EVIDENCE FOR THE CRESCENT VALLEY-INDEPENDENCE LINEAMENT, NORTH-CENTRAL NEVADA

By Stephen G. Peters

ABSTRACT

The Crescent Valley-Independence lineament (CVIL) in north-central Nevada is defined by deformation, igneous intrusions, and hydrothermal activity of several ages along a N20E- to N30E-striking zone. This zone extends for about 90 km from near the Independence Mining District in the north to near the Cortez Mine in the south. The center parts the CVIL mark the southeastern edge of the Tuscarora Mountains near the gold deposits along the Carlin trend. The southwestern part extends through Crescent Valley and the Cortez-Pipeline Mining District.

The CVIL is well exposed along its center segment in the Bob's Flat, Richmond, and the Carlin Mine areas where it contains intensely tectonized rock of the upper-plate of the Roberts Mountains allochthon, probably Ordovician Vinini Formation, northeast-striking faults, or Cretaceous or Tertiary northeast-striking dikes. Fabrics in deformed zones have characteristics of mélange that also exhibit fabric orientation parallel to fold orientations that result from deformation between the late Permian and late Jurassic (Sonoma and Elko orogenies). In addition, Tertiary-age jasperoid, breccia, calcite veins, and decalcification locally are present along the CVIL. Clusters of sedimentary rock-hosted gold deposits in the north and south ends of the CVIL contain several mineralogical features common to deposits in the Carlin trend area. All the districts contain northeast-striking faults that cross cut tectonic windows and structural highs through the upper-plate of the Roberts Mountains allochthon. The CVIL may be a major fluid conduit that was instrumental in formation of some of the gold deposits.

INTRODUCTION

This paper presents geologic and geomorphologic evidence for the Crescent Valley-Independence lineament (CVIL) in north-central Nevada, a 90–km-long tectonic feature that intersects three major sedimentary rock-hosted gold districts, the Cortez-Pipeline, Carlin, and Independence Mining Districts (fig. 1). Geologic features recognized in the center part of the CVIL, near the Carlin trend, suggest that deformation, igneous intrusion, and hydrothermal activity were focused along the lineament periodically between the late Paleozoic and middle Tertiary.

Many sedimentary rock-hosted gold deposits in north-central Nevada cluster in mining districts that lie along northwest-trending belts (Roberts, 1960, 1966; Thorman and Christensen, 1991), or are associated with regional-scale lineaments (see Shawe, 1991). Belts and lineaments are compatible with genetic theories of sedimentary-rock-hosted gold deposit ore formation, which call for deep-seated, over-pressured fluids and associated conduits (Kuehn and Rose, 1995; Lamb and Cline, 1997). Alignment of these and other gold ore bodies has been suggested by Shawe (1991) to be an important factor in producing the large crustal endowment of gold in Nevada. Lineaments have been postulated to be the main conduits for deep-sourced metal-bearing fluids (Kerrich, 1986; Kerrich and Kyser, 1994) and may interact with these fluids near or in the ore depositional environment (Phillips, 1986; Henley and Ethridge, 1994; Hickman and others, 1994).

GENERAL GEOLOGY

Reconstructions of the tectonic history of north-central Nevada indicate that early and middle Paleozoic, deep-water sedimentary and igneous rocks were thrust eastward approximately 75 to 200 km during the Late Devonian to Early Mississippian Antler orogeny (Roberts, 1958; Roberts, 1964). These rocks compose the Roberts Mountains allochthon, which lies upon coeval shallow-water rocks of the continental platform. The two packages of rocks, the upper and lower-plates, are separated by the Roberts Mountains thrust (Merriam and Anderson, 1942; Roberts and others, 1958). Emplacement of the allochthon produced a topographic high, which shed sediments, that constitute the overlap assemblage of rocks, to the east and west in the late Paleozoic (Roberts, 1960; Madrid and others, 1992), and were followed by local volcanism in the early Mesozoic (fig. 1). Other tectonic reconstructions suggest that some geologic relations in the region also may be due to: (**1**) local Early Triassic remobilization of the Roberts Mountains allochthon (Ketner and Alpha, 1992; Ketner and others, 1993); (**2**) significant tectonism in the region during

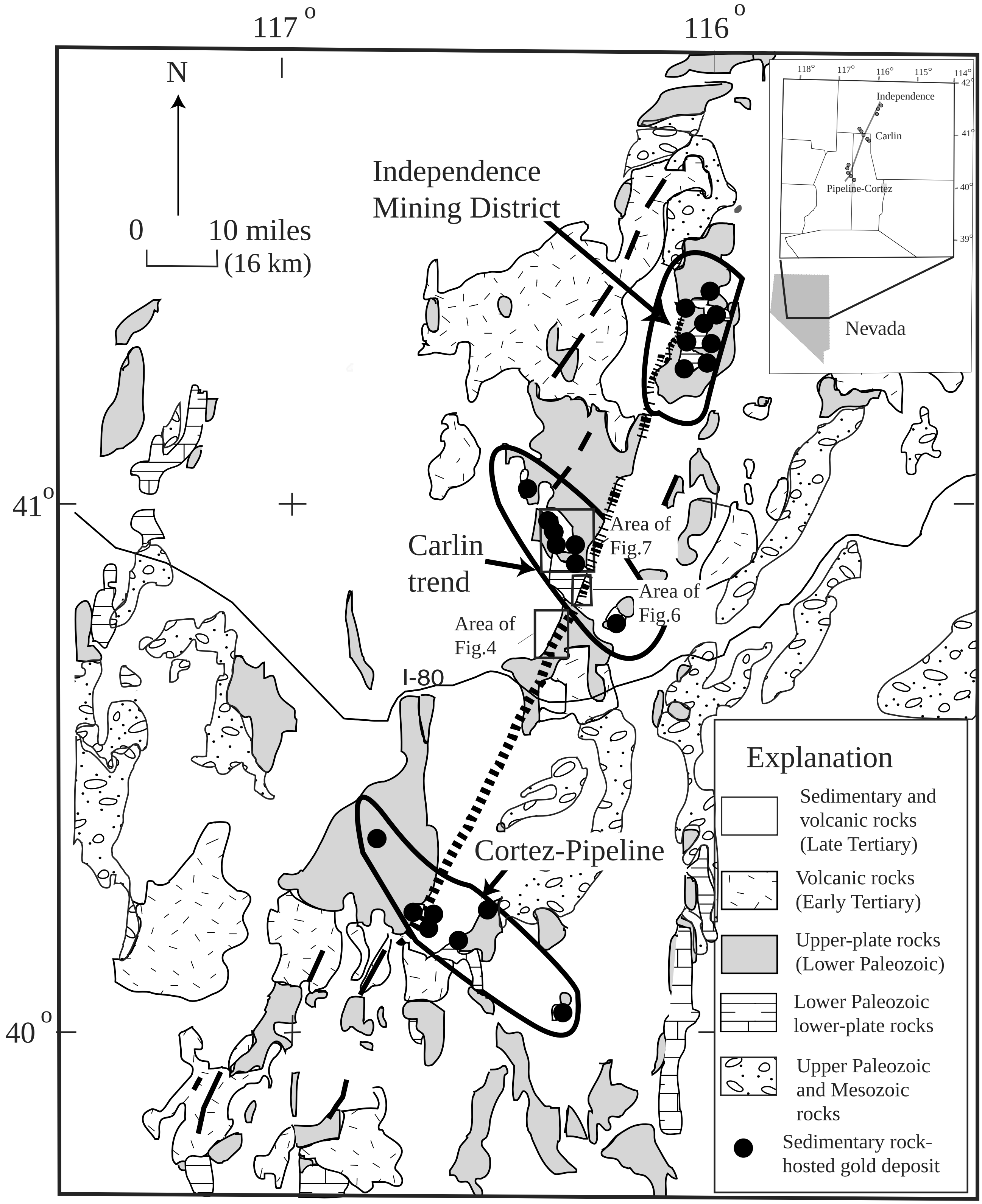

Figure 1. Location of the Crescent Valley-Independence lineament (CVIL) in north-central Nevada. The main focus of the lineament is indicated by the northeast-trending, partially dashed, black line that intersects the Independence, Carlin and Cortez-Pipeline Mining Districts. Note location of figures referred to in text, Bob's Flat, Richmond, and Carlin Mine. (Geology simplified from Stewart and Carlson, 1976).

the Late Jurassic Elko orogeny; (**3**) the Cretaceous to Early Tertiary Sevier orogeny; and (**4**) large-scale extensional detachment faulting in the late Eocene to early Oligocene (Thorman and others, 1991a, b; Seedorff, 1991; Wallace, 1991).

Orientation, nature, and geometric relations among tectonic fabrics in and near the CVIL may constrain the timing of events along it. Most fold axes in Paleozoic rocks in north-central Nevada plunge at low angles to the northeast and southwest (Evans and Theodore, 1978; Oldow, 1984; Peters and Evans, 1996). These folds have axial planes and fold axes that are roughly parallel to the CVIL; however, fold axes near major mineralized trends plunge at shallow angles to the northwest (Madrid, 1987; Madrid and Bagby, 1986; Peters, 1996, 1997a). The northwest-trending fold axes along the Carlin trend were postulated by Evans and Theodore (1978) to be due to Jurassic tectonism, which apparently is synchronous with some tectonic events recognized by Ketner and Smith (1982), Ketner (1987) and Thorman and others (1991a) in northeastern Nevada. This implies that much of the northeast-trending tectonic fabric in the CVIL predates the Jurassic; however, as detailed below, younger geologic events may also have northeast orientations in the CVIL.

The CVIL is defined by a N20E- to N30E–striking zone of linear geologic and geomorphologic features. As defined here, the lineament is present in the north on the west side of the Independence Mountains, on the east side of Independence Valley, and may include parts of the Independence Mining District (fig. 1). Farther to the southwest it marks the southeast edge of the Tuscarora Mountains near the Carlin trend. In its central parts, the CVIL passes through rocks of the Ordovician Vinini Formation in the southern Tuscarora Mountains near Boulder Valley and Bob’s Flat. It then continues south through Beowawe on the northeast side of Crescent Valley and may extend into Carico Lake Valley and farther to the southwest.

The central parts of the CVIL constitute a 3- to 5-km-wide zone that may, in part, be part of a much larger, composite 20-km-wide zone containing additional northeast-trending linear features (fig. 2). The CVIL also roughly marks the western edge of a 80–km-wide Tertiary basin lying between the Independence and Ruby Mountains (see Regina, 1960; Stewart and Carlson, 1976; Solomon and others, 1979; Mueller, 1992). The northern projection of CVIL marks the eastern edge of the Boulder batholith (see Muehlberger, 1992), suggesting that it may be part of a larger crustal-scale feature. The importance of the CVIL for gold ore genesis is that it traverses or is adjacent to three major sedimentary-rock-hosted gold mining districts that have deposit styles and mineralogic characteristics of sedimentary-rock-hosted gold (“Carlin-type”) deposits (Kuehn and Rose, 1995; Arehart, 1996; see also Peters and others, 1996). These characteristics are arsenian rims on older pyrite, presence of late orpiment, realgar, and stibnite, and alteration minerals assemblages formed during decalcification, carbonation and argillitization

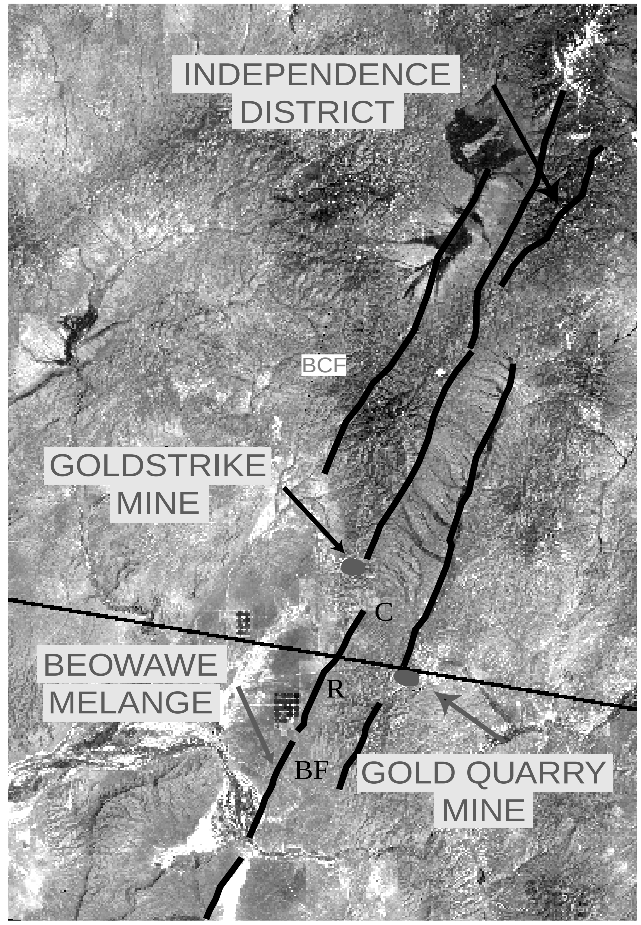

Figure 2. Annotated Landsat image of the northern part of the Crescent Valley-Independence lineament. Topographic features have been highlighted with dark lines. Using this image, the composite lineament zone is approximately 20 km wide, and contains three strands each of which may be 2 to 3 km wide. Large mines shown for location. BF, Bob’s Flat; R, Richmond, C, Carlin Mine. BCF, Boulder Creek fault segment (from Theodore and others, this volume) of larger photo-linement. Field of view approximately 77 by 144 km

of calcareous host rocks, typify. Because of the spatial and temporal relation to the three mining districts, it is possible that some geologic features present in the CVIL could have formed synchronous with the deposits.

CHARACTER, TERMS, AND GENESIS OF MÉLANGE ROCKS ALONG THE CVIL

Rock types near and in the CVIL contain fabrics that are typical of mélange zones (see Peters, 1996, 1997a). Mélange is a mappable body of fragmented and mixed rock, with phacoidal shapes, in a scaly, shaley matrix, commonly called *clast-in-matrix rock* or *brokenite* (Raymond, l984a, b; Peters, 1993). The chaotic nature of mélange is caused by either sedimentary or tectonic processes that produce fragmentation, mixing, disruption, and dismemberment. Although the laws of lateral continuity and superposition are not generally applicable in mélange (Hsu, l968), the mélange outcrops near or in the CVIL retain symmetrical linear fabrics that trend northeast, parallel to fold axes in the region, which is compatible with formation under tectonic, uniform stress.

Generation of clast-in-matrix rock may be due to progressive bulk inhomogeneous shortening (Bell, 1981), where deformation and dissolution are concentrated at the margins of lesser deformed phacoids (fig. 3*A*). These margins commonly are anastomosing or conjugate shear zones where strain and fluid has been partitioned around the undeformed phacoidal-shaped rocks, although they commonly retain internal symmetry (fig. 3*B*). This boudinage-style of deformation is important at all scales along the CVIL, particularly near the boundary of the upper and lower-plate rocks. Deformation of upper-plate rocks may have been the result of the Antler orogeny, and directly related to the emplacement of the Roberts Mountains allochthon, or could have been produced during, but also before or after allochthon emplacement. Similar mélange-type fabrics also characterize some ores of sedimentary rock-hosted gold deposits (Peters, 1997b; Lou Xiaohuan, 1993) (fig. 3*C*).

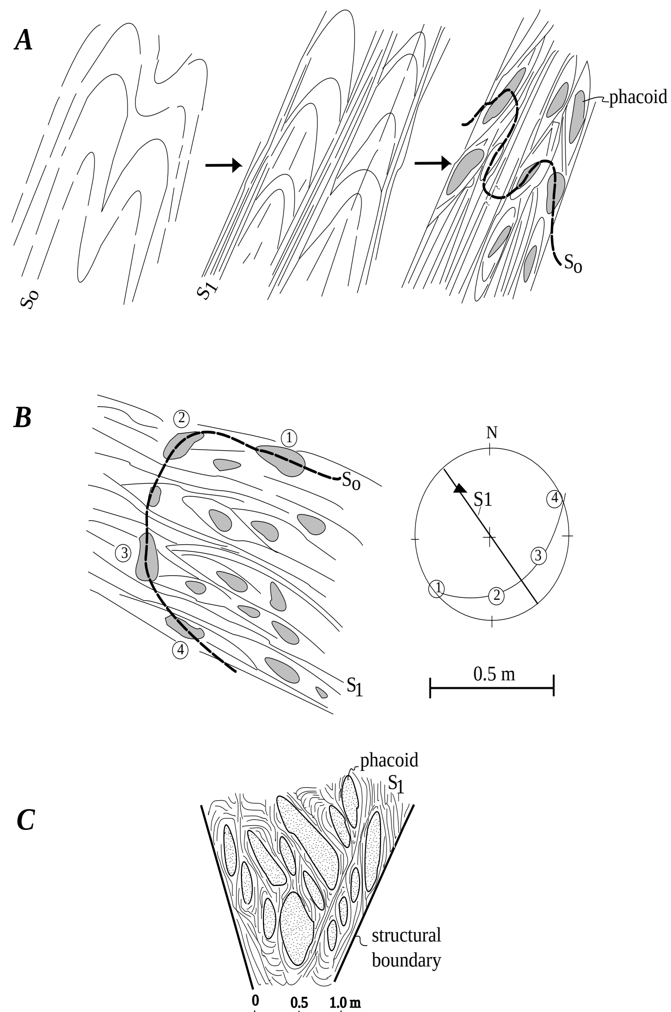

Figure 3. Sketches showing relict folds and symmetry preserved inside zones of intense deformation in clast-in-matrix rock (S_o = bedding, S_1 = axial plane cleavage): (***A***) Domainal cleavage formation on fold limbs preserves competent fold hinges as phacoids; (***B***) Limbs and hinges are preserved and S_o measurements in clasts define a fold with an axial plane that is coincident with cleavage in clast-in-matrix rocks. Solid triangle represents fold axis. Remnant folds from flexural slip transposition may also be preserved (Peters, 1993, 1996). (***C***) Clast-in-matrix zone in ore zone of Lannigou sedimentary rock-hosted gold deposit, Guizhou Province, P.R. China, (Lou Xiaohuan, 1993) showing that deformation resulting in phacoidal-shaped wallrock in a sheared matrix. This is a common texture in many structural-type sedimentary rock-hosted gold deposits (see Peters, 1996, 1997c).

DESCRIPTION OF STUDY AREAS ALONG THE CVIL

Along the CVIL, examples of mélange-type deformation in upper-plate rocks are present in the Bob's Flat and the Carlin Mine areas discussed below. The Richmond area lies between these two areas along the CVIL lower-plate rocks, and contains no mélange-type deformation. Additional evidence of the CVIL is also present in the Independence and Cortez-Pipeline Mining Districts.

Area of Bob's Flat

In the area of Bob's Flat, about 40 km west of the town of Carlin, evidence for the CVIL consists of northeast-elongated ridges of intensely tectonized rock of the upper-plate, assigned by Stewart and Carlson (1976) to the Ordovician Vinini Formation, and by adjacent northeast-trending valleys (fig. 1). Tectonized fabrics and foliation strike northeast. A northeast-striking dacite dike of probable Tertiary age, on the basis of its association with volcanic rocks, also lies along the CVIL zone (fig. 4). Detailed exposure of intensely tectonized rocks in the CVIL zone is present at the Beowawe turnoff (fig. 5), a 500–m-long road cut along the west-bound lane of Interstate Highway I–80. Deformed rocks include laminated pelitic chert, massive chert, silty and calcareous sandstone, and massive dolomitic, fine-grained sandstone. Bedding has been dismembered and transposed such that competent layers, which are 1- to 100-cm-thick, have been broken or deformed into phacoids in a matrix of irregularly cleaved shale or clast-in-matrix rock.

Strain in the tectonized rocks is concentrated in the in-

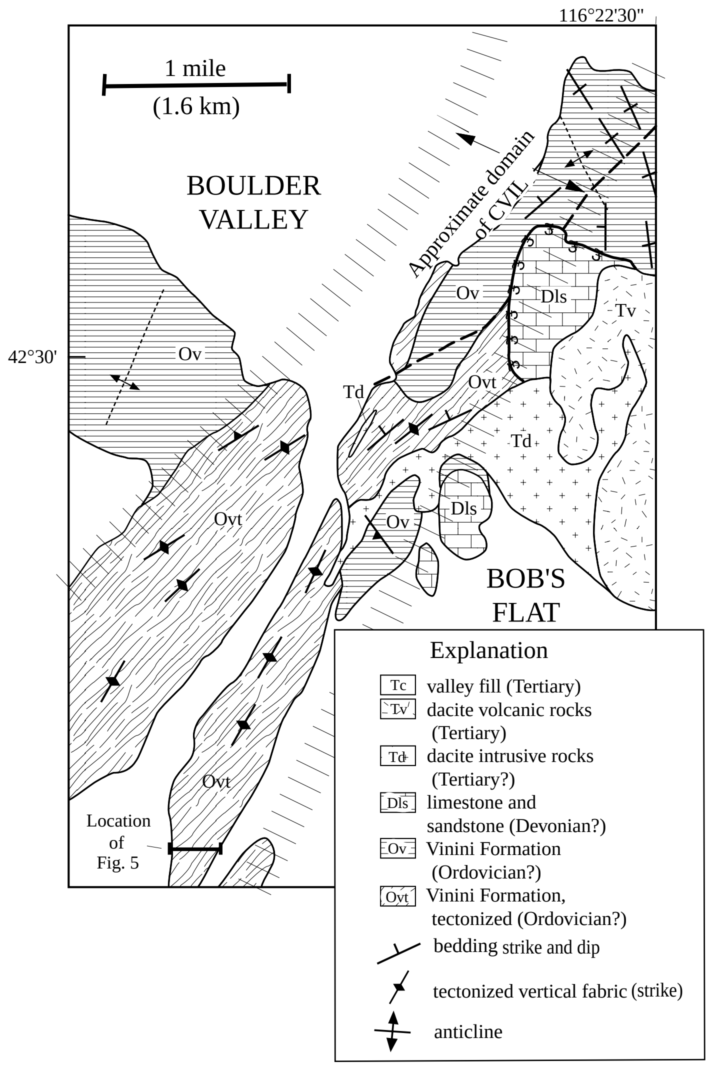

Figure 4. Geologic sketch map of the CVIL zone in the area of Bob's Flat (see fig. 1 for location). Evidence of the lineament is shown in the intensely deformed zones, defined by planar foliation and northeast-striking fabric and by northeast-striking dacite dikes. See fig. 1 for location (note location of Beowawe turnoff sketch–fig. 5).

competent, pelitic matrix of the clast-in-matrix rock, which contains blocks of undeformed, thick-bedded locally deformed chert and massive dolomitic sandstone as much as 2-m-long (fig. 5). Although the deformed bedding, form line patterns, and broken appearance suggest chaotic, random symmetry, a consistent northeast, shallow-plunging, linear fabric has been documented by Peters (1996, 1997a).

The northeast-striking linear and planar fabrics in the mélange zones in the central part of the CVIL near Bob's Flat are parallel to fold axial planes and fold axes formed during deformation between the Late Permian and Late Jurassic, during the Sonoma and Elko deformation events, according to Peters (1997c). Folding and transposition of bedding and shearing in the tectonized zones imply local northwest–southeast shortening, internal strain, and possible dissolution along cleavage planes in the zone of the CVIL during that time. Early Tertiary(?) dacite emplacement along the CVIL zone also suggests that the lineament contained linear dilational segments during this later time, which were injected by the dikes.

Richmond Area

The CVIL in the Richmond area, along the Carlin trend, is present on the eastern margin of the Tuscarora Mountains range front (figs. 1 and 6). Here the northeast-striking Richmond Summit fault cuts Tertiary rocks along the main drainage (Evans, 1980). In addition, a northeast-trending zone of jasperoid, breccia, calcite veining, and decalcification crops out along the range front. Further, apophyses and dikes of the Cretaceous Richmond granite stock extend northeast-southwest. Finally, northeast-striking thrust faults interleave rocks belonging to the Ordovician Eureka Quartzite and the Silurian Hanson Creek Formation (fig. 6). Foliation and other deformation fabrics are not pronounced in the igneous or contact metamorphosed sedimentary rocks. Hydrothermal alteration along the range front and displacement along the Richmond Summit fault indicate both hot-spring and tectonic activity along the CVIL in the Tertiary. Injection of the Richmond dike and Richmond stock also suggest that the CVIL had dilational segments during the middle Cretaceous.

Carlin Mine Area

The CVIL has an expression in the Carlin Mine area, in the Carlin trend, as an east-bounding edge to the range front, and as a series of parallel, northeast-striking faults (fig. 7). The Carlin trend contains over 100 million oz Au. Many northeast-striking faults lie along ore bodies or have jasperoid in outcrop (Peters, 1997d), and provided local structural controls for many of the orebodies (Teal and Jackson, 1997). There is a tendency for there to be more of these northeast-striking faults in a 3–km-wide zone adjacent to the projected center of the CVIL (fig. 7), indicating that hydrothermal fluids used faults in the CVIL zone as conduits.

The CVIL may also have an expression in the upper-plate rocks in mélange zones that contain northeast-trending fabrics in the Carlin Mine area. For example, on the east side of the Leeville fault zone (fig. 7), upper-plate rocks contain low-angle shear zones, which separate several 4- to 20-m-thick slabs of deformed rocks that are similar to mélange (fig. 8). The juxtaposition of distinctly different deformation styles and rock types on either side of the shear zones indicates that significant transport is likely to have taken place in the rock mass. Axes of folds in all rocks in the outcrop, regardless of slab position, plunge at low angles to the southwest and are parallel to fold axes in deformed rocks of the Vinini Formation north of the Carlin Mine (Peters, 1996, 1997d). This linear fabric is parallel to the linear and planar tectonized fabric in the area of Bob's Flat and may have predated the northeast-striking faults.

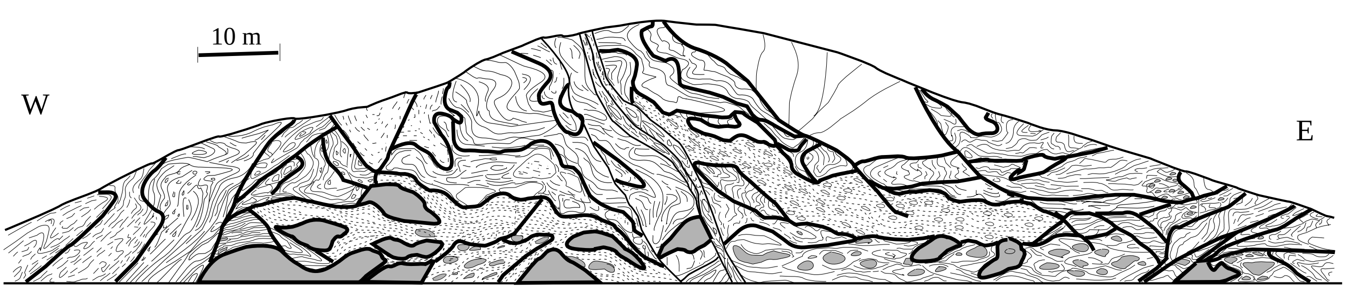

Figure 5. Sketch of exposed geology from the Beowawe turnoff road cut. Solid lines in sketch represent form lines of undifferentiated bedding (S_0) . Dashed, dash-dot lines either bedding or foliation (S_1); Patterned or plain areas represent phacoids of competent rocks in sheared rock or clast-in-matrix rock (lensoid pattern). Rock types include laminated pelitic chert, massive chert, silty and calcareous sandstone, and massive dolomitic, fine-grained sandstone. See fig. 4 for location in area of Bob's Flat. See Peters (1996, 1997a) for detailed geologic legend and rock types.

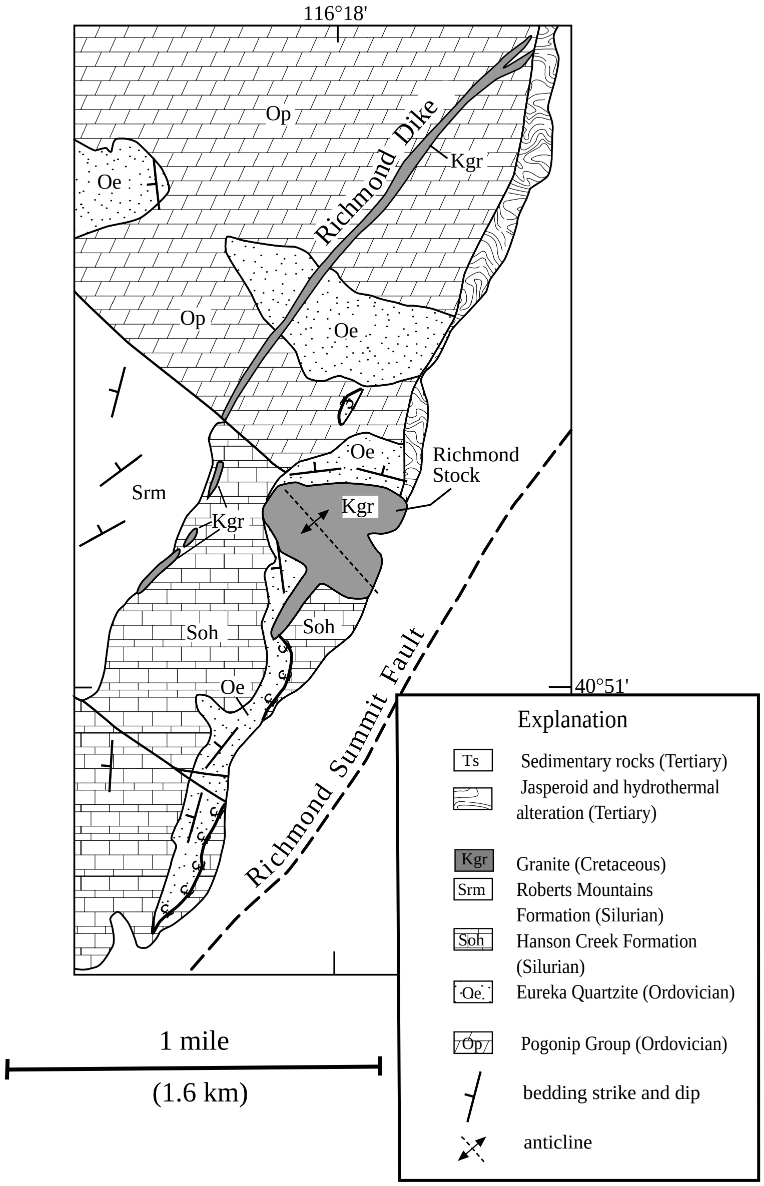

Figure 6. Geologic map of Richmond area in the cental part of the CVIL. See fig. 1 for location. Modified from Evans (1980).

Independence and Cortez-Pipeline Mining Districts

Clusters of sedimentary rock-hosted gold deposits at the north and south ends of the CVIL contain structural features common to gold deposits in the Carlin trend area, specifically northeast-striking faults that cross cut tectonic windows through the upper-plate of the Roberts Mountains allochthon or associated structural highs below the allochthon. The gold deposits in the Independence, Carlin and Cortez-Pipeline Mining Districts also share similar mineralogic and geochemical signatures, such as elevated As, Sb, Tl, and Hg contents.

The Cortez-Pipeline Mining District lies along the Battle Mountain-Eureka trend and contains about 10 million oz Au in sedimentary rock-hosted gold orebodies (Bonham and Hess, 1996). The orebodies are mainly hosted in lower-plate rocks to the Roberts Mountain allochthon (Radtke and others, 1987; Foo and others, 1996a; McCormack and Hays, 1996). Northeast-striking faults have significant ore control, particularly the Fence fault in the Pipeline deposit (not shown on fig. 1; see Foo and others, 1996b) and the Gold Acres and Island faults in the Gold Acres deposit (Hays and others, 1991) (fig. 9*A*). These faults are interpreted here as expressions of the CVIL.

The Independence Mining District has produced approximately 6 million oz Au from sedimentary rock-hosted

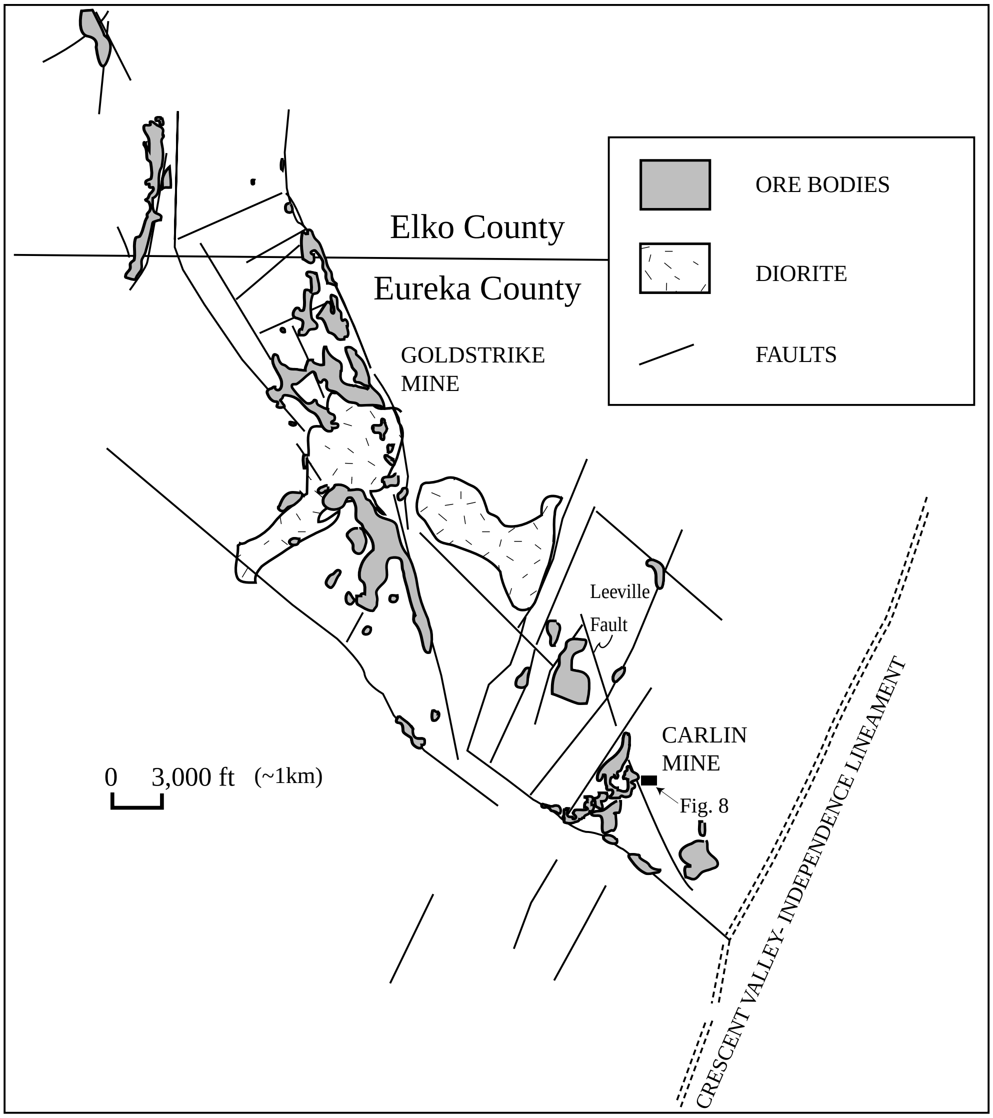

Figure 7. Orebody outlines, main intrusive bodies and faults in the north-central Carlin trend area. Note location of fig. 8. (Adapted from Teal and Jackson, 1997).

gold deposits (Bonham and Hess, 1996). The outline of the district-scale orebody cluster defines a 6.5- to 8-km-wide northeast-trending zone containing tectonic windows through the upper-plate rocks of the Roberts Mountains allochthon (fig. 9*B*). The ore deposits mainly are hosted in lower Paleozoic carbonate rocks of the lower-plate, particularly in the Jerritt Canyon and Big Springs (not shown on fig. 9*B*) areas. Fold axial planes in the windows trend east or west-northwest and are cut by a set of northeast-striking faults, which outline the general trend of the gold deposits. The orebodies are structurally controlled, many by northeast-striking faults (Birak and Hawkins, 1985; Coats, 1987; Bratland, 1991; Daly and others, 1991; Lapointe and others, 1991), or have associations with early Tertiary dikes (Phinisey and others, 1996). This northeastern elongation of faults, orebodies and windows is interpreted here as the expression of the CVIL.

DISCUSSION

Geologic features along the CVIL indicate deformation may have taken place repeatedly within the zone during late Paleozoic to early Mesozoic, Cretaceous, and Tertiary times. The post-Paleozoic time span coincidentally overlaps the most probable, but controversial, time interval of sedimentary rock-hosted gold deposits formation (Christensen, 1993). Such a temporal association would be consistent with the CVIL providing a high permeability conduit for a common ore fluid that could have produced all three major gold districts (see

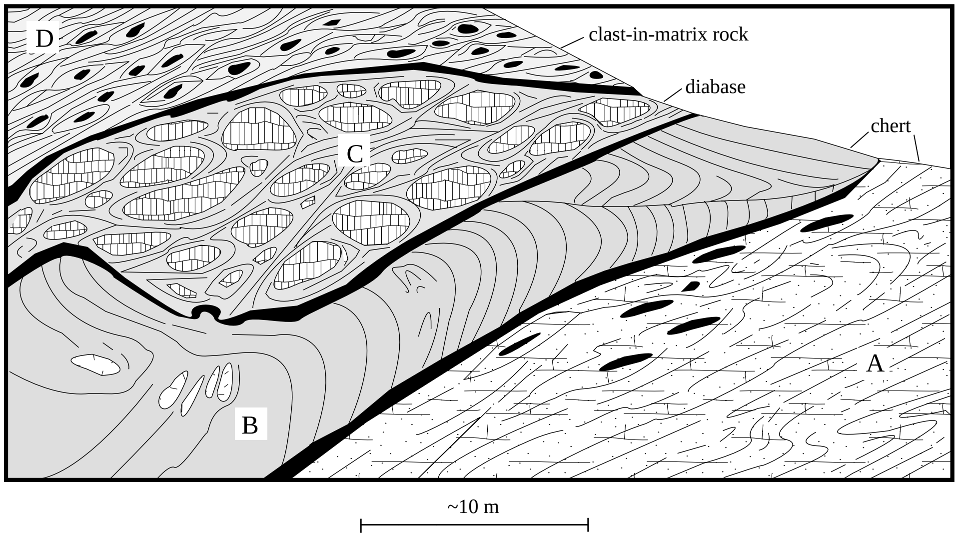

Figure 8. Sketch of Carlin Mine mélange, Carlin Mine area. Four rock packages are: (A) lower laminated isoclinally folded siliciclastic (chert); (B) cylindrically folded siliciclastic (chert); (C) latitic dacite (dolerite) deformed into phacoids; and, (D) black carbonaceous clast-in-matrix rock, containing <20% white, siliceous, 10 cm-scale phacoids in a planar phyllonitic matrix. Each package is separated by shallow-dipping shear zone (dark heavy lines). Fold orientations in each package are northeast–southwest, shallow-plunging (see text and Peters, 1996, 1997d).

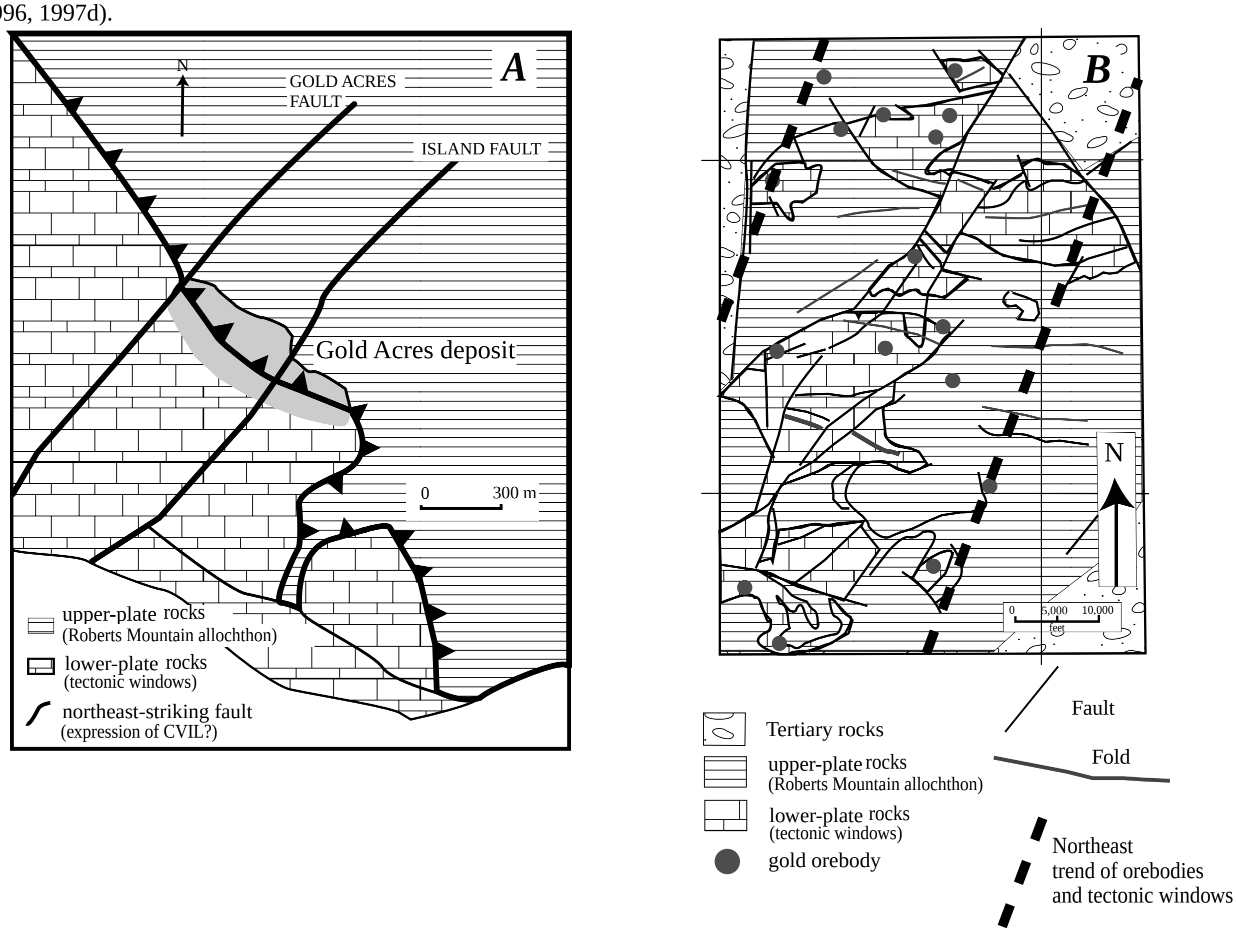

Figure 9. Examples of northeast-striking faults and trends in the northern and southern parts of the CVIL. (***A***) Gold Acres sedimentary rock-hosted gold deposit in the Cortez-Pipeline Mining District, showing control of northeast-striking Gold Acres and Island faults (adapted from Hays and Foo, 1991). (***B***) Independence Mining District, showing northeast-trend of windows and associated faults and orebodies (adapted from Daly and others, 1991, and Lapointe and others, 1991).

Scholz and Anders, 1994). In order to be related in a common way to ore genesis in all three mining districts, several mechanisms must have operated along CVIL. These are: (**1**) a single homogenous ore fluid may have traversed the entire lineament, producing clusters of ore deposits in the tectonic windows that served as permeable "traps" (see Hyndman, 1994); or (**2**) the intersection of the CVIL and northwest-striking structural trends and windows may have provided permeable foci to deep-seated ore; or (**3**) tectonism, crustal-scale hydrologic flow, and heat flow provided unique settings at different times in each mining district (see Logan and Decker, 1994). The CVIL, thus, could have provided a coincidental and local enhancement at these times and places to the ore-forming processes.

The three sedimentary rock-hosted gold districts along the CVIL are associated closely with tectonic windows through or structural highs beneath the Roberts Mountains allochthon. Polyphase deformation of the upper-plate rocks near the tectonic windows and the Roberts Mountains thrust partially may be the result of regional allochthon emplacement (D_1) and subsequent regional tectonic events, or may be attributable to local tectonism associated with development of the tectonic windows or structural highs (fig. 10). The geometric relations and relative ages of folds, faults, and lineaments in the Roberts Mountains allochthon and in the lower-plate rocks facilitate interpretation of how the gold deposits are related to deformation styles in and near the structural highs.

Deformation in upper-plate rocks, similar to intensely deformed mélange rocks at Bob's Flat and the Carlin Mine areas, is commonly interpreted to be the result of the Antler orogeny (D_1), and therefore directly related to the emplacement of the Roberts Mountains allochthon (see deformation nomenclature in fig. 10). Folding and transposition of bedding and shearing along cleavage of the clast-in-matrix rock reflect local northwest–southeast shortening, internal strain, and bulk transport within the allochthon. These fabrics parallel folding that is superimposed on the allochthon after emplacement. However, mélange zones that are part of the CVIL could also have formed after allochthon emplacement ($D_{2\text{-}3}$). Although the fold axes, fold axial planes, shear zones, and tectonized zones in the Bob's Flat and East Carlin Mine areas parallel late Paleozoic to early Mesozoic folds, the dissolution and intense deformation indicated in these rocks may have occurred later and could have been superimposed on the earlier northeast-trending fabric. This would be compatible with high rates of fluid flow in the CVIL in late Mesozoic or early Tertiary times that would be necessary for the formation of the gold ore bodies.

Mélange development is commonly associated with dissolution, progressive bulk shortening of the rock mass, and local fluid flow (Bell, 1981). Upper-plate mélange zones and northeast-striking tectonite fabrics, such as in the Bob's Flat (Beowawe turnoff) and the Carlin Mine areas, most likely pre-dated gold mineralization ($D_{1\text{-}2}$?). However, several mélange-like fabrics in the D_3 shear folds, such as the Dillon deformation zone in the Goldstrike Mine (Peters, 1997c), have spatial associations with mineralization that suggest that they were active during the gold mineralizing event. Syn-deformational ore deposition has been proposed for some sedimentary rock-

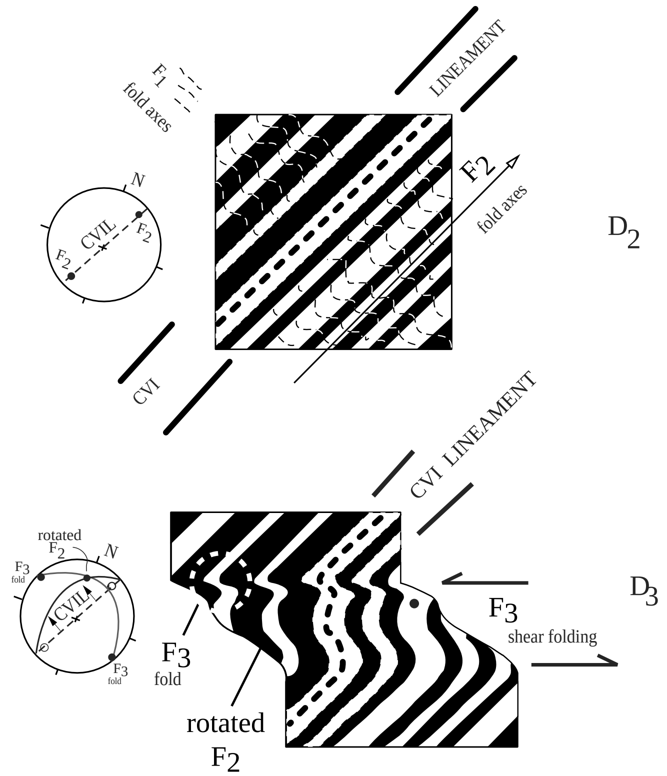

Figure 10. Shear fold model for deformation near the CVIL. The numerous deformations affecting rocks in Carlin trend area, including CVIL, between Paleozoic and middle Tertiary time are generalized by Peters (1997) as a three-phase (D1 to D3) sequence of tectonic events. These events are: (1) Late Devonian and Late Pennsylvanian Antler and Humboldt orogeny (Peters, 1997) (D1, F1 folds) synchronous with and following emplacement of the Roberts Mountains allochthon; (2) Late Permian and Late Jurassic Sonoma and Elko deformation (Peters, 1997) (D2, F2 folds), which was characterized by penetrative, shallow northeast- and southwest-plunging fold axes, local intrusions, and northwest-striking faults; and (3) Late Jurassic and Early Eocene Sevier deformation (D3, F3 folds) which rotated or refolded many F2 folds to north- and northwest-trends and produced local west northwest-trending F3 shear folds. Pre-deformation events are designated as D_0. Stereo nets show fold axes as circles. Of specific interest are the D2, F2 folds, which parallel the CVIL. The examples of shear zones and shear folds illustrate the deformation style that may have been present in north-central Nevada near the CVIL. The west northwest-striking shear zones produced shear (F3) folds by refolding original F2 folds from northeast-southwest to northwest orientations (adapted from Ramsey, 1980). This may also have resulted in refolding of northeastern planar fabric in the CVIL, resulting in westerly dips (see second stereonet). Early events along the CVIL may have been coeval with the F2 folds and therefore would also be folded or dilated, particularly near the northwest-trending gold belts.

hosted gold deposits by Peters and others (1997) in Nevada and by Lou Xiaohuan (1993; 1996) for some Carlin-type gold deposits in China. The host structural zones in the syn-deformational gold deposits are interpreted in the Carlin trend area by Peters (1996, 1997d) to act like F_3 shear folds that may have folded F_2 folds in a right lateral sense (fig. 10). These D_3 shear zones are deformed, broad, 200-m-thick zones with multiple, sheared strands, breccia bodies, and phacoidal-shaped blocks and slabs (Peters, 1997c).

Although relative ages of mineralization have not been resolved or are enigmatic in north-central Nevada, the formation of sedimentary rock-hosted gold deposits, deformation in the CVIL and the crosscutting northwest-striking deformation zones, may have been synchronous during the time of gold transport and deposition.

Hot saline ore fluids capable of traveling distances of over 100 km with metals have been described by Sverjensky (1984) in sedimentary basin settings similar to those in north-central Nevada. Much of the rock traversed by such fluids would be through the porous, calcareous lower-plate rocks below the Roberts Mountains allochthon. If the ore fluid had a composition similar to that described by Woitsekhowskaya and Peters (this volume) capable of producing sedimentary rock-hosted gold deposits, it could retain metals in solution and be able to transport metals over regional-scale distances within these rocks, due to the large buffering capacity of the carbonate in the rocks (see Crerar and others, 1985). Such fluid flow could have been channeled into high permeability conduits (see also Rodriguez, 1997), such as the CVIL, and may have been accompanied by deformation, coeval dissolution, magmatism, and crustal heat flow.

Fabrics related to emplacement of the Roberts Mountains allochthon (D_1) were overprinted by subsequent penetrative deformation events that most likely also penetrated the lower-plate rocks. One or more of these deformation events may have been synchronous with gold mineralization. Because there are similarities between deformation styles in each of the three generalized deformation events, it is possible that a number of unrecognized D_3 deformation zones may be present in the CVIL as northeast-trending masses that served as regional-scale conduits for fluids that formed sedimentary rock-hosted gold deposits.

REFERENCES CITED

Arehart, G. B., 1996, Characteristics and origin of sediment-hosted gold deposits: a review: Ore Geology Reviews, v. 11, p. 383–403.

Bell, T.H., 1981, Foliation development—The contribution, geometry and significance of progressive, bulk, inhomogeneous shortening: Tectonophysics, v. 75, p. 273–296.

Birak, D.J., and Hawkins, R.B., 1985, The geology of the Enfield Bell Mine and the Jerritt Canyon District, Elko County, Nevada, *in* Tooker, E.W., ed., Geologic characteristics of sediment- and volcanic-hosted disseminated gold deposits— search for an occurrence model: U.S. Geological Survey Bulletin 1646, p. 95–105.

Bonham, H.F., Jr., and Hess, R.H., 1996, Major precious-metal deposits, in the Nevada Mining Industry–1995: Nevada Bureau of Mines and Geology Special Publication MI-1995, p. 21–34.

Bratland, C.T., 1991, Geology of the Winters Creek gold deposit, Independence Mountains, Elko County, Nevada, *in* Raines G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and Ore Deposits of the Great Basin, Geologic Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April, 1990, v. 1, p. 607–618.

Christensen, O.D., 1993, Carlin trend geologic overview, *in* Christensen, O.D., ed., Gold Deposits of the Carlin Trend, Nevada: Society of Economic Geologists Guidebook Series, v. 18, p. 12–26.

Coats, R.R., 1987, Geology of Elko County, Nevada: Nevada Bureau of Mines and Geology Bulletin 101, 112 p., 1 plate [scale 1:250,000].

Crerar, D., Scott, W., and Brantley, S., 1985, Chemical controls on solubility of ore-forming minerals in hydrothermal solutions: Canadian Mineralogist, v. 23, p. 333–352.

Daly, W.E., Doe, T.C., and Lavanger, R.J., 1991, Geology of the Northern Independence Mountains, Elko County, Nevada, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and Ore Deposits of the Great Basin, Geologic Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April, 1990, p. 583–602.

Evans, J.G., 1980, Geology of the Rodeo Creek northeast and Welches Canyon quadrangles, Eureka County, Nevada: U.S. Geological Survey Bulletin 1473, 81 p.

Evans, J.G., and Theodore, T.G., 1978, Deformation of the Roberts Mountains allochthon in north-central Nevada: U.S. Geological Survey Professional Paper 1060, 18 p.

Foo, S.T., Hays, R.C., Jr., and McCormack, J.K., 1996a, Geology and mineralization of the South Pipeline gold deposit, Lander County, Nevada, *in* Coyner, A.R., and Fahey, P.L., eds., Geology and Ore Deposits of the American Cordillera: Geological Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April, 1995, p. 111–121.

Foo, S.T., Hays, Jr., R.C., and McCormack, J.K., 1996b, Geology and mineralization of the Pipeline gold deposit, Lander County, Nevada, *in* Coyner, A.R., and Fahey, P.L., eds., Geology and Ore Deposits of the American Cordillera: Geological Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April, 1995, p. 95–109.

Hays, R.C., Jr., and Foo, S.T., 1991, Geology and mineralization of the Gold Acres deposit, Lander County, Nevada, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and Ore Deposits of the Great Basin: Geologic Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April, 1990, p. 677–685.

Henley, R.W., and Ethridge, M.A., 1994, Syn-deformational gold transport and deposition in brittle-ductile shear zones - some chaotic thoughts, *in* Hickman, Stephen, Sibson, Richard, and Bruhn, Ronald, eds., 1994, Proceedings of Workshop LXIII The Mechanical Involvement of Fluids in Faulting, 6-10 June, 1993: U.S. Geological Survey Open-File Report 94-228, p. 204–215.

Hickman, Stephen, Sibson, Richard, and Bruhn, Ronald, eds., 1994, Proceedings of Workshop LXIII The Mechanical Involvement of Fluids in Faulting, 6-10 June, 1993: U.S. Geological Survey Open-File Report 94-228, 615p.

Hsu, K.J., 1968, Mélanges and their distinction from olistostromes: Society of Economic Paleontologists and Mineralogists, Special Paper 19, p. 321–333.

Hyndman, R.D., 1994, Widespread fluids in the lower crust: a source to crustal penetrating faults, *in* Hickman, Stephen, Sibson, Richard, and Bruhn, Ronald, eds., Proceedings of Workshop LXIII The Mechanical Involvement of Fluids in Faulting, 6 - 10 June, 1993: U.S. Geological Survey Open-File 94–228, p. 178-189.

Kerrich, Robert, 1986, Fluid transport in lineaments: Philosophical Transactions Royal Society London, v. A317, p. 216–251.

Kerrich, Robert, and Kyser, T.K., 1994, The geochemistry and role of fluids in large continental structures: an overview, *in* Hickman, Stephen, Sibson, Richard, and Bruhn, Ronald, eds., 1994, Proceedings of Workshop LXIII The Mechanical Involvement of Fluids in Faulting, 6-10 June, 1993: U.S. Geological Survey Open-File Report 94-228, p. 349–389.

Ketner, K.B., 1987, Post-Early Triassic, pre-middle Eocene folds and thrust faults, northern Adobe Range, Nevada: Geological Society of America Centennial Field Conference-Cordilleran Section, no. 21, p. 91–94.

Ketner K.B., and Alpha, A.G., 1992, Mesozoic and Tertiary rocks near Elko, Nevada—evidence for Jurassic to Eocene folding and low-angle faulting: U.S. Geological Survey Bulletin 1988–C, 13 p.

Ketner, K.B., Murchey, B.L., Stamm, R.G., and Wardlaw, B.R., 1993, Paleozoic and Mesozoic rocks of Mount Icabod and Dorsey Canyon, Elko County, Nevada—evidence for Post-early Triassic emplacement of the Roberts Mountains and Golconda allochthons: U.S. Geological Survey Bulletin 1988—D, 12 p.

Ketner, K.B., and Smith, J.F., Jr., 1982, Mid-Paleozoic age of the Roberts thrust unsettled by new data from northern Nevada: Geology, v. 10, p. 298–303.

Kuehn, C.A., and Rose, A.W., 1995, Carlin gold deposits, Nevada: Origin in a deep zone of mixing between normally pressured and over pressured fluids: Economic Geology, v. 90, p. 17–36.

Lamb, J.B., and Cline, J.M., 1997, Depths of formation of the Meikle and Betze/Post deposits, *in* Vikre, P., Thompson, T.B., Bettles, K., Christensen, O, and Parratt, R., eds., Carlin-type Gold Deposits Field Conference: Society of Economic Geologists Guidebook Series, v. 28, p. 101–108.

Lapointe, D.D., Tingley, J.V., and Jones, R.B., 1991, Mineral resources of Elko County, Nevada: Nevada Bureau of Mines and Geology Bulletin 106, 236p., 1 plate [scale 1: 250,000].

Logan, J.M., and Decker, C.L., 1994, Cyclic fluid flow along faults, *in* Hickman, Stephen, Sibson, Richard, and Bruhn, Ronald eds., 1994, Proceedings of Workshop LXIII The Mechanical Involvement of Fluids in Faulting, 6-10 June, 1993: U.S. Geological Survey Open-File Report 94-228, p. 190–203.

Lou Xiaohuan, 1993, Exploration of the mechanisms and features of ore-control faults (F_3) and structural metallogenic processes at the Lannigou gold deposit: Guizhou Geology, v. 1, no. 1, p. 26–40 (in Chinese).

———1996, A study on the control of geometric and kinetic features of fault structures on the location of gold deposits–example from Carlin-type gold deposits of southwest Guizhou: Guizhou Geology, v. 14, no. 1, p. 46–54 (in Chinese).

Madrid, R.J., 1987, Stratigraphy of the Roberts Mountains allochthon in north-central Nevada: Stanford University, Ph.D. dissertation, 341 p.

Madrid, R.J., and Bagby, W.C., 1986, Structural alignment of sediment-hosted gold deposits in north central Nevada: An example of inherited fabric: Geological Society of America Abstracts with Programs, v. 18, p. 393.

Madrid, R.J., Poole, F.G., and Wrucke, C.T., 1992, Rocks of the Antler orogen—The Roberts Mountain allochthon, *in* Burchfiel, B.C., Lipman, P.W., and Zoback, M.L., eds., The Cordilleran Orogen: Conterminous U.S.: Geological Society of America, The Geology of North America, Volume G—3, p. 28–34.

Merriam, C.W., and Anderson, C.A., 1942, Reconnaissance survey of the Roberts Mountains, Nevada: Geological Society America Bulletin, v. 53, no. 12, p. 1675–1727.

McCormack, J.K., and Hays, R.C. Jr., 1996, Crescent Valley: a model for reconstruction of district mineralization in Basin and Range, *in* Coyner, A.R., and Fahey, P.L., eds., Geology and Ore Deposits of the American Cordillera: Geological Society of Nevada Symposium Proceedings, Reno/Spark, Nevada, April, 1995, p. 635–646.

Muehlberger, W.R., 1992, Tectonic Map of North America: Association of Petroleum Geologists, Tulsa, 2 sheets, [scale 1:5,000,000].

Mueller, K.J., 1992, Tertiary basin development and exhumation of the northern East Humboldt-Wood Hills metamorphic complex, Elko County, Nevada: Ph.D. dissertation, Laramie, University of Wyoming, 205p.

Oldow, J.S., 1984, Spatial variability in the structure of the Roberts Mountains allochthon, western Nevada: Geological Society of America Bulletin, v. 95, p. 174–185.

Peters, S.G., 1993, Polygenetic mélange in the Hodgkinson goldfield, Northern Tasman orogenic zone: Australian Journal of Earth Sciences, v. 40, p. 115–129.

———1996, Definition of the Carlin trend using orientation of fold axes and applications to ore control and zoning in the central Betze orebody, Betze-Post Mine, *in* Green, Steve ed., Trip B, Structural Geology of the Carlin Trend, Geology and Ore Deposits of the American Cordillera—A Symposium, Field Guide Compendium: Geological Society of Nevada, Reno, Nevada, p. 59–95.

———1997a, Structural transect across the southern Carlin trend, Eureka County, Nevada: U.S. Geological Survey Open-File Report 97–0347, 27 p. 2 sheets, [scale 1:500].

———1997b, Structural transect across the north-central Carlin trend, Eureka County, Nevada: U.S. Geological Survey Open-File Report 97-83, 41 p., 6 sheets, [scale 1:500].

———1997c, The nature of some upper- and lower-plate rocks near the Roberts Mountains thrust, Carlin trend, *in* Perry, A.J., and Abbot, E.W., 1997, The Roberts Mountains Thrust, Elko and Eureka Counties, Nevada: Nevada Petroleum Society, 1997 Field Trip Guidebook, Reno, Nevada, p. 35–40.

———1997d, Structural transect across the central Carlin trend, Eureka County, Nevada: U.S. Geological Survey Open-File Report 97–55, 40 p., 2 sheets, [scale 1:6,000].

Peters, S. G., and Evans J.G, 1995, Mesoscopic and Megascopic fabric geometries in parts of the Carlin trend, Eureka and Elko Counties, Nevada *in* Symposium, Geology and Ore Deposits of the American Cordillera, April 1995, Program with Abstracts: Geological Society of Nevada, Reno/Sparks, Nevada p. 61–62.

Peters, S. G., Nash, J.T., John, D.A., Spanski, G.T., King, H. D., Connors, K.A., Moring, B.C., Doebrich, J. L., McGuire, D.J., Albino, G.V., Dunn, V.C., Theodore, T.G., and Ludington, Steve, 1996, Metallic mineral resources in the U.S. Bureau of Land Management's Winnemucca District and Surprise Resource Area, northwest Nevada and northeast California: U.S. Geological Survey Open-File Report 96–712, 147 p., 11 sheets, [scale 1:100,000].

Peters, S.G., Leonardson, R.W., Ferdock, G.C., and Lauha, E.A., 1997a, Breccia types in the Betze orebody, Goldstrike Mine, Eureka County, Nevada, *in* Vikre, P., Thompson, T.B., Bettles, K., Christensen, O, and Parratt, R., eds., Carlin-type Gold Deposits Field Conference: Society of Economic Geologists Guidebook Series, vol. 28, p. 87–107.

Phillips, J.W., 1986, Hydraulic fracturing effects in the formation of mineral deposits: Transactions Institute Mining and Metallurgy, v. 95, p. B17–24.

Phinisey, J.D., Hofstra, A.H., Snee, L.W., Roberts, T.T., Dahl, A.R., and Loranger, R.J., 1996, Evidence for multiple episodes of igneous and hydrothermal activity and constraints on the timing of gold mineralization, Jerritt Canyon District, Elko County, Nevada, *in* Coyner, A.R., and Fahey, P.L., eds., Geology and Ore Deposits of the American: Geological Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April, 1995, p.15–39.

Radtke, A.S., Foo, S.T., and Percival, T.J., 1987, Geologic and chemical features of the Cortez gold deposit, Lander County, Nevada, *in* Johnson, J.L., ed., Bulk Mineable Precious Metal Deposits of the Western United States, Guidebook for Field Trips: Geological Society of Nevada, Reno, Nevada, p. 319–325.

Ramsey, J.G., 1980, Shear zone geometry: a review: Journal of Structural Geology, v. 2, no. 1/2, p. 83–99.

Raymond, L.A., 1984a, Classification of mélanges: Geological Society of America Special Paper 198, p. 7–20.

———ed., 1984b, Mélanges, their nature, origin and significance: Geological Society of America Special Paper 198, 170 p.

Regnier, J., 1960, Cenozoic geology in the vicinity of Carlin, Nevada: Geological Society America Bulletin, v. 71, p. 1189–1210.

Roberts, R.J., 1960, Alignment of mining districts in north-central Nevada: U.S. Geological Survey Professional Paper 400–B, p. 17–19.

———1966, Metallogenic provinces and mineral belts in Nevada: Nevada Bureau of Mines Report 13, pt. A, p. 47–72.

Roberts, R.J., Hotz, P.E., Gilluly, J., and Ferguson, H.G., 1958, Paleozoic rocks of north-central Nevada: American Association of Petroleum Geologists Bulletin, v. 42, no. 12, p. 2813–2857.

Rodriguez, B.D., 1997, Deep resistivity structure across the Carlin trend, *in* Vikre, P., Thompson, T.B., Bettles, K., Christensen, O, and Parrat, R., eds., Carlin-type Gold Deposits Field Conference: Society of Economic Geologists Guidebook Series, v. 28, p. 39–46.

Seedorff, Eric, 1991, Magmatism, extension, and ore deposits of Eocene to Holocene age in the Great Basin—mutual effects and preliminary proposed genetic relationships, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and Ore Deposits of the Great Basin, Geologic Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April, 1990, p.133–178.

Scholtz, C.H., and Anders, M.H., 1994, The permeability of faults, *in* Hickman, Stephen, Sibson, Richard, and Bruhn, Ronald, eds., 1994, Proceedings of Workshop LXIII The Mechanical Involvement of Fluids in Faulting, 6-10 June, 1993: U.S. Geological Survey Open-File Report 94-228, p. 247–253.

Shawe, D.R., 1991, Structurally controlled gold trends imply large gold resources in Nevada, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and Ore Deposits of the Great Basin: Geologic Society of Nevada Symposium Proceedings, Reno/ Sparks, Nevada, April, 1990, p. 193–212.

Solomon, B.J., McKee, E.H., and Anderson, D.W., 1979, Paleogene rocks near Elko, Nevada, *in* Armentrout, J.M., Cole, M.R., and TerBest, H. Jr., eds., Cenozoic Paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section III, p. 75–79.

Stewart, J.H., and Carlson, J.E., 1976, Geologic map of north-central Nevada: Nevada Bureau of Mines and Geology, Map 50, 1 sheet, [scale 1:250,000].

Sverjensky, D.A., 1984, Oil field brines as ore-forming solutions: Economic Geology, v. 79, p. 38–49.

Teal, Lewis, and Jackson, Mac, 1997, Geologic overview of the Carlin trend gold deposits and descriptions of recent deep discoveries, *in* Vikre, P., Thompson, T.B., Bettles, K., Christensen, O, and Parrat, R., eds., Carlin-type Gold Deposits Field Conference: Society of Economic Geologists Guidebook Series, v. 28, p. 3–38.

Theodore, T.G., Armstrong, A.K., Harris, A.G., Stevens, C.H., and Tosdal, R.M., this volume, Geology of the northern terminus of the Carlin trend, Nevada: links between crustal shortening during the Late Paleozoic Humboldt orogeny and northeast-striking faults, *in* Tosdal, R.M., ed., Contributions to the Au metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Thorman, C.H., and Christensen, Odin, 1991, Geologic settings of gold deposits in the Great Basin, western United States, *in* Ladeira, E.R., ed., Proceedings of Brazil Gold '91, An international symposium on geology of gold: Belo Horizonte, 1991, A.A. Balkena, Rotterdam, p. 65–76.

Thorman, C.H., Ketner, K.B., Brooks, W.E., Snee, L.W., and Zimmerman, R.A., 1991a, Late Mesozoic-Cenozoic tectonics in northeastern Nevada, *in* Raines, G.I., Lisle, R.W., Schafer, R.W., and Wilkinson, W.H., eds., Geology and Ore Deposits of the Great Basin, Symposium Proceedings: The Geological Society of Nevada, p. 25–45.

Thorman, C.H., Ketner, K.B., Snoke, A.W., Brooks, W.E., and Mueller, K.J., 1991b, Evidence for the involvement of the Roberts Mountains allochthon in Mesozoic tectonics and its effect on mineral deposit and petroleum accumulation models in northeast Nevada, Field Trip 13, *in* Buffa, R.H., and Coyner, A.R., eds., Geology and Ore Deposits of the Great Basin—Field Trip Guidebook Compendium—Great Basin Sympo-sium, April, 1990: Geological Society of Nevada, Reno/Sparks, p. 869–905.

Wallace, A. R., 1991, Effect of Late Miocene extension on the exposures of gold deposits in north-central Nevada, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Geology and Ore Deposits of the Great Basin: Geologic Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April, 1990, p. 179–184.

Woitsekhowskaya, M., and Peters, S.G., this volume, Geochemical modeling of alteration and gold deposition in the Betze deposit, *in* Tosdal, R.M., ed., Contributions to the Au metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.