RECOGNITION AND SIGNIFICANCE OF EOCENE DEFORMATION IN THE ALLIGATOR RIDGE AREA, CENTRAL NEVADA

By C.J. Nutt *and* S.C. Good

ABSTRACT

The Alligator Ridge area, which is at the southern end of the Carlin Trend in central Nevada, includes scattered outcrops of Tertiary sedimentary rocks that are folded about northwest-trending axes. Lacustrine limestone from the sedimentary sequence yielded gastropod ages of latest Early to early Middle Eocene. The Eocene sedimentary rocks are unconformably overlain by undeformed, about 35-Ma volcanic rocks. This relationship indicates a period of Eocene deformation that is interpreted as transpressive and includes strike-slip movement on west- to northwest-trending faults. Transpressive deformation probably occurred along accommodation faults related to the Eocene extension occurring in the Ruby Mountain-East Humboldt Range core complex. Eocene deformation, including uplift and local transpression, is widespread in the eastern Great Basin and may extend into the Carlin trend.

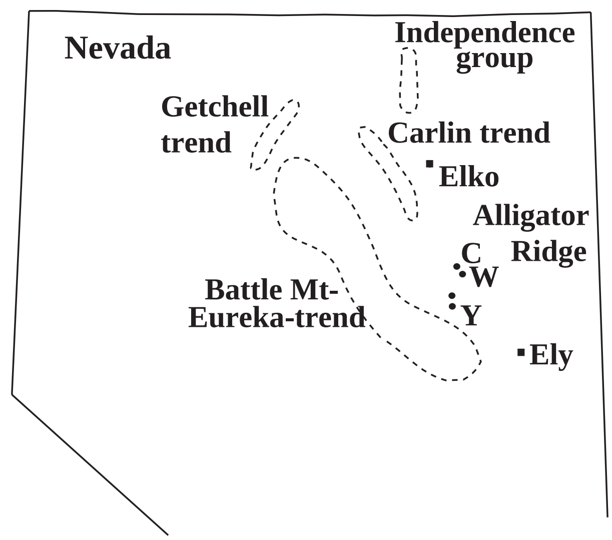

Figure 1: Location of Alligator Ridge in relation to the mineral belts of north-central Nevada. Other Carlin-type Au deposits in the Alligator Ridge-Bald Mountain area. C, Casino; Y, Yankee, W, Windrock.

INTRODUCTION

The Alligator Ridge area, which hosts disseminated gold deposits in Devonian and Mississippian rocks, is in central Nevada, about 70 miles northwest of Ely, Nevada, and along the southern extension of the Carlin trend (fig. 1). The disseminated character, geochemistry, and lack of age constraints of the Alligator Ridge area are typical of Carlin-type deposits (Ilchik, 1990). The position of the Alligator Ridge deposits is atypical of the Carlin Trend as they are east of the Roberts Mountain thrust, the edge of the relatively intact Proterozoic continent (Wooden and others, 1997), and most of the known Carlin-type deposits. The age of the Alligator Ridge deposits is unknown: Ilchik (1990) suggests a Tertiary age whereas Hitchborn and others (1996) interpret a Jurassic age and mineralization associated with a pluton at Bald Mountain. This paper recognizes a previously undocumented Eocene deformation event, related to the initiation of extension in the Great Basin and encompassing both extension and compression, that was accompanied or soon followed by silicification. Recognition of this event is important because of its possible relation to mineralization, as either starting the process of fluid flow or opening structures for later mineralization, or by deforming or remobilizing earlier deposits.

Previously published geologic maps have depicted the Alligator Ridge-Bald Mountain area as an uplift that preserves relatively little pre-Basin and Range deformation located between the isoclinally folded and thrusted Diamond Mountains on the west side of Newark Valley and the broad syncline in the Butte Mountains on the east side of Long Valley (fig. 2) (Hose and Blake, 1976). Recent mapping at 1:24,000 scale (C.J. Nutt, unpublished mapping, 1994-1996) of the quadrangles encompassing the Alligator Ridge area reveals a more complex geology than implied on earlier maps (Rigby, 1960; Ilchik, 1990).

GEOLOGIC SETTING

Alligator Ridge is considered part of the Bald Mountain-

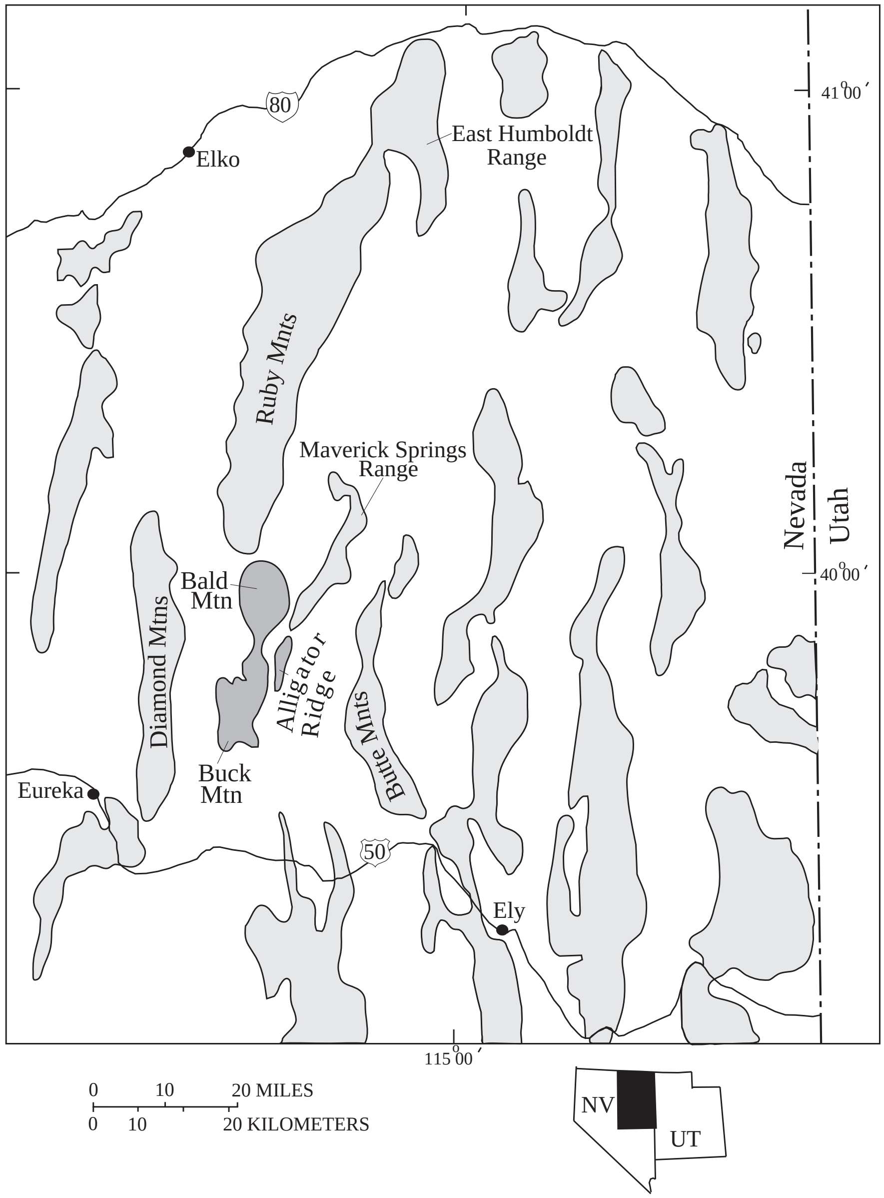

Figure 2. Location of Alligator Ridge and Bald Mountain in the eastern Great Basin, Nevada.

Buck Mountain region that is at the southern end of the Ruby Mountains (fig. 2). The Bald Mountain-Buck Mountain area, including Alligator Ridge, is underlain by Cambrian to Permian carbonate and clastic rocks, a Jurassic pluton, and Tertiary volcanic rocks (figs. 3 and 4). The Cambrian rocks and Jurassic pluton are restricted to the Bald Mountain area, and are on the upthrown side of a normal fault that cuts across the western edge of Bald Mountain. Middle and Lower Ordovician Poginip Group, Upper and Middle Ordovician Eureka Quartzite, and Upper Ordovician, Silurian and Devonian dolomites make up most of the western side of the range south of Bald Mountain and north of Buck Mountain. Upper and Middle Devonian Guilmette Formation, Lower Mississippian and Upper Devonian Pilot Shale, Lower Mississippian Joana Limestone, Upper and Lower Mississippian Chainman Shale and Upper Mississippian Diamond Peak Formation crop out in the central part of Bald Mountain-Buck Mountain, and host the gold deposits in the Alligator Ridge area.

Lower Permian, Pennsylvanian, and Upper Mississippian Ely Limestone makes up the high ridge of Buck Mountain, and the more easily eroded Lower Permian Arcturus Formation and Rib Hill Sandstone underlie the flanks. Tertiary sedimentary rocks are only known in the Alligator Ridge area, whereas Tertiary volcanic rocks are widespread east and south of Bald Mountain.

The eastern Great Basin, including the Bald Mountain-

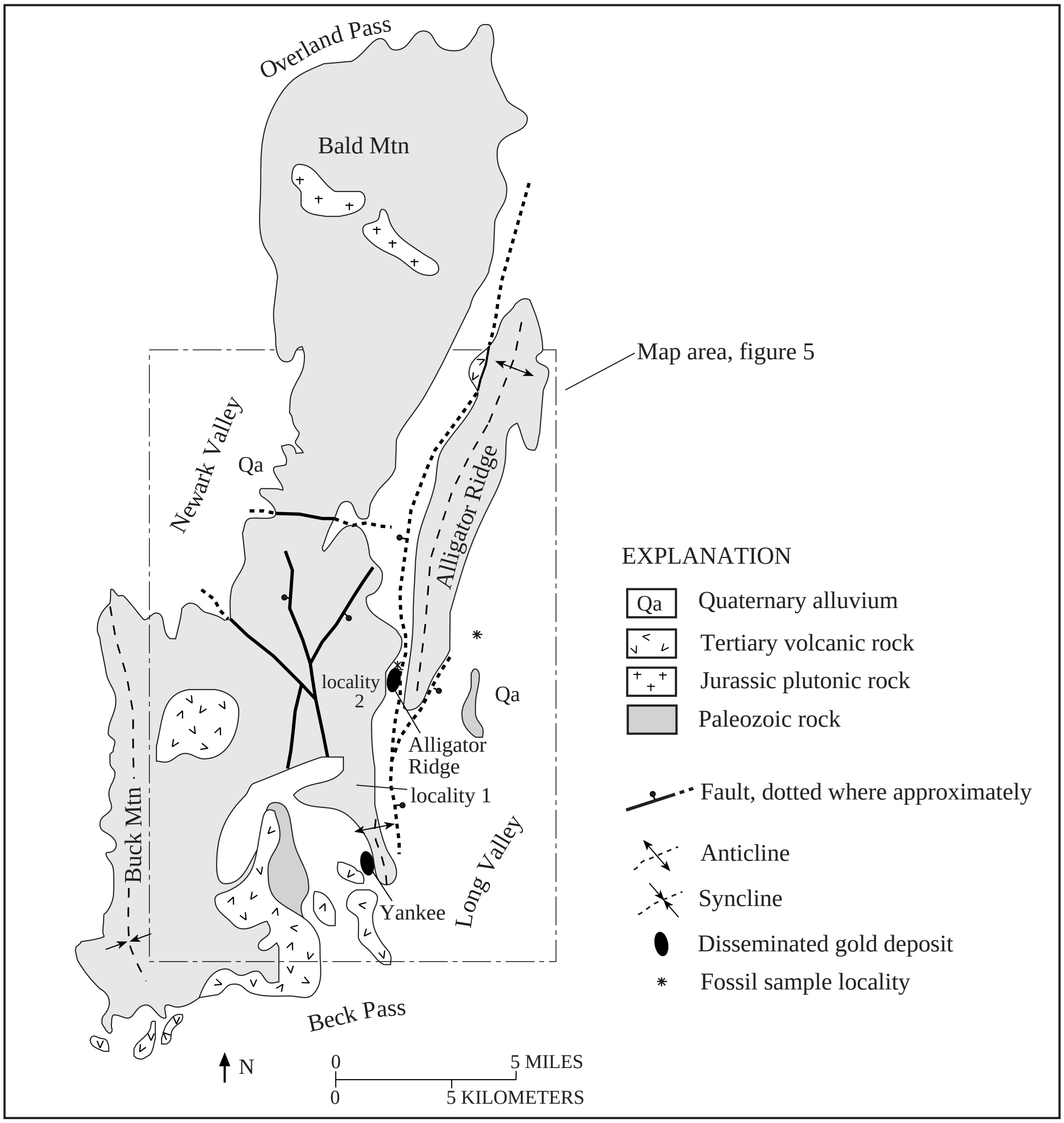

Figure 3. Simplified geologic map of the Bald Mountain-buck Mountain region, including the Alligator Ridge area. Modified from Rigby and Hose and Blake (1976).

Buck Mountain area, was affected by enigmatic Jurassic deformation, Cretaceous to early Tertiary contraction (the Sevier orogony), and middle Tertiary extension. Mesozoic to early Tertiary structures in the Alligator Ridge area include regional north-trending gentle to overturned folds, younger-over-older low-angle faults (attenuation faults), reverse faults, and west- to northwest-striking strike-slip faults (Rigby, 1960; Nutt, 1997). Middle Tertiary and younger north-striking normal faults cut the area and in many places follow and disrupt earlier fold axes and reactivate earlier faults. The Ruby Mountain-East Humboldt Range core complex that is to the north of Alligator Ridge underwent rapid Oligocene and Miocene uplift (Wright and Snoke, 1993); McGrew and Snee (1994) interpret $^{40}Ar/^{39}Ar$ dates as also showing early Tertiary uplift.

Alligator Ridge area

The Alligator Ridge area, as used herein and coincident with the mapped area, is the central part of the Bald Mountain-Buck Mountain range, and hosts the Alligator and Yankee deposits (fig. 3). Devonian through Permian rocks dominate the outcrops, and jasperoid is common as a replacement of the Joana Limestone and as a replacement of massive to thin-bedded limestone at and near the contact between the Guilmette Formation and overlying Pilot Shale. Gold is in the Mississippian-Devonian Pilot Shale and in jasperoid at the top

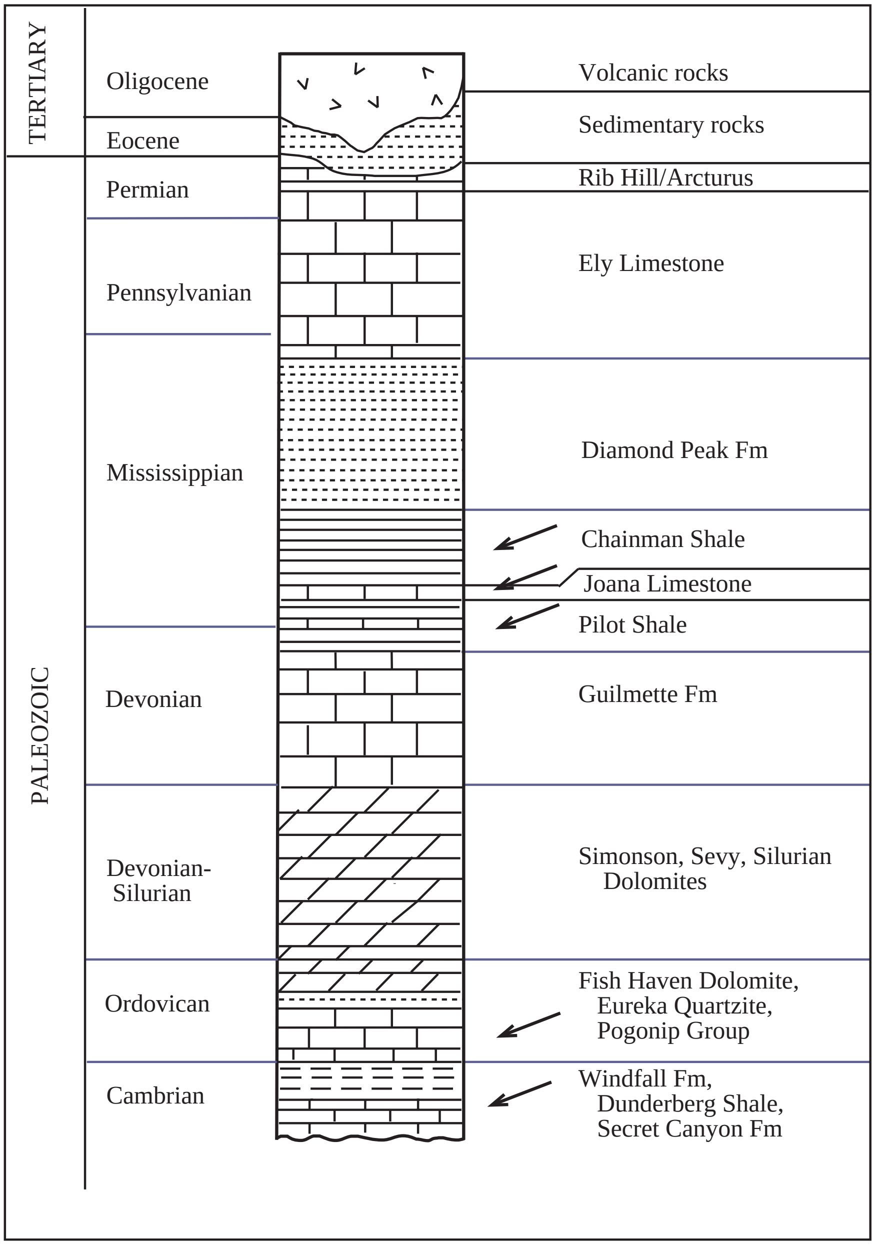

Figure 4. Stratigraphic section of Paleozoic and Tertiary rocks at Bald Mountain and Alligator Ridge. Arrow's point to hosts of disseminated gold ore: upper three are at Bald Mountain and in Alligator Ridge area, lower two are at Bald Mountain.

of the Devonian Guilmette Formation.

Structures in the Alligator Ridge area are shown on figure 5 (map area on fig. 3). Two sets of folds, north- and northwest-trending, deform the Alligator Ridge area. The north-trending folds are Mesozoic to early Tertiary in age and include a syncline at Buck Mountain, an anticline near Yankee,a steep to overturned anticline at Alligator Ridge, and anticline and syncline in the central part of the area that are disrupted by later faults (fig. 5). Shorter wave-length northwest-trending folds deform earlier north-trending folds (fig. 5). Almost all faults show normal offset that reflects Miocene and younger extension of the area, but many faults are interpreted as having a pre-Miocene history.

EOCENE SEDIMENTARY ROCKS

Eocene sedimentary rocks crop out in the eastern part of the Alligator Ridge area, including at the Alligator Ridge deposits. The sequence consist of fluvial and lacustrine

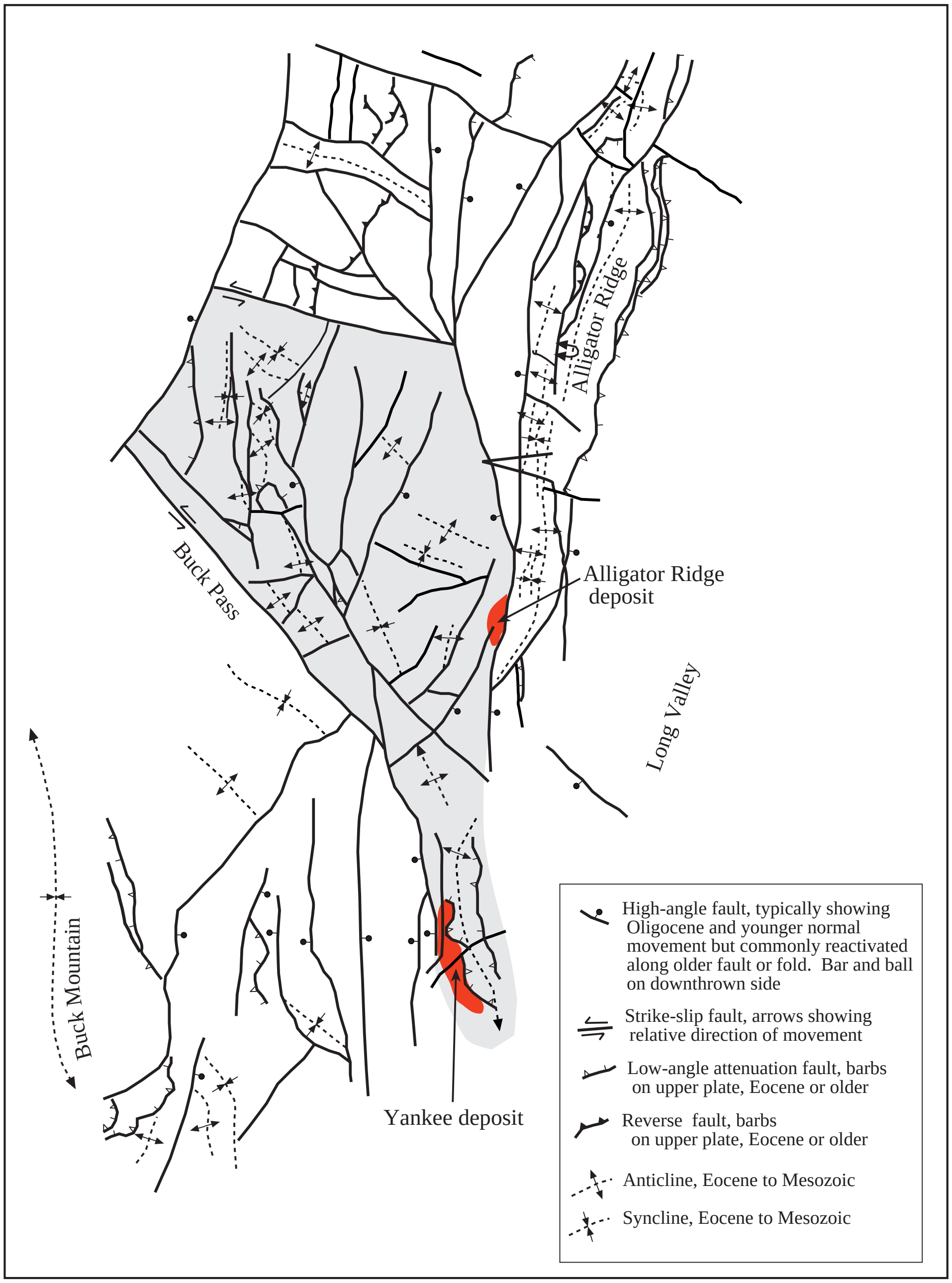

Figure 5. Structures from the map area on figure 3 (C.J. Nutt, unpublished mapping). Shaded area underlain by rotated fault blocks, as explained in text. Dark gray areas are Alligator Ridge and Yankee deposits.

sandstone, siltstone, and conglomerate, in part volcaniclastic or igneous-derived, and limestone. The clastic rocks contain chert clasts and quartz derived from the Diamond Peak Formation, and white, clay-altered fragments of an unknown igneous source. The Eocene rocks depositionally, and in places unconformably, overlie Upper and Lower Mississippian Chainman Shale, Lower Mississippian Joana Limestone, Lower Mississippian and Upper Devonian Pilot Shale, and Upper and Middle Devonian Guilmette Formation. They are also unconformably overlain by biotite-quartz lithic tuff, in places reworked to a quartz-biotite sandstone, of about 35 Ma (Nutt, 1996).

Cretaceous, Paleocene, and Eocene sedimentary rocks are scattered throughout the eastern Great Basin (Fouch and others, 1979). Fouch and others (1979) and Soloman and others (1979) show that a volcanogenic component is in some places present in Eocene rocks, and as old as about 45 Ma.

An Eocene age for lacustrine limestone in the Alligator

Table 1. Fossil data from Alligator Ridge area

97ARlm1	
Phylum Mollusca	
Class Gastropoda	
Subclass Pulmonata	
Order Basommatophora	
Family Lymnaeidae	
Pleurolimnaea tenuicosta (Meek and Hayden, 1856)	Paleocene-Early Eocene
Lymnaea sp. Indet., resembles *L. similis* (Meek, 1860)	Bridgerian, latest Early to early Middle Eocene
97ARlm2	
Lymnaea similis Meek (1860)	Bridgerian, latest Early to early Middle Eocene
Lymnaea sp. C Good (1983, 1987)	upper Sheep Pass Formation, Bridgerian

Ridge area was determined by identification of gastropods from two localities: the Vantage pit at Alligator Ridge and from outcrop on the eastern side of Alligator Ridge (localities shown on fig. 3). The gastropods are recrystallized. However, excellent morphological details are available from external and internal molds. The sample from the Vantage pit at Alligator Ridge (ARlm1 on table 1) is from a limestone interbedded with volcaniclastic sandstones, siltstones, and mudstones. The gastropod fauna is *Pleurolimnnaea tenuicosta* (Meek and Hayden, 1856) and *Lymnaea* sp. indeterminate, but resembles *L. similis* Meek (1860). The sample from the east side of Alligator Ridge (97ARlm2 on table 1) contains gastropods preserved in random orientations on bedding planes. The gastropod fauna consists of *Lymnaea similis* Meek (1860) and *Lymnaea* sp C. Good (1983, 1987).

Age of the limestone can be inferred from the stratigraphic distribution of these gastropod species in the Rocky Mountain region where they are associated with ostacodes, charaphytes and fossil mammals (Henderson, 1935; Hanley, 1974, 1976; Good, 1983, 1987). Both samples are interpreted as Bridgerian (latest Early to early Middle Eocene); see table 1 for the age ranges of each species. These mollusks indicate the limestone at Alligator Ridge is age correlative to the White Sage Formation in the Deep Creek Mountains, Nevada and Utah, (Potter and others, 1995) and the upper part of the Sheep Pass Formation (Good, 1987).

The depositional environment of the mollusk-bearing limestone is inferred from the paleoecological tolerances of the modern representatives (Dodd and Stanton, 1981). Paleoecological interpretations are drawn at the level of the Family Lymnaeidae. Lymnaeids are basommatophoran pulmonate gasropods (air-respiring gastropods that have returned to aquatic habitats). They can exchange gases through subcutaneous exchange or by bring the pneumostome to the air-water interface to intake air into the mantle cavity. Lymnaeids prefer quiet-water habitats, live on aquatic-rooted, emergent vegetation, and are herbivorous (Good, 1987; Hanley, 1976). Lymnaeids are abundant in very small bodies of water with mud bottom and little aeration (Larocque, 1968). The mollusk assemblage indicates the depositional environment was a small, eutrophic, perhaps even ephemeral pond.

Geologic relationships support the proposal that the basins were small and derived sediment from local sources, and the variety of units that underlie Eocene rocks suggests that extensive tectonic denudation and/or erosion preceded deposition. The outcrops are scattered and small, and, even recognizing that they were in places eroded prior to Oligocene volcanism, most likely were never thick, widespread units. At locality 1 (fig. 3), Eocene rocks overlie Upper and Middle Devonian Guilmette Formation, Lower Mississippian and Upper Devonian Pilot Shale, Lower Mississippian Joana Limestone, and Upper and Lower Mississippian Chainman Shale, all within about a square mile. The range in rock units underlying the Eocene rocks implies significant uplift and erosion after deposition of Mississippian rocks and prior to deposition of the Eocene rocks.

EOCENE DEFORMATION

Eocene deformation in the Alligator Ridge area is evident by the presence of deformed Eocene rocks overlain by tilted, but not folded, 35 Ma volcanic rocks. At locality 1 (figs. 3 and 6), the Eocene rocks, along with the Paleozoic rocks, are folded about a northwest-trending axis. Involvement of the Eocene rocks suggests that all of the northwest-trending folds are of Eocene, and not of Mesozoic, age. Slightly less dips in the Eocene rocks than in the underlying Paleozoic rocks indicate deposition along a slight angular unconformity. This discordance is also visible at locality 2 on figure 3. Outcrops

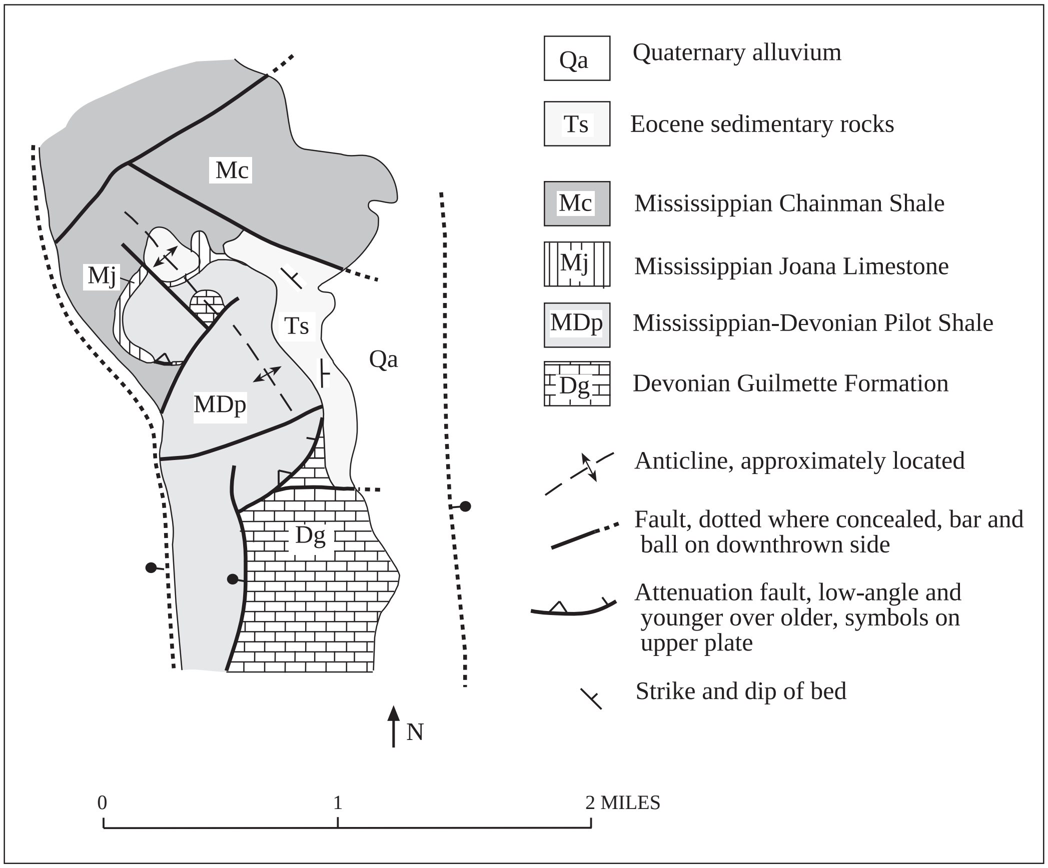

Figure 6. Geologic map of locality 1 (fig. 3) that shows Eocene sedimentary rocks folded northwest-trending fold axis.

at locality 2 and in the Vantage pit at Alligator Ridge show that the Eocene rocks are discordantly overlain by reworked 35 Ma tuff.

Eocene deformation is interpreted as primarily transpressional and expressed as strike-slip faults, with contemporaneous northwest-trending folding, and block rotation. Strike-slip movement along west- to northwest-striking faults is indicated by the presence of the northwest-trending folds, which are oriented near and at about an angle of 30 degrees or less to the faults (fig. 5). These domain-bounding west- to northwest-striking faults probably have a pre-Eocene history; the west to northwest elongation of the Jurassic pluton at Bald Mountain suggests west- to northwest-striking structures were active by the Jurassic. In addition, the faults were reactivated during younger Tertiary extension, and in most places now show normal offset. Block rotation in a left-lateral shear system is indicated by rotation of earlier Mesozoic to early Tertiary north-trending folds in the shaded area of figure 5. Rotation in this area is evident, in part, because of widespread outcrop of Pilot Shale that is easily deformed.

Quartz-flooding accompanied or soon followed deformation. At locality 1 (fig. 3), Joana Limestone and Eocene sedimentary rocks are silicified, whereas nowhere are the 35-Ma volcanic rocks silicified. Eocene silicified rocks are not gold-bearing, although gold-bearing rocks are present in nearby Pilot Shale.

The silicified Joana limestone at locality 1 is aphanitic, gray green and contains relic bedding, characteristics typical of silicified Joana Limestone throughout the map area. This similarity strongly suggests that the widespread silicification of Joana Limestone in the Alligator Ridge area was likely an Eocene event.

Eocene deformation at Alligator Ridge is interpreted as related to uplift of the Ruby Mountain-East Humboldt Range core complex to the north. Using $^{40}Ar/^{39}Ar$ methods, McGrew and Snee (1994) documented Oligocene and Miocene uplift of the Ruby Mountain-East Humboldt Range core complex, and suggested that poorly constrained hornblende ages from rocks at high structural level indicate initial uplift was in the early Tertiary, estimated between 63-49 Ma. Our data constrain deformation to post-early Middle Eocene, indicate transpression along the southern edge of the uplifted complex, and demonstrate a distinct period of deformation. The Alligator Ridge area was near the terminus of uplift in the Ruby Mountains and East Humboldt Range, and was subjected to transpressive deformation. Earlier west- to northwest-striking

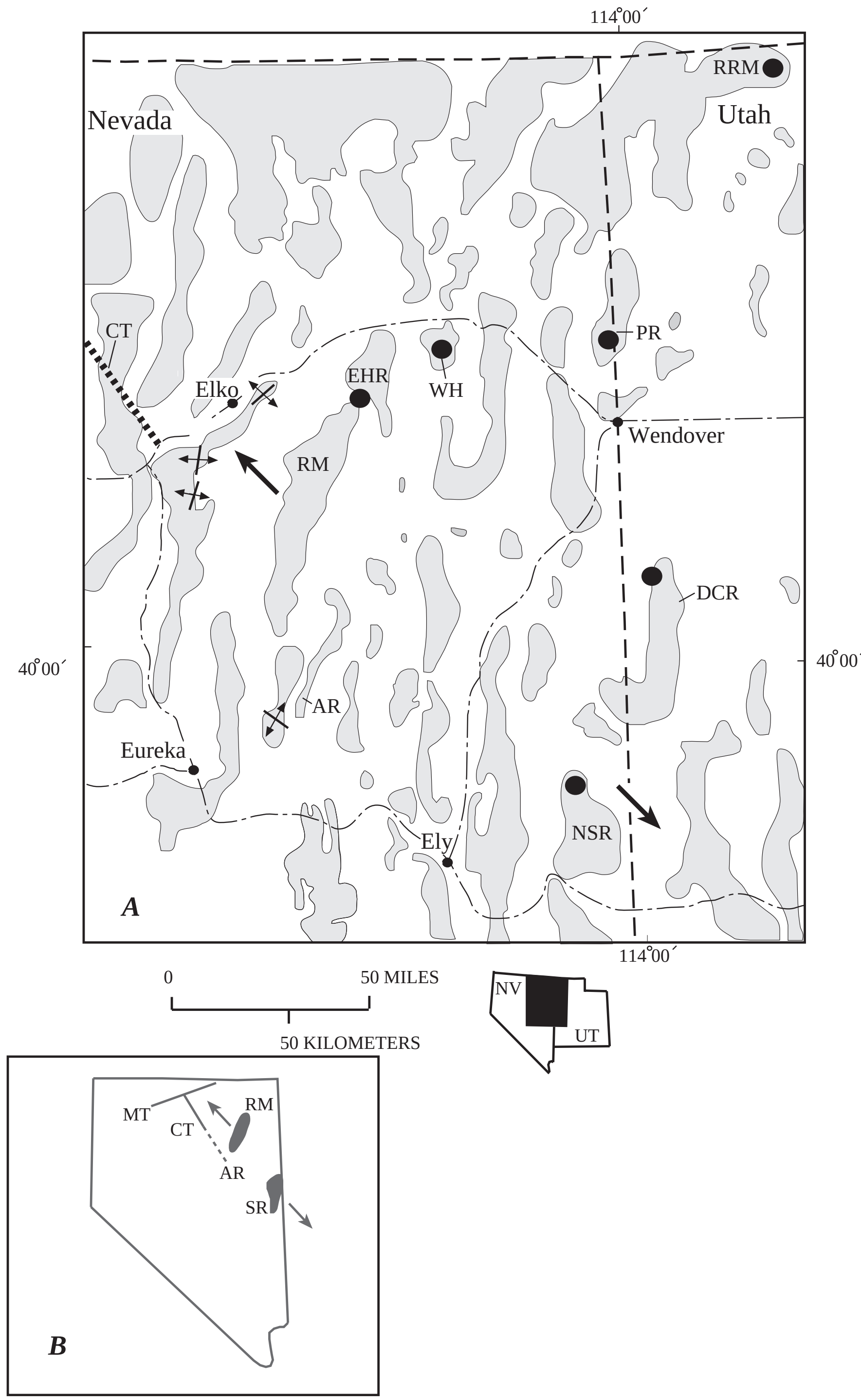

Figure 7. ***A***. Locality map showing ranges in eastern Great Basin documented as having Eocene uplift (black circles) and folding (fold axes). Fold axis for Alligator Ridge is from this paper; fold axes in Eocene rocks in the Elko area are from Ketner and Alpha (1988). Approximate location of Carlin trend (CT) shown as dotted line. Bold arrows showing Tertiary extension direction from Wust (1986). AR, Alligator Ridge; DCR, Deep Creek Range; NSR, Northern Snake Range; PR, Pilot Range; RM, Ruby Mountains; RRM, Raft River Mountains; HER, East Humboldt Range, and WH, Wood Hills. ***B***. Locality map showing the northwest striking Carlin trend (CT, dotted where extends to the south)m and Midas trough (MT) in present-day Nevada in relationship to Tertiary extension. AR, Alligator Ridge; RM, Ruby Mountains, and SR, Snake Range.

faults were reactivated at this time, probably because of differential Tertiary extension manifested by strike-slip offset in cover rocks.

REGIONAL IMPLICATIONS

Evidence for widespread Eocene deformation in the central and eastern Great Basin is increasing. Localities where Eocene deformation, primarily extensional, has been documented are shown on figure 7*A*. Eocene uplift in the Ruby Mountain- East Humboldt Range is documented McGrew and Snee (1994). In the northern Deep Creek Range, northwest Utah, Potter and others (1995) mapped tilted early Eocene White Sage Formation overlain by flat-lying 39.6 Ma volcanic rocks. Miller and others (1987) inferred Eocene movement on a major detachment fault cut by 40 Ma dikes and sills in the Pilot Range, Utah and Nevada. Wells and others (in press) showed rapid cooling in the Raft River Mountains at 47-45 Ma. In the northern Snake Range, Nevada, Lee (1995) documented by $^{40}Ar/^{39}Ar$ methods that the earliest movement on the northern Snake Range detachment fault was middle Eocene (48-41 Ma). A probable middle Eocene age for displacement was interpreted along the Wood Hills detachment (Thorman and Snee, 1988; Hodges and others, 1992). In the Elko area and west and north of the Ruby Mountains, Ketner and Alpha (1988) documented Eocene-age folds in the Eocene Elko Formation. Extensional uplift was centered in the areas of core complexes in east-central Nevada; documented compressive structures are primarily located along the western edge of the area of core complexes (fig. 7A).

The age of uplift and related folding, based on the above geologic and isotopic data, was about 50 to 41 Ma. The presence of volcanic rocks in the folded Eocene rocks at Alligator Ridge suggest that at least in some areas the folding is 45-41 Ma. Stock and Molar's (1988) plate reconstructions indicate plate relations and movements in the time period of the Eocene deformation at about 50 Ma-42 Ma. Stock and Molar (1988) document that between 68 to 42 Ma, the Farallon plate approached the North American plate from the southwest and the boundary between the plates was a subduction zone. Between 56 and 42 Ma, the Vancouver plate broke from the Farallon plate and plate convergence of the Farallon/Vancouver and North America plates decreased. This decrease in convergence is about the same time as the Eocene deformation (Potter and others, 1995), and may coincide with initiation of extension in the area of core complexes in eastern Nevada.

The age of formation of Carlin deposits is controversial, but hypotheses include deposition related to fluid flow associated with Eocene volcanism (Hofstra, 1995) or extensional development of Tertiary core complexes (Ilchik and Barton, 1997). Gold deposition at Twin Creeks dated at about 42 Ma shows that at least some mineralization was during the Eocene (Hall and others, 1997). The Eocene deformation in the Alligator Ridge area apparently occurred just prior to volcanism and possible mineralization. Because Eocene rocks are poorly documented in the Carlin trend, the extent and(or) type of Eocene deformation along the trend is unknown. If present, Eocene structures are likely be misinterpreted as Paleozoic or Mesozoic.

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