CONTRIBUTIONS TO THE GOLD METALLOGENY OF NORTHERN NEVADA—PREFACE

By R.M. Tosdal

INTRODUCTORY COMMENTS

The northern Great Basin, specifically northern Nevada, is one of the Earth's premier Au producing regions. Here, gold (Au) and silver (Ag) are produced from a range of deposit types, with production being dominated by sedimentary-rock-hosted deposits, particularly those that lie along the Carlin trend (fig. 1) (Christensen, 1993, 1996). This small area is North America's most prolific gold mining district. Across the state of Nevada, gold production during 1998 will account for approximately 64 percent of U.S and 9 percent of the world total. Clearly the impact of these deposits on nearby local economies and on our national balance of payments will be profound well into the next century.

Knowledge of the major Au-Ag deposit types as well as crustal structure is critical to understanding the gold metallogeny of northern Nevada. This information is a basis for mineral exploration, for land-use planning decisions, and for environmental questions. Of principal importance in this region are the giant, sedimentary-rock-hosted or Carlin-type deposits, which are some of the largest deposits in the world. Despite their economic importance, their genesis is not fully understood, even though aspects of them have been investigated for over 35 years. For example, there still is no agreement as to the source of gold, the age of gold deposition, the source of heat driving hydrothermal convection systems, and the geologic reasons for linear arrays of deposits (Christensen, 1993, 1996; Arehart, 1996). In contrast to the uncertain origin of the Carlin-type deposits, other sedimentary-rock hosted deposits in northern Nevada, known as the distal-disseminated Ag-Au type (Theodore, 1998), are genetically related to shallow plutonic complexes (Theodore, 1998, this volume). These sedimentary-rock-hosted deposits bear many similarities to a typical Carlin-type deposit, an observation that has lead to models linking them to the plutonic environment (Sillitoe and Bonham, 1990). Hot-spring Au-Ag systems associated with Tertiary volcanic rocks represent a third type of precious metal deposit in northern Nevada. These deposits, although generally smaller than the sedimentary-rock-hosted gold deposits, are important gold resources.

Aspects important to the varied geologic environments of these different gold deposits in northern Nevada (fig. 1), which are the focus of ongoing research, are addressed in the twenty-two chapters that compose this volume. These chapters are organized along four themes: (1) crustal structure; (2) Carlin-type deposits; (3) pluton-related Au-Ag deposits near Battle Mountain; and (4) hot-spring Au-Ag deposits. The chapters represent contributions from scientists of the U.S. Geological Survey, University of Nevada at Reno, University of Nevada at Las Vegas, Nevada Bureau of Mines and Geology, University of Arizona, West Chester University, San Jose State University, Barrick Goldstrike Mines Inc., Uranerz U.S.A. Inc., and Sierra Exploration Inc.

CRUSTAL STRUCTURE

Linear arrays of Au-Ag deposits in northern Nevada, the Carlin trend and the Battle Mountain-Eureka mineral belt (fig. 1), are thought to reflect a fundamental deep crustal structural control on ore deposition (Shawe, 1991), although other tectonic models have been proposed (Madrid and Roberts, 1991). Understanding the control these inferred crustal-scale faults exerted on ore formation is not straightforward. There is neither structural evidence linking ore formation to the inferred north-northwest trending deep crustal faults, nor is there surface outcrops of such faults (Christensen, 1995), nor is there widespread evidence suggesting their geometry or crustal persistence. Grauch and others (1995) have observed a major northwest–trending gravity gradient that is coincident with the Battle Mountain-Eureka mineral trend and partially coincident with the northern Nevada rift. Combining this gravity gradient with other geophysical evidence, Grauch and others (this volume) demonstrate a discontinuity in geophysical properties coincident with the Battle Mountain-Eureka mineral belt. They interpret the discontinuity to reflect a crustal-scale fault. Rodriguez (1997, this volume) extended the magnetotelluric profile of Grauch and others (this volume) across northern Nevada crossing the Carlin trend where a similar discontinuity in crustal resistivity is evident. This implies that the Carlin trend also lies along a major crustal fault system.

Whereas the geophysical data are interpreted to indicate that the Battle Mountain-Eureka mineral belt and the Carlin trend are indeed associated with faults, or fault zones, penetrating deep in the crust, these data provide little

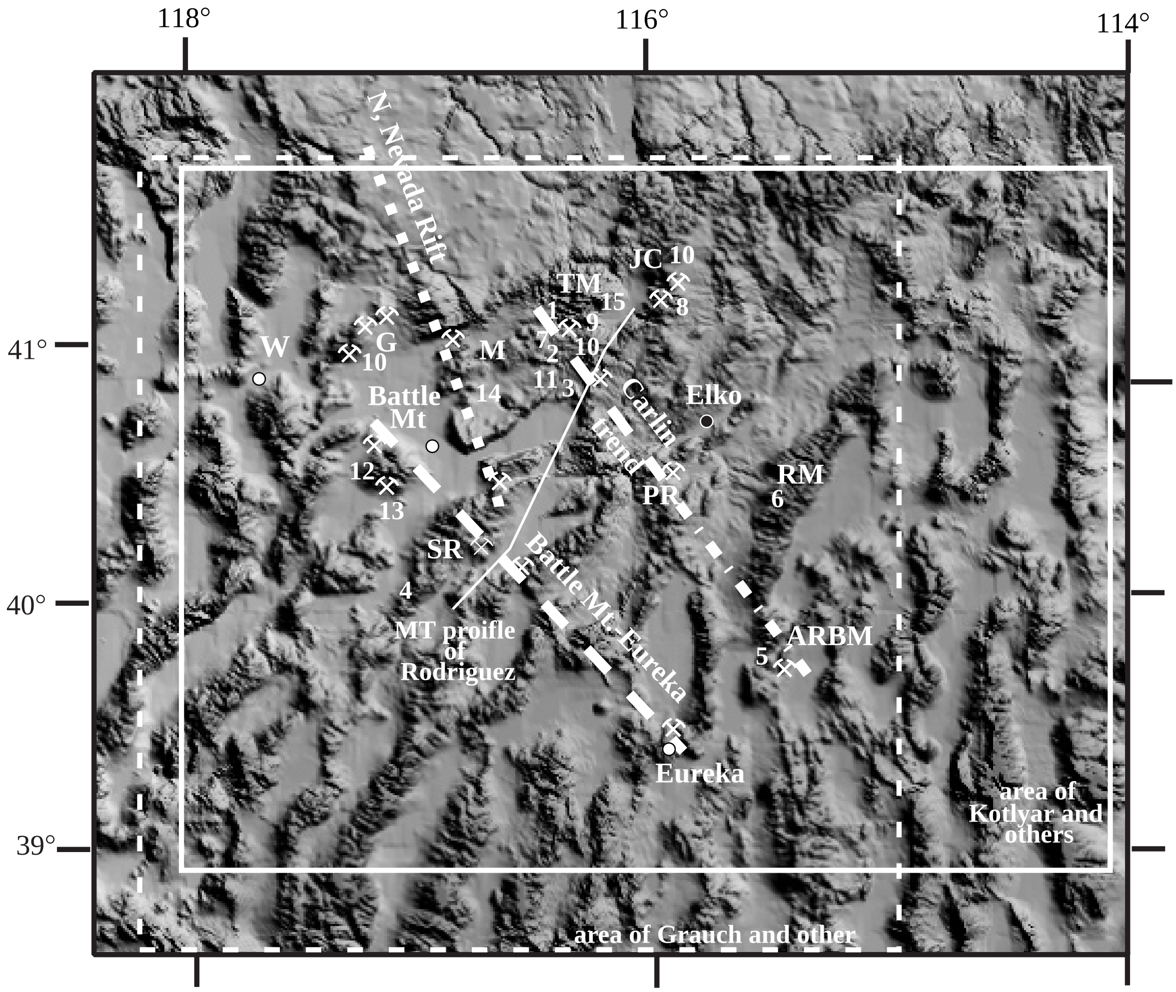

Figure 1. Shaded digital topographic map of northern Nevada showing location of geophysical and isotopic studies described herein, selected geographic locations and mines, Battle Mountain-Eureka mineral belt, Carlin trend and the southeastern extension to Alligator Ridge (dash-dot line), and the northern Nevada Rift. ARBM, Alligator Ridge-Bald Mountain; G, Getchell Mine; JC, Jerritt Canyon Mining District; M, Midas; RM, Ruby Mountains, SR, Shoshone Range; TM, Tuscarora Mountains; and W, Winnemucca.

Area of study by Grauch and others (this volume) included within large box outlined by white dashed lines. Magnetotelluric traverse of Rodriguez (this volume) is shown in solid white line. Area of Pb and Sr isotopic mapping described by Wooden and others (this volume) extends beyond the area of the map. Grauch (this volume) summarized these contributions across a traverse broadly parallel to the magnetotelluric profile of Rodriguez (this volume). Area of regional geochemical and geophysical analysis by Kotlyar and others (this volume) is outlined in the box (solid white line). Stable isotopic study by Hofstra and Rye (this volume) covers the central part of the map. Site specific studies are: **1**, Armstrong and others (this volume); **2**, Theodore and others (this volume); **3**, Peters (this volume); **4**, Moore and Murchey (this volume); **5**, Nutt and Good (this volume); **6**, Berger and others (this volume); **7**, Fleck and others (this volume); **8**, Folger and others (this volume); **9**, Woitsekhowskaya and Peters (this volume); **10**, Tosdal and others (this volume); **11**, McCarthy and McGuire; **12**, Battle Mountain Mining District summarized by Theodore (this volume), **13**, Kotlyar and Theodore (this volume); **14**, John and Wallace (this volume), and **15**, Henry and others (this volume).

evidence as to their origin. To address this question, Wooden and others (this volume), using Pb and Sr isotopic maps of Mesozoic and Tertiary igneous rocks, recognize regional differences in the composition of the lower and middle crust. Combining the Pb and Sr isotopic maps with stratigraphic facies variations (Elison and others, 1990), they propose that isotopic provinces, and the boundaries between them, were established during rifting along the western (present coordinates) margin of North America in the late Proterozoic and early Paleozoic. The Carlin trend lies along the Pb isotopic boundary which separates relatively intact and largely unmodified Archean and Proterozoic crust to the east from transitional continental crust to the west. This places most large gold deposits in the Great Basin over transitional continental crust and west of relatively intact and unmodified crust in northeastern Nevada, an observation also made by Cunningham (1988) using other data.

Integrating the geophysical constraints with the radiogenic isotopic data permit Grauch (this volume) to present a schematic cross section across northern Nevada. Deeply penetrating fault zones are interpreted to coincide with the Battle Mountain-Eureka and Carlin trends. These faults separate broad west to east changes in crustal composition, and mark fundamental changes from oceanic crust to thinned transitional continental crust to relatively intact and unmodified continental crust.

CARLIN-TYPE GOLD DEPOSITS

Sedimentary-rock-hosted or Carlin-type deposits represent the major gold deposit-type in northern Nevada. The largest concentration of these deposits lies in the Carlin trend (fig. 1), a 60-km-long array of deposits and prospects, which has produced approximately 21 million ounces of gold since 1965 (Christensen, 1996). The many studies of these deposits have recognized the importance of reactive calcareous sedimentary rocks to their formation (summarized by Christensen, 1993, 1995, 1996; and Arehart, 1996). A facies analysis of Silurian and Devonian rocks, the principal host rocks in the northern Carlin trend (fig. 1), by Armstrong and others (this volume) suggest that essential attributes derived from their depositional environments contributed significantly to subsequent gold deposition. They point out that the vast bulk of Carlin-type deposits are hosted in the Roberts Mountains and Popovich Formations because these rocks had porosity at the time of gold deposition due to early diagenetic crystallization of dolomite in a lime mud. Abundant intercrystalline sulfur-rich carbon also contributed to their being favorable host rocks.

Structure, particularly an allochthonous thrust sheet of deep-water eugeoclinal rocks emplaced over reactive calcareous rocks along the Devonian and early Mississippian Roberts Mountains thrust system, is another important aspect of Carlin-type deposits (Roberts, 1966; Christensen, 1995, 1996). Younger contractile late Paleozoic and Mesozoic deformations further complicate the structural architecture of the deposits (Ketner, 1977, 1998), but their impact on the structural fabric of the Carlin trend is not widely appreciated. Theodore and others (this volume), building upon geologic mapping at the northern end of the Carlin trend, (fig. 1) outline the regional importance of southward shortening in the Late Paleozoic Humboldt orogeny. Deformation at this time was marked by west-northwest to northwest trending folds, thrust faults, and moderate-dipping reverse faults. These faults cut at high angles across the northerly striking Devonian and early Mississippian Roberts Mountains thrust system. The Rain fault in the northern Piñon Range, along which the Rain Carlin-type deposit is localized (Longo and Williams *in* Teal and Jackson, 1997), is one of these late Paleozoic contractile structures (Theodore and others, this volume).

Peters (this volume) describes a north-northeast trending lineament, the Crescent Valley-Independence lineament, which extends from the Independence Mountains on the northeast to near Cortez, Nevada, on the southwest (fig. 1). This lineament is formed by the alignment of modern physiographic and geologic features. The central part of the Crescent Valley-Independence lineament is marked by tectonized rocks characterized by melange fabrics. Peters (this volume) argues that the lineament is a long-lived structural feature that has been reactivated multiple times since formation in the Paleozoic. It is also suggested to have focused hydrothermal fluid flow leading to the formation of Carlin-type deposits.

To the west near the Battle Mountains-Eureka mineral belt, Moore and Murchey (this volume) outline the Paleozoic stratigraphic, biostratigraphic, and structural framework of a part of the Shoshone Range (fig. 1). Here, eugeoclinal rocks of the Roberts Mountain allochthon are unconformably overlain by the upper Paleozoic Antler overlap sequence, consisting of a shoaling upward sequence of clastic rocks and minor limestone. These rocks regionally are structurally buried beneath deep-water upper Paleozoic rocks of the Golconda allochthon in the late Paleozoic (Stewart, 1980). However in the northern Shoshone Range, new fossil data suggest that the transition from the overlap sequence to the deeper water sedimentary rocks is not obviously a major thrust fault, as would be expected based upon regional relations. Evidently, there are structural complexities of regional importance that need to be resolved.

In the Alligator Ridge-Bald Mountain area at the southeastern terminus of the Carlin trend (fig. 1), Nutt and Good (this volume) document Eocene transpressive deformation. Hydrothermal circulation and silicification of similar style to Carlin-type deposits accompanied deformation. Strike-slip faulting, block rotation, and folding in this area record Eocene sinistral slip across a deeper fault in the subsurface. This fault reactivates an old crustal boundary (see Wooden and others, this volume) and separates Eocene and subsequently Oligocene and Miocene deformation into discrete domains of differential extensional strain and kinematics (Gans and Miller, 1983). How far along strike to the northwest into the northern Carlin trend Eocene transpressional strain extends is an important unresolved question, although Eocene folding and normal faulting is known in this area (Henry and Boden, 1997; Henry and others, this volume; Ketner and Alpha, 1988). As flow of auriferous hydrothermal fluids in the northern Carlin trend was controlled by the fault architecture (Teal and Jackson, 1997), and in view of the opinion Carlin-type deposits are of Eocene age (Henry and Boden, 1997; Ilchik and Barton, 1997; but see Arehart, 1996, for a dissenting opinion), understanding regional Eocene strain patterns will constrain genetic model of Carlin-type deposits, as well as provide exploration criteria.

Large-scale crustal extension in the Oligocene and Miocene formed metamorphic core complexes in the Ruby and Snake Mountains (fig. 1) (Gans and Miller, 1983; MacCready and others, 1997). Implicit in these models is the possibility that the mid-crustal plutonic-metamorphic environment now outcropping in the Ruby Mountains core complex to the east of the Carlin trend may be the deep crustal roots to the upper crustal Carlin-type deposits. Analysis of the varied ore deposits formed at different crustal levels within the Ruby Mountains by Berger and Oscarson (this volume) indicates that this was not the case. In fact the deposits represent a zoned magmatic-hydrothermal system peripheral to plutons. The deposits are also generally impoverished in gold.

Unconformably overlying gold deposits in the Carlin trend is the middle Miocene Carlin Formation. Precise $^{40}Ar/^{39}Ar$ laser-fusion ages of alkali-feldspar-bearing air-fall tuff interbedded in the middle of the Carlin Formation at the northern end of the Carlin trend (fig. 1) demonstrate emplacement of the tuff occurred over a short period of time between 14.4 and 15.1 Ma (Fleck and others, this volume). Evidently, deposition took place after local silicic volcanic centers, such as those in the Midas and Ivanhoe Mining Districts, were active (Wallace and John, this volume). The mid-Miocene age and major-element chemistry of glass shards composing the tuffs suggest their derivation not from local sources but from distal silicic volcanic centers associated with the Yellowstone hotspot or with the northern Nevada rift.

Stable isotopic compositions of minerals and fluid inclusions indicate that the hydrothermal fluids which formed most Carlin-type gold deposits were variably exchanged meteoric water, except along the Getchell Trend (fig. 1) where ore fluids contained an additional component of magmatic or metamorphic fluids (Hofstra and others, this volume). The unusually low δD_{H_2O} values of these fluids also suggests ore deposition during a cool climate, which characterized the mid-Tertiary (42 to 30 Ma), and not during a warm climate, which typified the Late Jurassic and Cretaceous.

Several of the problems which have inhibited development of a genetic model for Carlin-type deposits are the uncertainties regarding the age, or ages, of mineralization, the fluid evolution, and the source of gold (Christensen, 1993). Much of the debate regarding the age, or ages, of Carlin-type deposits stems from the interpretation of K-Ar and $^{40}Ar/^{39}Ar$ ages of illite (Arehart, 1996; Hofstra, 1995; Ilchik, 1995). Illite in the deposits is of detrital, diagenetic, and hydrothermal origin (Folger and others, this volume). Folger and others (this volume) address the ambiguity of K-Ar and $^{40}Ar/^{39}Ar$ ages of illite by comparing $^{40}Ar/^{39}Ar$ ages for different grain sizes recovered from unaltered and altered calcareous rocks that host <40.8-Ma Carlin-type deposits in the Jerritt Canyon Mining District (fig. 1). In all size fractions of illite, including the smallest (<0.1-micron) which is dominated by neoformed hydrothermal illite, the $^{40}Ar/^{39}Ar$ ages are too old. This age discrepancy is due to the influence of older detrital or diagenetic illite.

The evolution of ore fluids and mechanism of ore deposition are critical to formation of ore deposits. Woitsekhowskaya and Peters (this volume) modeled fluid evolution during formation of the giant Betze deposit in the northern Carlin trend (fig. 1). They conclude that the natural evolution of a CO_2, H_2S, and NaCl bearing fluid as it moves from below the site of ore deposition through reactive calcareous sedimentary rocks at the site of ore deposition can explain the distribution of alteration mineral phases in the deposit. Gold precipitation in association with arsenic in pyrite resulted from sulfidation of reactive iron in host rocks. Sulfidation resulted in higher hydrogen and lower aqueous sulfur activity and destabilization of arsenic- and gold-bearing aqueous complexes.

Establishing the source, or sources, of gold in Carlin-type deposits is also critical to genetic models for their formation (Christensen, 1993). Tosdal and others (this volume) address this question using Pb isotopic compositions of sulfide minerals in three Carlin-type deposits (fig. 1) along with Pb isotopic data for miogeoclinal and eugeoclinal sedimentary rocks and for Mesozoic and Eocene igneous rocks (Wooden and others, this volume). They demonstrate that mixing of two distinct Pb isotopic sources occurred during ore formation, a conclusion consistent with much geochemical information (summarized by Arehart, 1996).

On a regional scale, Kotlyar and others (this volume) modeled NURE geochemical surveys, gravity surveys, and magnetic surveys (fig. 1). They demonstrate that regional-scale distribution patterns of stream-sediment arsenic anomalies in northeast Nevada bear striking similarities to some important mineralized trends. The arsenic anomalies also correspond to some isostatic residual gravity anomalies and their gradients, which result from density distributions in the pre-Cenozoic rocks of the middle and upper crust. This coincidence of geochemical and geophysical data suggests that arsenic, as well as precious metals, may have been derived from the middle and upper crust, and then concentrated along linear structural zones during regional fluid flow.

Lastly, McCarthy and McGuire (this volume) conducted soil-gas surveys measuring inorganic and organic gases along widely spaced traverses that crossed the Carlin trend. Gas anomalies were found 7-11 km west and east of the center of the Carlin trend where the gold deposits are localized. The flanking gas anomalies extend northwest of the last known gold deposit along the Carlin trend. If the gas anomalies are in some way a reflection of the Carlin trend, then the northwestward extension of flanking gas anomalies suggests some exploration potential for this region.

PLUTON-RELATED GOLD DEPOSITS IN THE BATTLE MOUNTAIN AREA

The Battle Mountain Mining District, near the northwest terminus of the Battle Mountain-Eureka mineral belt in north central Nevada, contains a copious and varied metal endowment. Included in the mining district are four Tertiary porphyry Cu-Au and three Cretaceous stockwork Mo systems (fig. 1) (Theodore, 1998, this volume). A large number of distal-disseminated Ag-Au deposits and Cu-Au skarns are spatially and genetically related to Tertiary porphyry Cu systems (Theodore, 1998, this volume). Deposits in the northern part of the mining district represent shallow levels of zoned hydrothermal and plutonic systems. The southern part of the mining district represents deeper crustal levels of magmatic-hydrothermal systems where porphyry cores and flanking auriferous skarn deposits are concentrated along with more peripheral sedimentary-rock-hosted Ag-Au deposits. In the Copper Canyon area (fig. 1) Kotlyar and others (this volume), using three–dimensional modeling of geochemical data provided by Battle Mountain Gold Co., demonstrate district-scale geochemical zoning patterns that emanate outward from a Cu-Au core through the peripheral Fortitude Au skarn to a distal Pb-Zn halo.

HOT-SPRING GOLD DEPOSITS

Hot-spring Au-Ag deposit, the third major deposit type in northern Nevada, are near-surface deposits representing the shallowest setting of ore genesis. They provide a critical link between magmatic and hydrologic environments (Hedenquist and Lowenstern, 1994). Of importance in defining their genesis and role in the metallogeny of the region is understanding their environments, their age, and relationship to tectonomagmatic events in the Tertiary. Wallace and John (this volume) describe the geologic framework of Miocene volcanic complexes along the Northern Nevada Rift in the Shoshone and Sheep Creek Ranges and Snowstorm Mountains (fig. 1). Here, the interplay between east-northeast–directed extension and compositionally expanded magmatism localized precious metal mineralization in hot-spring deposits. The Mule Canyon deposit (~1 million oz Au) is the largest of the hot-spring type deposit (fig. 1).

In the Tuscarora Mountains (fig. 1), Henry and Boden (this volume) describe the complex volcanic history of the Eocene Tuscarora volcanic field. They demonstrate that a large quantity of igneous rocks were erupted or emplaced in different volcanic-plutonic environments over less than 1 m.y. In the Tuscarora Mining District, low-sulfidation hot-spring deposits formed during the waning stages of volcanism. Here, two spatially related but separate hydrothermal systems, one Au-rich and the other Ag-rich, were partially superposed. The superposition of hydrothermal systems of differing metal associations suggests that complex fluid circulation systems were established during the waning stages of volcanism.

REFERENCES CITED

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

Arehart, G.B., Foland, K.A., Naeser, C.W., and Kesler, S.E., 1993, $^{40}Ar/^{39}Ar$, K/Ar, and fission track geochronology of sediment-hosted disseminated gold deposits at Post/Betze, Carlin Trend, northeastern Nevada: Economic Geology, v. 88, p. 622-646.

Armstrong, A.K., Theodore, T.G., Oscarson, R.L., Kotlyar, B.B, Harris, Anita, Bettles, K.H., Lauha, E.G., Hipsley, R.A., Griffin, G.L., Abbott, E.W., and Cluer, J.K., (this volume), Preliminary facies analysis of Silurian and Devonian autochthonous rocks that host gold along the Carlin trend, Nevada, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Berger, Vladimir I., and Oscarson, Robert L., (this volume), Tungsten-polymetallic- and barite-mineralized rocks in the Ruby Mountains, Nevada, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

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

Christensen, O.D., 1995, The Carlin trend giant gold camp: is it the strata, the structure or the stocks, *in* Clark, A.H., ed., Giant ore deposits II, controls on the scale of orogenic magmatic-hydrothermal mineralization: Proceedings of the Second Giant Ore Deposits Symposium, Kingston, Ontario, April, 1995, p. 340-352.

Christensen, O.D., 1996, Carlin trend geologic overview, *in* Peters, S.G., Williams, C.L., and Volk, Jeff, Field trip guidebook for Trip B—Structural geology of the Carlin trend, *in* Green, S.M., and Struhsacker, Eric, eds., Field Trip Guidebook Compendium: Reno, Nevada, Geological Society of Nevada, Geology and ore deposits of the American Cordillera, p. 147–156.

Cunningham, C.G., 1988, The relationship between some disseminated gold deposits, the western edge of the Precambrian craton, and paleothermal anomalies in Nevada, *in* Schafer, R.W., Cooper, J.J., and Vikre, P.G., eds., Bulk mineable precious metal deposits of the western United States; Symposium proceedings: Reno, Nevada, Geological Society of Nevada, p. 35-48.

Elison, M.W., Speed, R.C., and Kistler, R.W., 1990, Geologic and isotopic constraints on the crustal structure of the northern Great Basin: Geological Society of America Bulletin, v. 102, p. 1077-1092.

Fleck, R.J., Theodore, T.G., Sarna-Wojcicki, Andrei, and Meyer, C.E., (this volume), Age and possible source of air-fall tuffs of the Miocene Carlin Formation, northern Carlin trend, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Folger, H.W., Hofstra, A.H., Snee, L.W., and Eberl, D.D., (this volume), K-Ar and $^{40}Ar/^{39}Ar$ dating of illites from Carlin-type gold deposits-Nature of the problem and guidelines for future studies, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Gans, P.B., and Miller, E.L., 1983, Styles of mid-Tertiary extension in east-central Nevada, *in* Gurgel, K.D., ed., Geologic excursions in the overthrust belt and metamorphic core complexes of the Intermontain region, Nevada: Utah Geological and Mineral Survey Special Studies 59, p. 107-160.

Grauch, V.J.S., (this volume), Crustal structure and relation to gold belts in north-central Nevada: overview and progress report, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Grauch, V.J.S., Jachens, R.C., and Blakely, R.J., 1995, Evidence for a basement feature related to the Cortez disseminated gold trend and implications for regional exploration in Nevada: Economic Geology, v. 90, p. 203–207.

Grauch, V.J.S., Klein, D.P., and Rodriguez, B.D., (this volume), Progress on understanding the crustal structure near the Battle Mountain-Eureka mineral trend from geophysical constraints, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Hedenquist, J.W. and Lowenstern, J.B., 1994, The role of magmas in the formation of hydrothermal ore deposits: Nature, v. 370, p. 519-527.

Henry, C.D., and Boden, D.R., 1997, Eocene magmatism of the Tuscarora volcanic field, Elko County, Nevada, and implications for Carlin-type mineralization, *in* Vikre, P., Thompson, T.B., Bettles, K., Christensen, O., and Parratt, R., eds., Carlin-type gold deposits field conference: Society of Economic Geology Guidebook Series, v. 28, p. 193–202.

Henry, C.D., Boden, D.R., and Castor, S.B., (this volume), Geology and mineralization of the Eocene Tuscarora Volcanic Field, Elko County, Nevada, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Hofstra, A.H., 1995, Timing and duration of Carlin-type gold deposits in Nevada and Utah—Relation to back-arc extension and magmatism: Geological Society of America Abstracts with Programs, v. 27, no. 6, pp. A-329.

Hofstra, A.H. and Rye, R.O., (this volume), δD and $\delta^{18}O$ data from Carlin-type gold deposits-Implications for genetic models, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Ilchik, R.P., 1995, $^{40}Ar/^{39}Ar$, K-Ar, and fission track geochronology of the sediment-hosted disseminated gold deposits at Post-Betze, Carlin trend, northeastern Nevada—a discussion: Economic Geology, v. 90, p. 208-210.

Ilchik, R.P., and Barton, M.D., 1997, An amagmatic origin of Carlin-type gold deposits: Economic Geology, v. 92, p. 269-288.

Ketner, K.B., 1977, Deposition and deformation of lower Paleozoic western facies rocks, northern Nevada, *in* Stewart, J.H., Stevens, C.H., and Fritsche, A.E., eds., Paleozoic paleogeography of the western United States: Pacific Coast Paleogeography Symposium 1: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 251–258.

Ketner, K.B., 1998, The nature and timing of tectonism in the western facies terrane of Nevada and California—An outline of evidence and interpretations derived from geologic maps of key areas: U.S. Geological Survey Professional Paper 592, 19 p.

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

Kotlyar, B.B., and Theodore, T.G., (this volume), Multilevel geochemical patterns at the Fortitude gold skarn, Battle Mountain Mining District, Nevada, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Kotlyar, B.B., Singer, D.A., Jachens, R.C., and Theodore, T.G., (this volume) Regional analysis of the distribution of gold deposits in northeast Nevada using NURE arsenic and geophysical data, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

MacCready, T., Snoke, A.W., Wright, J.E., and Howard, K.A., 1997, Mid-crustal flow during Tertiary extension in the Ruby Mountains core complex, Nevada: Geological Society of America Bulletin, v. 109, p. 1576-1594.

Madrid, R.J, and Roberts, R.J., 1991, Origin of gold belts in north central Nevada, *in* Buffa, R.H., and Coyner, A.R., eds., Geology and ore deposits of the Nevada: Geological Society of Nevada Field Trip Guidebook Compendium, Reno, NV, 1990, p. 927-939.

McCarthy, Howard, and McGuire, Emmet, (this volume), Soil gas studies along the Carlin trend, Eureka and Elko counties, Nevada, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Moore, T.E., and Murchey, B.L., (this volume), Stratigraphic and structural framework studies in the southern Battle Mountain trend, The Cedars area, Shoshone Range, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Nutt, C.J., and Good, S.C., (this volume), Recognition and significance of Eocene deformation in the Alligator Ridge area, central Nevada, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Peters, S.G., (this volume), Regional implications of the Crescent Valley-Independence Lineament, north-central Nevada, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Roberts, R.J., 1966, Metallogenic provinces and mineral belts in Nevada: Nevada Bureau of Mines Report 13, pt. A, p. 47-72.

Rodriguez, B.D., 1997, Deep regional resistivity structure across the Carlin trend, *in* Vikre, P., Thompson, T.B., Bettles, K., Christensen, O, Parratt, R., eds., Carlin-type gold deposits field conference: Society of Economic Geologist Guidebook Series, v. 28. p.39-45.

Rodriguez, B.D., (this volume), Regional crustal structure beneath the Carlin Trend, Nevada based on deep electrical geophysical measurements, *in* Tosdal, R.M., ed., Contributions to the Au metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Shawe, D. R., 1991, Structurally controlled gold trends imply large gold resources in Nevada, *in* Raines, G. L., Lisle, R. E., Schafer, R. W., and Wilkinson, W. H., Eds., Geology and ore deposits of the Great Basin: Geological Society of Nevada, Reno, Nevada, p. 199-212.

Sillitoe, R.H., and Bonham, H.F., 1990, Sediment-hosted gold deposits—Distal products of magmatic-hydrothermal systems: Geology, v. 18, p. 157-161.

Smith, J.F., and Ketner, K.B., 1976, Stratigraphy of post-Paleozoic rocks and summary of resources in the Carlin-Pinon Range area, Nevada: U.S. Geological Survey Professional Paper 867-B, p. B1-B48.

Stewart, J.H., 1980, Geology of Nevada: Nevada Bureau of Mines and Geology Special Publication 4, 136 p.

Teal, L., and Jackson, M., 1997, Geologic overview of the Carlin Trend gold deposits and description of recent deep discoveries: Society of Economic Geologist Newsletter, no. 31.

Theodore, T.G., 1998, Geology of pluton-related gold mineralization at Battle Mountain, Nevada: Tucson, Arizona, University of Arizona and U.S. Geological Survey Center for Mineral Resources Monograph 2 (in press).

Theodore, T.G., (this volume), Pluton-related Au in the Battle Mountains Mining District— Overview, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Theodore, T.G., (this volume), Large distal-disseminated precious-metal deposits, Battle Mountain Mining District, Nevada *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

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

Tosdal, R.M., Cline, J.S., Hofstra, A.H., Peters, S.G., Wooden, J.L., Young-Mitchell, M.N., (this volume), Mixed sources of Pb in sedimentary-rock-hosted Au deposits, northern Nevada, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Wooden, J.L., Tosdal, R.M., and Kistler, R.W., 1997, Pb and Sr isotopic mapping of crustal structure in the Northern Great Basin, *in* Vikre, P., Thompson, T.B., Bettles, K., Christensen, O., Parratt, R., eds., Carlin-type gold deposits field conference: Society of Economic Geologist Guidebook Series, v. 28. p. 47-53.

Wooden, J.L., Kistler, R.W., and Tosdal., R.M., (this volume), Pb isotopic mapping of crustal structure in the northern Great Basin and relationships to Au deposit trends, *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

Wallace, A.R., and John, D.A., (this volume), New studies on Tertiary volcanic rocks and mineral deposits, northern Nevada rift *in* Tosdal, R.M., ed., Contributions to the gold metallogeny of northern Nevada: U.S. Geological Survey Open-File Report.

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