fashion by the westernmost fault that Hose and Ziony (1963) map as a younger-over-older "thrust" fault. Surficial debris along that fault near locality B, figure 8, includes clasts of volcanic rocks that are exotic to the area together with juxtaposed masses of poorly exposed highly disrupted Paleozoic rocks that may represent horse blocks dragged along the fault. The exotic volcanic clasts were probably derived from the fault zone where they may represent structurally attenuated remnants of the Tertiary stratal succession.

At locality A (fig. 9), a fault surface that separates brecciated and comminuted variegated Paleozoic rocks on the west from pulverized volcanic rock on the east was exposed by excavation of a pit with hand tools. Well-defined slip surfaces in the excavation dip 30° to 50°ENE and striations on quartzite in the pit suggest normal displacement of the Tertiary volcanic rocks. Similarly, striations on quartzite in nearby surface exposures have an average easterly bearing on fault and fracture surfaces that dip gently eastward. Tertiary strata in that area dip west toward Paleozoic rocks requiring a faulted contact. These data suggest that the younger-over-older "thrust" fault mapped south of locality A (fig. 9) by Hose and Ziony (1963) should be shifted west 100-300 m and shown as an attenuation fault with Cenozoic displacement.

At and to the north of locality A (fig. 9), newly acquired and previously published stratal attitudes indicate that an open syncline depicted in cross section as pre Cenozoic by Hose and Ziony (1963, D-D') is expressed in the Tertiary rocks and is therefore of Cenozoic rather than pre Cenozoic age.

## Summary

Newly acquired data show that much of the conglomerate in the northern part of the Confusion Range is interstratified with the Oligocene tuffs and, therefore, correlates approximately with widespread conglomerate in the Conger Range-Tom's Knoll area in the southern Confusion Range as well as with conglomerate in the Tunnel Spring Mountains-Burbank Hills areas. Throughout the Confusion Range, many of the conglomerates contain clasts of exotic rocks not found in locally exposed bedrock. These exotic clasts together with the interstratification with lacustrine limestone and extracaldera ash-flow sheets suggests coarse clastic deposition of sheet like bodies derived from sites of distant deformation. Thus, local and distant Oligocene deformation is documented.

The Oligocene rocks were apparently spread widely across the area now occupied by the Confusion Range. With the exception of the Browns Wash locality, they rest on pre-Tertiary rocks disconformably or with low angle unconformity. The highly folded and steeply tilted pre-Tertiary rocks common in axial parts of the range may represent highly deformed zones that have been elevated above less deformed zones by post Oligocene uplift. That those highly deformed rocks have been uplifted subsequent to Oligocene deposition is obvious. Whether they represent highly deformed zones that, prior to Oligocene deposition, were restricted areally or vertically is not known.

Both limbs of the CRST have been modified by folds that involve Oligocene rocks. Some of these folds, such as the Toms Knoll syncline and its anticlinal neighbor to the east, are genetically related to displacements on the faults that bound them. They could have formed in a compressional stress regime associated with tectonic displacement of rock toward the axis of the CRST.

The Tertiary strata in the Confusion Range-Conger Range area are cut by high-angle faults of known or inferred normal displacement. In each area the estimated amount of extension on these faults is less than 20 percent and in most areas it is probably about 10 percent. Extension related to high-angle faulting is probably greatest in the Dissappointment Hills where fault-related tilting of Oligocene or younger age has apparently reversed the regional pattern of dips in the eastern limb of the CRST.

A regionally extensive system of low-angle faults that either parallel bedding or cut it at low angles was mapped by Hose (1977). Over most of their mapped lengths, these faults are buried beneath alluvium and are therefore inferred in the subsurface. West of the axis of the CRST in the Toms Knoll area and in the area between the Foote and Confusion Ranges two important members of this regional system are now known to cut rocks of Tertiary age. The possibility seems good that the entire system is of Tertiary age. Because they are approximately bedding-parallel faults, estimates of displacement on them is difficult or impossible. Where they juxtapose large blocks of contrasting structural pattern or where there is evidence along them of important stratal attenuation such as west of Toms Knoll they could be large-displacement faults that acommodate large amounts of extension.

## DUCK CREEK-CENTRAL SCHELL CREEK RANGES

The central Schell Creek Range of east central Nevada is separated from the Duck Creek Range to the west by a topographically low area that is drained by Duck Creek and North Creek and their tributaries (fig. 10). The topographic low, referred to herein as Duck Creek Valley, owes its origin in part to the erosional denudation of relatively weak clastic sediments from an ancient basin and the westward transport of the eroded material into Steptoe Valley through a bedrock gap at the north end of the Duck Creek Range. Fair-quality exposures of the sediments and structures of the ancient basin resulted from the erosional denudation. A reconnaissance study of these exposures together with published mapping by Young (1960) and newly acquired radiometric ages provides a basis for evaluating the timing and mechanics of formation of the ancient breached basin.

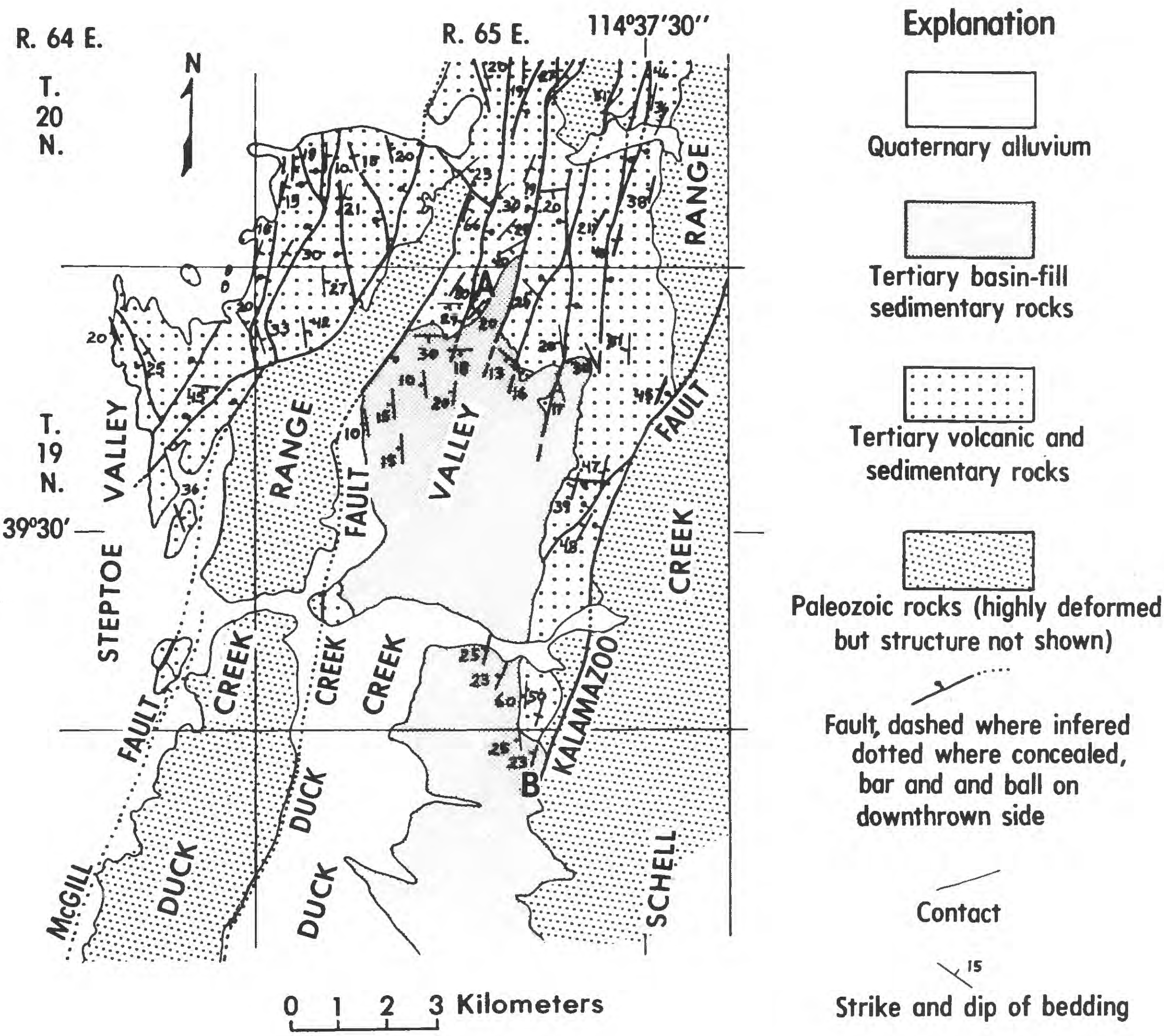



Figure 10.--Geologci map of the northern part of Duck Creek Valley, White Pine County, Nevada, showing selected attitudes and faults in Tertiary rocks. Map is generalized from mapping by Young (1960) and includes modifications based on field studies and photogeologic interpretation. Structures in areas underlain by Paleozoic rocks are omitted. Localities marked A and B are discussed in text.

Only the northern part of the Duck Creek Valley area is included in the geologic map (fig. 10). Young (1960) mapped and described several very important geologic relationships in that area; (1) Tertiary and older rocks are cut by an extensive system of low-angle, large-separation faults that consistently place younger rocks on older rocks (attenuation faults), (2) high-angle faults of predominantly normal separation cut the low-angle faults and are of several ages, (3) stratal rotations associated with Tertiary normal faulting formed the only large-scale fold--a broad synclinal warp the axis of which lies approximately along the NNE projection of the axis of the ancient basin beneath Duck Creek Valley, (4) sediments deposited in the ancient basin are downfaulted against complexly deformed Paleozoic rocks of the Duck Creek Range on the Duck Creek fault which has an estimated dip slip of 1 km, (5) the basin sediments were deposited unconformably on Paleozoic rocks and on various units of a thick faulted sequence of Tertiary volcanic rocks. Of these relationships the fault-formed syncline, the diverse ages of normal faults, the major west-bounding basin fault, and the unconformable contact are critical to understanding the evolution of the ancient basin.

At locality A (fig. 10) an ash-flow tuff belonging to the youngest of six widespread units of volcanic rock mapped by Young (1960) is downdropped in a narrow NNE-trending graben where it is overlain by landslide debris and coarse clastic sediments of the basin-fill sequence. Displacement of volcanic rocks in the graben is estimated to be 300 m. In the blocks east and west of the graben the basin-fill sediments rest on the next oldest volcanic unit. The basin-fill sediments are offset much more on the east graben fault than on the west graben fault. The east graben fault cuts the oldest basin-fill sediments with a throw of about 1/4 that of the underlying volcanic rocks and the fault appears to die out southward as it climbs higher into the basin-fill sediments. Three other NNE-trending faults east of the graben offset the volcanic rocks several times as much as they offset the overlying basin-fill sediments and all die out southward into stratigraphically higher basin-fill sediments. One of these faults, the Kalamazoo fault, is a major structure that transects the entire Schell Creek Range and locally has right-oblique normal slip estimated to be more than 1 km (Young, 1960). Where it enters Duck Creek Valley from the north it appears to juxtapose the lower 100 m of basin-fill fanglomerate against bedrock of the Schell Creek Range and to be overlapped by stratigraphically higher fanglomerate.

Despite the widespread evidence for pre-basin faulting, stratal attitudes of the oldest basin-fill sediments in the northern part of Duck Creek Valley are para conformable with the underlying volcanic rocks. Attitudes in both units describe a south-plunging open synclinal sag that developed synchronously with faulting. To the south, along the east limb of the syncline where younger basin-fill sediments rest on volcanic bedrock, dips in the volcanics are about twice those in the sediments. The youngest basin-fill sediments, although covered by Quaternary alluvium over large areas, dip homoclinally westward into the Duck Creek fault, and no sag is suggested.

The combined evidence of faulting, folding, and sedimentation suggest a history of; (1) extensive pre-basin faulting and graben formation, (2) early-basin faulting and the synchronous development of a sag along the basin axis, (3) termination of movement on the closely-spaced early faults, (4) continuous basin sedimentation associated with movement on a single fault at the west basin margin. All these events followed an episode of major attenuation faulting that probably reflects large-magnitude crustal extension.

Zircon extracted from the youngest ash-flow tuff in the volcanic sequence yields a fission-track age of 31.6 ± 1.5 m.y. whereas zircon from pumiceous air-fall tuff interstratified with coarse alluvial sediments about 150 m stratigraphically above the base of the basin-fill sediments yields an age of 27.4 ± 1.3 m.y. (table 1). These age data show that the basin began forming in Oligocene time. Unfortunately age-datable material was not found in the upper part of the basin fill. Those beds are assumed to be part of a single episode of basin formation and also to be of Oligocene age. Young (1960) suggested that the steep east-facing escarpment along the Duck Creek fault represents evidence of geologically young faulting, but I interpret it as an erosionally exhumed scarp that developed in response to highly contrasting resistance to erosion subsequent to erosional breaching of the bedrock ridge of the Duck Creek Range--probably during Pleistocene time. I interpret the Oligocene basin to have been uplifted with the Schell Creek-Duck Creek Ranges as a single structural block 25 km wide between the McGill fault on the west and the Schell Creek fault on the east (Young, 1960).

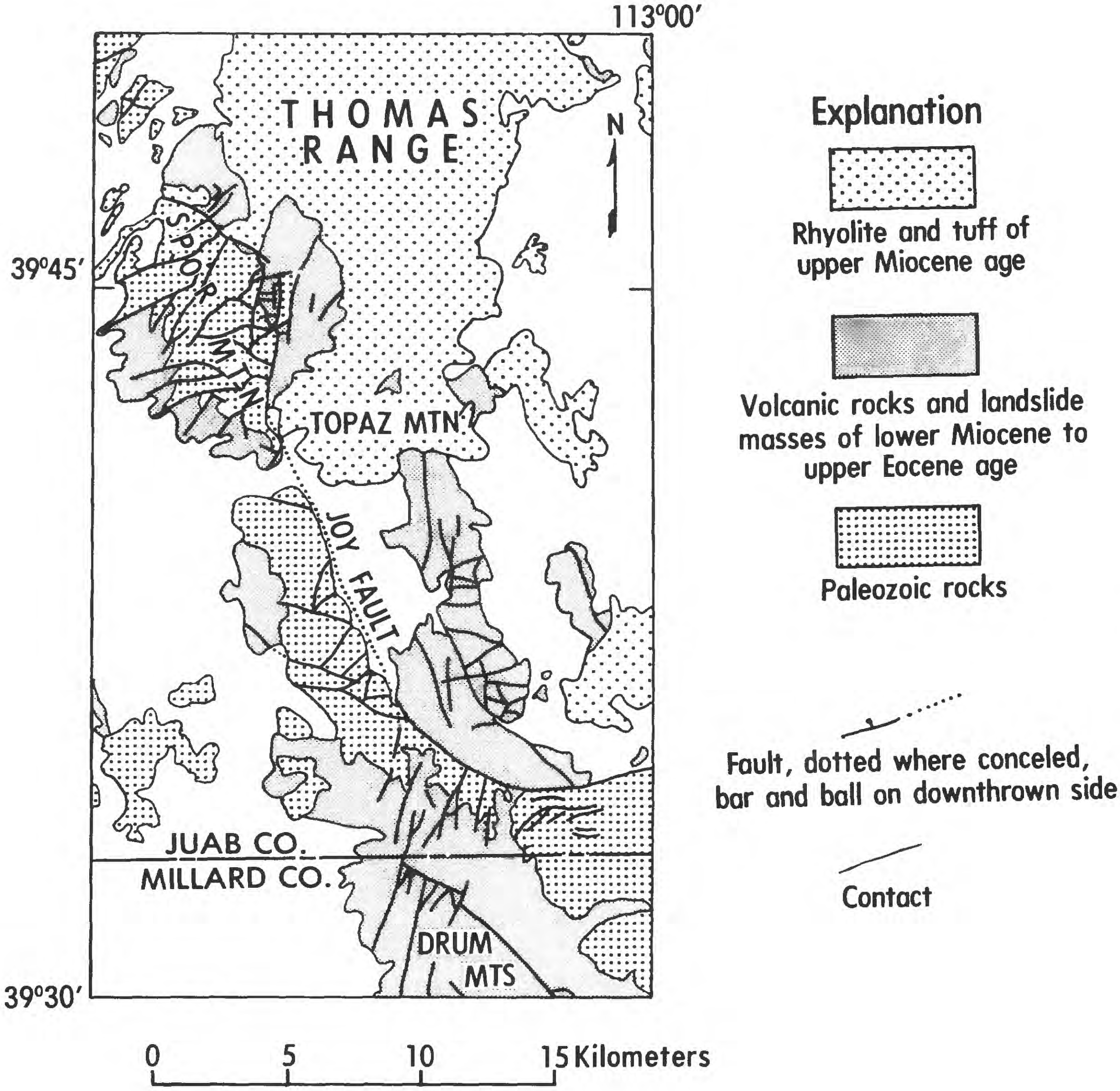
Available data from the Duck Creek Valley area suggest a continuum of structural evolution during Oligocene time from large-magnitude extension and structural attenuation on low-angle normal faults through an episode of moderate extension on steeper normal faults spaced about 1 km apart to minimal extension associated with minor faulting and structural sagging and ultimately to basin formation controlled by a single major fault. Uplift of the Duck Creek-Schell Creek structural block on faults spaced about 25 km apart could be a separate and much younger event that is currently in progress on the Schell Creek fault (Young, 1960).

## OTHER AREAS

### Spor Mountain-Drum Mountains

The Cenozoic structural history of central Juab County, Utah is dominated by events related to the development of an Oligocene volcanic cauldron complex the western and southwestern boundaries of which are well known (Shawe, 1972; Lindsey, 1979a, 1979b). Moderately good exposures of Cenozoic and pre Cenozoic rocks at Spor Mountain and in the northern Drum Mountains beyond the western and southwestern limits of the cauldron complex provide a basis for evaluating the nonvolcanogenic structural history of those areas (fig. 11).

Paleozoic rocks in the Spor Mountain-Drum Mountains area of western Juab County are so highly fractured and faulted that Crittenden (written commun., 1980) refers to them as possessing a "shattered glass" aspect such that maps at scales ranging from 1:62,500 to 1:100 tend to show faults with similar patterns and densities. Staatz and Osterwald (1959) mapped almost a thousand faults in an area of about 60 $km^2$ centered on Spor Mountain. Most of these can be classified as strike or transverse faults of small (less than 150 m) displacement. In the Detroit mining district, in the northern Drum Mountains, the most important structures are abundant steep NE- to E-trending transverse faults of small (less than 150 m) displacement (Crittenden and others, 1961).




Firgure 11.--Generalized geologic map of the Spor Mountain-northern Drum Mountains area showing distribution of selected faults (heavy lines) many of which cut Tertiary and Paleozoic rocks. The arcuate Joy fault and its northerly extension that passes between Spor Mountain and the Thomas Range (referred to as the Dell fault system by Lindsey, 1979) mark the approximate western boundary of a major volcanic caldera complex (Shawe, 1972). Large portions of the area mapped as lower Miocene to upper Eocene rocks east and north of the Joy fault consist of Paleozoic rocks that are herein interpreted to be landslide masses of Tertiary age. Some faults in those rocks may predate their emplacement as landslides.

Early workers interpreted the highly fractured and faulted aspects of rocks in the Spor Mountain and Drum Mountains areas to have formed prior to the latest Eocene volcanic rocks that flank the Paleozoic rocks (Staatz and Carr, 1964; Crittenden and others, 1961). However, recent studies by Lindsey (1979a, b) have shown that almost all major faults on Spor Mountain, whatever their trend, extend beyond the Paleozoic rocks and cut volcanic rocks of Eocene, Oligocene, and early Miocene age (21 m.y.). Of equal importance is the fact that the attitudes of the Paleozoic rocks in the core of Spor Mountain match those of Tertiary rocks exposed along strike to the northeast and southwest. Available data support an interpretation analogous to that made for the Tunnel Spring Mountains (Anderson, 1980) where a similar style and intensity of deformation of the core Paleozoic rocks and flanking Miocene rocks suggests little, if any, pre Miocene faulting and stratal rotation.

Compared to the Tunnel Spring Mountains, structural relationships are not as clear-cut in the Drum Mountains where the contact between Tertiary and Paleozoic rock is mostly covered (Crittenden and others, 1961) and volcanic rocks are massive, unbedded, and uniformly fine grained making the identification of faults in them difficult or impossible. Limited exposures of the contact show that it is faulted locally and, where known, the attitude of the volcanic rocks is approximately parallel to that of the adjacent Paleozoic rocks. A search of the contact failed to reveal features suggestive of deposition on a paleosurface. There are no chilled or flow brecciated basal lithofacies in the volcanic rocks, nor could any evidence be found of prevolcanic weathering or deposition of clastic debris between the volcanic and prevolcanic rocks. Lindsey (1979a, b) noted several faults of various trends in volcanic rocks in the northern Drum Mountains (fig. 11) and Leedom (1974) mapped NE- and NW-trending transverse faults in Tertiary volcanic rocks in the nearby Little Drum Mountains. Hintze (1978) designated nearby areas to the west in which rocks are broken by a myraid of high-angle faults of small displacement as having been "jostle faulted". Aerial photos of such areas show contacts to be fuzzy or poorly defined. Many of the Paleozoic and Tertiary rocks of the Drum Mountains have this appearance. Taken together these observations raise the question of how much faulting and stratal tilting in the Drum Mountains, if any, preceeded deposition of the volcanic rocks. Mapped faults in the Drum Mountains are similar in trend, form, and density to those of known Miocene or younger age in the Spor Mountain area and are inferred by me to be of similar age. Most of the faulting is interpreted to be of late Cenozoic age.

Fault-related stratal tilt directions in the Spor Mountain area suggest NW-SE extension. Two cross-strike structure sections constructed through the core of Paleozoic rocks by Staatz and Osterwald (1959) indicate 13 and 8 percent extension. An unpublished parallel structure section constructed through Cenozoic rocks southwest of Spor Mountain and based on structural data collected by me indicates a comparable amount of 10 percent NW-SE Miocene or younger extension as does a structure section prepared by Lindsey (1979b). Because strike faults are generally not recognized in the Drum Mountains (Crittenden and others, 1961) the area is unfavorable for estimating directions or amounts of Cenozoic extension.

Breccias

Two units of coarse breccia of Oligocene (?) age are found in the area north and east of Spor Mountain (Lindsey, 1979a, b). The oldest unit consists of variegated weakly cemented coarse sedimentary breccia in which the average clast assemblage is comprised of about 80 percent volcanic fragments (including vitrophyric, amygdaloidal, and flow-layered types ranging from rhyolite to dacite) and 20 percent fragments of Paleozoic carbonate rocks. Fragments range from fine sand to 2 m in diameter and from angular to moderately rounded. Indistinct bedding and size grading is seen in some exposures, and in one it is of good enough quality to yield a reliable attitude of N35E 30 NW. A widespread delicate color banding strikes parallel to the measured bedding and is conspicuous on aerial photographs suggesting that the measured attitude is representative of a large area of breccia. The sedimentary breccias are overlain by a unit that includes sheets and lenses of crackled and deformed landslide breccia composed of Paleozoic dolomite and minor quartzite shuffled together with lenses of brecciated volcanic rock. Exposures of individual landslide sheets range to 400 m in length, and internal bedding features can be traced through most of them, indicating dislocation but incomplete disruption during transport. Locally, internal bedding features are sufficiently intact and the boundaries of the sheets sufficiantly well exposed to suggest that they are essentially parallel. The sheets strike NE and dip NW--approximately parallel to bedding in the underlying sedimentary breccia. Because these attitudes match those of the structurally tilted Paleozoic rocks on Spor Mountain and the Oligocene and Miocene rocks on the southwest flank of Spor Mountain, they are interpreted as resulting from Miocene fault-related tilting. The coarseness and general lack of conspicuous stratification in the sedimentary breccias suggest that they were deposited as colluvium or fanglomerate at or near the base of a steep mountain front. The crackeled aspect of the landslides is consistent with emplacement at or near a steep mountain front. Lindsey (1979) interpreted the breccias as landslides and debris flows related to collapse of caldera walls formed during cauldron subsidence following eruption of ash-flow tuffs 42-32 m.y. ago. However, the sedimentary breccias do not resemble caldera-fill deposits, are not underlain by ash-flow tuffs, nor do they contain clasts of ash-flow tuffs. They probably predate all Oligocene ash-flow tuffs in the area. Likewise, ash-flow tuff debris is not represented in the landslides. Also, the main area of known distribution of debris in the vicinity of Spor Mountain is outside of (west of) the cauldron margin as defined by Lindsey (1979a). The debris is herein interpreted as evidence of an episode of precaldera latest Eocene or early Oligocene mountain building--probably fault-generated mountain building.

In summary, available data suggest at least two episodes of Cenozoic deformation in the Spor Mountain area unrelated to volcanotectonic disturbance. The causative structures for the first, during latest Eocene or early Oligocene time are not known. The second, during Miocene or later time, produced numerous faults and stratal rotations that appear to have resulted from localized NW-SE extension. The Drum Mountains area was probably involved in the second episode of deformation.

## Sand Pass Area

The Sand Pass area is located in the northernmost House Range, Juab County, Utah (fig.1). Extensive studies of thickness variability in lower Paleozoic rocks in the Fish Springs and House Ranges north and south of Sand Pass together with high-quality geologic mapping in those ranges forms the basis for estimating the amount and distribution of structual attenuation of the stratigraphic section (Hintze, 1978). Attenuation is produced by brittle failure (faulting). The amount varies abruptly from area to area and highly attenuated areas are commonly bounded by transverse faults (fig. 12). Over most of the Fish Spring and northern House Ranges it is not recognized, but it ranges to as much as 50% locally (Hintze, 1978). One of the attenuated areas reported by Hintze (1978) extends in a band southward from the Sand Pass area discussed herein (fig. 12). In that area about one-third of the lower Paleozoic rocks are missing as a result of structural attenuation.

I have done no mapping in the Sand Pass area. I offer herein an interpretation of the age of the attenuation faulting that differs from the Jurassic and Cretaceous age assigned to it by Hintze (1978). Latitic intrusive masses at locality A (fig. 12) were mapped by Chidsey (1977) and described as cutting attenuated Paleozoic strata. Good-quality exposures in that area show that most of the exposed latite is highly fractured and faulted. Some faults are internal to the latite and others juxtapose highly fractured latite and highly fractured Paleozoic rock. Faults are marked by gouge zones as much as 20 cm wide and zones of shattered or brecciated rock several meters wide. Some brecciated contacts between latite and marine sedimentary rocks are highly silicified. At some, clasts of silicified breccia are included in silicified breccia indicating multistage faulting and associated alteration. In some places the true width of brecciated and altered latite contacts is indeterminate because of small exposures. The dip of faults and breccia zones that involve latite ranges from steep to shallow as do faults in the highly attenuated area of Paleozoic rock to the north and south (fig. 12). These observations suggest that the latite is involved in the attenuation faulting as well as in faulting of steeper dip.

Apatite grains extracted from a porphyritic quartz latite containing about 15 percent phenocrysts consisting of altered plagioclase, quartz, biotite, and alkali feldspar in a finely maculose groundmass yields a fission-track age of $30.6 \pm 3.75$ m.y. indicating an Oligocene or younger age for the deformation (table 1). The revised age assignment for fault deformation in the Sand Pass area has important implications for the structural history of central Juab County, Utah. Hintze (1978) schematically illustrated a three-stage history of faulting for the southern Fish Springs Range (fig. 13). This history is completely consistent with my observations in the Sand Pass area directly to the south. The first-stage faults in this area, which is far removed from the area of major volcanotectonic disturbances of central Juab County, are low-angle attenuation faults that result in strong stratal attenuation by displacements on surfaces that are approximately parallel to bedding. This style of faulting is highly restricted to specific areas in the Fish Springs and northern House Ranges (fig. 12). Despite its highly restricted nature and a strong indication of southeast-directed tectonic transport, this younger-on-older attenuation faulting has been interpreted as physically and

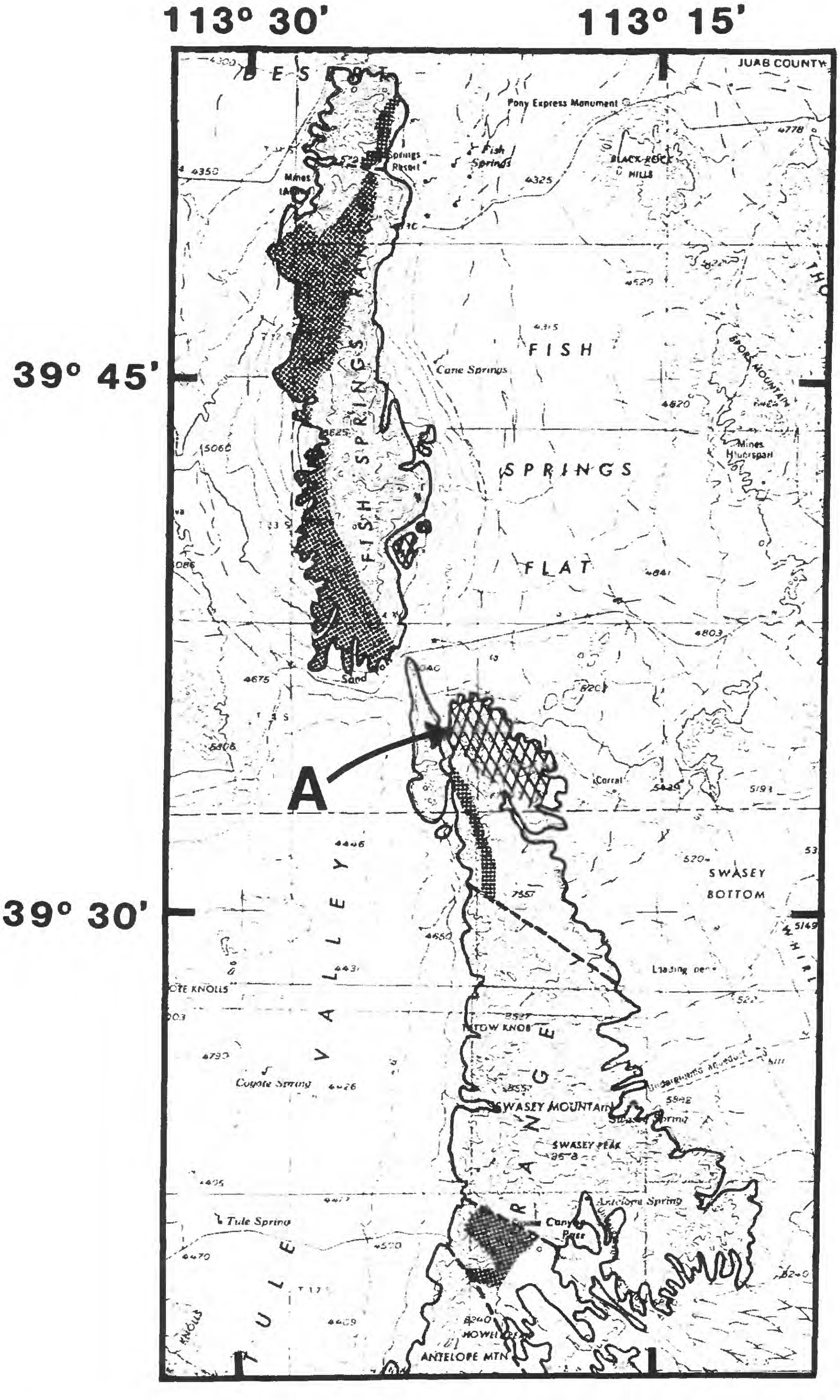



Figure 12.--Map of Fish Springs and northern House Ranges outlining exposed areas of concentrated attenuation faulting (shaded) and "jostle" faulting (cross-ruled). Heavy dashed lines are major transverse faults that bound areas of attenuation. Bold letter refers to locality discussed in text. Illustration after Hintze, 1978.

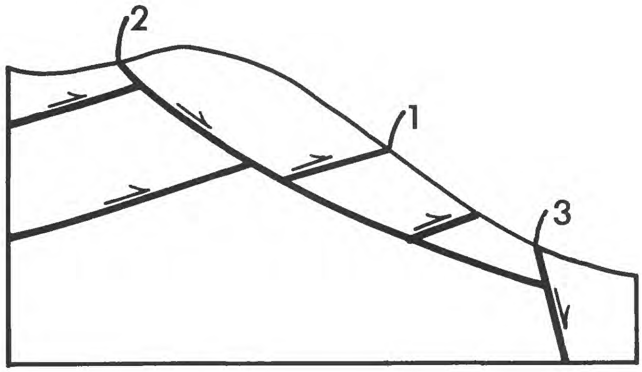



Figure 13.--Schematic diagram showing sequence of faulting (heavy lines with arrows) in the southern Fish Springs Range, Utah. Stage-one faults are approximately parallel to bedding; they are inferred to be large-displacement faults because they locally result in large-magnitude stratal attenuation. Stage-one faults are rotated by stage-two faults. Illustration by Hintze, 1978.

genetically linked to the broad east-directed overthrust sheets of the Sevier orogenic belt to the east (Hose and Danes, 1973, Hintze, 1978). These interpretations imply that the attenuation faults and related structures represent removal of rocks from the hinterland and structural transport of those rocks toward the foreland thrust belt. The great dimensional contrast between the relatively small areas in central-west Utah that have been subjected to significant amounts of attenuation faulting and the great breadth of the overthrust sheets seems to me to preclude the physical and genetic link implied in those interpretations. The reinterpreted age of the attenuation faulting also precludes such interpretations. It is not plausible to look farther west for a solution to the dimensional dilemma. In that region in the Snake, Schell Creek, and Egan Ranges of eastern Nevada, where a 110 km-wide northerly trending belt of strong structural attenuation-type deformation is well documented, the age of the deformation is equally discordant. It is of mid to late Cenozoic age (Miller and others, 1982, Gans, 1982) and thus post-dates the overthrusting associated with the Sevier orogeny.

The great contribution of L. F. Hintze and his students in documenting the nature, amount, and areal extent of strong stratal attenuation in central west Utah should not be overlooked or underestimated. Those data form the basis for a comprehensive structural interpretation only the age of which is variously interpreted.

## SUMMARY AND CONCLUSIONS

New data that include the widespread occurrence of tectonically significant coarse clastic deposits of Oligocene and younger age raise important questions regarding the Cenozoic structural history of west-central Utah. (1) How much of the deformation is Oligocene or younger? (2) Within what stress regime did those structures form? (3) How did that stress regime compare with the one in which older structures were produced? (4) How much time, if any, separated the old structures from Neogene structures? Not all of these questions can be answered satisfactorily.

Limited new data from the central Schell Creek Range fit nicely into a pattern of Oligocene structural evolution that begins with voluminous igneous activity and large-magnitude extension on closely spaced faults and evolves into clastic-dominated basin sedimentation possibly controlled by a single fault. That this evolutionary pattern apparently ran its course in Oligocene time is of considerable interest because it seems to be a short-term small-scale analogue of the structural evolution of many areas in the Basin and Range province (Zoback and others, 1981, Eaton, 1982). The evolution of the basin beneath Duck Creek Valley is of interest because it seems to be a partially exposed analogue of some other basins in the Great Basin which, on the basis of seismic reflection data, appear to have formed initially as sags and to have evolved from early displacements on several faults that were subsequently deactivated as the basin grew wider. Ultimately the development of those basins was controlled by displacement on one or two widely separated main faults (Anderson and others, in press).

The main significance of limited new data from Spor Mountain, the Drum Mountains, and the Sand Pass area of the House Range pertains to the timing of deformation in those areas. At Spor Mountain an Eocene or early Oligocene event that produced precipitous terrain from which coarse detritus and landslide blocks were shed predates the major episodes of caldera formation in that region. The early deformation is inferred to have developed in an extensional regime that persisted throughout, and outlasted, the major Oligocene and Miocene caldera-forming events. Faults in the Drum Mountains are similar in trend, form, and spacing to those of known Miocene or younger age at nearby Spor Mountain and are inferred to be of similar age. At Sand Pass very limited new data indicate that the geographically restricted zones of well-documented attenuation faulting in that area, as well as the two episodes of subsequent normal faulting, are younger than about 30 m.y. If the indicated relationship is true, it precludes a physical or a genetic association between the attenuation faulting and thrusting in the Sevier orogenic belt to the east. The least principal stress direction inferred from fault orientations in the Sand Pass and Spor Mountain areas is NW-SE.

Together with extensive published geologic mapping, the observations reported herein provide a basis for tentatively evaluating the distribution, style, magnitude, and age of deformation across the CRST. The opportunity to make such an evaluation from surface exposures is greater east of the axial region where exposures tend to be tied together by range blocks that adjoin one another than to the west where bedrock is buried beneath the broad north-trending Hamblin and Snake Valleys. For example, in the Confusion, northernmost Wah Wah, and southernmost House Ranges Oligocene rocks rest on progressively younger rocks toward the northwest, that is, the critical contact rises stratigraphically toward the axis of the CRST. This relationship together with appropriately oriented low-angle unconformities and local severe paleotopography at the base of the Oligocene rocks proves that the CRST is older than those rocks.

The intensity of deformation in Paleozoic rocks increases westward from the northern Wah Wah, and southern Confusion and House Ranges toward the axis of the CRST. Lower Paleozoic rocks in the former area form mildly faulted flat-lying to gently tilted broad blocks (Hintze, 1963), whereas Hose (1977) mapped complex fold and fault structures that include open and isoclinal harmonic and disharmonic folds, recumbant folds, a narrow mushroom fold, rooted thrusts, and decollement faults in upper Paleozoic and Triassic rocks in the axial region of the CRST. He interpreted all these structures to be older than the Oligocene rocks in the area and to have resulted from thin-skinned gravitational gliding and flowage toward the axis of the CRST.

Throughout the area where the critical contact rises through the Paleozoic section as the axis of the CRST is approached, Oligocene rocks are generally slighly less deformed than the Paleozoic rocks on which they rest or than the nearest exposed Paleozoic or Mesozoic rocks. High-angle unconformities at the critical contact are sparce. Even where Paleozoic rocks are highly folded over broad areas, as in the axial parts of the Confusion Range, well documented exposed high-angle unconformities at the critical contact are sparce. I have observed such contacts in only one area--Browns Wash, and Hose (1977, p. 1) describes another. Several published cross sections depicting high-angle unconformities are invalid on the basis of newly acquired and previously published data. At several localities where there seems to be a good possibility of documenting a high-angle unconformity, the rocks of the two age groups are separated by faults or by inferred buried faults. Perhaps the scarcity of documented high-angle unconformities is fortuitous--related only to the low level of opportunity associated with the scarcity of Tertiary rocks. Alternatively, Neogene sites of deposition may have been localized by differential vertical movements similar to those that produced the older systems of folds and faults. Because most of the steep and overturned attitudes in pre-Tertiary rocks are associated with zones of sharp uplift, continued or renewed movement in those zones during the Neogene would have greatly limited the development of high-angle unconformities. The possibility also exists that the intensely deformed rocks represent a tectonically stratified zone of deformation that, prior to its uplift in the axial areas, was buried beneath a skin of less-deformed coeval rock that included the Oligocene and directly subjacent pre-Tertiary strata. It is equally possible that prior to Oligocene deposition the intensely deformed rocks were areally restricted to narrow zones such as those seen at current levels of exposure (fig. 4).

Oligocene strata throughout the axial region of the CRST contain large amounts of conglomerate that record major local and distant Oligocene deformational events. Together with the distribution of sheet-form bodies of ash-flow tuffs, the Oligocene stratigraphic record allows for paleogeographic reconstruction of an Oligocene basin across what is now the northern Confusion Range and one or more basins in the southern part of the CRST. The basins are inferred to have been fault-controlled by reactivation of previously formed faults or steep fold flanks. Examples are the Browns Wash fault and the west-bounding fault of the Toms Knoll syncline. Parts of early-formed basins were cannibalized as local syndepositional deformation took place in the axial region of the CRST. Both limbs of the CRST in the Conger-Confusion Range area have been modified by folds that involve Oligocene rocks. As with the older folds, some of the Neogene folds appear to be genetically related to bounding faults. The Toms Knoll syncline, the best known of the Neogene folds, probably formed contemperaneously with deposition of Oligocene coarse clastic and lacustrine carbonate rocks within it. The Neogene folds could be related to thin-skinned tectonic gliding toward the axis of the CRST.

Most stratal tilting in the Tunnel Spring Mountains is fault-related and postdates the Oligocene rocks. It represents a major extensional event of possible Miocene age. Cross-strike alternations in fault-related tilt directions produced fold-like structures within the extended terrain. Though relationships in the nearby Burbank Hills are not so clear-cut, stratal dips in Oligocene and younger rocks, and possibly also in pre-Oligocene rocks, are apparently related to extensional deformation. Stratal tilts in the Disappointment Hills resulted mostly from Oligocene or younger faulting. The relationship between this tilting and the Cenozoic uplift of the much more highly deformed core of the northern Confusion Range is not known.

Hose (1977) described two decollement faults in the northern part of the CRST. Regarding the upper fault, he concluded (p. 8):

> "As the Confusion Range structural trough developed, the flanks became steeper. When some unknown critical slope was reached, competent units high in the section sheared loose from

> weak gypsiferous zones of the upper Arcturus Formation and moved in a quasi-viscous manner toward the axis of the trough. The inward-directed movement of this upper plate produced isoclinal and recumbent folds whose basal disharmonic surfaces became coincident with the major glide surface, or decollement. The occurrence of recumbent folds with opposing directions of overturn toward the axis of the Confusion Range structural trough is best explained by gravity sliding...."

Regarding the lower one, he concluded (p. 8):

> "The intermediate plate formed in a similar way to the upper plate, but it developed on a lower stratigraphic level and was confined to the west flank [of the CRST]."

Hose (1977) concluded that the evolving CRST was filled with folded rock as a result of axially directed gravity gliding and flowage on the two decollement faults.

There are no new data pertaining to the origin, significance, or age of the upper decollement fault. I accept the interpretation of that structure as a pre-Oligocene fault along which rocks moved toward the axis of the evolving CRST (Hose, 1977). However, I acknowledge that because it is neither overlapped by Tertiary rocks nor are such rocks cut by it, its Tertiary history is not known. Whatever its age, it forms the sole for numerous complex structures above it. The general picture is one of highly complex, thin-skinned deformation that does not alter the overall simple form of the CRST.

As noted by Hose (1977), the lower of the two décollement faults is restricted to the west flank of the CRST. My studies show that at all localities where previous workers show it to be overlapped by Oligocene rocks, it actually cuts those rocks. Its north and south parts may not connect. I named the south part the Buckskin Hills fault (fig. 4). I interpret it to be one of several faults on the west flank of the CRST characterized by stratal omission or attenuation; that is, they place younger rock on older rock. Other examples are the Conger Range and Salt Marsh Range faults of Hose (1977, and fig. 4, this report) which place upper Paleozoic rocks against Silurian and Devonian rocks. The Paleozoic section is severely attenuated in a zone along the Conger Range fault (Hose, 1965) and below the Salt Marsh Range fault (Hose and Ziony, 1963). The surface trace of subsidiary faults above and below the Conger Range fault (Hose, 1965) and below the Salt Marsh Range fault (Hose and Ziony, 1963) strongly suggest that they and the main faults represent a younger-over-older fault system that cuts bedding, especially bedding in the footwall blocks, at low angles. Because there is no evidence to the contrary, I interpret these faults to be of Cenozoic age and to have developed in an extensional regime. Together with the widespread occurrence of high-angle late Cenozoic normal faults, they represent major extentional tectonic events.

The Confusion Range structural trough is located between a broad (110 x 65 km) area of intense Cenozoic extension to the west in the Egan, Schell Creek, and Snake Ranges (Gans, 1981) and an equally broad area (about 8000 $km^2$) of Cenozoic basin fromation in the Sevier Desert basin to the east

(McDonald, 1976; Anderson, Zoback, and Thompson, in press). In the western area, displacement of hanging wall blocks above shovel-shaped normal faults is mainly eastward relative to footwall blocks (Gans, 1981). In the structural block closest to the CRST, the Snake Range, extensional faults of that type merge downward into the east-dipping Snake Range decollement fault (Gans, 1982; Miller and others, 1982). If projected eastward, the Snake Range decollement should exist in the deep subsurface beneath the CRST. Extensional deformation in the area west of the CRST is Oligocene or younger (Gans, 1982; Miller and others, 1982).

In the Sevier Desert basin east of the CRST, extensional faulting related to basin formation of late Oligocene and younger age appears, on the basis of seismic reflection profiles, to be restricted to a zone above a west-dipping decollement fault (Anderson and others, in press). If projected down dip, this decollement should also exist in the deep subsurface beneath the CRST.

The extensional structures of the Sevier Desert basin are separated from those in the axial region of the CRST by a zone about 25 km wide within which there is remarkably little evidence of Oligocene or younger deformation at exposed structural levels. Oligocene rocks in that area are cut by a few north- and northwest-trending high-angle faults of small displacement and show little, if any, stratal tilting. If the Sevier Desert detachment fault extends beneath this area, as I suspect it does, the little-deformed rocks represent a structural block that is involved in, but does not bear an internal record of, regional extension. Such a block was illustrated by Wernicke (1981, fig. 3c) as one of several structural elements above a rooted low-angle normal fault.

Westward from the area of little-deformed Oligocene rocks the intensity of Cenozoic deformation increases--just as it does in the pre Cenozoic rocks as noted above. The low-angle attenuation faults of known or inferred Cenozoic age on the west flank of the CRST are of special significance. With the possible exception of the Conger Range fault, their mode of displacement is similar to that of rocks cut by the Snake Range decollement which is inferred to exist several kilometers beneath them. Available evidence suggests attenuation-related Cenozoic detachment at more than one structural level in the axial region of the CRST. The shallow detachment may be coeval with and conformable in displacement sense to the deeply penetrating axially vergent decollement zones. Blocks beneath the deep decollement faults may have moved away from the axial region. Extension above them may, in part, reflect such movement.

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