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FIELD TRIP GUIDE TO THE SOUTHERN EAST HUMBOLDT RANGE AND NORTHERN CURRIE HILLS, NORTHEAST NEVADA: AGE AND STYLE OF ATTENUATION FAULTS IN PERMIAN AND TRIASSIC ROCKS

by

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INTRODUCTION

One of the most difficult aspects in unraveling Basin and Range geology is dating attenuation faults, which are low-angle younger-over-older faults that can be interpreted as contractional or extensional in origin. Units are typically thinned or eliminated, commonly with little discordance between juxtaposed beds. Hintze (1978) documented this style of faulting in western Utah and attributed it to the Sevier orogeny. Attenuation faults abound in the region, but are commonly difficult to date because of a lack of crosscutting or overlapping features (Nutt and others, 1992; Nutt and Thorman, 1994). Being unable to date an attenuation fault makes it difficult to relate the fault to extensional or contractional tectonics. In the case of the southern East Humboldt Range, we consider the attenuation faulting to be related to Jurassic (Elko) or Cretaceous (Sevier) contractional tectonics; on this field trip we will see some of the field evidence on which this conclusion is based. In the northern Currie Hills, sufficient data have not been compiled to allow us to confidently restrict the timing of attenuation to the Mesozoic.

THE SOUTHERN EAST HUMBOLDT RANGE

The Ruby and East Humboldt Ranges have been mapped by Sigmund Snelson (1957), Keith Howard (1980), and Howard and others (1979), and have been the subject of much work by Art Snoke (University of Wyoming) and a cadre of his graduate students for the past 15 years or so. These ranges constitute one of the better studied metamorphic core complexes in the North American Cordillera. Metamorphic core complexes are most often thought of in the context of their Tertiary extensional deformation; commonly their contractional record is ignored. This field trip deals with structures that would most likely be assigned to middle Tertiary deformation if it were not for the preservation of Eocene igneous rocks that overlie and crosscut them.

The southern part of the East Humboldt Range (fig. 1), the subject of this morning's field trip, is underlain by both upper and lower plate rocks of the Ruby-East Humboldt Range detachment fault (Snoke and Lush, 1984; Dokka and others, 1986; Snoke and Miller, 1988). Footwall rocks primarily are regionally metamorphosed Cambrian to Lower Mississippian strata with minor pegmatitic bodies. The hanging wall rocks include unmetamorphosed Permian and Triassic sedimentary strata and Eocene volcanic rocks. We will be

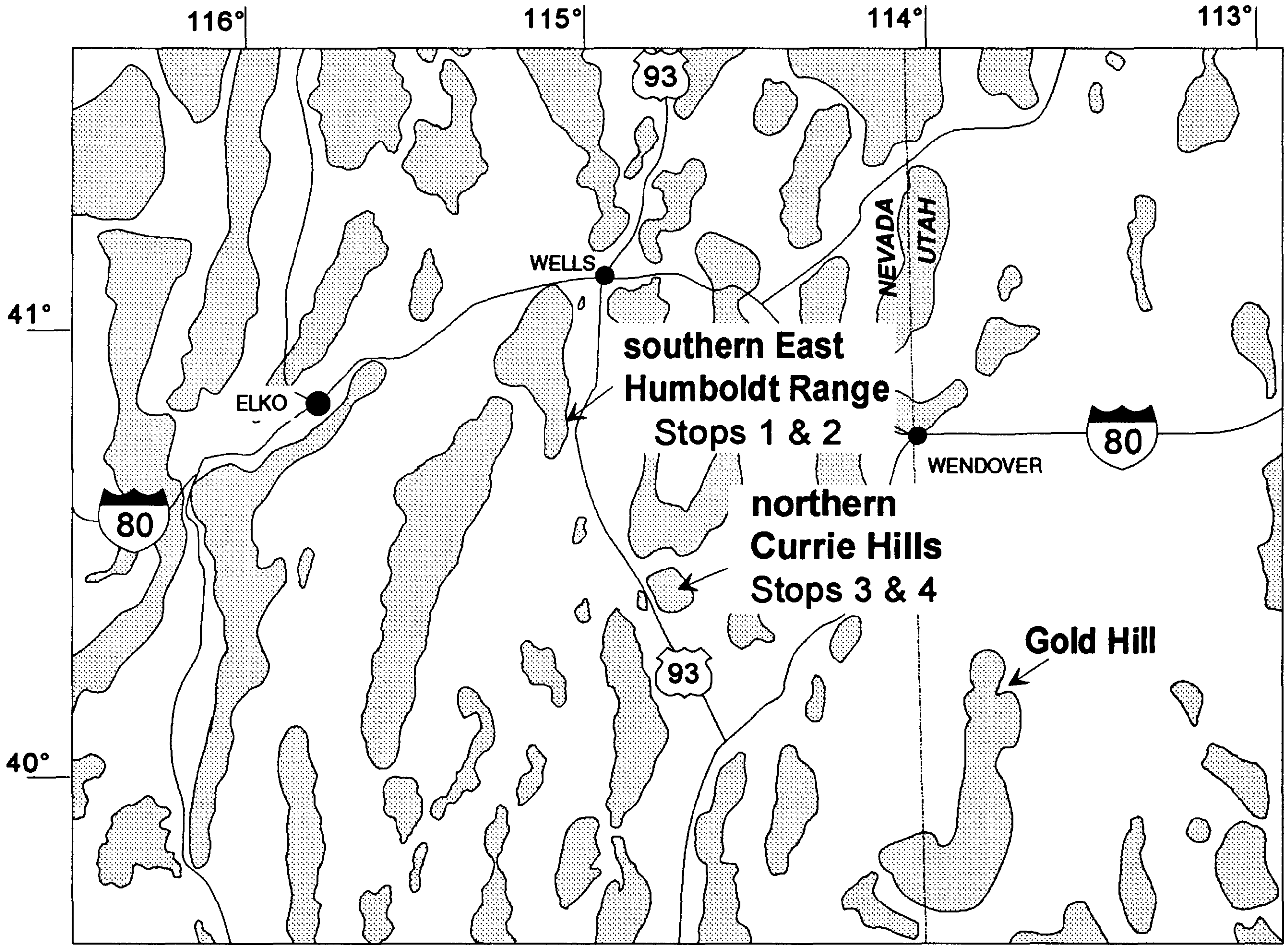

Figure 1. Index map of northeastern Nevada and northwestern Utah showing the location of the areas to be visited during the field trip.

concerned with two aspects of the footwall rocks, the basal Tertiary (middle Eocene) unconformity (Stop 1) and attenuation, or near bedding-parallel, faults (Stop 2). The Permian and Triassic units are tectonically thinned or completely removed along two low-angle younger-over-older, attenuation fault zones. Unconformably overlying and intruding these strata are middle Eocene (39 to 41 Ma) andesitic and rhyolitic flows and dioritic rocks that date the attenuation faulting and related deformation as being pre-middle Eocene in age and therefore unrelated to middle Tertiary metamorphic core complex extensional tectonics.

STOP 1

Here the middle Eocene volcanic rocks rest unconformably on folded Lower Triassic Thaynes Formation strata. A basal conglomerate is preserved locally along the unconformity. We will examine the three units and emphasize the following points: nature of the volcanic field and its areal extent; importance of the clasts found in the basal conglomerate; and the significance of the age and nature of the angular unconformity.

Volcanic rocks -- These rocks are part of the Northeast Nevada Volcanic Field (see Brooks and others, in press), which consists of middle Eocene (42.9 to 39.0 Ma) calc-alkalic andesitic to rhyolitic rocks that were erupted across northeastern Nevada and western Utah. They are the oldest Tertiary volcanic rocks in the region and generally unconformably overlie deformed middle Paleozoic to lower Mesozoic strata. In a few areas, early Eocene lacustrine beds underlie the volcanic rocks, most notably near Elko, where the volcanic rocks rest on the Eocene Elko Formation and along the Nevada-Utah line west of Gold Hill where they overlie the Eocene White Sage Formation.

In the southern East Humboldt Range, middle Eocene volcanic rocks underlie low hills in a northwest-trending belt about three miles wide and six miles long. Based on photogeologic interpretation, the northern part of the belt is gently folded about a north-northeast-trending syncline. To the north, the volcanic rocks rest on deformed Triassic and Permian strata. The Permian and Triassic rocks on the western side are moderately, though extensively, altered to hornfels and marble in what we consider to have been the base for a middle Eocene volcano. Dioritic rocks intrude these strata in a northwest-trending belt. On first examination in the field, the dioritic rocks were extremely difficult to distinguish from the flow rocks. The southern part of the belt underlies two conical hills that may represent volcanic edifices.

Andesitic to dacitic flows and flow breccias are the dominant rock type and are typically poorly exposed as dark monolithologic rubble. Most commonly the rocks contain medium-grained phenocrysts of plagioclase, hornblende, pyroxene, and (or) biotite in a fine-grained trachytic matrix. A few interbeds of rhyolitic crystal-poor lithic tuff and vitric ash form light-colored patches in the dark landscape of the volcanic rocks. Two dacite flows are 38.8 and 39.5 Ma. A flow-banded rhyolite west of Curtis Spring is probably a small flow dome. No marker beds have been observed in the volcanic field.

The low, conical-shaped hills to the southeast, towards Spruce Mountain, are underlain by these volcanic rocks. Red, oxidized flow contacts are prominent in many locales. Several agglomerate and spatter-type features indicate probable local vents. No such features have been observed immediately north and south of the highway.

It is important to note the angular relation of the volcanic rocks on the Triassic strata, because just a short distance to the north and east, the volcanic and Triassic rocks are in low-angle fault contact with footwall rocks of the middle Tertiary detachment fault. This dates two episodes of deformation, folding of the pre-Tertiary rocks and faulting of the entire package in post-Eocene time. Along the route to Stop 2, we will drive over the unconformity where the volcanic rocks overlap a synclinal axis in the Thaynes.

Basal conglomerate -- This unit is poorly exposed beneath the middle Eocene andesitic rocks. The conglomerate contains clasts of rhyolite ash-flow tuff, upper Paleozoic and Triassic strata, and chips of ostracode-bearing lacustrine limestone that contain grains of biotite. One clast of biotite-bearing rhyolite ash-flow tuff in the conglomerate gave an $^{40}Ar/^{39}Ar$ of 41.0 Ma on biotite, dating the conglomerate as 41.0 to 39.5 Ma (the latter age being that of the oldest volcanic rock we have dated here). The conglomerate also contains clasts of upper Paleozoic and Triassic strata and ostracode-bearing lacustrine limestone that contain grains of biotite. Ostracode-bearing limestone clasts indicate the existence of lakes in the immediate vicinity. Such lakes have been reported from many localities in northeastern Nevada and northwestern Utah and indicate that in the early to middle Eocene time the region was of moderate to low relief similar to that of the Eocene Green River Formation farther east in Utah, Wyoming, and Colorado.

Eocene angular unconformity -- The middle Eocene volcanic rocks rest on Triassic Thaynes limestone, shale, and redbeds that are folded about a northeast-trending syncline along the northern edge of the field. As we drive southwest from Stop 1, we will pass over the unconformity where the volcanic rocks lap over the southeastern limb and the axis of the syncline. Along the northeastern part of the syncline beds on the southeast limb dip steeply to the northwest, but to the southwest the beds are overturned to the southeast. Thus, the syncline is upright in the east and overturned to the northwest at its western end. Similar trending folds are overturned to the northwest in the southern Pequop Mountains in upper Paleozoic and Triassic strata and in the Wood Hills in metamorphosed lower and middle Paleozoic rocks.

The axis is marked by red soil at several locales. Just to the right (north) of the road at several places along the route are patches of red soil along the volcanic rock-Triassic contact. This red soil marks the uppermost unit of the Thaynes. Along the synclinal axis, reddish shale is overlain by laminated limestone, which we interpret to be correlative to similar beds at the top of the Thaynes in the northern Currie Hills. Triassic Moenkopi Formation redbeds overlie the Thaynes in the Currie Hills, but we do not believe these are Moenkopi beds here.

Along the unconformity, a rib of quartzitic quartz- and chert-pebble conglomerate dips steeply to the southeast beneath the volcanic rocks and is underlain by deep red soil that has abundant rounded chert pebbles scattered on the surface. We interpret the red soil to be from weathered redbeds of the Moenkopi and the conglomerate to be the Shinarump Conglomerate member of the Triassic Chinle Formation (similar stratigraphic relationships are found in the northern Currie Hills). To accomplish this proposed stratigraphic succession requires that an anticline be present between this locale and the northwest overturned syncline, about 0.4 mile to the northwest. This hypothesized anticline would be covered beneath the intervening alluvium.

STOP 2

At this stop we will observe an attenuation fault that is localized along the Permian Kaibab-Arcturus boundary. We consider this type of structure to be one of the most common, yet most difficult to identify in Paleozoic and lower Mesozoic rocks in the eastern Basin and Range. This attenuation fault differentially cuts out the lowermost 20 m of the Kaibab, a fossiliferous, cherty limestone. Perhaps more of the Kaibab is eliminated, but the lack of marker beds higher in the section makes it difficult to ascertain if more of the Kaibab has been cut out. Similarly, a lack of marker beds in the upper Arcturus has made it difficult to determine how much of this unit has been cut out along the fault.

The upper Arcturus consists of a monotonous series of interbedded yellowish-weathering siltstone, thin- to medium-bedded gray limestone and dolomite, and laminated chert, all of which are barren of megafossils. The Kaibab consists of a lower member of gray, fossiliferous, nodular chert-bearing, thick-bedded limestone (about 20 m thick) and an upper member of light gray, thick-bedded dolomite with sparse nodular chert.

Along the attenuation fault, the lower Kaibab member is commonly missing or only a meter or so of limestone is preserved. Due to the monotonous nature of the upper Arcturus and lack of marker beds in that part of the section, it has not been possible to determine how much of this formation has been tectonically cut out. Commonly, beds in the Kaibab are discordant (up to 30°) with the underlying Arcturus; at a few sites the discordance is >60°.

THE NORTHERN CURRIE HILLS

The northern Currie Hills (about 10 miles north of Currie) is an area of very low relief east of Nevada Highway 93 in south-central Elko County (fig. 1) and has been an area of great interest in northwest Nevada for decades because it is underlain by the westernmost Triassic-Jurassic stratigraphic section in the northern Great Basin that resembles Colorado Plateau strata (Nelson, 1956). We will focus on evidence that constrains the timing of regional tectonism. Three groups of rocks record three deformational events. First, Permian through Jurassic strata are folded about a northerly trending syncline that was formed in Middle Jurassic to Late Cretaceous time. Second, lower Tertiary (?) conglomerate was deposited discordantly on the eastern limb of the syncline and was tilted steeply eastward in middle Eocene (?) time. Lastly, middle to late Eocene (?) volcanic rocks intruded and overlay the older units and were tilted gently eastward, probably in middle Tertiary time.

We will concentrate on an attenuation, or nearly bedding parallel, fault zone at the Permian-Triassic boundary (fig. 2), similar to attenuation faults we observed in the southern East Humboldt Range. Here the tectonic thinning of beds and the contrasting styles of deformation above and below the zone of deformation is readily demonstrated. We will show that the Paleozoic-Mesozoic strata were attenuated by low-angle faults prior to deposition of the lower Tertiary (?) conglomerate and are therefore early Tertiary or Mesozoic features. Before discussing the structure, a brief overview of the stratigraphic units is presented.

STRATIGRAPHY

PERMIAN, TRIASSIC, AND JURASSIC STRATA

Gerster Limestone -- The oldest exposed formation in the northern Currie Hills is the Upper Permian Gerster Limestone, which consists of cherty thick-bedded to massive, medium- to light-gray, fossiliferous limestone with thin interbeds of yellowish shale. These rocks form a characteristic bench-and-bluff topography. Limestone beds are composed of bioclastic hash, including well-preserved productid and spiriferid brachiopods as well as bryozoans, crinoid and echinoid fragments, algal laminae, and pelecypods; brachiopods are usually silicified. Chert is primarily nodular.

Thaynes Formation -- The Lower Triassic Thaynes Formation comprises four units (1-4) and is disconformable on the Gerster Limestone in the northern part of the map area and in attenuation fault contact in the southern part. This faulted contact will be the main stop for today's trip in the northern Currie Hills. Where the contact is more or less normal, the basal meter or so is chert-pebble to chert-grit limestone-matrix conglomerate that weathers yellowish to reddish. The lowest unit (1) includes 110 meters (m) of greenish-brown-weathering shale and thin-bedded limestone that form a strike valley above the Gerster Limestone. About 30 m above the base are two brownish-red limestone beds (3-4 m thick) that contain poorly preserved *Meekoceras* (?). These *Meekoceras*-bearing beds are important marker beds in unraveling the nature of the Thaynes-Gerster contact (these beds are in the same stratigraphic position in the southern East Humboldt Range). Unit 2 is a hogback-forming sequence (±85 m) of medium-bedded limestone with interbeds of platy limestone and shale.

Unit 3 is a strike-valley-forming succession of platy to thin-bedded limestone and shale about 300 m thick. The road to Stop 1 goes up the valley underlain by unit 3. Most of the valley is a thinly covered pediment surface cut on the shales and limestones. Resistant limestone beds appear to outcrop randomly in the valley, but on aerial photographs these limestone are seen to be continuous.

Unit 4 is a sequence of limestone and shale at the top of the Thaynes (±200 m thick), whose lower part is brownish-weathering sandy limestones that form a prominent hogback. The upper part of the sequence, on the dip slope of the hogback, is interbedded shale and thinner bedded limestone. At the top of the upper sequence are two distinctive members: a lower reddish weathering shale interval and an upper algal-laminated, thin-bedded limestone to dolomitic limestone. The reddish shale can be mistaken for the redbeds of the overlying Triassic Moenkopi Formation if the laminated limestones are not present.

Moenkopi Formation -- The Triassic Moenkopi Formation rests with apparent conformity on the Thaynes and consists of a sequence of interbedded redbeds and thin-bedded gray limestones that typically form a soft, reddish soil. A thin gritstone bed with rounded chert grains that is about one meter thick is an important marker in the upper part of the formation. Thickness of the Moenkopi is about 50 m.

Chinle Formation -- The Triassic Chinle Formation in the northern Currie Hills includes the Shinarump Conglomerate and the Petrified Forest members. In the northernmost part of the area, the Shinarump rests on the Moenkopi and Thaynes Formations, and at one locality cut a channel about 30 m wide through the Moenkopi down to the Thaynes; all three formations appear to be concordant. The Shinarump Conglomerate is primarily a poorly indurated quartz sandstone, but locally has a well-indurated basal quartz-pebble conglomerate. Thickness of the Shinarump is about 100 m.

The overlying Petrified Forest member includes fluvial and lacustrine sandstone, siltstone, and thin-bedded limestone. Upper parts of the Petrified Forest weather a deep brick red color. Thickness of the Petrified Forest member is greater than 100 m; the top is not exposed.

Aeolian sandstones -- The youngest Mesozoic unit in the northern Currie Hills is the Jurassic "Nuggajotec" sandstone. "Nuggajotec" is used informally herein for aeolian sandstones lithologically correlative to the Nugget, Navajo, and Aztec Sandstones in Utah and Wyoming; this term is preferred to assigning a specific name because of the great distance separating this area from any of these formations. No contact between the Nuggajotec and the Chinle was found.

EARLY TERTIARY(?) CONGLOMERATE

The early Tertiary (?) conglomerate rests discordantly on the Nuggajotec sandstone and is overlain with angular discordance by the Eocene (?) volcanic rocks. This unit is typified by resistant, poorly stratified chert- and quartzite-pebble conglomerate beds and monolithologic coarse-grained, biotite-hornblende syenitic boulder- to pebble-debris flows. The source of the quartzite and chert pebbles is upper Paleozoic to Jurassic rocks like those exposed in the immediate area. However, the source of the syenitic clasts is not known, but may be Jurassic plutons similar to those in the Dolly Varden Mountains a few miles to the east. Some of the syenitic debris flows are mistakenly shown on the Elko County geologic map (Coats, 1987) as intrusive bodies. Clasts of contact metamorphosed upper Paleozoic and Thaynes limestone and coarse-grained magnetite are in some of the debris flows, indicating that these pre-Tertiary rocks were intruded in at least hypabyssal conditions.

Several regional tectonic and paleogeographic questions will be answered when/if we are able to determine the age of this unit:

1) The conglomerates rest on the Nuggajotec sandstone on the east limb of an upright, open syncline which is cored by the Triassic and Jurassic rocks visited on this trip. The relation of this syncline to a northwest overturned syncline in the southern Pequop Mountains, the range a few miles to the north, has been a puzzle to many workers in the region. Both synclines are cored by Mesozoic strata, but one is overturned and the other is upright. How do they correlate? The answer now appears to be rather straightforward. Rotating the easterly dipping conglomerates back to horizontal makes the syncline a west overturned structure, and the two synclines then are correlative. Projecting the axes of the two synclines toward each other indicates a left separation fault separates the northern Currie Hills and the southern Pequop Mountains, which is consistent with other structural relations.

2) Dating of the conglomerates is essential in determining the age of the folding and the timing of the rotation of the syncline. If the conglomerates are Cretaceous or older, the folding is Elko orogeny (Middle Jurassic) and the tilting is Cretaceous to late Eocene in age. If the conglomerates are Eocene, as we suspect, then the folding can be Elko or Sevier and the tilting is Eocene. The Eocene age limit is assumed based on regional considerations for the age of the overlying volcanic rocks.

3) If the conglomerates are Eocene, then the tilting probably correlates with a middle Eocene deformational event on the edge of the Elko basin (Thorman and others, 1992) and in the White Sage basin at Gold Hill (Potter and others, 1994). Based on regional considerations, we prefer this interpretation at the present time, but have no evidence from this area to support it. We hope to be able to date some volcanic clasts from one of the conglomerate beds.

4) If the conglomerates are Cretaceous or older, then the possible age of the tilting is greatly expanded. A Cretaceous or Jurassic age for tilting could be interpreted as evidence for Mesozoic extensional tectonics. However, at this time, we feel it is premature to make such conjectures.

EOCENE (?) VOLCANIC ROCKS

The volcanic rocks, the youngest identified rocks in the northern Currie Hills, include ash-flow tuffs, flows, and flow domes ranging in composition from intermediate to silicic. The following descriptions are based on preliminary field data. We have no isotopic dates from this area. This sequence of rocks rests discordantly on Triassic and Jurassic strata and the early Tertiary (?) conglomerate.

Ash-flow tuffs -- The basal unit is a pumice-lithic rhyolite ash-flow tuff. Rocks are crystal poor and contain quartz, sanidine, and sparse biotite and hornblende. The lithics include volcanic fragments and quartz sandstone. Two ash-flow tuffs overlie the pumice-lithic unit, one in the northern part and the other to the south; they have not been observed in contact with each other, so we have not established a relative age between the two. The southern tuff commonly has a densely black, welded vitric zone with flattened pumice; the upper part of the tuff is salmon-colored and underlies hogbacks and isolated knobs. The northern tuff has a distinctive porous, sponge-like weathered appearance, probably due to weathering of pumice that was effected by vapor-phase crystallization; no basal vitric zone has been observed.

Rhyolite flows and intrusives -- Intruding and overlying the ash-flow tuffs are flow-banded rhyolite intrusive and extrusive units that underlie a series of hills in an east-west belt across the central part of the map area. Local vents may be present in some of the hills where jagged, irregular masses of steep-dipping rock contrast sharply with smoother topography; a few north-trending dikes cut the underlying pumice-lithic tuff. A north-trending rhyolite intrusive, about 300 m wide and 1800 m long, divides these rhyolites into a western and eastern series of domes or flows.

Western units -- A flow dome underlies the westernmost hill and is a biotite-quartz rhyolite with a jagged, spiny weathered character. Most of the rocks are flow-laminated and autobrecciated, the blocks being less than a meter in size. Locally, rafted blocks of conglomerate are near the base of the dome. The next dome to the east is a flow-banded, biotite-hornblende rhyolite with sparse quartz. It has a meter-thick basal black vitrophyre locally along its northern and southern margins.

Central intrusive -- Jagged-weathering gray to white rhyolite underlies a 3-km long north-south ridge. The rocks are crystal poor with phenocrysts of quartz and biotite. Blocks of gray vitric rhyolite are common throughout the body and give this intrusive a jagged appearance. Xenoliths of the underlying conglomerate are present within and along the margins of the body.

Eastern units -- Dark-colored rhyolite underlies the hills to the east, extending to the abandoned railroad in Goshute Valley. These rocks are typically dark red and purple, with phenocrysts of biotite, hornblende, and minor quartz. Steep, flow-laminated rocks are common throughout.

Other units -- A small rhyolite flow is east of the central intrusive and is a pink, porphyritic rock with biotite, hornblende, and sanidine phenocrysts. West of the central intrusive is a dark-greenish-brown-weathering andesitic flow with fine-grained oxidized hornblende and plagioclase phenocrysts.

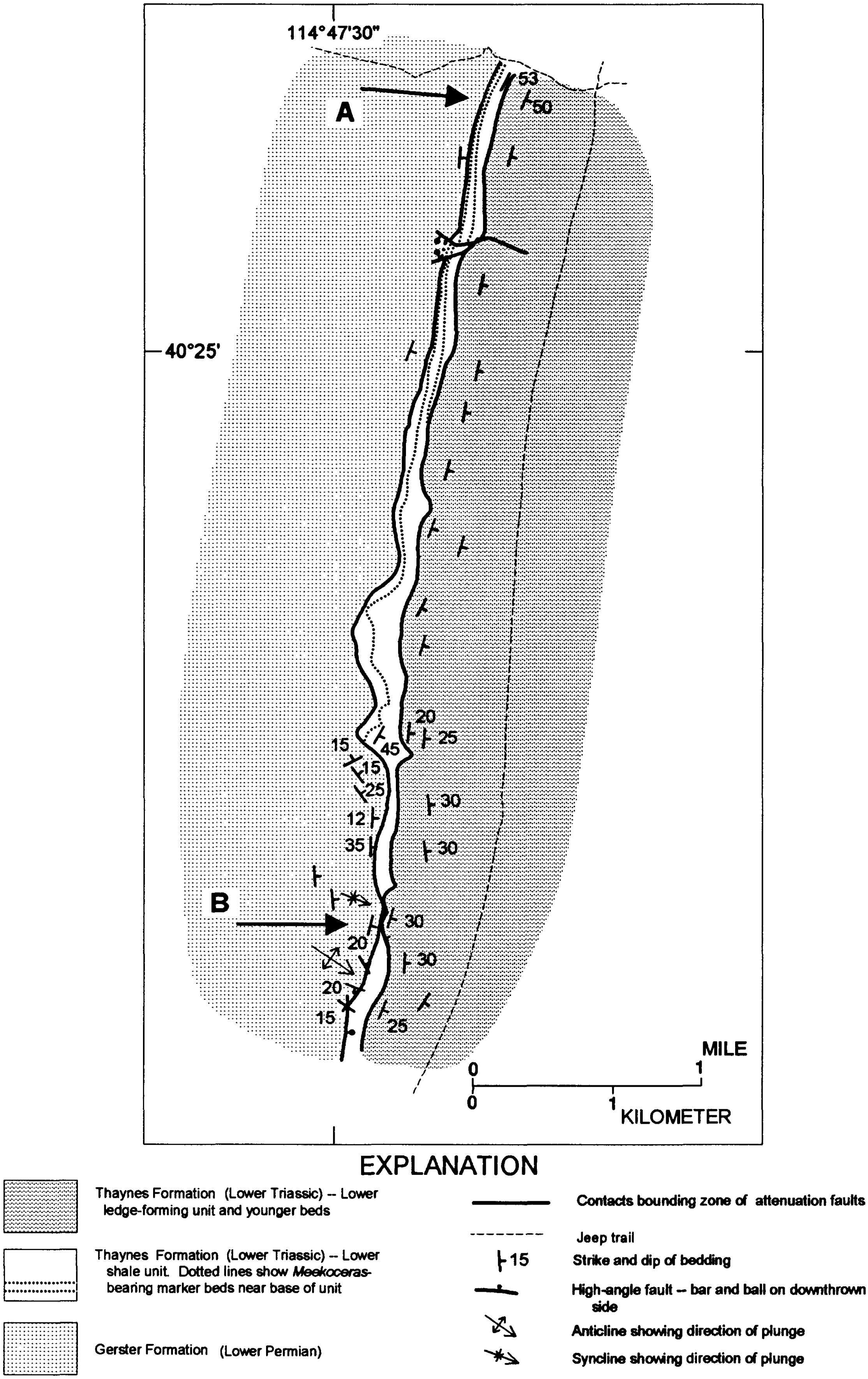

Figure 2. Geologic map of a part of the northern Currie Hills showing the attenuation fault zone along the Gerster-Thaynes contact.

STOP 3

After turning east off the main highway and traveling about 2.5 miles on a dirt road, we will stop at the northern end of some low hills where we will examine the uppermost part of the Upper Permian (Guadalupian) Gerster Limestone and the lower part of the Triassic Thaynes (fig. 2, locality A). Walking west to east, we will start in the uppermost Gerster, which is comprised of thick-bedded gray limestones with dark-weathering nodular chert. Thinner intervals of yellowish-gray calcareous shale separate the limestone beds and form a bench-and-bluff topography. Limestone beds are composed primarily of bioclastic hash, including well-preserved silicified productid and spiriferid brachiopods as well as bryozoans, crinoid and echinoid fragments, algal laminae, and pelecypods. Of special interest are the productid and spiriferid brachiopods, which are not present in the overlying Triassic limestones. The Triassic-Permian contact is characterized by a change from the thick-bedded chert- and brachiopod-bearing Gerster limestones to the basal Thaynes, a chert-grit- to chert-pebble-bearing calcarenite. The Permian-Triassic contact is erosional and locally has several meters of relief.

Walking toward the east, up section, the stratigraphically lowest limestone interval in the Thaynes is about 35 m thick and contains gray limestones interbedded with green calcareous shales and lesser amounts of orange calcareous siltstones. Of particular interest are two limestone beds near the top of the interval that are characterized by their brownish gray weathering and "honey comb," possibly stylolitic feature; the chocolate color of these beds is common for certain limestone intervals in the Thaynes. The lowest bed averages about 1 m thick and the higher bed averages about 3 m thick. Both contain rare examples of the ammonoid *Meekoceras*. This ammonoid is used to define the base of the Thaynes in northeastern Nevada, northern Utah, and southeastern Idaho.

STOP 4

The purpose of Stop 4 is to see an attenuation fault along the Gerster-Thaynes (Permian-Triassic) contact (fig. 2, locality B). Here, the lower Thaynes (35 m of limestone and 75 m of shale and limestone) is reduced by more than 100 m such that the cuesta-forming limestone interval and Gerster are separated by less than 10 m of shale and thin-bedded limestone. The Gerster is folded about several east-plunging folds with amplitudes exceeding 30 m, whereas the Thaynes is attenuated but not folded.

At first glance, the folded Gerster, overlain by what appears to be undeformed Thaynes, could be interpreted as a local high over which the Thaynes thins depositionally. A closer examination reveals that the basal Thaynes chert-grit limestone is folded along with the Gerster limestones and the thin-bedded limestone and shale are attenuated across the folds. Also, the chocolate-colored *Meekoceras*-bearing limestones are absent. Thus, the attenuation fault is a zone that occupies at least the lower 100 m of the Thaynes. Within the zone of attenuation and up into the overlying cuesta-forming interval, resistant limestone beds are broken by small-scale, down-to-the-south normal faulting (offsets are typically less than a few centimeters), but are not folded. The base of this zone is a transfer from folded competent limestone to much less competent attenuated shale and thin-bedded limestone.

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