GEOLOGY OF THE NORTHERN TERMINUS OF THE CARLIN TREND, NEVADA: LINKS BETWEEN CRUSTAL SHORTENING DURING THE LATE PALEOZOIC HUMBOLDT OROGENY AND NORTHEAST-STRIKING FAULTS

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ABSTRACT

Dating of depositional and structural events of Late Pennsylvanian to Miocene age in the Santa Renia Fields and Beaver Peak 7–1/2 minute quadrangles has allowed development of a more complete geologic history of northeastern Nevada. Upper Pennsylvanian and Lower Permian foreland clastic rocks of the Strathearn Formation extend into the area, and these rocks have been involved in what appears to be regionally extensive north-south shortening associated with the late Paleozoic Humboldt orogeny. A major thrust in the area, the Coyote thrust, places Ordovician rocks of the Vinini Formation on top of lower strata of the Strathearn Formation probably sometime in the late Paleozoic, because the Vinini Formation also is overlain depositionally by upper strata of the Strathearn Formation. The upper plate of the Coyote thrust includes a number of generally north-dipping, imbricate thrust surfaces—its lower plate includes structurally related south-verging tightly overturned folds. Similar styles of deformation with similar folds and thrust-surface orientations are present elsewhere in many northeastern Nevada mountain ranges, where they may have continued to form as late as the Jurassic Elko orogeny. North-south late Paleozoic shortening also may have been directly associated with development of transcurrent sinistral shear along a northeast-trending deformation zone, in places as much as 20–km-wide. This feature, which has three major fault segments along its outcrop in the quadrangles, has been termed the Crescent Valley-Independence Lineament. A major strand of the Crescent Valley-Independence Lineament in the Beaver Peak quadrangle coincides with the northeast-striking Boulder Creek fault, which shows approximately 0.8 km sinistral offset of the Strathearn Formation, but only about 0.2 km sinistral separation of the Coyote thrust. This suggests some movements of the high-angle sinistral faults may predate final emplacement of the upper plate of the Coyote thrust.

Early deformation in lower Paleozoic strata along the site of the future Carlin trend of gold deposits is inferred to include a dilational jog between two of the major fault strands that constitute the Crescent Valley-Independence Lineament. If a companion northwest-striking shear that is conjugate to the Crescent Valley-Independence Lineament is present somewhere in northern Nevada, a likely site for it is the present trace of the Miocene northern Nevada rift. We suggest that a "proto" northern Nevada rift during the late Paleozoic may have concentrated right lateral shear along its trace, largely in deeply buried lower Paleozoic rocks. Thus, a favorable environment for a "new" Carlin trend might be east-northeast-trending dilational jogs now reflected as horsts in Miocene rocks near the northern Nevada rift. Subsequent to late Paleozoic events, Paleozoic rocks in the northern Carlin trend were subjected to Mesozoic generally east-west shortening and emplacement of Jurassic and later plutons and dikes into the dilational jog, as well as Tertiary east-west extension. Tertiary extension is manifested by large numbers of faults of various orientations, and by largely unconsolidated deposits of the Miocene Carlin Formation, including widespread air-fall tuff, which has partly filled narrow pull-apart basins as much as 800 m deep.

INTRODUCTION

The purpose of this preliminary report is (**1**) to summarize recent geologic investigations in the Santa Renia Fields and Beaver Peak 7–1/2 minute quadrangles, (**2**) to integrate these investigations with others currently being completed along the trend (Peters, this volume; Fleck and others, this volume; Wallace and John, this volume; Rodriguez, this volume), and (**3**) to suggest, thereby, that a northwesterly zone of crustal weakness along the northern part of the Carlin trend, near which gold deposits eventually concentrated during Mesozoic and (or) Tertiary time, may be much older than previously envisaged. The northwest-trending zone of weakness along the Carlin trend may be a northwesterly-trending dilational jog across a northeast-trending, regional sinistral shear couple that initially formed during largely north-south shortening associated with the late Paleozoic Humboldt orogeny of Ketner (1977).

The northern part of the Carlin trend of gold deposits in northern Nevada—extending northwesterly from the Gold Quarry Mine to the Dee Mine (figs. 1 and 2)—is one of the richest and economically most important gold mining districts in the world since large-scale gold mining began in 1965 (Christensen, 1996; Teal and Jackson, 1997). These deposits collectively are referred to as Carlin-type systems, or sedimentary rock-hosted disseminated gold (Arehart's (1996) SHGD), which generally consist of submicron-sized gold, commonly within the crystal structure of pyrite that is disseminated in silicified, argillized, and decalcified sedimentary rocks and, to a lesser extent, in volcanic and other rocks (Tooker, 1985; Berger, 1986). Many of these deposits also are associated spatially either with syngenetic bedded barite occurrences or epigenetic vein occurrences, and recent investigations suggest that some of the Carlin-type deposits may have originated from CO_2–rich, Cl–poor, gold-bearing fluids separated from relatively deep-seated plutons (Ressel, 1998). Currently (1998), production from the State of Nevada is at the rate of approximately 7 million oz Au per year, roughly 9 percent of world gold production (Dobra, 1997), and most of the gold is being extracted from the northern part of the Carlin trend where 56 individual gold deposits are known (fig. 3). As noted by Christensen (1997), one of the crucial enigmatic questions still concerning Carlin-type deposits regards the geologic reasons that the deposits commonly are clustered in linear arrays as along the Carlin trend and elsewhere in Nevada. In order to address this question in the southern Tuscarora Mountains near the northern terminus of the Carlin trend, systematic 1:24,000 collaborative geologic mapping of the Santa Renia Fields and Beaver Peak quadrangles currently is underway by the U.S. Geological Survey and private industry (figs. 2, 4 and 5). The Santa Renia Fields quadrangle includes at least seven areas where epigenetic gold-mineralized rocks are prevalent and two areas where syngenetic bedded barite deposits have been exploited (fig. 4). The inactive (1997) Coyote bedded barite mine also is located in the southern part of the Beaver Peak quadrangle (Lapointe and others, 1991).

PREVIOUS WORK

Previous geologic investigations in the two quadrangles studied have spanned a period of approximately 130 years. The first systematic geologic observations recorded in the southern Tuscarora Mountains, then referred to as the Northern Cortez Range, were outlined by Emmons (1877, p. 608) who described "quartzites, and siliceous shales.....[as well as] peculiar greenish quartzitic conglomerates" cropping out at Dalton Peaks. These peaks are now known as Beaver Peak and the ridgeline immediately to its west. These carbonate-rich and conglomeratic rocks today are recognized as belonging to the Pennsylvanian and Permian Strathearn Formation, one of the formations that make up the largely clastic foreland of the late Paleozoic Humboldt orogeny (fig. 5; see below). Emmons (1877) also reported an approximately 200– to 250–m-thick sequence of thin-bedded limestone at Bootstrap Hill, from which a megafaunal assemblage then was assigned to an Early Devonian age (fig. 4). Middle Paleozoic juxtaposition of lower Paleozoic eastern carbonate (platform) rocks and western siliceous (basin) rocks along the regionally extensive Roberts Mountains thrust was not recognized until Merriam and Anderson's (1942) study in the Roberts Mountains (fig. 1). The thrust, as well as unconformably overlying Mississippian through Permian clastic rocks, subsequently were amalgamated conceptually into the Antler orogeny (Roberts and others, 1958; Roberts, 1964; and many others). In the part of the southern Tuscarora Mountains currently under study, the Roberts Mountains thrust crops out only in the general area of the Dee Mine and Bootstrap Hill (fig. 4).

A number of previous investigations bear directly on various aspects of the geology of the Santa Renia Fields and Beaver Peak quadrangles. The reconnaissance geologic map of Elko County (Coats, 1987) shows an undivided Ordovician, Silurian, and Devonian siliceous western assemblage unit, the Silurian and Devonian eastern assemblage limestones at Bootstrap Hill (fig. 4), and the much more areally restricted carbonate-rich rocks at Beaver Peak (fig. 5), which were assigned to the Permian Edna Mountain Formation. However, Evans and Mullens (1976) and Mullens (1980) mapped and described the eastern assemblage carbonate rocks at Bootstrap Hill as Silurian and Devonian Roberts Mountains Formation and an unnamed Devonian unit informally referred to as the Bootstrap limestone (see also, Armstrong and others, 1997). Coats and Riva (1983) assigned rocks at Beaver Peak to the Pennsylvanian and Permian Antler Peak Limestone of Roberts (1964) and attempted to explain a variability of dips in these rocks to an inferred Mesozoic thrust which they believed had since been removed by erosion. As will be described below, we find no evidence for such a thrust.

Various other aspects of the geology of the quadrangles also have been examined in a number of theses and published reports. The theses primarily have focused on mineralized areas, including both gold and barite (Greybeck, 1985; Ettner, 1989; Snyder, 1989). Snyder (1989) correctly assigned the chert-pebble conglomerate north of the Rossi barite mine (fig. 3) to the late Paleozoic overlap assemblage. A number of reports focused on the geology and mineralized rocks of the gold deposits in the Santa Renia Fields quadrangle (Wallace and Bergwall, 1984; Baker, 1991; Albino, 1994). Recently, an elegant evaluation of the stratigraphy and structure of rocks in the upper plate of the Roberts Mountains thrust in the Ren Mine area (fig. 4) was completed by Cluer and others (1997). In addition to all of the above investigations, the geology of

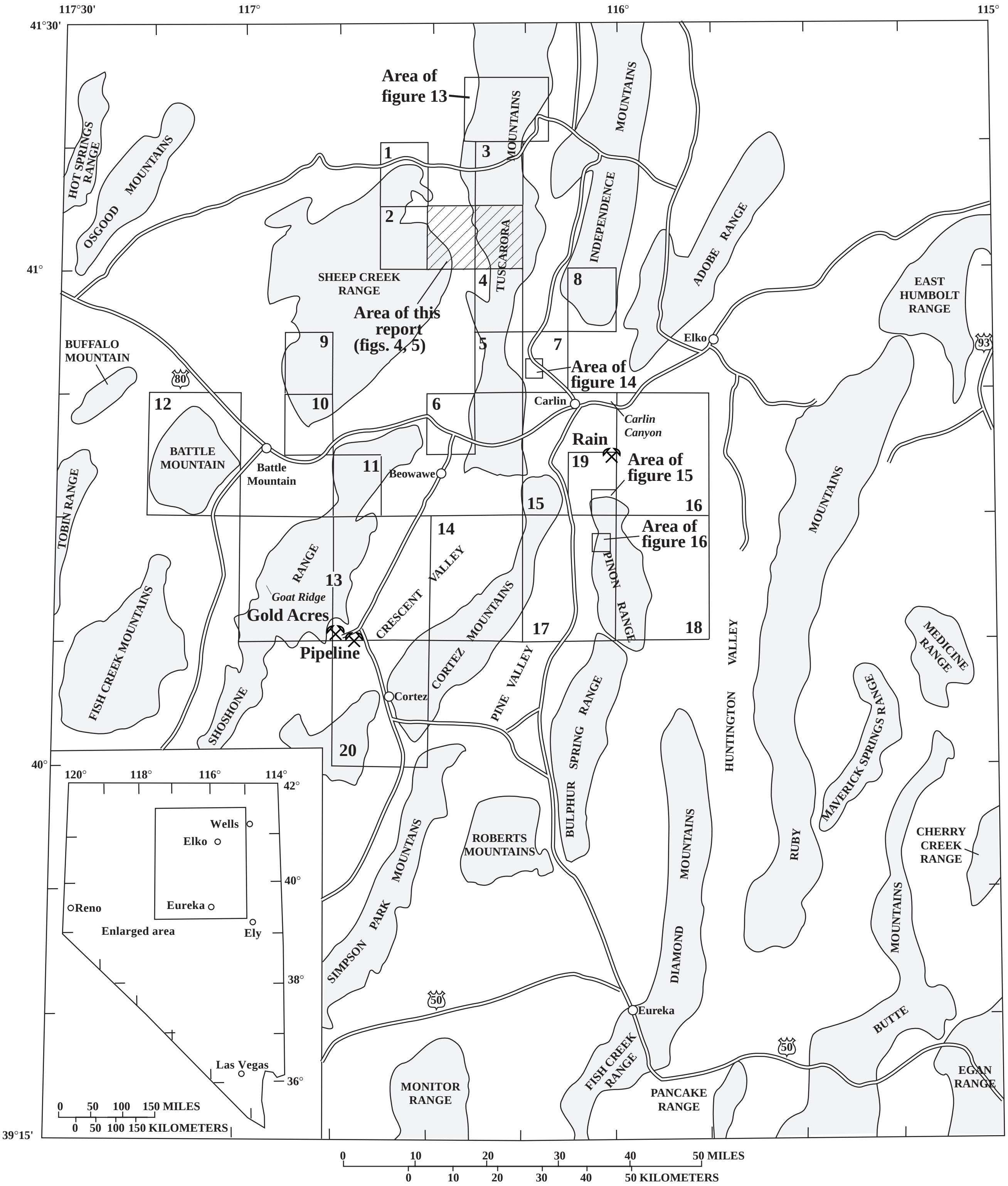


Figure 1. Index map showing location of major mountain ranges and areas discussed in northeast Nevada.

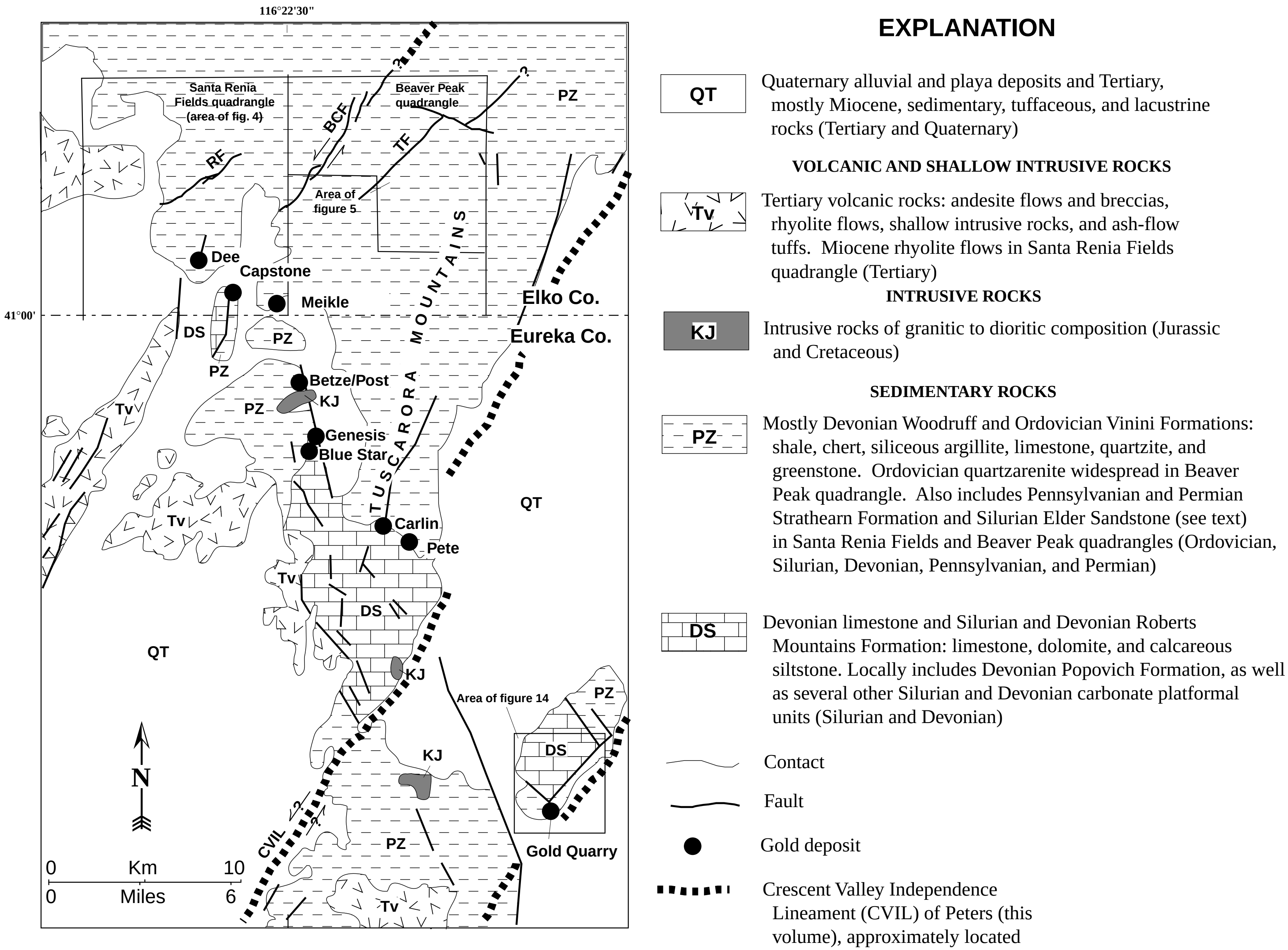


Figure 2. Generalized geology of the northern part of the Carlin trend showing location of Santa Renia Fields and Beaver Peak 7–1/2 minute quadrangles, Nev. Modified from Christensen (1996). Major faults with northeast strikes only shown in the two quadrangles. RF, Rossi fault; BCF, Boulder Creek fault; TF, Toro fault; CVIL, Crescent Valley Independence Lineament (modified from Peters, this volume).

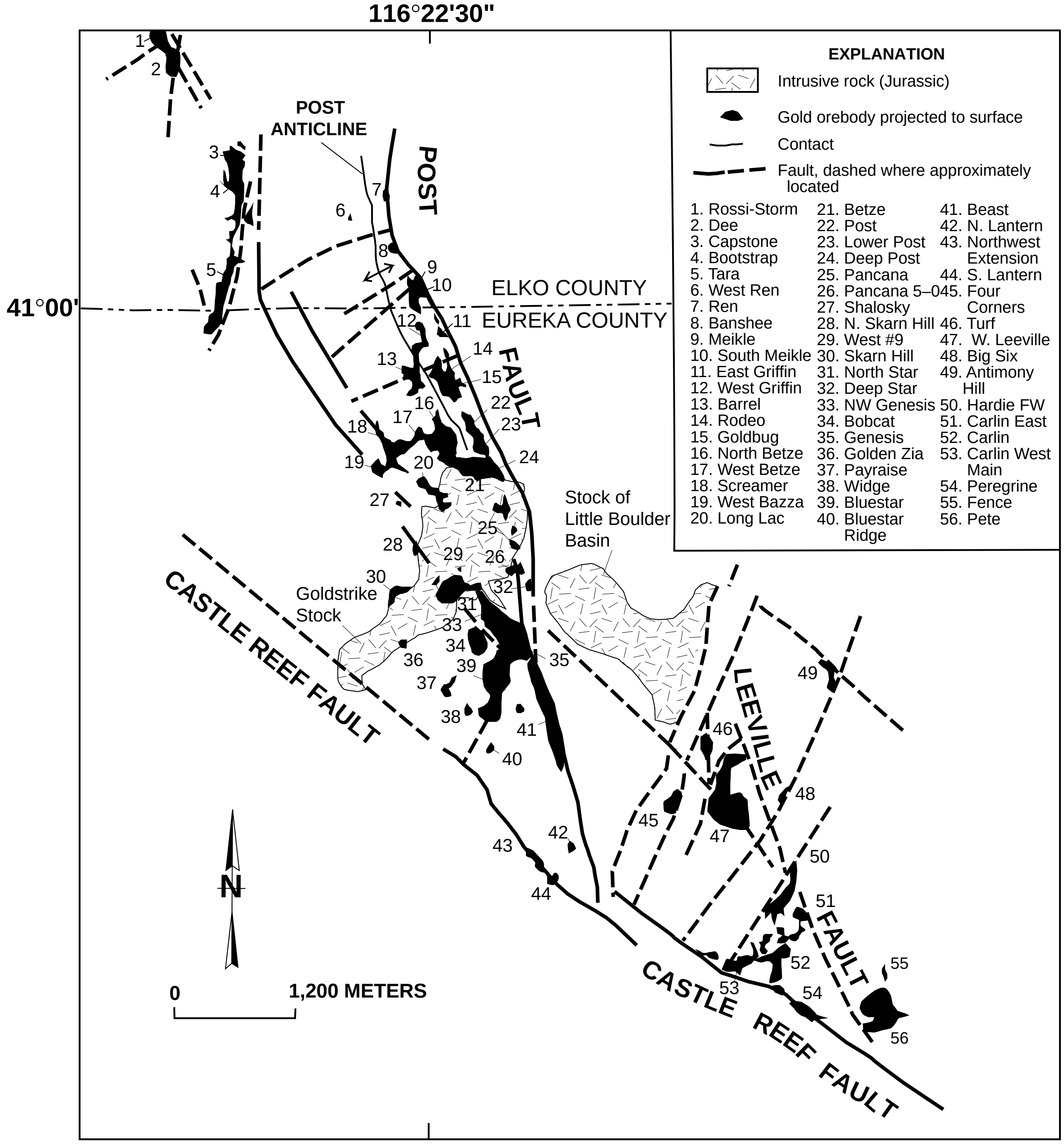


Figure 3. Sketch map showing gold deposits, major faults, and major intrusive bodies along the northern Carlin trend, Nev. Fifty-six deposits are aligned roughly along a N. 40° W., 12–km-long segment of the trend. Modified from Teal and Jackson (1997).

both quadrangles, but particularly that of the Santa Renia Fields quadrangle, has been the subject of a large number of unpublished proprietary company reports. Most of these reports describe exploration drilling projects that mainly have tested gold targets. Lastly, we would like to acknowledge the continuing positive impact on the regional geologic framework of the Carlin trend of the reports by Evans (1974a; 1974b) which concern the two quadrangles immediately south of the Beaver Peak quadrangle (fig. 1).

TECTONOSTRATIGRAPHIC RELATIONS IN THE SANTA RENIA FIELDS AND BEAVER PEAK QUADRANGLES

Structurally, from lowest to uppermost position, rocks in the stratigraphic column of the Santa Renia Fields and Beaver Peak quadrangles comprise a number of tectonostratigraphic packages (fig. 6). From the base, these include (**1**) sparse outcrops of autochthonous lower Paleozoic eastern assemblage

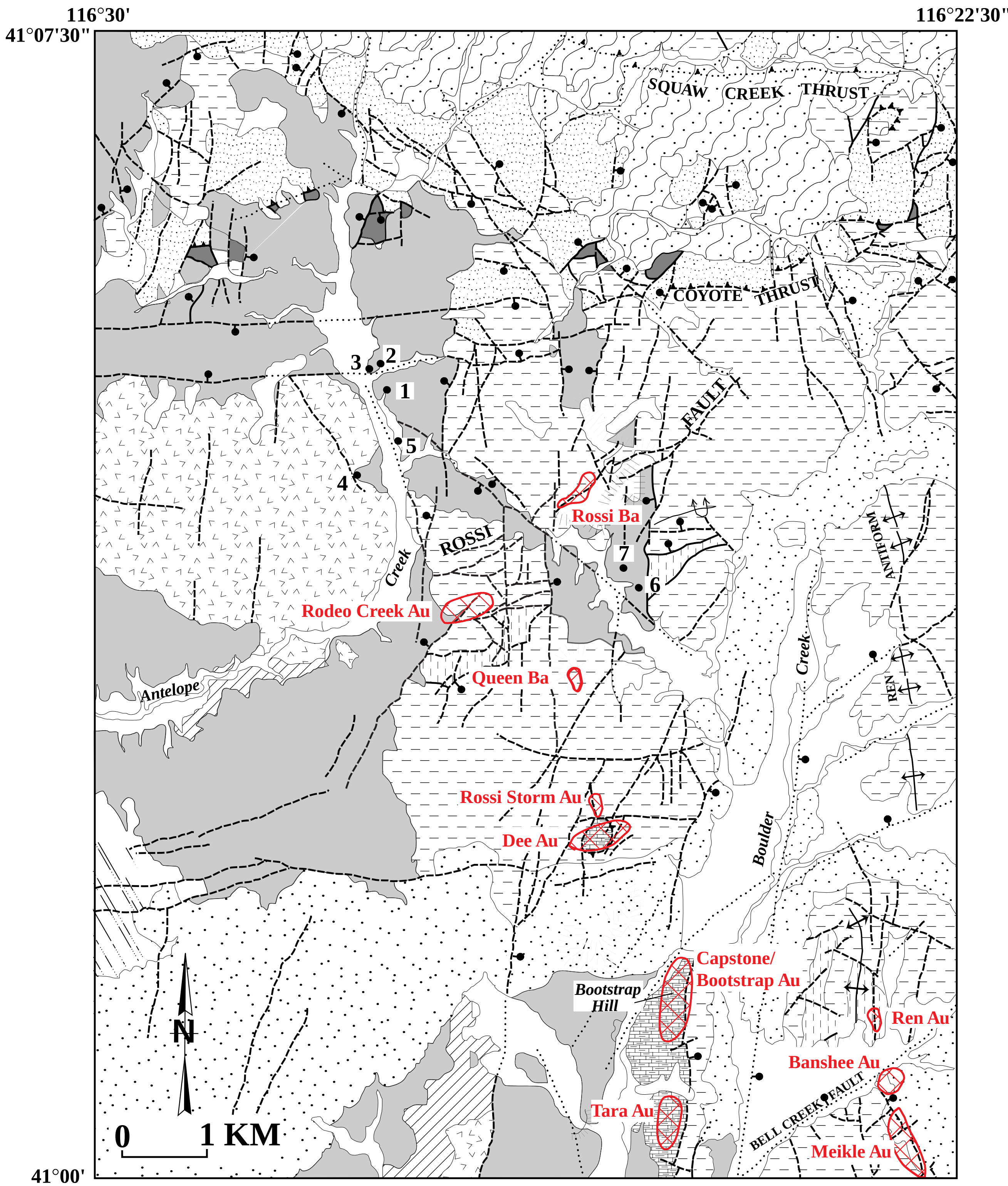


Figure 4. Geologic sketch map of the Santa Renia Fields quadrangle, Nev. Modified from T. G. Theodore, J.K. Cluer, and S.C. Finney (unpub. data, 1998). Includes area near Ren Mine modified from Cluer and others (1997); area near northwest corner modified from Rio Algom (unpub. data, 1998); area near Rossi Mine modified from Snyder (1989); area near Rodeo Creek Au modified from F.J. Menzer (written commun., 1996).

Figure 4 Explanation

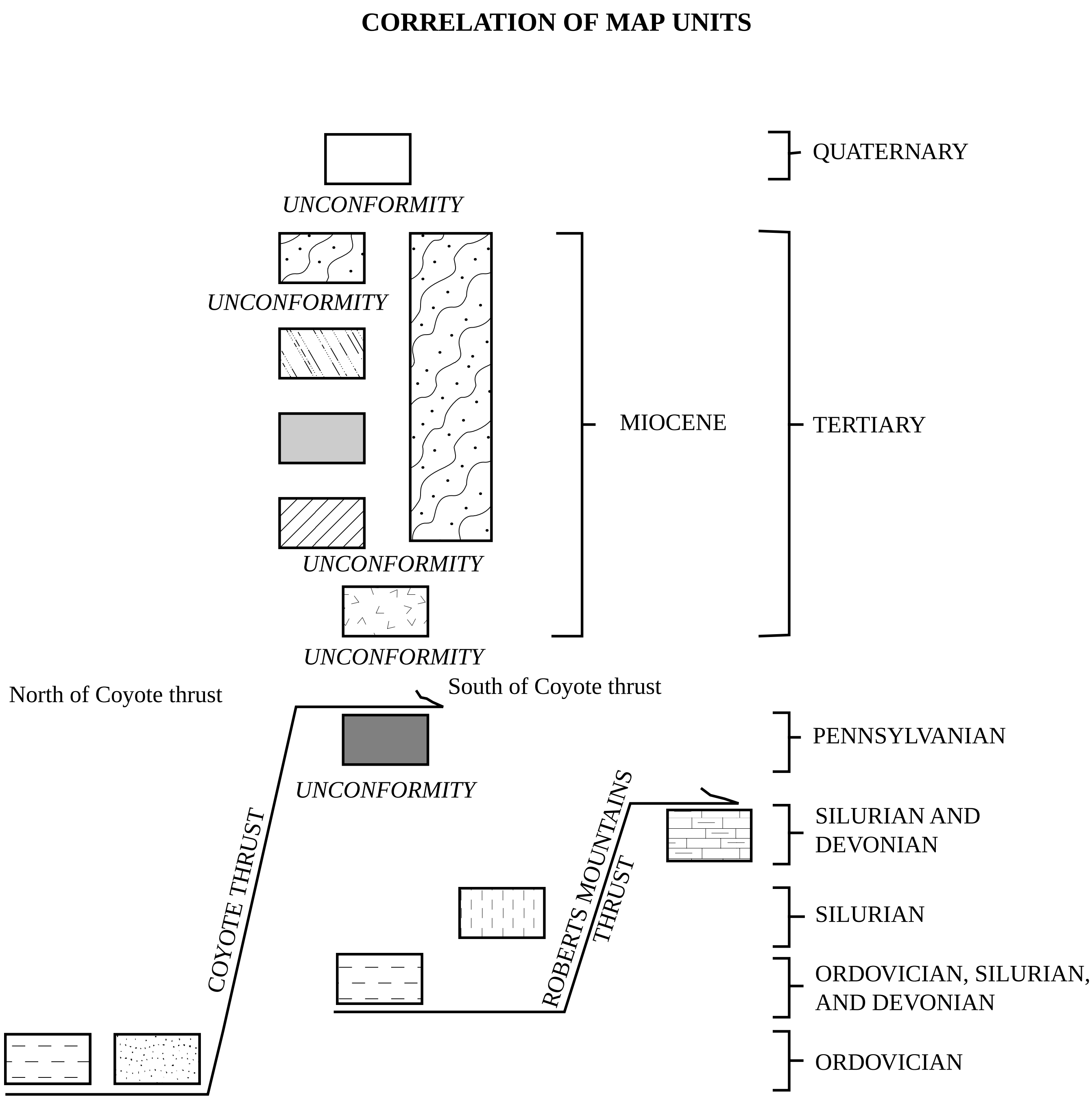


Figure 4 Explanation (*continued*)

DESCRIPTION OF MAP UNITS

Alluvium and other unconsolidated deposits (Quaternary)

Carlin Formation—Fanglomerate deposits, unconsolidated (Miocene)

Carlin Formation—Silts and sands, mostly unconsolidated (Miocene)

Carlin Formation—Silts and sands, mostly unconsolidated, sedimentary breccias, and abundant air-fall tuff (15.1 to 14.4 Ma, Miocene)

Carlin Formation—Tuff, partly welded, and minor silts and sands, mostly unconsolidated (Miocene)

Carlin Formation—Undivided (Miocene)

Porphyritic rhyolite vitrophyre (north of Antelope Creek) and peralkaline rhyolite (west of Boulder Creek). Same as informally named Craig rhyolite of Bartlett and others (1991) (Miocene)

Strathearn Formation—Chert-pebble conglomerate (Pennsylvanian and Permian)

Undivided autochthonous carbonate rocks below Roberts Mountains thrust—Includes laminated and shaly limestone of Silurian and Devonian Roberts Mountains Formation, ooid packstone of the informally named Devonian Bootstrap limestone,and laminated limey mudstone of the Devonian Popovich Formation

Elder Sandstone in upper plate Roberts Mountains thrust—Mostly siltstone and minor chert (Silurian)

Undivided siliceous sedimentary rocks in upper plate of Roberts Mountains thrust south of Coyote thrust—Mostly chert and argillite of Ordovician Vinini Formation, chert and argillite of probable Devonian Slaven Chert, and minor siltstone of Silurian Elder Sandstone. May include small areas of outcrop of cherty rocks belonging to Devonian Rodeo Creek unit (see text) (Ordovician, Silurian, and Devonian)

Undivided siliceous sedimentary rocks in upper plate of Coyote thrust—Siltstone, mostly, and some chert, probably belonging to Ordovician Vinini Formation (Ordovician)

Vinini Formation—Quartzarenite, mostly (Ordovician)

Contact

Thrust fault—Sawteeth on upper plate. Dashed where approximately located; dotted where concealed

Fault—Dashed where approximately located; dotted where concealed; bar and ball on down-dropped side

Mine dump

1 Fossil locality described in text; locality 4 same as table 1

BX–1 Diamond drill hole Baxter no.1 (see text)

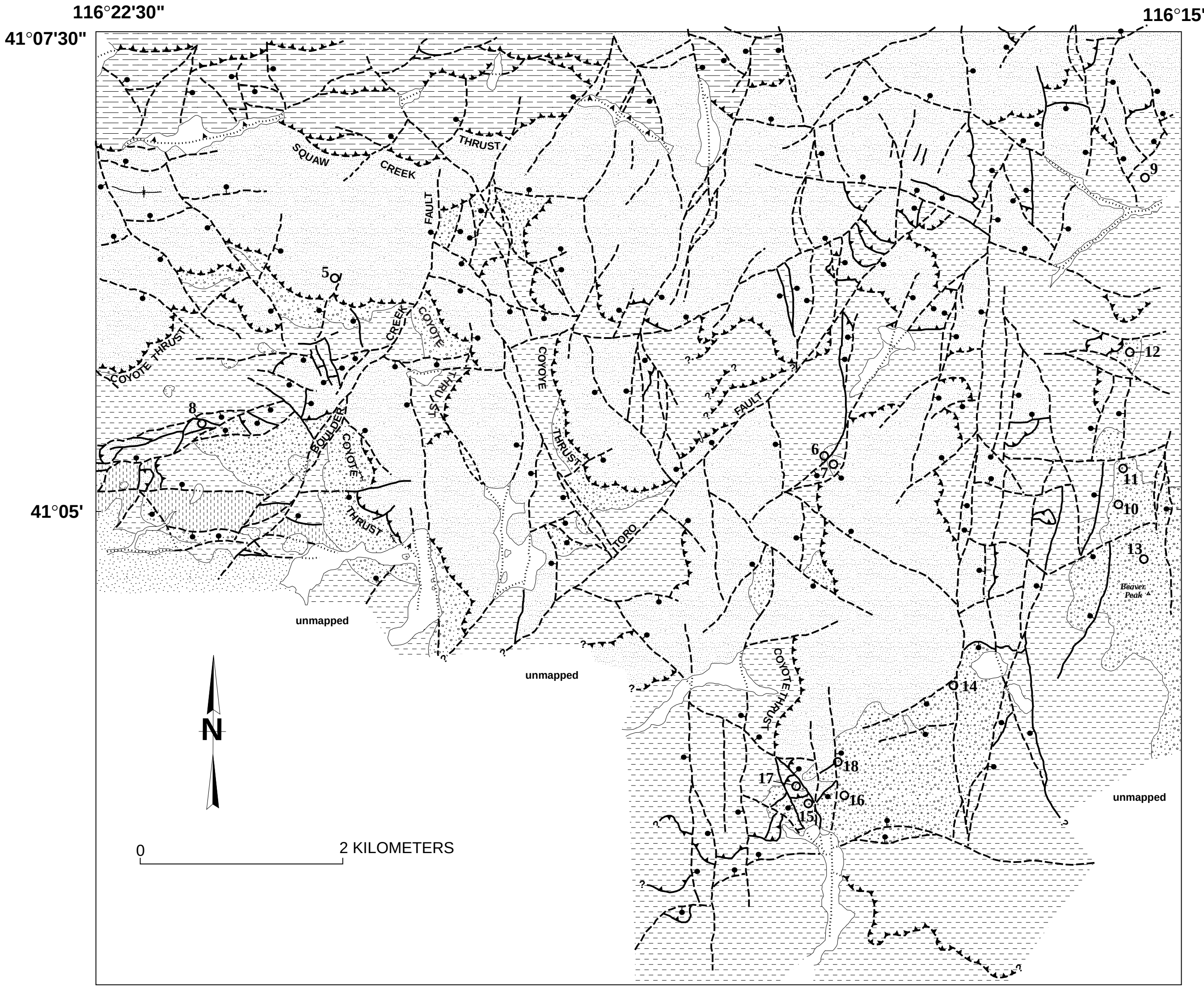


Figure 5. Geologic sketch map of northern part of Beaver Peak quadrangle, Nev. Modified from T.G. Theodore (unpub. data, 1998). See following pages for explanation of map units and symbols.

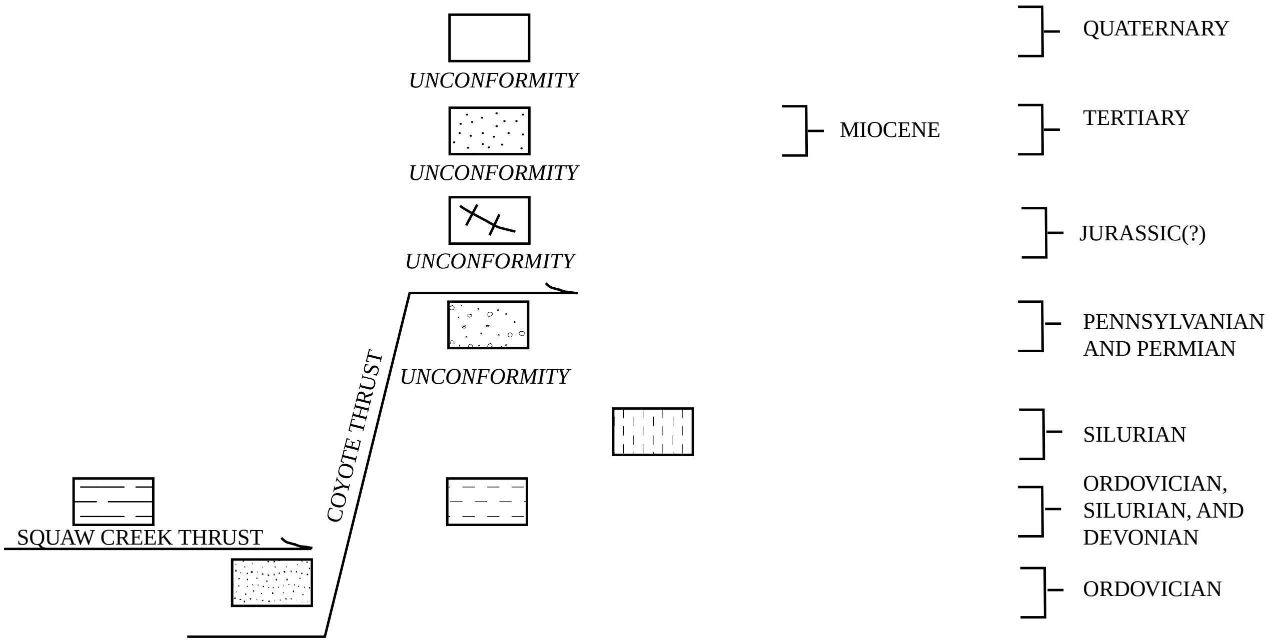
rocks; (**2**) widespread allochthonous lower Paleozoic western assemblage rocks in the upper plate of the Roberts Mountains thrust; (**3**) autochthonous upper Paleozoic overlap rocks belonging to a clastic foreland wedge of the Humboldt orogeny; (**4**) allochthonous lower Paleozoic rocks in the upper plate of the late Paleozoic Coyote thrust which has been emplaced above the overlap rocks; and, finally, (**5**) Miocene volcanic rocks as well as overlying unconsolidated deposits of the Miocene Carlin Formation (figs. 4 and 5). In addition, some major throughgoing northeast-striking faults—probably, in part, late Paleozoic in age—are present in the quadrangles, and their geology provides important information for our interpretation of regional tectonism of the northern Carlin trend. Furthermore, the Paleozoic rocks have been intruded locally by Jurassic(?) dikes.

Autochthonous Eastern Assemblage Rocks

Autochthonous eastern assemblage carbonate rocks crop out in the open pit of the Dee Mine and in an approximately 3–km-long, north-south-oriented horst at Bootstrap Hill where the rocks dip largely to the east (fig. 4). The sequence of carbonate rocks at Bootstrap Hill has been described by

Figure 5. Explanation

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Alluvium and other unconsolidated deposits (Quaternary)

Carlin Formation of Regnier (1960)—Fanglomerate deposits, unconsolidated (Miocene)

Altered dike—Monzonite and alkali granite dikes comprised either of stubby intergrown laths of clay-clouded plagioclase and K–feldspar or mostly K–feldspar. Abundant iron oxide minerals, native sulfur, and secondary iron-arsenate minerals in surrounding wallrocks, primarily along microcracks (Jurassic?)

Strathearn Formation of Dott (1955)—Chert-pebble conglomerate, mostly. Contains sparsequartzarenite fragments. Generally highly resistant ledges of drab gray brown to reddish brown, rubble strewn outcrops. Locally includes fossiliferous interbedded sandy micrite (as much as 30 m thick) containing abundant echinoderm spines, crinoids, brachiopods, and colonial rugose corals, as well as large concentrations of fusulinids (see text). Fusulinids concentrated in lower parts of micrite interbeds. Includes approximately 200–m-thick buff-weathering dolomitic siltstone near Beaver Peak (Pennsylvanian and Permian)

Elder Sandstone of Gilluly and Gates (1965)—Feldspathic siltstone, gray to greenish gray weathering rusty brick red. Includes approximately 1–m-thick gray micrite beds which typically crop out no more than 5 m along strike. Unit generally poorly exposed; forms gently rounded slopes (Silurian)

Allochthon of Squaw Creek thrust. Includes Ordovician and (or) Devonian mostly chert sequences as well as Elder Sandstone. Undivided (Ordovician, Silurian, and Devonian)

Figure 5. Explanation

DESCRIPTION OF MAP UNITS (*Continued*)

Chert and interbedded shaly argillite. Mostly gray to black, well-exposed, ridge-forming sequences in southern part of quadrangle where total exposed thickness is roughly 300 to 400 m. Basal parts of unit made up of relatively thin-bedded, rhythmically-bedded chert, mostly 2 to 4 cm between parting surfaces, whereas upper parts of unit include abundant thick-bedded sequences, mostly more than 4 cm between parting surfaces. Many sequences in upper part of unit severely tectonized. Unit probably includes sequences correlative with Ordovician Vinini Formation and Devonian Slaven Chert of Gilluly and Gates (1965). Unit also hosts a number of sedimentary exhalative barite occurrences and the inactive Coyote barite mine (Lapointe and others, 1991) located roughly 1.5 km south of south edge of map area (Ordovician, Silurian, and Devonian)

Vinini Formation. Generally orange-brown- to ochre-brown-weathering quartzarenite forming resistant, moderately rounded ridges. Includes green and black, thin discontinuous beds of chert that apparently increase in overall abundance downsection and to northwest in the northwest part of area. Includes sedimentary breccia and tectonic breccia, latter commonly shows recrystallization of angular quartz matrix among well-rounded monocrystalline detrital quartz grains. Commonly intensely recrystallized to white sucrose hornfels near Coyote thrust. Hornfels near thrust locally contains abundant brick-red iron-oxide minerals and breccia. Quartzarenite intensely lineated, in places including widespread slickensides, within 10 m of trace of Coyote thrust (Ordovician)

Contact

Fault—Dashed where approximately located; dotted where concealed; queried where uncertain; bar and ball on downdropped side

Thrust fault—Sawteeth on upper plate. Dashed where approximately located; dotted where concealed

Syncline

Fossil locality (locality number same as table 1 except locality 5, see text)

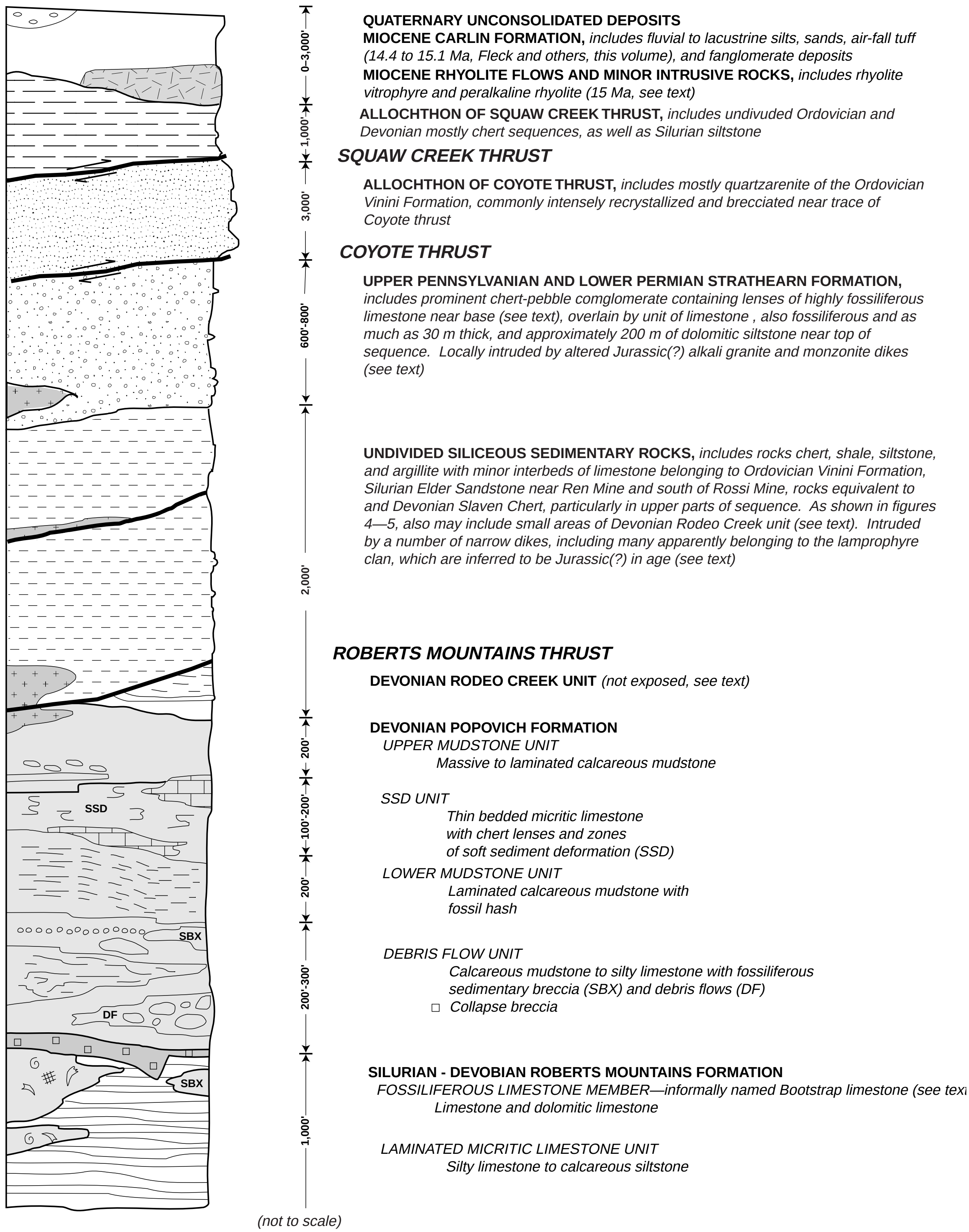


Figure 6. Schematic tectonostratigraphic column in general area of the Santa Renia Fields and Beaver Peak quadrangles, Nev. Modified from Armstrong and others (1997).

Evans and Mullens (1976) and Mullens (1980) as constituting a basal 180–m-thick section of mainly laminated limestone, which they assigned to the Silurian and Devonian Roberts Mountains Formation of Merriam (1940), and to an unnamed upper 280–m-thick section of Devonian coarse-grained limestone (fig. 6). This unnamed unit, which is primarily a peloid-ooid packstone to grainstone with rounded and broken bioclasts of brachiopods, bryozoans, mollusks, echinoderms, tabulate and rugose corals, and calcareous algae, is now referred to informally as the Bootstrap limestone (Armstrong and others, 1997). A deep drill hole at the Rodeo Creek gold resource area (fig. 4) cored approximately 320 m of peloid-ooid packstone belonging to the Bootstrap limestone, as well as an approximately 300–m-thick overlying section of dark-gray to black, fine-grained quartz silt, dolomicrite to lime mudstone characterized by millimeter-size laminations and soft sediment deformation (Armstrong and others, 1997). The latter unit is part of the Devonian Popovich Formation (Hardie, 1966; Evans, 1974b; Ettner, 1989), which elsewhere along the Carlin trend is overlain by cherty shale of the Devonian Rodeo Creek unit of Ettner (1989), also part of the eastern assemblage. Detailed petrographic examination at the Dee Mine of a cored sequence of carbonate rocks to depths as much as 700 m revealed that most carbonate rocks are Bootstrap limestone facies wackestones and packstones, as are the rocks as much as approximately 1,000 m below the Ren Mine as known from drill cores (see also, Armstrong and others, this volume). The Devonian rocks—including Bootstrap limestone, Popovich Formation, and Rodeo Creek unit—probably formed during drowning of a shallow carbonate platform (Armstrong and others, 1997; Armstrong and others, this volume). Some other deep drill holes near the southeast corner of the Santa Renia Fields quadrangle have penetrated strata belonging to the Ordovician and Silurian Hanson Creek Formation, which is present below the Roberts Mountains Formation (Armstrong and others, this volume).

Allochthonous Western Assemblage Rocks

In the Santa Renia Fields quadrangle, a wide expanse of generally north-dipping and broadly folded lower Paleozoic siliceous rocks—mostly chert, argillite, shale, and siltstone—make up the allochthonous western assemblage in the upper plate of the Roberts Mountains thrust (fig. 4). This sequence is shown as an undivided siliceous sedimentary rock unit, and includes tectonically interleaved rocks belonging to the Ordovician Vinini Formation of Merriam and Anderson (1942), Silurian Elder Sandstone of Gilluly and Gates (1965), and Devonian Slaven Chert of Gilluly and Gates (1965), as determined from a number of fossil collections (Snyder, 1989; Cluer and others, 1997; and many others). The undivided siliceous sedimentary rock unit also may include small areas of the eastern assemblage Rodeo Creek unit not separated because of the difficulty of distinguishing it from other siliceous rocks. The Roberts Mountains thrust crops out in the open pit of the Dee Mine and shows evidence of reactivation a number of times since the siliceous allochthonous rocks were first emplaced during Devonian and Mississippian tectonism (Roberts and others, 1958) associated with the Antler orogeny (see also, Greybeck, 1985).

Undivided siliceous sedimentary rocks near the top of the unit in the upper plate of the Roberts Mountains thrust, although assigned to an undivided Ordovician, Silurian, and Devonian unit (figs. 4 and 5), probably are Devonian in age and most likely belong to the Devonian Slaven Chert. A thin bed of silty light-bluish-gray limestone in chert in the Santa Renia Fields quadrangle (fig. 4, loc. 1) produced abundant conodonts of Lochkovian to early Emsian age (Early Devonian), and a few redeposited conodonts of Middle Ordovician age (N.R. Stamm and A.G. Harris, written commun., 1994, to J. Zimmerman and G.L. Griffin; S.B. Keith, written commun., 1996). Locality 1 is approximately 0.2 km south of the trace of the Coyote thrust and is in a sequence of chert the strike of which is at a moderately high angle to the trace of the thrust (Theodore and others, unpub. data, 1998). The thicknesses, tectonic and stratigraphic, of the chert are estimated conservatively to reach at least approximately 800 m (fig. 4). Substantial subsurface relief on the surface of the Roberts Mountains thrust probably has been accentuated locally by the large number of subsequent structural events associated with Mesozoic shortening and Tertiary extension described below. For example, near the Rodeo Creek gold resource area (fig. 4, loc. 3), roughly 3 km northwest of the Dee Mine, Ordovician rocks are present to as much as approximately 500 m below the surface on the basis of age diagnostic, late Middle to Late Ordovician marine palynomorphs in carbonaceous siliceous rocks (Rosemary Askin-Jacobson, written commun., 1997; see also, Armstrong and others, 1997). In the north-central part of the quadrangle, similar siliceous rocks continue to as much as 800 m below the surface in the BX–1 drill hole (E.A. Lauha, written commun., 1996).

The undivided siliceous sedimentary rock unit locally shows evidence of multiple deformations that probably spanned a relatively long period of time. In the southeast part of the Santa Renia Fields quadrangle near the Ren Mine, a north-northwest-trending and north-plunging hingeline of an east-verging overturned anticline—not shown on figure 4 and referred to as the Bell Creek nappe by Cluer and others (1997)—is present in siliceous rocks of the Vinini Formation, Elder Sandstone, and Slaven Chert in the upper plate of the Roberts Mountains thrust. The nappe is inferred to have formed syntectonically with Devonian and (or) Mississippian emplacement of the Roberts Mountains allochthon (Cluer and others, 1997). Somewhat farther to the northwest, roughly 1 km southeast of the Rossi barite mine (fig. 4), an approximately 1–km-long hinge of a south-verging, overturned anticline (see also, Snyder, 1989) has an east-west trend roughly parallel to the trace of the late Paleozoic Coyote thrust which crops out several km to the north. The east-west anticline, approximately at right angles to the probable middle Paleozoic Bell Creek nappe, is inferred to have formed during emplacement of the late Paleozoic Coyote thrust. Evans and Theodore (1978) determined that the trend of the Antler orogenic belt in the southern Tuscarora Mountains is approximately N 20°E on the basis of the orientation of small-scale folds in the siliceous sedimentary rocks. Moreover, the Bell Creek nappe and its surrounding rocks have been further uplifted by development of the Ren antiform, possibly during Mesozoic shortening (fig. 4). The hingeline of the Ren antiform can be followed approximately 6 km to the north beyond the Ren Mine, even though it has been systematically stepped to the east by a number of northeast-striking faults which parallel the Bell Creek fault (fig. 4). As will be described below, these dextral separations are inferred to reflect post-Mesozoic reactivation along fault zones that are believed to have formed originally in late Paleozoic time. The Ren antiform also can be traced 4 km to the southeast into the the Post anticline by Peters and others (1996). This structure hosts the giant Betze-Post Carlin-type gold system (fig. 3), which may contain as much as approximately 50 M oz Au as a geologic resource. Farther to the south, the structure has been referred to as the Tuscarora Spur anticline (Orobona, 1996).

Autochthonous Clastic Foreland Rocks

Chert-pebble conglomerate and interbedded limestone, as well as a relatively thick sequence of dolomitic siltstone and some shale near Beaver Peak (fig. 6) are part of an autochthonous clastic foreland of the Humboldt orogeny (Ketner, 1977)—they are assigned to the Upper Pennsylvanian and Lower Permian Strathearn Formation of Dott (1955). These rocks rest unconformably on the lower Paleozoic undivided siliceous sedimentary rock unit of the upper plate of the Roberts Mountains thrust (figs. 4 and 5)—the upper contact of the Strathearn Formation throughout much of the area is the Coyote thrust. Where rocks of the Strathearn Formation are well exposed close to the Coyote thrust, they have been severely brecciated or tectonized and show variably developed ductile fabrics locally including strongly lineated surfaces, and, in places, rodded mylonite. Presence of clastic foreland deposits throughout much of the northern part of the Beaver Peak quadrangle is critical from a structural standpoint because of the excellent marker and time-stratigraphic horizons that they provide. The type section of the Strathearn Formation is in Carlin Canyon (fig. 1), approximately 40 km southeast (Dott, 1955). However, rocks assigned to this formation in the Santa Renia Fields and Beaver Peak quadrangles also include Early Permian strata that are lithologically and stratigraphically similar to an undivided sequence of rocks described by Dott (1955) to lie conformably above the Strathearn Formation at its type section at Carlin Canyon (see below). Although Permian strata, conformably above the Strathearn Formation at Carlin Canyon, subsequently were divided by Fails (1960) into three formations—sequentially from base to top, Buckskin Mountain, Beacon Flat, and Carlin Canyon Formations. Smith and Ketner (1978) included these Permian strata as two undivided Upper and Lower Permian and Upper Pennsylvanian units in their map of the Carlin-Piñon Range area. Although Snyder (1989) and some later reconnaissance investigators in the quadrangles during the early 1990s recognized that chert-pebble conglomerate in the northern part of the Santa Renia Fields quadrangle were clastic foreland deposits (R.J. Roberts and R.J. Madrid, oral communs., 1996), many other geologists continued to believe that these rocks were an integral part of lower Paleozoic sequences because the strata were not shown separately on the regional map of Coats (1987). Nonetheless, where upper Paleozoic rocks provide a geologic record in the region, the Late Pennsylvanian and Early Permian apparently was a time of significant tectonism (see also, Marcantel, 1973).

A small number of isolated exposures of chert-pebble conglomerate assigned to the Strathearn Formation in the northern part of the Santa Renia Fields quadrangle overlie the lower Paleozoic undivided siliceous sedimentary rock unit that makes up the upper plate of the Roberts Mountains thrust (fig. 4). However, contact relations with surrounding rocks are obscure at best in this area because of generally poor exposures. Although samples from each exposure were thin sectioned, no fusulinids were found.

Rocks of the Strathearn Formation significantly expand eastwards into the Beaver Peak quadrangle in amount of areal exposure, thickness, and types of interbedded lithologies. The unit typically includes chert-pebble conglomerate near its base as well as interbedded limestone where best exposed near Beaver Peak (figs. 5 and 7*A*-*B*). The thickest sequence of the Strathearn Formation crops out on the western slopes of Beaver Peak where it includes a basal chert-pebble conglomerate, as much as 30 m thick, overlain by limestone as much as 100 m thick, and then a 200–m-thick sequence of buff to drab orange-buff, calcareous and (or) dolomitic siltstone interbedded with dolostone. Conodonts obtained from near the base of the limestone (fig. 5, loc. 10), where it is no more than 10 to 15 m thick, have an age range of Late Pennsylvanian to early Early Permian (table 1; fig. 8). The presence of a streptognathodid-hindeodid conodont biofacies indicates at least a middle shelf or deeper water depositional setting for the immediately surrounding rocks in this part of the stratigraphic section. Conodonts obtained from near the top of the sequence (fig. 5, loc. 13, 8,645–ft elevation) are latest Sakmarian-earliest Artinskian (middle Early Permian) in age (table 1; fig. 8), and represent a mesogondolellid biofacies indicative of a normal-marine, middle shelf or deeper water depositional setting, somewhat similar to locality 10 approximately 200 m lower

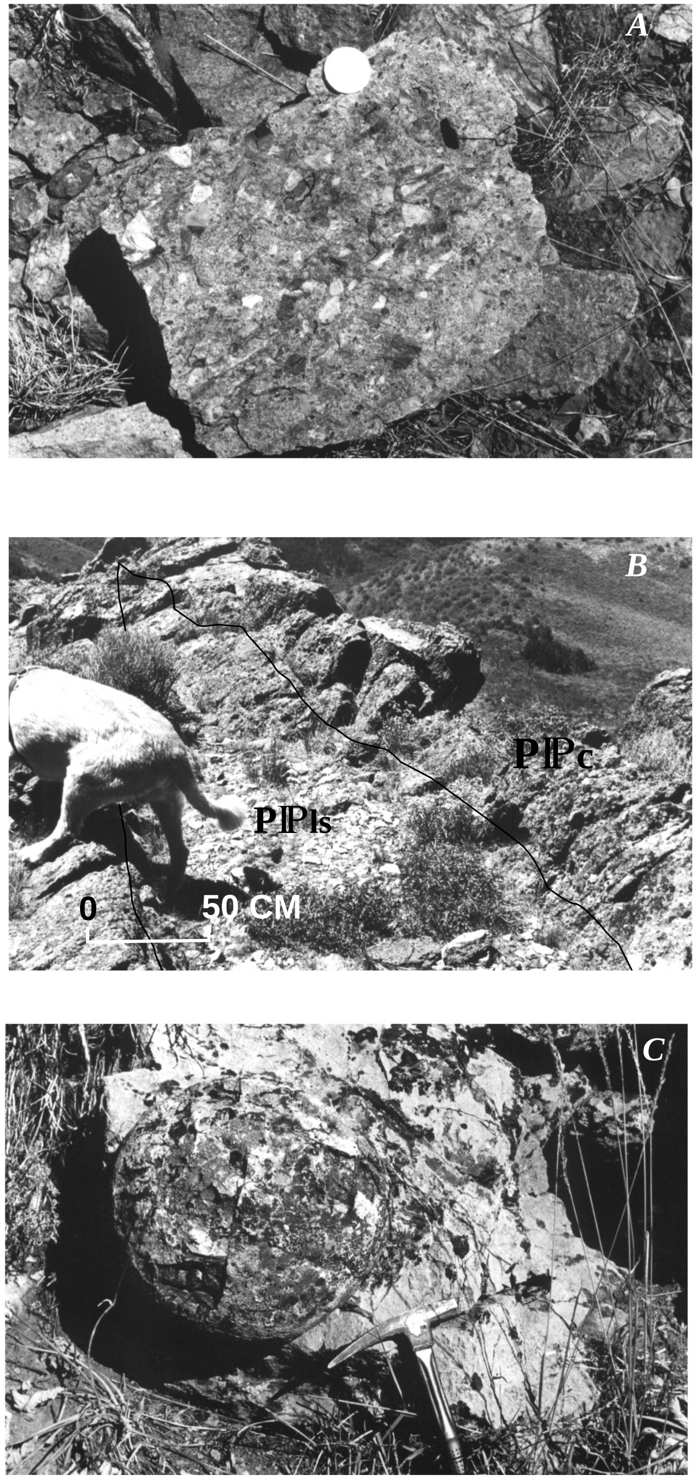


Figure 7. Photographs of Pennsylvanian and Permian Strathearn Formation. ***A***, Chert-pebble conglomerate in west central part of quadrangle. Note quarter at top of photograph for scale; ***B***, Lens of highly fossiliferous limestone (Pdls, loc. 6, fig. 5) interbedded with chert-pebble conglomerate (Pdc) near unconformity at base of unit; ***C***, closeup view of round chert nodule in dolomitic micrite (loc. 15, fig. 5).

Table 1. Description of selected conodont samples from the Santa Renia Fields and Beaver Peak quadrangles, Nevada.

[Conodont samples collected by T.G. Theodore; conodont analyses by A.G. Harris. Map locality number keyed to figures 4 and 5; all samples from Beaver Peak quadrangle except locality 4 from Santa Renia Fields quadrangle. CAI, conodont color alteration index]

MAP LOC. N0. (FIELD NO.; USGS COLLN. NO.) LAT. N./LONG. W.	STRATIGRAPHIC UNIT AND LITHOLOGY	CONODONT FAUNA	AGE AND CAI	CONODONT BIOFACIES AND DEPOSITIONAL ENVIRONMENT	SAMPLE WEIGHT AND COMPOSITION OF HEAVY-MINERAL CONCENTRATE (HMC)
4 (97TT-28) 41°01'38"/ 116°23'14"	Vinini Formation. Blackish-gray micrite, approximately 20 cm thick, interbedded in chert sequence. Sample also contains some quartz-calcite veins.	BARREN.			1.5 kg of rock proces-sed (50 g +20 and 129 g 20-200 mesh insoluble residue). HMC: chiefly ferruginous quartz and lesser rhombohedral dolomite.
6 (97TT-51; 33385-PC) 41°05'15"/ 116°17'25"	Strathearn Formation. Approximately 1–m-thick bed near base of chert-pebble conglomerate sequence resting on lower Paleozoic chert. Thin section contains abundant fusulinids.	*Streptognathodus* sp. 10 Pa and 3 Pb elements (small juveniles, subadults, and a few adults) (figs. 8A, B) 19 indet. bar, blade, and platform fragments	Desmoinesian-Sakmarian (Late Pennsylvanian-early Early Permian); fusulinids from same locality indicate a late Missourian age (late Late, but not latest, Pennsylvanian). 1.5-2	Indeterminate (too few generically identifiable conodonts); normal-marine depositional setting.	1.5 kg of rock proces-sed (80 g +20 and 74 g 20-200 mesh insoluble residue). HMC: chiefly anhedral and euhedral barite and lesser ferroan dolomite and composite ferruginous flakes.
7 97TT-52 41°05'11" 116°17'21"	Strathearn Formation. Buff-weathering dolomitic siltstone containing angular fragments of quartz and abundant K feldspar.	1 indet. bar or blade fragment	Ordovician-Triassic. 1.5 or 2	Indeterminate (too few conodonts).	0.5 kg of rock proces-sed (380 g +20 and 30 g 20-200 mesh insoluble residue). HMC: composition not recorded.
8 97TT-53; 11517-CO) 41°05'29"/ 116°21'46"	Vinini Formation. Gray-brown micrite. Approximately 1 m thick, interbedded with relatively thick siltstone sequence.	Virtually all conodonts are fragments of juveniles. *Amorphognathus* sp. indet. 2 Pa (small fragments), 1 Pb, 2 Sb, and 8 bar element fragments (figs. 8O-Q) 7 *Panderodus* sp. indet. elements 1 S element *Paroistodus mutatus* (Rhodes)? *Periodon* sp. indet. 2 S element fragments (fig. 8S) 2 *Protopanderodus liripipus* Kennedy, Barnes, and Uyeno? (fig. 8R) 5 *Protopanderodus* sp. indet.	Caradocian (= middle Middle-middle Late Ordovician; = Blackriveran-middle Maysvillian). 3	Indeterminate; the taphonomy of the fauna indicates a postmortem hydraulic winnow and the species association indicates derivation from at least a middle shelf or deeper water setting.	1.5 kg of rock proces-sed (0 g +20 and 11 g 20-200 mesh insoluble residue). HMC: chiefly phosphatized composite grains and composite phosphatic ferruginous grains and flakes.
9 97TT-59 41°06'43"/ 116°15'12"	Slaven Chert(?). Brown-black micrite with abundant carbonaceous material along seams. Interbedded with thick chert sequence below tectonically overthrust package of quartzarenite.	BARREN.			1.6 kg of rock proces-sed (480 g +20 and 116 g 20-200 mesh insoluble residue). HMC: chiefly composite ferruginous flakes and rare phosphatized composite grains and phosphatized spine steinkerns.
10 (97TT-63; 33386-PC) 41°04'58"/ 116°15'25"	Strathearn Formation. Buff-gray micrite, approximately 10–15 m thick, above basal chert-pebble conglomerate. Thin section contains abundant fusulinids.	*Hindeodus minutus* (Ellison)? 4 Pa, 2 Pb, 1 Sa, and 1 Sc elements (figs. 8E-G) *Streptognathodus* sp. 12 Pa and 1 M elements (fig. 8D) 19 indet. bar, blade, and platform fragments	Late Pennsylvanian-early Early Permian. 2	Streptognathodid-hindeodid biofacies; at least middle shelf or deeper water depositional setting.	1.2 kg of rock proces-sed (20 g +20 and 28 g 20-200 mesh insoluble residue). HMC: chiefly phosphatic brachiopod fragments and composite ferruginous flakes and grains, and minor ichthyoliths.
11 (97TT-64; 33387-PC) 41°05'11"/ 116°15'21"	Strathearn Formation. Same stratigraphic position as 97TT-63 but approximately 30 m thick at this locality. Buff-gray micrite with calcareous mud lumps and shell fragments.	*Streptognathodus* sp. indet. 4 juvenile Pa elements 1 unassigned Sc element 17 indet. bar, blade, and platform fragments	Late Pennsylvanian-early Early Permian. 1.5	Indeterminate (too few conodonts); the conodonts indicate a normal-marine depositional setting.	1.6 kg of rock proces-sed (15 g +20 and 77 g 20-200 mesh insoluble residue). HMC: chiefly phosphatic brachiopod fragments and composite dolomitic ferruginous grains.

Table 1. (continued)

MAP LOC. N0. (FIELD NO.; USGS COLLN. NO.) LAT. N./LONG. W.	STRATIGRAPHIC UNIT AND LITHOLOGY	CONODONT FAUNA	AGE AND CAI	CONODONT BIOFACIES AND DEPOSITIONAL ENVIRONMENT	SAMPLE WEIGHT AND COMPOSITION OF HEAVY-MINERAL CONCENTRATE (HMC)
12 (97TT-65) 41°05'48"/ 116°15'10"	Strathearn Formation. Dolomitic limestone with abundant angular silt-sized fragments of monocrystalline quartz. On strike with 97TT-63 and -64.	1 unassigned Sc element fragment 5 indet. bar, blade, and platform fragments	Silurian-Triassic, most probably Late Pennsylvanian-early Earlly Permian. 1.5-2	Indeterminate (too few conodonts).	1.8 kg of rock proces-sed (1.0 kg +20 and 85 g 20-200 mesh insoluble residue). HMC: chiefly dolomitic and baritic composite grains and minor weathered euhedral pyrite and composite ferruginous flakes.
13 (97TT-67; 33388-PC) 41°04'40"/ 116°15'12"	Strathearn Formation. Silty to sandy sparry limestone near top of Beaver Peak and approximately 200 m stratigraphically above samples 97TT-63 to -65.	*Mesogondolella bisselli* (Clark and Behnken) 2 Pa elements (figs. 8H-J) *Mesogondolella* sp. indet. 25 Pa element fragments *Streptognathodus* sp. indet. 6 Pa element fragments *Sweetognathus whitei* (Rhodes) 4 Pa element fragments (figs. 8K-N) 1 unassigned M element 30 indet. bar, blade, and platform fragments	latest Sakmarian-earliest Artinskian (late Wolfcampian; middle Early Permian). 2.5	Mesogondolellid; normal-marine, middle shelf or deeper water depositional setting.	1.8 kg of rock proces-sed (100 g +20 and 82 g 20-200 mesh insoluble residue). HMC: chiefly weathered pyrite euhedra, phosphatized bioclasts, phosphatic brachiopod fragments, and minor composite ferruginous grains and ichthyoliths.
14 (97TT-80) 41°04'02"/ 116°16'35"	Strathearn Formation. Drab light-gray to buff 2–m-thick sequence of silty limestone including abundant angular fragments of monocrystalline quartz.	3 indet. bar fragments	Silurian-Triassic. 1-1.5	Indeterminate (too few conodonts).	2.2 kg of rock proces-sed (1.46 kg +20 and 52 g 20-200 mesh insoluble residue). HMC: composition not recorded.
15 (97TT-82; 33389-PC) 41°03'27"/ 116°17'31"	Strathearn Formation. Dolomitic siltstone.	*Streptognathodus* sp. indet. 1 juvenile Pa element fragment	late Morrowan-earliest Artinskian, most probably no older than Missourian (Middle Pennsylvanian-middle Early Permian, most probably no older than middle Late Pennsylvanian). 1.5-2	Indeterminate (too few conodonts).	2.7 kg of rock proces-sed (180 g +20 and 132 g 20-200 mesh insoluble residue). HMC: chiefly barite and lesser ferruginous barite and baritized composite grains and minor dolomite.
16 (97TT-83; 33390-PC) 41°03'27"/ 116°17'20"	Strathearn Formation. Dolomitic siltstone including some rounded monocrystalline quartz sand grains. Sparry matrix partly replaced by barite.	*Polygnathus* sp. indet. 1 incomplete Pa element of Middle-Late Devonian morphotype (upper surface mostly covered by adventitious quartz grains) 1 juvenile Pa element fragment of Carboniferous-Permian morphotype 4 indet. bar, blade, and platform fragments	late Paleozoic (Late Mississippian-Early Permian) with redeposited Middle-Late Devonian conodonts. 1.5-2	Indeterminate (too few conodonts).	2.7 kg of rock proces-sed (120 g +20 and 363 g 20-200 mesh insoluble residue). HMC: chiefly baritized composite grains and minor dolomite.
17 (97TT-84; 33391-PC) 41°03'34"/ 116°17'34"	Strathearn Formation. Sparry dolomitic siltstone rests unconformably above tectonically emplaced quartzarenite of Vinini Formation.	*Streptognathodus* sp. indet. 16 Pa element fragments (chiefly juveniles and subadults) (fig. 8C) 1 digyrate Sa element fragment 11 indet. bar, blade, and platform fragments	late Morrowan-Sakmarian, probably Missourian-Sakmarian (probably Late Pennsylvanian-early Early Permian. 1.5-2	Postmortem transport from or within the streptognathodid biofacies suggesting middle shelf or deeper water depositional setting.	4.2 kg of rock proces-sed (300 g +20 and 337 g 20-200 mesh insoluble residue). HMC: chiefly barite and lesser phosphatic composite grains and minor dolomite.
18 (97TT-85) 41°03'39"/ 116°17'21"	Strathearn Formation. Flaggy, brown-gray dolomitic siltstone.	BARREN.			3.0 kg of rock proces-sed (2.5 kg +20 and 24 g 20-200 mesh insoluble residue). HMC: chiefly barite, rock fragments and minor ferruginous rock fragments and composite ferruginous flakes.

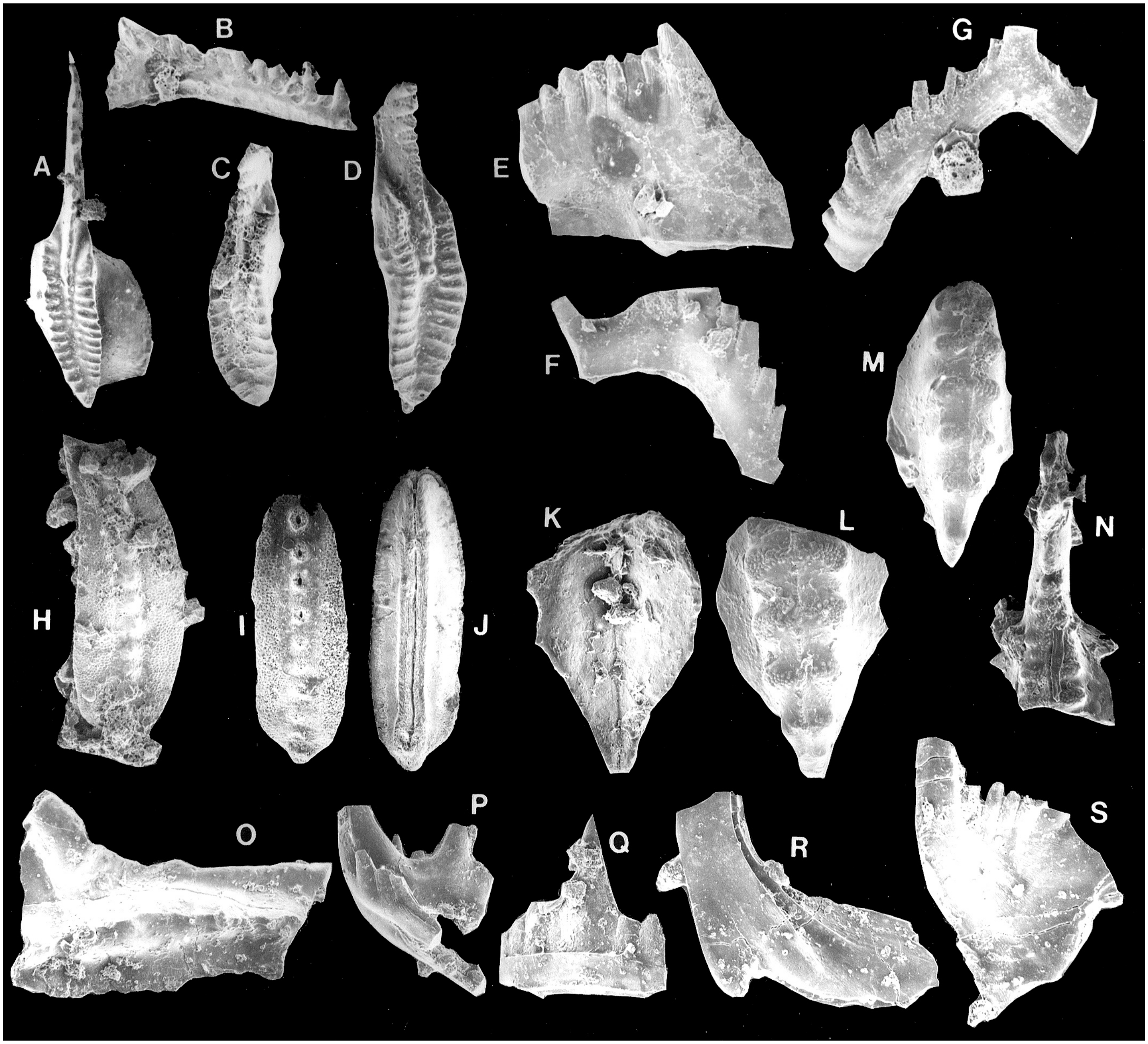


Figure 8. Scanning electron micrographs of conodonts from selected collections from the Strathearn (A-N) and Vinini (O-S) Formations (locality numbers keyed to table 1 and figs. 4 and 5). **A**, **B**, *Streptognathodus* sp., Pa (x35) and Pb (x50) elements, upper and inner lateral views, loc. 6 (same locality that produced late Missourian fusulinids). **C**, **D**, *Streptognathodus* sp., Pa elements, upper views, x50, locs. 17 and 10, respectively. **E-G**, *Hindeodus minutus* (Ellison)?, Pa, Pb, and Sa elements, two lateral and one posterior views, x75, loc. 10. **H-J**, *Mesogondolella bisselli* (Clark and Behnken), upper view of Pa element, (x50) and upper and lower views of another Pa element (x75), loc. 13. **K-N**, *Sweetognathus whitei* (Rhodes), three Pa element fragments, upper and lower views of posterior platform fragment (x100), upper view of posterior platform fragment (x100), and upper view of anterior platform fragment and free blade (x75); the presence of *M. bisselli* and *S. whitei* restrict the age of this collection to a narrow interval that straddles the Sakmarian-Artinskian boundary (late Wolfcampian of western North America). **O-Q**, *Amorphognathus* sp. indet., Pa (x75) and Sb and bar (x100) fragments, loc. 8. **R**, *Protopanderodus liripipus* Kennedy, Barnes, and Uyeno?, lateral view, x100, loc. 8. **S**, *Periodon* sp. indet., Sc element, inner lateral view, x100, loc. 8. The conodont faunule from loc. 8 is a cosmopolitan cool-water species association typical of the middle Middle to middle Late Ordovician part of the Vinini Formation.

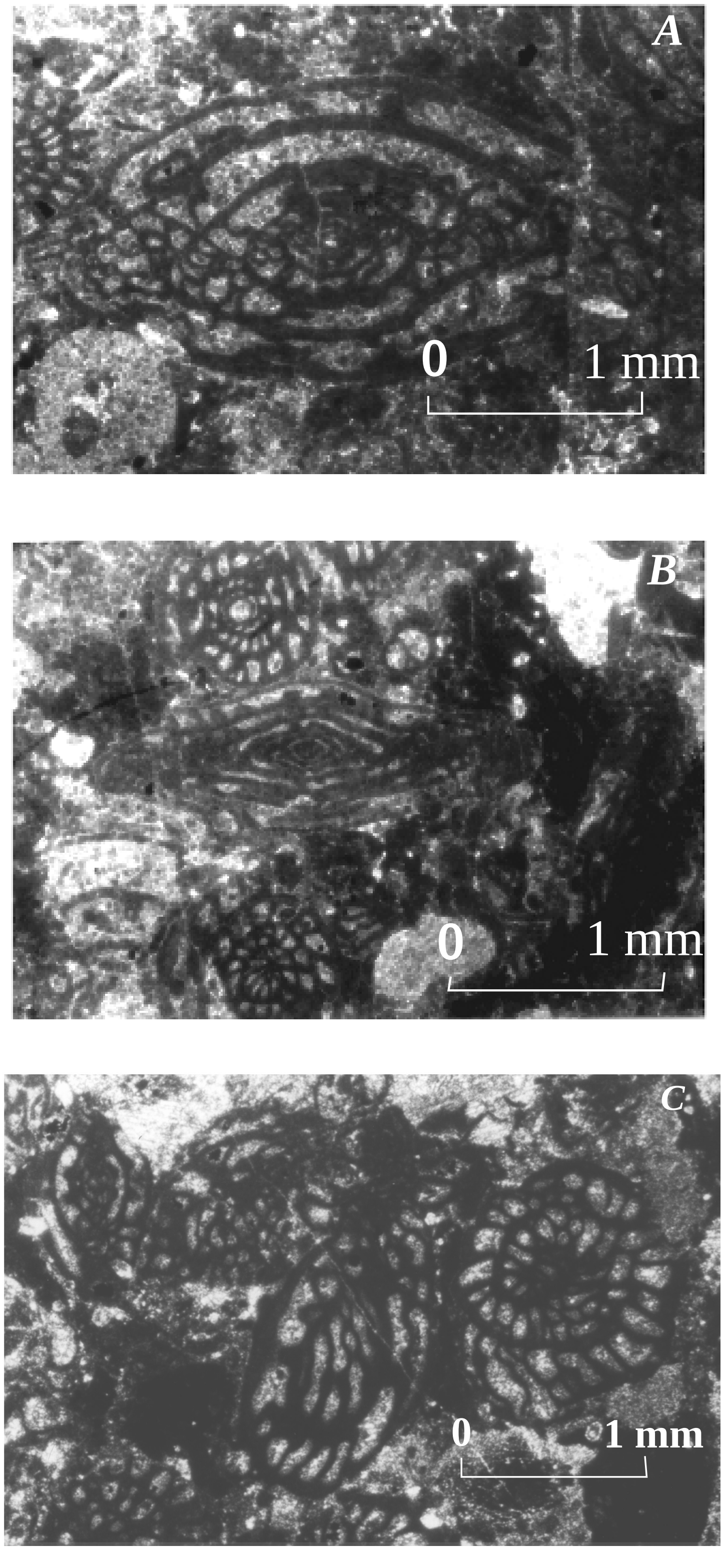


Figure 9. Photomicrographs of fusulinids from limestone lens shown in figure 7*B* near base of Pennsylvanian and Permian Strathearn Formation (loc. 6, fig. 5). Plane polarized light. ***A***, *Triticites newelli* Burma; ***B***, *Pseudofusinella* sp. cf *Pseudofusinella utahensis* Thompson; ***C***, probably *Triticites newelli* Burma.

in the sequence of the Strathearn Formation near Beaver Peak. A conodont collection from dolomitic siltstone of the Strathearn Formation at locality 16 (fig. 5) includes redeposited Middle or Late Devonian conodonts together with younger conodonts. Further, rocks at locality 13 contain sparse infilling of their open spaces by low temperature, crossfiber-textured chalcedonic quartz. The conodont color alteration index (CAI) at this locality is 2.5 suggesting these rocks reached at least 100 to 125 °C (Epstein and others, 1977).

In addition, a narrow exposure of the Strathearn Formation near Hill 8026, approximately 3.5 km northwest of Beaver Peak (fig. 5, loc. 6; closeup of locality shown in fig. 7*B*), contains an approximately 1.5–m-thick limestone lens in a sequence of largely chert-pebble conglomerate no more than 5 m above the base of the unit. This conglomerate also contains small amounts of quartzarenite fragments. The limestone lens hosts a phenomenal concentration of fusulinids near its base in a zone of carbonate sand the upper and lower contacts of which grade into surrounding bioclastic sands that contain abundant fragments of echinoderm spines, crinoids, brachiopods, and the colonial rugose coral *Durhamina*. The latter are quite rare in Pennsylvanian sequences in the western United States. The presence of *Triticites newelli* Burma and *Pseudofusinella* cf. *P. utahensis* Thompson (fig. 9) suggests a late Missourian age (late Late, but not latest Pennsylvanian). Overall depositional environment of the limestone lens is that of a shallow shoal, and, when compared to the middle shelf environments determined for most of the overlying sequence of the Strathearn Formation, suggests a progressive deepening or drowning with time.

Petrographic examination of the dolomitic siltstone facies that makes up much of the upper part of the Strathearn Formation reveals a number of additional striking features. First, presence of low temperature silica that partly fills voids in otherwise fresh-appearing rocks, as described above, is quite unexpected. Second, buff-weathering, dark-gray dolomitic siltstone near locality 13 (fig. 5) contains roughly 10 to 15 volume percent K–feldspar as angular framework grains, together with angular quartz fragments and much less abundant detrital white mica. A source for the detritus that makes up these rocks might be an uplifted granitic terrane that is pre-Late Pennsylvanian in age. However, another possible source is the Silurian Elder Sandstone in the nearby Roberts Mountains allochthon. Near the Ren Mine, these rocks contain abundant detrital grains of white mica and some K–feldspar.

Stratigraphic relations of the Late Pennsylvanian and Early Permian (Missourian to Wolfcampian) Strathearn Formation in Carlin Canyon provide important controls on late Paleozoic history of the region that impact our interpretations of geologic relations of the formation in the Santa Renia Fields and Beaver Peak quadrangles. The strata of the Strathearn Formation are as much as 300 m thick in Carlin Canyon and rest on a spectacularly exposed 15°– to 30°–angular unconformity developed on underlying Late Mississippian through Middle Pennsylvanian (Meramecian through Desmoinesian) rocks belonging to the Tonka, Moleen, and Tomera Formations of Dott (1955). Most of the Tonka Formation is considered to be part of the Mississippian Newark Valley sequence of Trexler and Nichtman (1990) and Trexler and Cashman (1991), who found an important unconformity in the Mississippian Diamond Peak Formation in the Diamond Mountains (fig. 1; see also, Silberling and others, 1997). The Strathearn Formation in Carlin Canyon mostly includes “quartz-silty limestones, and thin commonly cross-bedded, chert granule and pebble conglomerate,” which are notably rich in fusulinids in the lower and upper sequences of the formation (Dott, 1955, p. 2,248). The lower strata of the formation contain several species of *Triticites*. On top of the Strathearn Formation near Carlin Canyon, Dott (1955, p. 2,256) described the undivided, conformably overlying, approximately 300–m-thick Permian sequence as “grayish yellow-weathering, calcareous siltstones, and fine sandstone, generally very poorly exposed in grassy slopes.” This sequence of Permian rocks is lithologically similar to the upper part of the clastic foreland sequence included with the Strathearn Formation in the Beaver Peak quadrangle, and is best exposed on the west slopes of Beaver Peak (see above).

Jansma and Speed (1990) questioned the presence of an unconformity at the base of the Strathearn Formation in Carlin Canyon (fig. 1), and others, as described below, have shown that the rocks are variably deformed below the Strathearn Formation, suggesting that the base of the Strathearn Formation is a low-angle fault of probable Mesozoic age, and that the Humboldt orogeny of Ketner (1977) primarily involved vertical tectonics. We will present evidence in the next section that widespread largely horizontal tectonism in the Santa Renia Fields and Beaver Peak quadrangles is indeed associated with the Humboldt orogeny. Ketner (1998) further points out that faults are ubiquitous in the region and that the unconformity at the base of the Strathearn Formation in Carlin Canyon may in fact be faulted locally. It would not be surprising that some minor shearing may have occurred along the unconformity in response to north-south shortening associated with the Coyote thrust (see below), or with any other subsequent structural event. Snyder and others (1997) recorded low-angle thrust faults and map-scale fault propagation folds at Carlin Canyon to be especially concentrated in middle Paleozoic rocks and that strata younger than Middle Pennsylvanian are less deformed. Peters and others (1996) and Peters (1997) described similar styles of deformation in the same general area—northeast-striking fault zones with chaotic geometries and truncated northeast-trending monoclines—as being concentrated in the Middle Pennsylvanian Tomera Formation and the Middle and Lower Pennsylvanian Moleen Formation of Dott (1955). These deformation events appear to have predated emplacement of the Coyote thrust in the Santa Renia Fields and Beaver Peak quadrangles because the dislocations are present only in rocks beneath the pre-Strathearn unconformity.

Allochthonous Rocks above the Coyote Thrust

Ordovician rocks belonging to the Vinini Formation as well as Silurian rocks apparently comprise an allochthonous package of rocks that was emplaced tectonically along the Coyote thrust onto rocks of the Strathearn Formation and its underlying undivided siliceous sedimentary rock unit (figs. 4–6). The Coyoye thrust is a generally east-west-striking structure that is highly disrupted by later high-angle faults in the Santa Renia Fields quadrangle, where much of its trace has been covered by Tertiary and Quaternary unconsolidated deposits. The upper plate of the Coyote thrust actually comprises two major structural packages that apparently were coevally emplaced into the area—a lower one made up mostly of quartzarenite belonging to the Vinini Formation and marked by the Coyote thrust as its sole, and an upper one which has the Squaw Creek thrust at its base (figs. 4 and 5). The Coyote thrust is envisioned as forming the master dislocation surface along which regional (see below) horizontal dislocations occurred. Rocks in the upper plate of the Coyote thrust are referred to as the Coyote nappe by Cluer and others (1997).

Confirmation of presence of a major thrust fault in the area involving late Paleozoic rocks of the clastic foreland resulted from a number of investigations. First documented occurrence of an older-over-younger sequence in western facies siliceous units in this general area was verified in conodont collections obtained from Barrick's diamond drill hole BX–1 which was collared near the northwest corner of the Santa Renia Fields quadrangle (fig. 4; E.A. Lauha, oral commun., 1994). In this hole, an age reversal between 300– and 800–m depths places rocks containing conodonts of latest Llandoverian age (middle Early Silurian) on top of rocks containing early Late Devonian conodonts (N.R. Stamm and A.G. Harris, written commun., 1994, to J. Zimmerman and G.L. Griffin). Subsequently, large-scale mapping by S.B. Keith (written commun., 1997) in the northern part of the quadrangle confirmed that the Coyote thrust can be recognized in outcrop. Concurrently, mapping by the senior author (Theodore and others, unpub. data, 1998) verified that Ordovician rocks unquestionably are structurally above chert-pebble conglomerate of the Strathearn Formation near the east edge of the Santa Renia Fields quadrangle where a narrow sliver of the conglomerate crops out low on a hillside beneath quartzarenite of the Vinini Formation. Moreover, continued mapping farther to the east-southeast across much of the northern half of the Beaver Peak quadrangle during 1997 revealed numerous unequivocal, probably even more convincing geologic relations wherein the Ordovician quartzarenite unit has been emplaced structurally along a relatively shallow-dipping surface above conglomerate of the Strathearn Formation (fig. 10*A*-*B*). This fault, in places, also is well exposed in the northeast part of the Beaver Peak quadrangle where it crops out as a planar, shallow-dipping fault between Ordovician quartzarenite and the underlying Ordovician, Silurian, and Devonian undivided siliceous sedimentary rock unit (fig. 10*C*).

Rocks in the upper plate of the Coyote thrust are largely Ordovician in age. The Ordovician age of quartzarenite structurally widespread above conglomerate of the Strathearn Formation is confidently assigned on the basis of Middle Ordovician graptolites identified by S.C. Finney (written commun. to J.K. Cluer, 1997) including *Cryptograptus schaeferi*, *Glossograptus* sp., *Nemagraptus* sp., (?)*Leptograptus*, and *Pseudoclimacograptu*s sp. at locality 5 (fig. 5) in shale interbedded in green chert and quartzarenite in allochthonous rocks about 30 m above the trace of the Coyote thrust. In addition, at locality 8 (fig. 5), an approximately 1–m-thick limestone bed, which is present in a fault sliver of siltstone apparently downdropped into the surrounding Ordovician, Silurian, and Devonian undivided siliceous sedimentary rock unit, contains a Caradocian (middle Middle to middle Late Ordovician) conodont faunal assemblage (table 1 and figs. 8*O*–*S*).

The Coyote thrust is a regional tectonic feature. To the west-northwest, quartzarenite in the upper plate of the Coyote thrust may comprise the paleotopographic high beneath Tertiary volcanic rocks at the Hollister Mine in the Ivanhoe Mining District described by Bartlett and others (1991) (see also, Wallace and John, this volume). To the east, the Coyote thrust extends across the entire Beaver Peak quadrangle as a relatively gently north-dipping surface that has been variably offset along a number of high-angle late Paleozoic, Mesozoic(?), and Tertiary normal faults. The southernmost leading edge of the thrust crops out approximately 4 km southwest of Beaver Peak (fig. 5). To the north of Tuscarora, Nev., the Coyote thrust probably also is present in a block of Paleozoic rocks largely surrounded by middle Tertiary volcanic rocks (see below).

Ordovician quartzarenite in the upper plate of the Coyote thrust may have been emplaced into the basin where Upper Pennsylvanian and Lower Permian rocks of the Strathearn Formation were being deposited on the basis of relations at localities 15 and 17 (fig. 5). Rocks of the Strathearn Formation are present tectonically below a thin sheet of Ordovician quartzarenite (loc. 15) as well as being present depositionally on the quartzarenite (loc. 17). This relation tightly constrains emplacement of allochthonous rocks in the upper plate of the Coyote thrust to sometime during deposition of rocks of the Strathearn Formation in this area—Upper Pennsylvanian and Early Permian (fig. 8; see map locality nos. 15 and 17, table 1, for specific conodont descriptions and ages at these localities). According to the geologic time scale of Harland and others

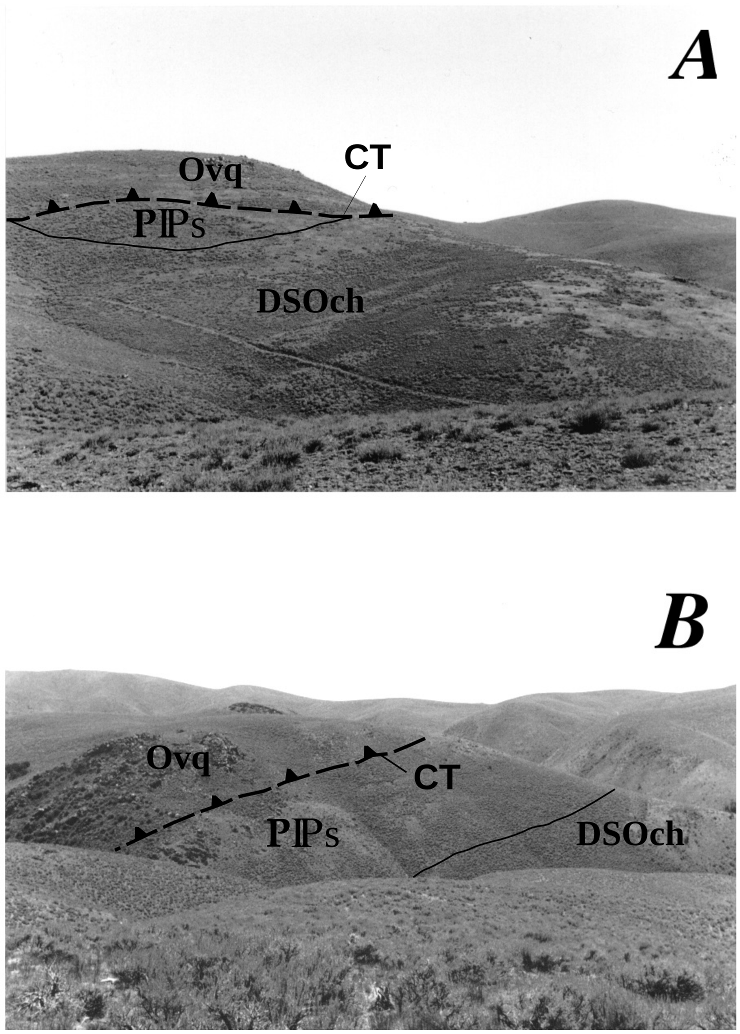


Figure 10. Photographs showing geologic relations in Beaver Peak quadrangle, Nev. ***A***, View to north near east edge of quadrangle showing trace of Coyote thrust. Quartzarenite (Ovq) of the Ordovician Vinini Formation makes up upper plate and Pennsylvanian and Permian Strathearn Formation (Pds) as well as undivided Ordovician, Silurian, and Devonian chert and shale unit (DSOch) make up lower plate; ***B***, view to southeast near south-central part of figure 5 showing trace of Coyote thrust between upper plate quartzarenite of Vinini Formation (Ovq) and lower plate Strathearn Formation (Pds) which, in turn, rests unconformably on undivided chert and shale unit (DSOch).

(1989), this allows an interval of approximately 18 m.y. during deposition of the Strathearn Formation in this area. In addition, Smith and Ketner (1977) postulated that the unconformity at the base of the Strathearn Formation in Carlin Canyon represents a time interval of about 6 m.y. Thus, tectonism during development of the unconformity and thrusting has a maximum time interval of about 24 m.y. to have occurred, which we believe is more than sufficient. Kerr (1962) and Coats and Riva (1983) also described a number of east-west thrusts that involve overlap assemblage rocks farther to the north. However, Coats (1987) had suggested that the Humboldt orogeny be downgraded to a "disturbance" on the basis of relatively minimal volumes of Upper Pennsylvanian and Permian clastic rocks present in the region, but structural and depositional relations described herein provide further evidence that crustal shortening involved significant horizontal

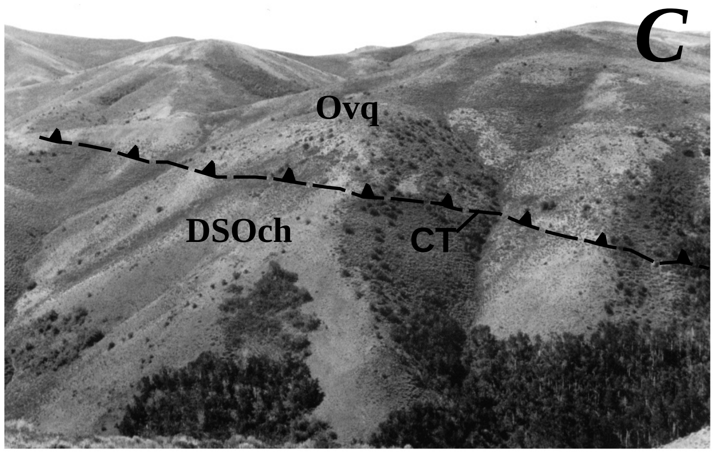


Figure 10 (cont'd)—***C***, view to southwest near the northeast corner of quadrangle showing trace of quadrangle showing trace of Coyote thrust (CT) between upper plate quartzarenite of Vinini Formation (Ovq) and undivided chert and shale unit (DSOch); ***D***, Close up view of stickensides (at head of arrow) near trace of Coyote thrust near west edge of quadrangle.

transport during the late Paleozoic Humboldt orogeny of Ketner (1977).

The Squaw Creek thrust, the trace of which is inferred to be about 2 km north of the Coyote thrust in the Santa Renia Fields quadrangle, is an east-west-striking imbricate thrust structurally higher than, but temporally related to the late Paleozoic Coyote thrust (fig. 4). As shown in the Beaver Peak quadrangle, the undivided allochthon of the Squaw Creek thrust includes a structurally complex package of Ordovician and (or) Devonian mostly undivided siliceous rocks as well as probable Silurian Elder Sandstone (fig. 5). Many of these rocks are present in the upper plate of the Squaw Creek thrust in blocks of rock bounded by high-angle normal faults. Reconnaissance excursions north into the Sugarloaf Butte quadrangle (fig. 1) suggest that the upper plate of the Squaw Creek thrust contains a number of quartzarenite- and chert-rich packages bounded by additional imbricate thrust faults associated with the Squaw Creek and the Coyote thrusts.

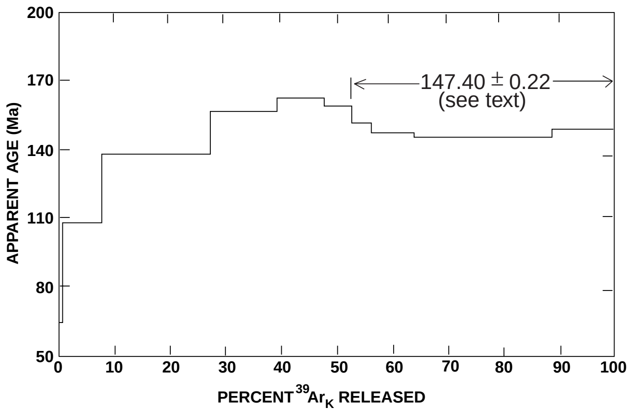


Figure 11. $^{40}Ar/^{39}Ar$ age spectrum for biotite from informally named Arturo dike at Dee Mine. Sample no. 94B50/49/DD58. Modified from L.W. Snee (written commun., 1997).

Jurassic(?) Dikes

A number of igneous dikes, inferred to be Jurassic(?) on the basis of lithologic similarities with other radiometrically dated igneous rocks along the Carlin trend, crop out in the Santa Renia Fields and Beaver Peak quadrangles, but most are too small to show at the scale of our maps (figs. 4 and 5). Many dikes of various composition and texture also have been encountered in drill holes during exploration programs in the quadrangles. Although in places intensely altered, many dikes have fabrics with common euhedral aligned biotite or amphibole phenocrysts. This suggests that the dikes are varieties of lamprophyres, or lamprophyric microdiorites in the terminology of Orobona (1996), which are quite common in the northern Carlin trend (M.W. Ressel and D.C. Noble, written commun., 1998). Arehart and others (1993) established a Jurassic age (157.2 to 158.1 Ma) for emplacement of the Goldstrike stock (fig. 3), and its roughly coeval lamprophyre dikes also are Jurassic (157 to 165.7 Ma) (M.W. Ressel and D.C. Noble, written commun., 1998). During the Jurassic magmatic event, dikes were intruded parallel to the trend, and several large Jurassic plutons have been emplaced into it south of the Betze gold orebody (fig. 3). On the basis of granodiorite sills of the Goldstrike pluton that have been folded along with the Tuscarora Spur anticline in the Genesis deposit, Orobona (1996) concluded that development of major northwest-trending folds in the Carlin trend resulted from Mesozoic compression. A prominent dike is present in the open pit of the Dee Mine and has been informally referred to as the Arturo dike—biotite yielded an apparent 132±5–Ma age by the K–Ar method (A. Lande, written commun., 1994). Another biotite sample from this dike examined by $^{40}Ar/^{39}Ar$ techniques yields a highly disturbed age spectrum that has a maximum plateau at an apparent age of 162 Ma on a percent $^{39}Ar_K$ released versus apparent age diagram (fig. 11; L.W. Snee, written commun., 1997 to W.E. Brooks). The apparent age calculated from the last six heating steps is 147.40±0.22 Ma. Thus, the dike is apparently Jurassic in age, similar to ages of some other igneous rocks elsewhere along the trend.

Cursory petrographic studies were conducted on igneous rocks from below the Dee Mine, below the Ren Mine, and two dikes southeast of Boulder Creek (fig. 5). Four of five intensely clay-altered narrow dikes from a drill hole between 330– and 510–m-depths collared in the Dee Mine were examined, and they show a variety of poorly preserved textures suggestive of emplacement either as porphyritic lamprophyres or as felsic granite (*sensu lato*). The dikes are extremely porous and contain abundant secondary calcite—only vague shadows remain in thin section indicative of the former presence of primary biotite. Some also are intensely silicated. Sparse pyrite is present as fine-grained crystals locally concentrated in clots. Those dikes assumed to be some type of felsic granite probably are variants of the somewhat fresher alkali granite or monzonite dikes in the Beaver Peak quadrangle (see below). Six porphyritic dikes encountered below the Ren Mine between depths of 370 and 570 m in one drill hole and two dikes at 1,050–m and 1,110–m depths in another—although generally altered intensely to carbonate mineral(s), low-temperature quartz, clay, and pyrite, as well as sparse white mica and barite assemblages—show diagnostic fabrics that suggest all the dikes originally were emplaced as part of the clinopyroxene-biotite lamprophyre clan described elsewhere along the Carlin trend (M.W. Ressel and D.C. Noble, written commun., 1998). Phenocrystic quartz is absent from the dikes examined below the Ren Mine. However, because of widespread presence of secondary carbonate mineral(s), it is impossible to ascertain former presence of olivine, primary carbonate minerals, plagioclase, or K–feldspar, if any, whereby proper assignment of the dikes within the lamprophyre clan of Rock (1991) might be made. In the classification scheme of Mitchell and Bergman (1991), they would be termed minettes. However, most phenocrystic clinopyroxene has been altered to carbonate mineral(s). Where unaltered, aligned brown-to-red brown small biotite grains are quite abundant and impart a felted aspect to the groundmass; clinopyroxene is best preserved just interior to chilled margins of narrow dikes. Contacts with surrounding wallrocks are either intensely brecciated and partly filled by small sparse clots of pyrite, or they form knife-edge contacts with marble which contains much less than 1 volume percent pyrite near the dikes.

Two dikes exposed in the Beaver Peak quadrangle, southeast of Boulder Creek (fig. 5), also are presumed to be Jurassic(?)—they apparently are petrographically similar to some of the dikes observed at the Dee Mine (see above). These dikes are present in an approximately 1.5–km-long, S 20° E–trending zone of altered and fractured rocks of the Strathearn Formation, which also apparently contain some secondary arsenate minerals. Mineralogically, these medium-grained dikes show highly variable compositions, ranging from K–feldspar-rich alkali granite to monzonite containing clouded and crowded laths of oligoclase and K–feldspar. Narrow seams of yellow limonite±iron-oxide mineral(s) as well as white mica are common. The dikes are inferred to have been emplaced along a zone of weakness developed subparallel to the main Carlin trend.

The Jurassic emplacement age for the dike at the Dee Mine should not be assumed necessarily to be the age of the mineralizing event there. Circulation of fluids associated with introduction of gold may have occurred long after intrusion of the dike. Two altered dikes encountered near mineralized zones deep in the Rodeo Creek gold-mineralized area, approximately 3 km northwest of the Dee Mine (fig. 4), have yielded 30–Ma and 40–Ma fission-track ages on apatite grains (A.M. Grist and M. Zentilli, written commun., 1998).

Northeast-striking Sinistral Faults

Three major sets of northeast-striking faults are present in the Santa Renia Fields and Beaver Peak quadrangles (figs. 4 and 5). One has significant sinistral separations along its trace, and the others are inferred to have initially broken with similar senses of displacement. The faults comprise a southwesterly-stepped en echelon fault set that, from west to east, include the Rossi fault, the Boulder Creek fault, and the Toro fault, the latter deriving its name from its fault segment along Toro Canyon near the northeast corner of the Beaver Peak quadrangle. The northeast-striking faults have a distinct geomorphic expression (fig. 12), and appear to parallel three major strands of a 20–km-wide set of linear features recognized by Peters (this volume) on Landsat imagery and called the Crescent Valley-Independence Lineament (CVIL). This feature extends northeast from the general area of the Pipeline gold deposits near Gold Acres (fig. 1), passes through the Carlin trend south of the Pete deposit, and finally reaches the gold deposits near Jerritt Canyon in the Independence Mountains, a distance of roughly 90 km. In addition, a large number of northeast-striking faults are present throughout the northern Carlin trend (fig. 3), many of which were instrumental in localizing gold-mineralized rocks either along their traces or in the immediately adjoining wallrocks.

The Boulder Creek fault, whose geomorphic expression defines the northwesternmost strand of the Crescent Valley-Independence Lineament (fig. 2), is a prominent northeast-striking fault close to the west edge of the Beaver Peak quadrangle. It has an approximate 0.8 km sinistral separation of the unconformity at the base of the Strathearn Formation (fig. 5). The magnitude of this separation cannot be accounted for by reasonable separations associated with normal displacements along west-dipping segments of the fault. Near the west edge of the quadrangle, northeast-striking zones of cataclastically brecciated rocks as much as 30 m wide are present along the trace of the Boulder Creek fault. Farther to the northeast, the Boulder Creek fault shows a sinistral separation of the trace of the Coyote thrust of only roughly 0.2 km. These relations suggest that horizontal displacements along northeast-striking faults in the area may be quite old, and may be related to the Humboldt orogeny. They may even predate final emplacement of the Coyote allochthon, which is inferred to have been active some time during the Late Pennsylvanian and Early Permian (see above). Near the Dee Mine, Greybeck (1985) suggested that the northeast-striking faults are the oldest of the various fault sets that he recognized, whereas Snyder (1989) believed that northeast-striking faults near the Rossi Mine are the youngest. Displacements also probably occurred repeatedly along the northeast-striking faults and many other faults in the area in response to regional shortening during the Mesozoic and recurrent extension during the Tertiary. For instance, the dextral separations of the Ren antiform along northeast-striking faults near the southeast corner of the Santa Renia Fields quadrangle may be due to a regional stress regime related to Tertiary extension. The dextral separations may have focused along zones of weakness developed previously under an entirely different regional stress regime.

Miocene Rocks and Miocene Unconsolidated Deposits

Miocene rocks and Miocene unconsolidated deposits in the Santa Renia Fields quadrangle include several varieties of mostly rhyolite flows and minor intrusive rhyolite, as well as the overlying largely unconsolidated Carlin Formation—much of this section is modified from Fleck and others (this volume) (fig. 4). Although these rocks and unconsolidated deposits generally are considered to post-date mineralized rocks along the Carlin trend, their geology, nonetheless, is important because of what might be inferred about underlying strata. Miocene rhyolite porphyry that was informally named the Craig rhyolite by Bartlett and others (1991) in the Ivanhoe Mining District, 5 km to the northwest, extends into the west part of the Santa Renia Fields quadrangle where it is overlain by a 30–m- to 50–m-thick basal tuff unit of the Carlin Formation that includes thin beds of partly welded tuff and lesser amounts of siltstone, mudstone, and gravel. W.E. Brooks (written commun., 1997) reports an $^{40}Ar/^{39}Ar$ incremental-heating plateau age of 15.03±0.05 Ma for rhyolite porphyry from a locality just to the west in the adjacent Willow Creek Reservoir SE quadrangle near Antelope Creek.

The Carlin Formation crops out widely in the west and north parts of the Santa Renia Fields quadrangle where moderately good exposures have allowed determination of the stratigraphy of these largely unconsolidated deposits. The Carlin Formation originally was defined by Regnier (1960) for a sequence of mostly unconsolidated silts, sands, fanglomerate, and pyroclastic rocks that overlie Ordovician to Miocene(?) strata in the vicinity of Carlin, Nev. In that area

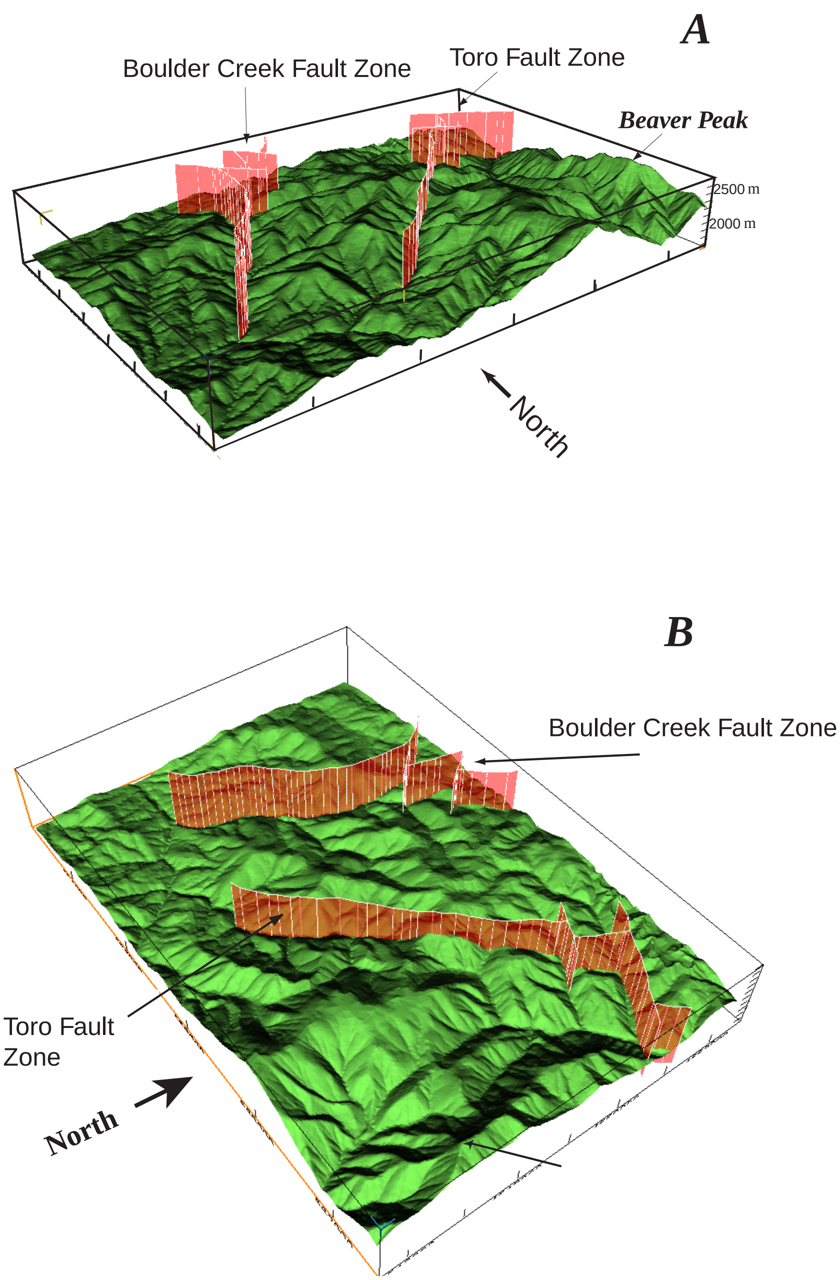


Figure 12. Oblique block diagram showing topographic expression of the Boulder Creek and Toro faults in the Beaver Peak quadrangle, Nev. Digital geomorphometric analysis prepared by R.J. Miller and B.C. Moring.

the Carlin Formation is approximately 130–200 m thick (Regnier, 1960). Originally thought to be entirely Pliocene in age (Regnier, 1960), on the basis of vertebrate fossils collected approximately 5 km northeast of Carlin, the strata were assigned a late Miocene and (or) Pliocene age by Evans and Cress (1972), a Pliocene age by Evans (1974a), and a Miocene and Pliocene age by Evans (1974b). In the west part of the Santa Renia Fields quadrangle, the Carlin Formation has been divided into four units, but, in the northeast part of the quadrangle, the formation also includes an undivided unit (fig. 4). The basal tuff unit of the formation in the west part of the quadrangle is overlain by as much as 400 m of mostly unconsolidated silts, sands, and sedimentary breccia, as well as abundant volcanic ash and air-fall tuff (see also, Fleck and others, this volume). Bedded air-fall tuff crops out prominently throughout the quadrangle as either horizontal or gently dipping sequences; most exposed sequences are horizontal and ample evidence is present in the form of pisolites and abundant worm burrows to indicate subaqueous deposition, probably lacustrine. Roadcuts through the formation reveal that many well-layered sequences of air-fall tuff are broken by high-angle normal faults that have separations of as much as 1 to 1.5 m. Where the air-fall-tuff-rich unit laps unconformably onto lower Paleozoic rocks, an underlying, thin, yellow-brown, sandy silt or massive olive-brown mudstone is present. In places, the underlying units form mud lumps in beds of gray-white, air-fall tuff. Thin beds of granitic debris, possibly derived from the Jurassic Goldstrike stock (fig. 3), also are present locally in the air-fall-rich sequence. The tuff-bearing unit is overlain, in turn, by poorly exposed mostly unconsolidated silts and sands that are conspicuously free of air-fall tuff. All of these units are overlain with a slight angular discordance by unconsolidated fanglomerate deposits, typically as much as 130 m thick and locally as much as 600 m thick. They appear to have been derived principally from Paleozoic rocks in the area of Beaver Peak. Twelve $^{40}Ar/^{39}Ar$ laser-fusion ages, obtained from alkali-feldspar-bearing air-fall tuffs in the formation, range from 14.4 to 15.1 Ma (Fleck and others, this volume).

Near the Ren Mine, two elongate areas of outcrop of an extremely thick fanglomeratic facies of the Carlin Formation, the uppermost unit of the four units recognized in the area, show apparent partial closure around the Ren antiform (fig. 4). The fanglomerate roughly follows bedding in the unconformably underlying Vinini Formation giving the appearance that the fanglomerate deposits were folded along with the underlying rocks. However, actually the fanglomerate deposits apparently were deposited in narrow channels that partly followed zones of weakness and faulting in the previously folded underlying rocks, which channels then acted as foci for debris being shed from the east during uplift of the entire Ren-Beaver Peak tectonic block. These channels were the conduits for a wide area of thick fanglomerate deposits that extend southwest into the northern parts of the Sheep Creek Range (Wallace and John, this volume). Some faults probably were active during deposition of the fanglomerate deposits, as well as possibly during uplift of the Ren antiform, indicated by locally extreme thickness of fanglomerate relative to its narrow width of outcrop; in places the fanglomerate is reported to be as much as 600 m thick. Indeed, many normal faults in the area now bounding unconsolidated deposits of the Carlin Formation and Paleozoic bedrock must have had senses of early displacement different from the last major movements recorded along them. Lastly, as described in Fleck and others (this volume) quartz adularia veins locally cut some sequences of the Carlin Formation, mostly along joints and fractures, suggesting that circulation of potentially gold-bearing fluids continued during the Miocene.

HUMBOLDT OROGENY AND NORTHEAST-STRIKING FAULTS IN THE CARLIN TREND

Geometric relations suggest a direct genetic link among three major structural phenomena in the quadrangles: (**1**) north-south shortening associated with south-directed thrust faults of the late Paleozoic Humboldt orogeny, (**2**) northeast-striking sinistral shear faults along the Crescent Valley-Independence Lineament zone, and (**3**) a roughly N 40° W–trending dilational zone of crustal weakness along the Carlin trend of gold deposits. These three phenomena are consistent with a regional shortening or compressive tectonic regime the maximum principal paleostress direction of which was oriented roughly north-south and near horizontal during the late Paleozoic Humboldt orogeny (fig. 2). Although a sense of displacement has not been determined for the southern part of the Crescent Valley-Independence Lineament zone south of the Carlin Mine (Peters, this volume), if we assume that this segment of the zone also was due to sinistral shear, then the most logical interpretation for the Carlin trend is that it represents a dilational jog between two major strands of the zone (fig. 2). We do not suggest that the Carlin trend entirely represents only a dilational jog caused by northeast-southwest extension without any accompanying shear. Rather, the northwest orientation is envisioned as representing an ancestral zone of weakness that subsequently focused shear strains at various times as orientation of prevailing regional stress directions shifted periodically during subsequent Mesozoic and Tertiary events. These events converged along the northern Carlin trend primarily because it had earlier become a zone of crustal weakness.

Yet, why did the jog occur where it did? The answer to this perplexing question may lie in deep crustal structures that reside in crystalline basement. Rodriguez (1997) has shown from magnetotelluric soundings that a deep structure may underlie the lower Paleozoic miogeocline along the Carlin trend. The presence of such a structure also is suggested by the lead-isotope data of Wooden and others (this volume). Thus, regional sinistral shear along the northernmost strand of the Crescent Valley-Independence Lineament may have stepped to the southeast when it encountered a prexisting structural break in crystalline basement near the present trace of the Carlin trend. Indeed, part of the northwest orientation of outcrop-scale fold axes along the Carlin trend (Peters, 1996) may have resulted from a counterclockwise sense of rotation along the Carlin trend during development of the regional sinistral shear couple that involved reactivated parts of the northeast-trending Crescent Valley-Independence Lineament (fig. 2). Left-lateral sense of shear along northwest-striking axial planes of mesoscopic folds that plunge shallowly to the northwest and southeast along the Carlin trend (Peters, 1996) also is compatible with such a regional interpretation. Further, presence of Jurassic plutons and dikes parallel to the Carlin trend suggests that it existed as a dilational zone at the time of their emplacement. Previously, Gillett and Karlin (1996) speculated that many structures along the Carlin trend may be late Paleozoic, and Dean (1991) proposed, on the basis of fracture-pattern distribution in the southern part of the Carlin trend, that divergent dextral wrench faulting might account for the linearity of distribution of gold deposits along the entire trend.

Geologic relations are prevalent throughout many mountain ranges in northeastern Nevada that north-south shortening may have begun during the late Paleozoic Humboldt orogeny and may have continued into the Jurassic. As we described above, late Paleozoic rocks of the clastic foreland in the Santa Renia Fields and Beaver Peak quadrangles are overlain structurally by siliceous western assemblage Ordovician rocks of the Vinini Formation, which make up the lowermost structural package in the Coyote thrust, as well as additional structurally higher imbricate packages of rock such as above the Squaw Creek thrust (see above). Generally south-directed thrusting associated with the Humboldt orogeny was completed in this area during Late Pennsylvanian and Early Permian time. In addition, south-verging tightly overturned folds well away from the trace of the Coyote thrust attest to the district-scale pervasive character of deformation associated with north-south shortening (see above).

Evidence is widespread in northeastern Nevada for generally north-south shortening from the Independence Mountains in the north to the Piñon Range in the south (fig. 1). In the Independence Mountains, as well as in the Adobe Range east of the northern Carlin trend (fig. 1), rocks as young as Early Triassic were involved in north-south shortening (Ketner, 1987; Ketner and Smith, 1982; Ketner and Alpha, 1992; Ketner and others, 1993; Ketner, 1998), possibly at the time of the Jurassic Elko orogeny of Thorman and others (1990). In the Mount Blitzen area, approximately 35 km to the north in the Tuscarora Mountains, a major thrust fault between Ordovician quartzarenite and lower plate Silurian and Devonian chert and siltstone sequence mapped by Henry and Boden (1997; see also, this volume) may be a correlative with the Coyote thrust (fig. 13). These relations were interpreted as showing “outcrop-scale thrust faults, all in the southern package, [which] dip gently to the northwest, and slickenlines on striated surfaces on the quartzite pods trend mostly northwest or southeast. All these data are consistent with major shortening with transport toward the southeast” (C.D. Henry, written commun., 1997). Near the Gold Quarry Mine (fig. 2), Cole (1995) determined that the principal compressive stress had a near-horizontal, north-northeast orientation during generation of the northeast-striking Gold Quarry fault, which apparently is a fault segment coplanar with one of the major strands of the Crescent Valley-Independence Lineament (fig. 14). In addition, the Gold Quarry fault has a sinistral sense of displacement (Cole, 1995), which is compatible with the sinistral sense of displacements that we infer dominated the early tectonic history of the Crescent Valley-Independence Lineament. In the area of Carlin Canyon, Jansma and Speed (1990) describe the presence of an isoclinal recumbent fold in Pennsylvanian limestone and conglomerate below the Strathearn Formation that they believe is related to shear faulting toward the southeast. At the Rain gold deposit, approximately 30 km south of Carlin, Nev. (fig. 1), north-dipping low-angle thrust faults are present in the Devonian Woodruff Formation, and they apparently show vergence to the south (J. Schilling, L. Shallow, and T. Thompson, written commun., 1998). However, the Rain fault—a N 60° W-striking structure that dips 50–70° southwest (Longo and Williams, 1997)—also may have formed during the Humboldt orogeny on the basis of two lines of evidence. First, its fault geometry is identical to other high-angle reverse faults of late Paleozoic age in the Piñon Range, being the youngest shortening structure in the area that cuts rocks of the Mississippian Newark Valley sequence. The only difference is that the dip of the Rain fault is to the southwest rather than to the northeast, or it is more like a back thrust. Second, bedding attitudes are reoriented near the fault from their generally regional northward strikes. This characterizes bedding as it approaches all other late Paleozoic faults and folds in the Ferdelford Creek area of the Piñon Range, Nev., approximately 60 km southeast of the Santa Renia Fields and Beaver Peak quadrangles (fig. 15). In this area, the Mississippian Newark Valley sequence also is cut by east-northwest, north-dipping thrust faults that must have a component of north-south shortening. These faults also cut rocks correlative with the Strathearn Formation. Silberling and others (1997) described roughly north-south shortening that is reflected in a broad open syncline that involves undivided Pennsylvanian and Permian rocks belonging to the foreland sequence in the Papoose Canyon area of the Piñon Range (fig. 16). Also in the northern Piñon Range, Smith and Ketner (1977) described a number of late Middle to early Late Pennsylvanian anticlines, synclines, and thrust faults, some of the folds showing a significant north-south component of shortening.

Direct linkage during tectonism between regional-scale low-angle thrust faults and high-angle strike-slip faults has been reported elsewhere in the Great Basin. Morris (1983) showed that the northeast-striking Leamington transcurrent fault in the central Sevier orogenic belt of west-central Utah is directly related to a number of thrust lobes. As pointed out by Morris (1983), wrench faults or strike-slip faults (see also, Wilcox and others, 1973) that result primarily from horizontal compression or shortening should develop as conjugate pairs. We do not know of a readily identifiable companion to the Crescent Valley-Independence Lineament. However, a throughgoing northwest-trending linear feature, the northern Nevada rift (NNR) (Zoback and others, 1994; Wallace and John, this volume), passes along the west edge of the Sheep Creek Range approximately 40 km west of the Crescent Valley-Independence Lineament at a latitude of 40°45' (fig. 16). Although it is widely known that the NNR is related primarily to Miocene extension (Zoback and others, 1994), deformation along a “proto” NNR may be much older. On the basis of admittedly somewhat tenuous evidence, including its geometric relation with the Crescent Valley-Independence Lineament and the presence of ductile-style northwest shear zones in lower Paleozoic rocks parallel to its trace in the Shoshone Range,

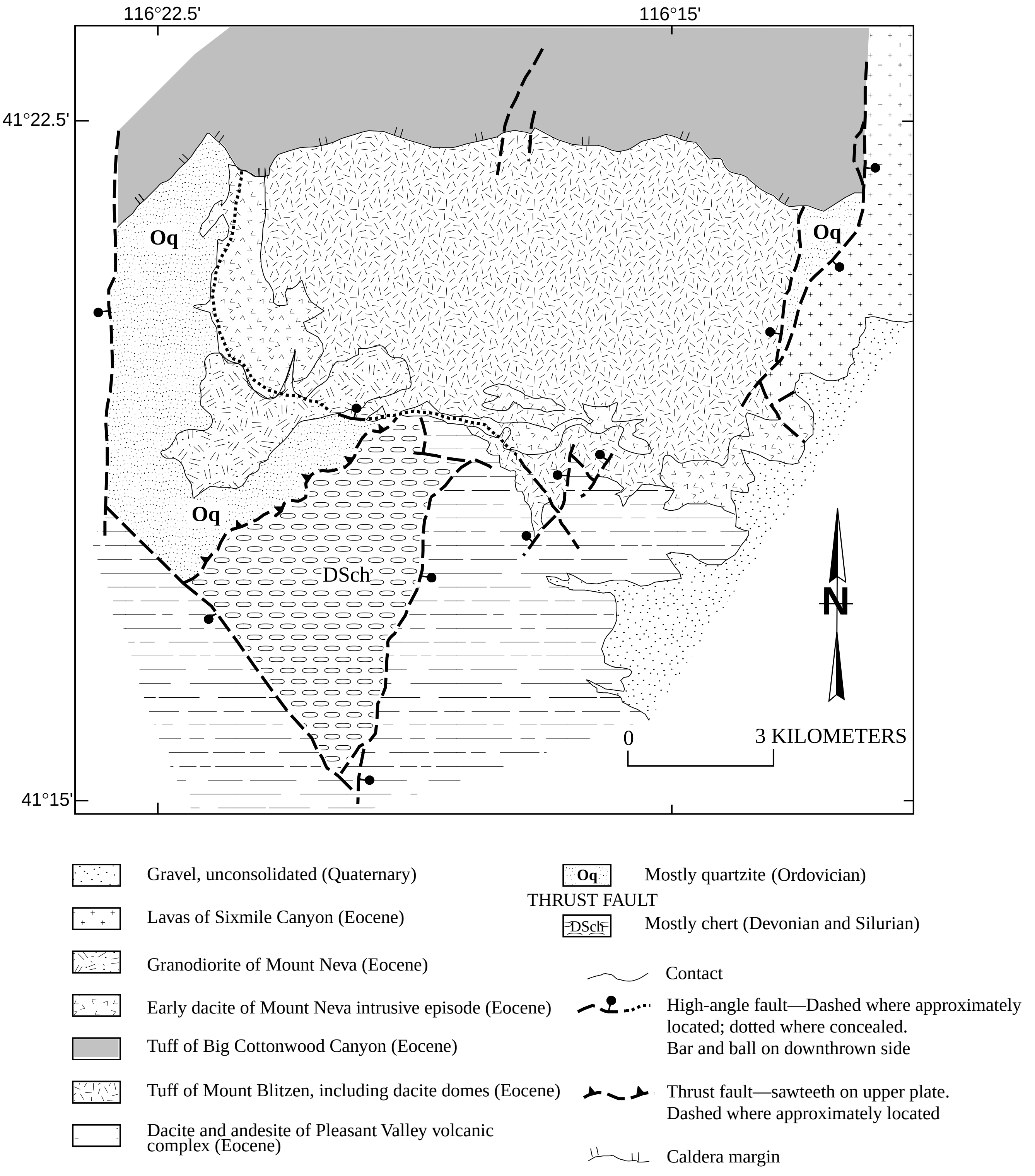


Figure 13. Simplified geologic sketch map of southeastern part of Tuscarora, Nev., volcanic field showing northeast-striking trace of thrust fault between upper plate Ordovician mostly quartzarenite unit (cq) and lower plate Silurian and Devonian mostly chert unit (cch). Modified from Henry and Boden (1997) and C.D. Henry (unpub. data, 1998).

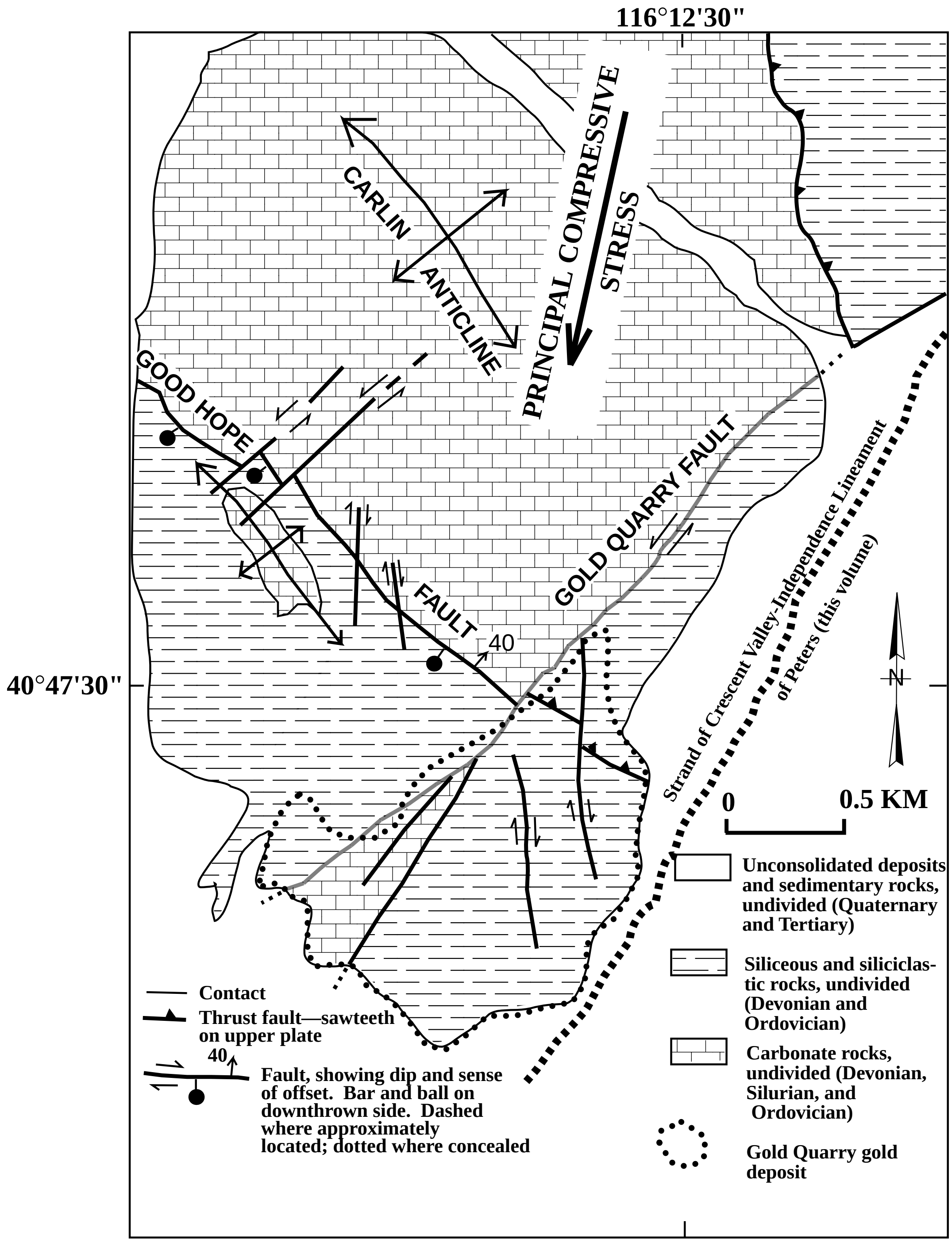


Figure 14. Inferred structural model for area around Gold Quarry gold deposit, Nev. Modified from Cole (1995).

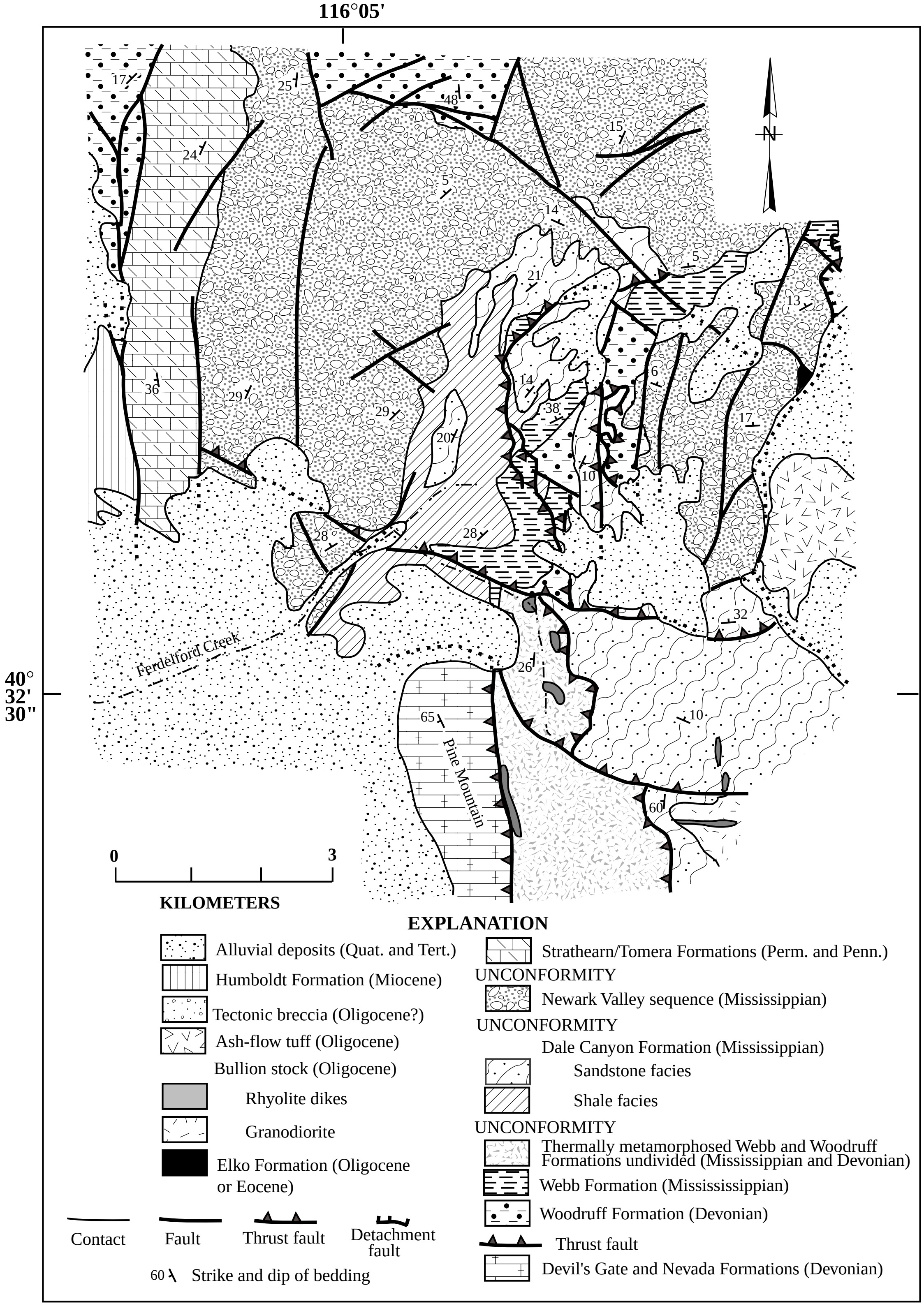


Figure 15. Geologic sketch map of the Ferdelford Creek area, Piñon Range, Nev., showing east-southeast striking thrust faults that cut the Mississippian and Pennsylvanian Newark Valley sequence. Modified from R.M. Tosdal (unpub. data, 1998).

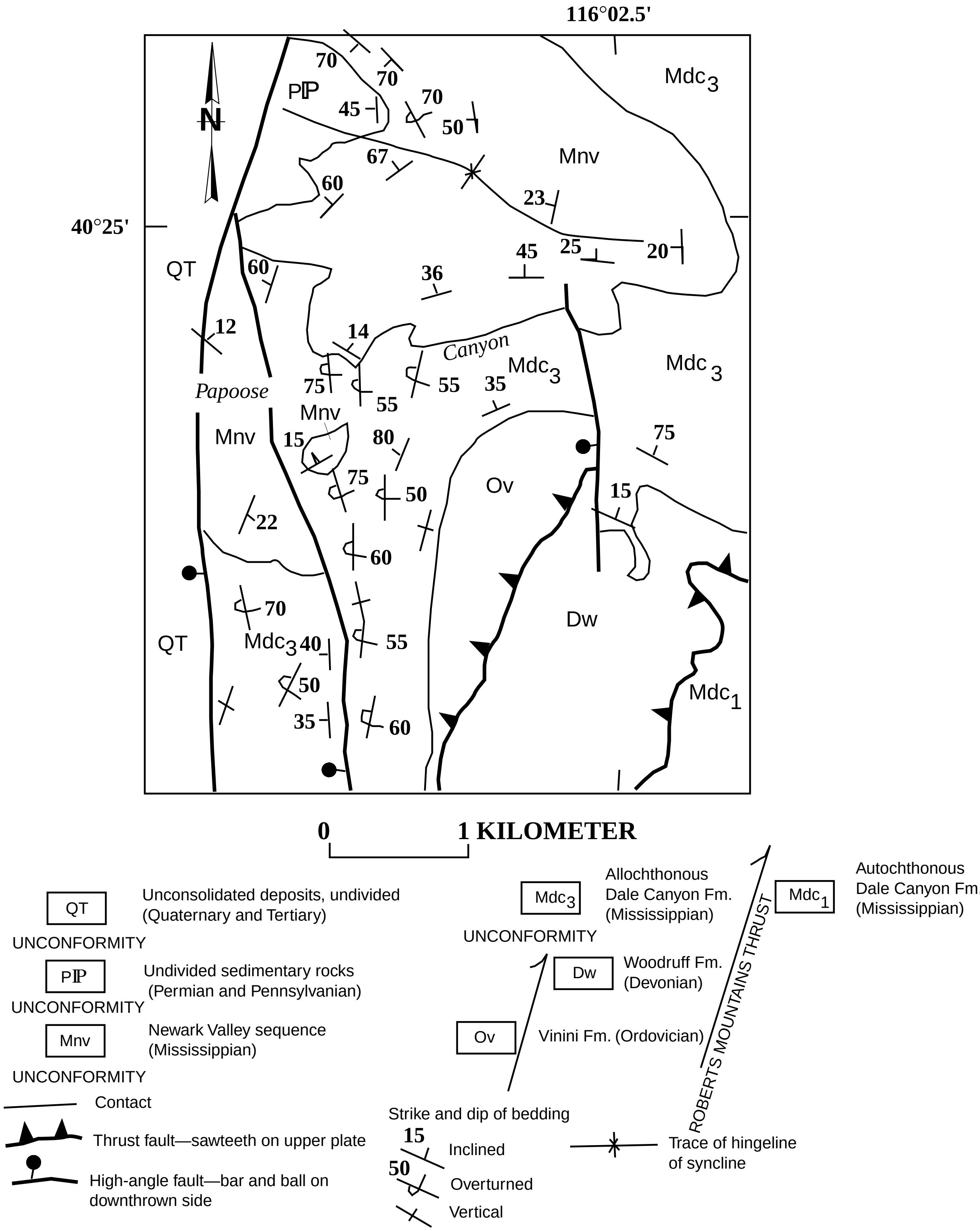


Figure 16. Simplified geologic sketch map of area around Papoose Canyon near west flank of Piñon Range, Nev., showing roughly east-west trending hingeline for fold involving rocks as young as Pennsylvanian and Permian (unit Pd). Modified from Silberling and others (1997).

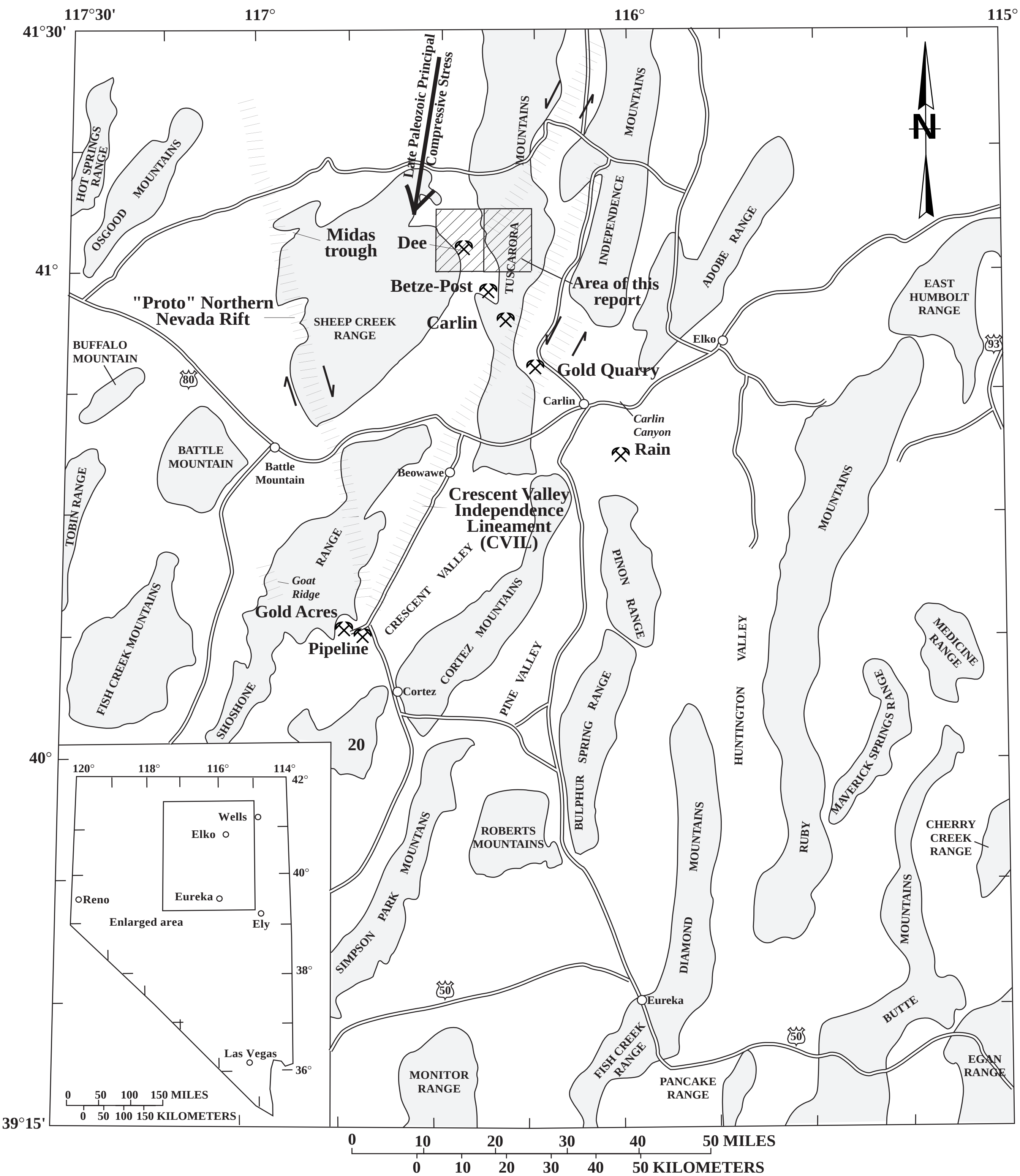


Figure 17. Summary diagram showing location of Crescent Valley Independence-Lineament (CVIL) of Peters (this volume), "proto" northern Nevada rift ("proto" NNR), and inferred senses of transcurrent dislocations. Locations of major mines discussed in text also shown, as is the inferred orientation of late Paleozoic, regional principal paleostress associated with formation of the CVIL and the "proto" NNR.

we suggest that orientation of the NNR is compatible with its including late Paleozoic right-lateral shear as a conjugate to the Crescent Valley-Independence Lineament.

In places, quite intense deformation occurred along both the NNR and the Crescent Valley-Independence Lineament. Gravity variations produced by pre-Tertiary basement show a prominent gravity gradient, a deep crustal fault zone, that coincides with the trace of the NNR—they do not show, however, a comparable gradient along the Crescent Valley-Independence Lineament (Jachens and Moring, 1990; Grauch and others, 1995; Ponce, 1997). Paleozoic rocks in the Tenabo area of the northern Shoshone Range have a strong north-northwest structural grain (Wrucke, 1974; C.T. Wrucke, unpub. data, 1998). Miogeoclinal rocks exposed in the lower plate of the Roberts Mountains allochthon at Goat Ridge in the Shoshone Range, albeit approximately 20 km from the trace the NNR (fig. 1), also include prominent northwest-striking shear fabrics that parallel the NNR (Prihar and others, 1996). Where the Crescent Valley-Independence Lineament and the NNR are projected to intersect near the Gold Acres and Pipeline gold deposits in the Shoshone Range (fig. 17), structural fabric of the rocks is dominated by northwest- and northeast-striking fault sets parallel to the trends of the NNR and the Crescent Valley-Independence Lineament (Foo and others, 1996). With regards to magnitude of overall shear along the major faults that comprise these inferred conjugate shear zones along the "proto" NNR and Crescent Valley-Independence Lineament, we speculate that it probably measures at most several km, and that it is highly unlikely to amount to as much as tens of km. Other geological evidence in the Cortez, Nev., area (fig. 17) indicates as much as approximately 5 km of right-lateral separation along the trace of the present-day NNR (J.K. Cluer, written commun., 1998; see also, McCormack and Hays, 1996). In the Cortez area, McCormack and Hays (1996) determined that the Cortez-Pipeline fault, which parallels the NNR, apparently shows approximately 5 km dextral offset of lower Paleozoic carbonate rocks and Jurassic igneous rocks after closure of Miocene extension across Crescent Valley. Rocks broken along the "proto" NNR undoubtedly ruptured subsequently again mostly in the Miocene as extension culminated during the time interval 14 to 17 Ma.

If these speculations concerning direct linkages between the Crescent Valley-Independence Lineament and a "proto" NNR have any merit, then it is appropriate for us to speculate further that a companion to the Carlin trend may be present somewhere along the NNR. However, because of inferred dextral shear along the "proto" NNR (see above), an analogous dilation jog there should have an orientation of about N. 40° E. prior to late Miocene extension, as opposed to the N. 40° W. trend of the Carlin trend (fig. 17). The Midas trough, a zone of east-northeast trending late Tertiary grabens in Tertiary volcanic rocks (Wallace, 1991; Wallace and John, this volume), is present along the NNR at the latitude of the presently known northwest terminus of the Carlin trend (fig. 17). If the "proto" NNR involved dextral shear, the Midas trough may be a preferred site for prior development of a dilation jog in underlying pre-Tertiary basement, in particular where horsts are present in Miocene volcanic rocks near east-northeast grabens.

CONCLUSIONS

Critical to our structural syntheses in the Santa Renia Fields and Beaver Peak quadrangles has been documentation that Upper Pennsylvanian and Lower Permian rocks of the Strathearn Formation extend into the area, and that these rocks have been involved in what appears to be regionally extensive north-south shortening associated with the late Paleozoic Humboldt orogeny. A major thrust in the area, the Coyote thrust, places Ordovician rocks of the Vinini Formation on top of the Strathearn Formation, and the upper plate of the Coyote thrust includes a number of north-dipping imbricate thrust surfaces. Some south-verging tightly overturned folds also are present in deformed rocks in the lower plate of the Coyote thrust. Similar styles of deformation with similar orientations of their folds and thrust surfaces are present elsewhere in many northeastern Nevada mountain ranges, and the structures may have continued to form as late as the Jurassic Elko orogeny. North-south shortening also may have been directly associated with development of transcurrent sinistral shear along the northeast-trending Crescent Valley-Independence Lineament deformation zone. Early deformation of lower Paleozoic strata along the site of the future Carlin trend of gold deposits is inferred to include a dilational jog between two major fault strands that constitute the Crescent Valley-Independence Lineament. Finally, if a companion northwest-striking shear conjugate to the Crescent Valley-Independence Lineament is present in northern Nevada, then a likely site is the present trace of the northern Nevada rift, which we suggest may have included right-lateral shear also during the late Paleozoic. Subsequent to all these events, Paleozoic rocks in the northern Carlin trend show evidence of Mesozoic east-west shortening and emplacement of Jurassic and later plutons and dikes into the dilational jog, and Tertiary east-west extension. Tertiary extension is manifest by large numbers of faults of various orientations, and by largely unconsolidated deposits of the Miocene Carlin Formation, including widespread air-fall tuff that is 15 to 14 Ma and that partly fills narrow pull-apart basins as much as 800 m deep.

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