U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

RESOURCE ASSESSMENT OF THE BUREAU OF LAND MANAGEMENT'S WINNEMUCCA DISTRICT AND SURPRISE RESOURCE AREA, NORTHWEST NEVADA AND NORTHEAST CALIFORNIA --

GEOLOGY, AND ITS RELATION TO RESOURCE GENESIS

by

Jeff L. Doebrich[1]

Open-File Report 96-30

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

1996

[1] U.S. Geological Survey, Reno Field Office, MS 176, Mackay School of Mines, University of Nevada, Reno, Reno, NV 89557-0047

CONTENTS

Introduction 1
- Acknowledgments 1

Paleozoic Geologic History 4
- Late Proterozoic and Early Paleozoic Autochthonous and Parautochthonous Rocks 4
- Early Paleozoic Allochthonous Rocks 5
- Late Paleozoic Overlap Assemblage 7
- Late Paleozoic Allochthonous Rocks 7
- Late Paleozoic Rocks of Uncertain Affinity 9

Mesozoic Geologic History 12
- Triassic Autochthonous Rocks 12
- Triassic-Jurassic Allochthonous Sedimentary and Plutonic Rocks (Jungo Terrane/ Fencemaker Allochthon) 13
- Middle(?) and Late Paleozoic and Mesozoic Allochthonous Magmatic-Arc Rocks (Black Rock Terrane) 15
- Jurassic Intrusive Rocks 16
- Cretaceous Fluvial and Lacustrine Rocks 16
- Cretaceous Plutonic Rocks 17
- Late Cretaceous Shear Zones 18

Cenozoic Geologic History 22
- Late Eocene to Early Miocene Magmatism and Tectonics 22
  - Interior Andesite-Rhyolite Assemblage 22
    - Volcanic Rocks 23
    - Plutonic Rocks 23
  - Volcanic Troughs and Calderas 24
- Early and Middle Miocene Magmatism and Tectonics 24
  - Western Andesite Assemblage 24
- Middle Miocene to Holocene Magmatism and Tectonics 25
  - Bimodal Basalt-Rhyolite Assemblage 25
  - Volcanic Centers 27
  - Northern Nevada Rift 28
  - Midas Trough 28
  - Quaternary Normal Faults 29
  - Pleistocene Pluvial Deposits 29

References Cited 34

Introduction

The U.S. Geological Survey (USGS) is a party to joint interagency Memorandum of Understandings (MOUs) with the Bureau of Land Management (BLM) and the U.S. Bureau of Mines (USBM) to coordinate resource assessments and evaluations of BLM administered lands. Resource assessments of BLM Resource Areas, that are conducted by the USGS under these MOUs, assist the BLM in meeting inventory and evaluation, resource-management planning, and other management requirements of the Federal Land Policy and Management Act of 1976 (FLPMA). This report is one of several to be generated as part of a resource assessment of BLM-administered lands in northwest Nevada and northeast California.

The project area is composed of three contiguous BLM Resource Areas (RAs), totalling 13.5 million acres, in northwest Nevada and northeast California (figs. 1, 2). The Sonoma-Gerlach and Paradise-Denio Resource Areas in northwest Nevada together comprise the BLM's Winnemucca District. The Surprise RA is located in extreme northwest Nevada and northeast California and is part of the BLM's Susanville District, which is administered by the BLM's California state office. Henceforth in this report, the project area will be referred to as the Winnemucca-Surprise Resource Assessment Area (WSRAA).

Sources of geologic data used in this compilation include the state geologic maps of Nevada (Stewart and Carlson, 1978) and California (Jennings, 1977). Other regional, larger-scale geologic maps of the area that were used include the 1:250,000 scale Nevada county geologic maps (Willden, 1964; Bonham, 1969; Willden and Speed, 1974; Johnson, 1977), 1:125,000-scale geologic quadrangle maps (Ferguson and others, 1951, 1952; Muller and others, 1951), 1:62,500-scale geologic quadrangle maps (Gilluly, 1967; Silberling and Wallace, 1967; Wallace and others, 1969a, b) and several 1:48,000- and 1:24,000-scale geologic quadrangle maps (e.g., Erickson and Marsh, 1974 b, c; Vikre, 1985b; Theodore, 1991 a, b; 1994; Doebrich, 1994, 1995; Jones, in press a, b).

The geology of the WSRAA records a complex history of Paleozoic and Mesozoic accretionary and plutonic events followed by Tertiary extensional tectonism and magmatism. This report chronologically outlines sedimentologic, magmatic, and tectonic events that shaped the geology of the WSRAA and relates these events to the genesis and distribution of the region's mineral and non-mineral resources. This is the initial report of several scheduled to be prepared on the WSRAA. Others reports include geochemistry, geophysics, hydrothermal alteration classification using Landsat Thematic Mapper imagery, assessment of metallic mineral resources, assessment of non-metallic mineral resources, and assessment of oil and gas resources.

Acknowledgments

The author wishes to thank all those who contributed their time and knowledge to achieve a better understanding of the geology of the project area and how it relates to the genesis of the area's mineral and non-mineral resources. In particular, George Albino, Charles Barker, Vic Dunn, David John, Mike Miller, Tom Nash, Norm Silberling, and Ted Theodore contributed their expertise and are gratefully acknowledged. Katherine Connors provided much needed GIS support of the project data bases and assisted in the generation of report illustrations. Ted Theodore provided critical technical review of an early draft of this report.

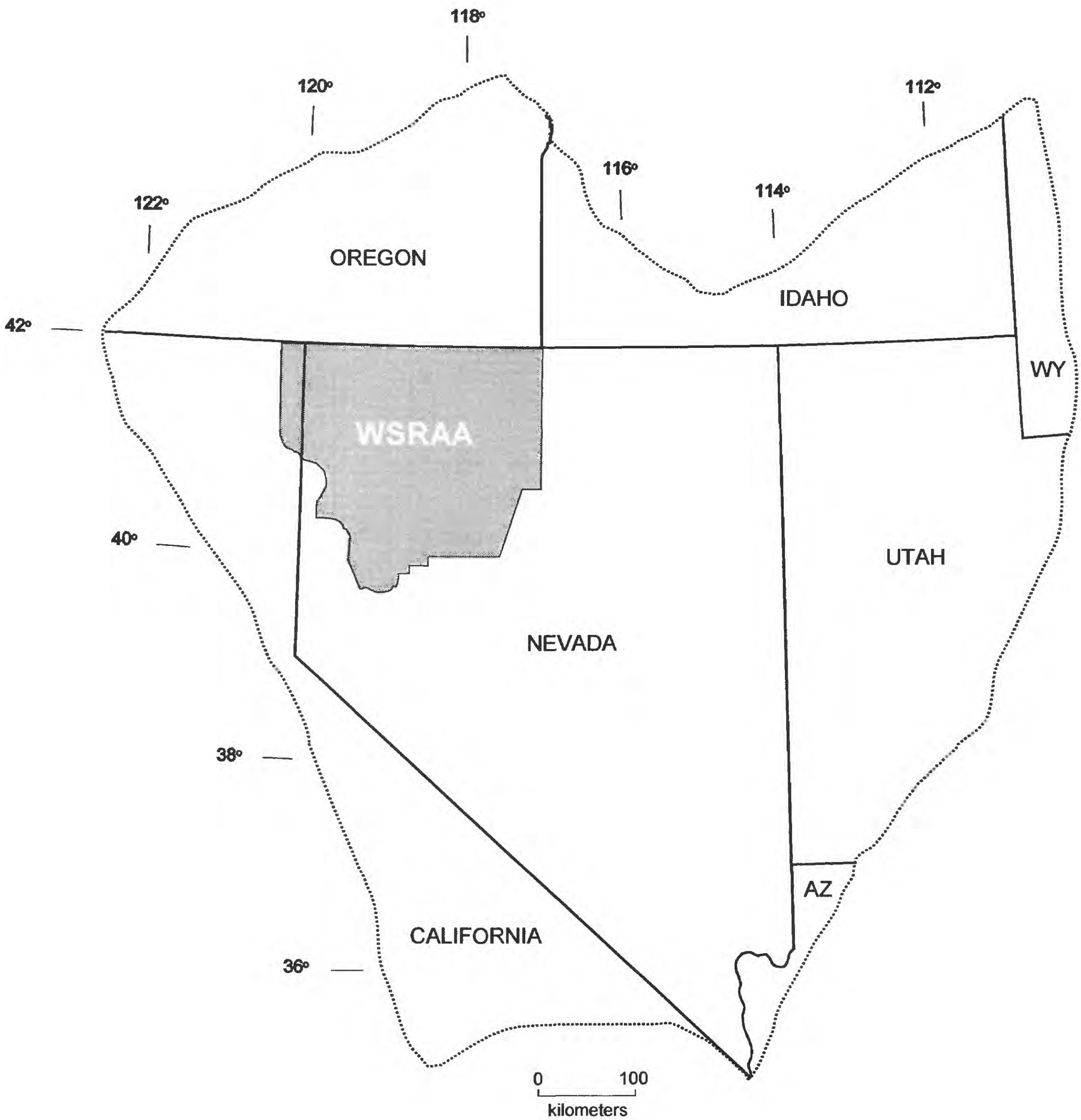

Figure 1. Index map of Great Basin showing location of Winnemucca-Surprise Resource Assessment Area (WSRAA).

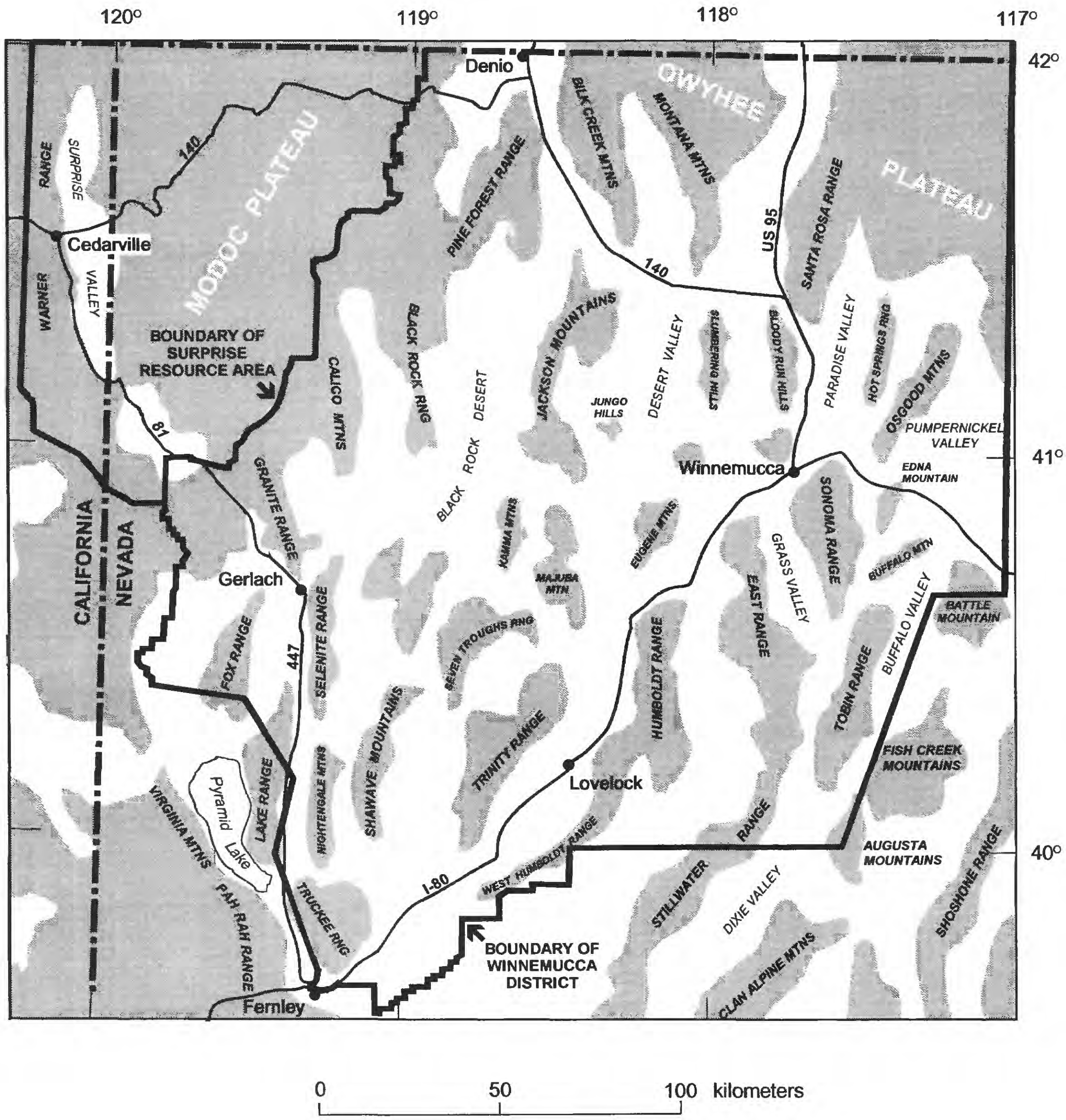

Figure 2. Map of the Winnemucca-Surprise Resource Assessment Area showing locations of selected geographic and cultural features and state and Bureau of Land Management boundaries. Shaded areas represent ranges and areas of exposed rock. White areas represent alluvium-covered basins.

Paleozoic Geologic History

Paleozoic rocks crop out in the east part of the WSRAA and consist of late Proterozoic and early Paleozoic parautochthonous and autochthonous miogeoclinal and slope facies rocks, early Paleozoic allochthonous slope facies and basinal rocks of the Roberts Mountains allochthon (Roberts and others, 1958; Hotz and Willden, 1964; Roberts, 1964; Madrid, 1987), late Paleozoic overlap assemblage rocks (Pennsylvanian and Permian Antler sequence) (Roberts, 1964; Saller and Dickinson, 1982), and late Paleozoic allochthonous slope, basinal, and turbiditic rocks of the Golconda allochthon (Devonian, Mississippian, Pennsylvanian, and Permian Havallah sequence) (Silberling and Roberts, 1962; Roberts and Thomasson, 1964; Stewart and others, 1977a, 1986; Murchey, 1990; Doebrich, 1995; Theodore, unpub. data, 1996) (fig. 3). Minor mafic plutonism within the allochthonous assemblages was associated with basaltic seafloor volcanism (fig. 3). Emplacement of the Roberts Mountains and Golconda allochthons occurred during the Antler orogeny (Late Devonian to Early Mississippian) and Sonoma orogeny (Late Permian to Early Triassic), respectively (Roberts and others, 1958; Silberling and Roberts, 1962; Roberts, 1964; Gabrielse and others, 1983). Paleozoic rocks also are present in the western part of the WSRAA, but these rocks constitute the lower part of the largely Mesozoic allochthonous Black Rock terrane, and will be discussed below in the section on Mesozoic geologic history. Mineral resource genesis during the Paleozoic was largely related to seafloor hydrothermal processes that resulted in relatively minor volcanogenic deposits of base metals and manganese, as well as locally significant deposits of bedded barite (e.g., Snyder, 1978; Rye and others, 1984) (fig. 3).

Late Proterozoic and Early Paleozoic Autochthonous and Parautochthonous Rocks

Late Proterozoic, Cambrian, and Ordovician autochthonous and parautochthonous rocks are present in three structural windows: the Osgood Mountains window, the Lee Peak window, and the Hot Springs window. These early Paleozoic rocks include map units *Czq, Ct,* and *Os* on the geologic map of Nevada (Stewart and Carlson, 1978) (fig. 4). The Osgood Mountains window is exposed in the Osgood Mountains, the north part of Edna Mountain, and the east part of the Sonoma Range. The Lee Peak and Hot Springs windows are exposed in the East Range (figs. 2, 4).

Late Proterozoic and Early Paleozoic rocks exposed in the Osgood Mountains window (fig. 4) include Late Proterozoic to Early Cambrian Osgood Mountains quartzite, Middle to Late Cambrian Preble Formation, and Early to Middle Ordovician Comus Formation. Osgood Mountains quartzite is overlain by Preble Formation along a gradational depositional contact (Hotz and Willden, 1964; Erickson and Marsh, 1974b, c). Contact relationships between Comus Formation and Preble Formation are both depositional and structural. Osgood Mountains quartzite consists of cross-bedded pure quartzite, quartz arenite, and phyllitic shale (Hotz and Willden, 1964; Erickson and Marsh, 1974c). Preble Formation consists of a lower unit of predominantly limestone with interbedded shale and sandstone and an upper unit of shale and phyllite (Hotz and Willden, 1964; Madden-McGuire, 1991). Comus Formation consists of characteristic dolomitic calcareous clastic rocks (siltstone and shale), and locally abundant basaltic volcanic and volcaniclastic rock (Hotz and Willden, 1964; Erickson and Marsh, 1974b; Bloomstein and others, 1991). Hotz and Willden (1964) consider the Comus Formation in the Osgood Mountains to be autochthonous whereas Erickson and Marsh (1974a) interpret the Comus at Edna Mountain to be part of the Roberts Mountain allochthon.

Early Paleozoic rocks exposed in the Lee Peak window (fig. 4) consist of Cambrian and Ordovician argillite, phyllite, marble, and quartzite (Whitebread, 1994). These rocks were originally mapped as Mesozoic in age (Whitebread, 1978) and are shown as such on the geologic map of Nevada (Stewart and Carlson, 1978). Consequently, no map units appear in the window when plotting Paleozoic units as defined on the geologic map of Nevada (fig. 4). Identification of Early Ordovician to Late Cambrian(?) microfossils in these rocks has led to a reinterpretation of their age (Whitebread, 1994) and dictates that their area of exposure is a structural window through the overlying rocks of the Roberts Mountains allochthon (see below). The existence of the Hot Springs window (fig. 4) is inferred by correlating the rocks exposed there with rocks exposed in the Lee Peak window (Lahren and others, 1995).

Early Paleozoic autochthonous and parautochthonous rocks were deposited in submarine environments along the western margin of the North American craton. Osgood Mountains quartzite represents shallow-water terrigenous detritus deposited in a continental shelf environment (Hotz and Willden, 1964; Stewart, 1980). Rocks of the Preble Formation are believed to have been deposited in open deep water on the outer shelf and locally on the continental slope (Hotz and Willden, 1964; Stewart, 1980). Rocks of the Comus Formation represent deepest water conditions for the autochthon, deposited westward or oceanward of the continental shelf , and locally interpreted to be associated with seamount environments on an abyssal plain (Bloomstein and others, 1991).

Rocks of the early Paleozoic autochthon and parautochthon are host to several types of syngenetic and epigenetic mineral deposits. Bedded barite deposits are present in the lower limestone-bearing unit of the Preble Formation indicating local exhalative activity on the Cambrian seafloor (Madden-McGuire, 1991). This same limestone-bearing unit of the Preble Formation acted as a favorable host for Carlin-type gold ore deposits at the Getchell and Preble Mines (Joralemon, 1951; Kretschmer, 1984a; Berger, 1985), and to tungsten-skarn deposits around the margin of the Cretaceous Osgood Mountains stock (Hotz and Willden, 1964). Preble Formation also hosts hot-spring type occurrences, epithermal and polymetallic vein deposits, and copper-skarn deposits in the Adelaide Mining District on the east side of the Sonoma Range (Cookro and Theodore, 1989) (fig. 2). The Comus Formation has been a favorable host for Carlin-type gold ore at the Getchell, Preble and Mag deposits (Joralemon, 1951; Kretschmer, 1984b; Berger, 1985; Foster and Kretschmer, 1991) and at the Rabbit Creek deposit of the Twin Creeks Mine (Bloomstein and others, 1991). At the Rabbit Creek deposit a stratabound exhalative lens of Zn-Pb-Ag massive sulfide minerals is present in basaltic hydroclastic tuff (Bloomstein and others, 1991), indicating that exhalative processes were also at work on the Ordovician seafloor in this region .

Early Paleozoic Allochthonous Rocks

Early Paleozoic rocks of the Roberts Mountains allochthon are exposed in several areas in the eastern part of the WSRAA, including the north and east parts of Battle Mountain, the central part of the East Range, the Sonoma Range, and the Hot Springs Range (figs. 2, 4). Small exposures of these rocks are also present in the Osgood Mountains and at Edna Mountain. The Roberts Mountains allochthon includes maps units *Ch* and *Osv* on the geologic map of Nevada (Stewart and Carlson, 1978) (fig. 4).

In this region, the Roberts Mountains allochthon consists of Late Cambrian(?) Paradise Valley Chert, Late Cambrian Harmony Formation, and Ordovician Valmy and Vinini

Formations. Paradise Valley Chert, exposed only as scattered localities in the Hot Springs Range (Hotz and Willden, 1964; Jones, in press a), consists of chert with interbedded shale and limestone near its upper contact with Harmony Formation. The nature of the contact between the Paradise Valley Chert and the Harmony Formation is uncertain and has been interpreted as depositional by some and structural by others. Harmony Formation is predominantly feldspathic and micaceous sandstone with interbedded shale and lesser amounts of pebble conglomerate and limestone (Hotz and Willden, 1964; Gilluly, 1967; Theodore, 1994; Jones, in press a, b). Valmy Formation consists of a variable sequence of chert, quartzite, pillowed metabasalt, argillite, shale, and sandstone (Ferguson and others, 1951; Gilluly, 1967; Theodore, 1991a, b; 1994). Vinini Formation is lithologically similar to Valmy Formation, but contains less metabasalt and sandstone and more shale than Valmy Formation.

Rocks of the Roberts Mountains allochthon were deposited in a submarine environment west of the North American craton. Rocks of the Harmony Formation are believed to represent midfan turbidite deposits, probably deposited on a continental rise (Suczek, 1977; Stewart, 1980). Rocks of the Valmy Formation represent a variety of eugeoclinal environments including reduced basins and submarine fans and possibly shallower environments than these locally (Stanley and others, 1977; Ketner, 1977; Wrucke and others, 1978; Madrid, 1987).

Rocks of the Roberts Mountains allochthon were transported eastward, on the Roberts Mountains thrust, during the Late Devonian to Early Mississippian Antler orogeny (Roberts and others, 1958; Roberts, 1964; Speed and Sleep, 1982) (fig. 3). During this orogeny, deep-water eugeoclinal and slope-facies rocks were thrust over coeval but lithologically dissimilar shallow-water, carbonate-bearing, miogeoclinal and slope-facies rocks to create the Antler highland along the western margin of North America. The lower plate autochthonous rocks are now locally exposed in structural windows as described above. This structural relationship, siliciclastic and volcanic rocks over predominantly carbonate-bearing rocks along the Roberts Mountains thrust, has been the most important tectonostratigraphic control on the distribution of Carlin-type gold deposits in Nevada. Studies indicate that in northeastern Nevada the Antler orogeny may have produced uplift and erosion and not thrusting (Ketner and others, 1993), and that some thrusting may have occurred during the Mesozoic (Ketner and Smith, 1982). Paleozoic structural fabric, primarily fold axes, imparted on rocks of the Roberts Mountains allochthon during the Antler orogeny, is largely N. 20° W. to N.20° E. in orientation (Evans and Theodore, 1978, Theodore, 1991a, 1994; Doebrich, 1994; Peters and Evans, 1995). Imbricate thrusting within the allochthon is common. The contact between Harmony Formation and Valmy Formation is always a structural contact and commonly a thrust fault that places rocks of the Valmy Formation over those of the Harmony Formation or vice versa (Roberts, 1964; Gilluly, 1967; Doebrich, 1994; Theodore, 1994).

Rocks of the Roberts Mountains allochthon are host to a variety of epigenetic mineral deposits. The Harmony Formation hosts low-fluorine porphyry molybdenum, porphyry copper, and related skarn, polymetallic vein, and distal disseminated silver-gold deposits in the Battle Mountain Mining District (fig. 2) (Roberts and Arnold, 1965; Theodore and others, 1992; Doebrich and others, 1995; Doebrich and Theodore, 1996), hot-spring mercury deposits in the Dutch Flat Mining District in the southern Hot Springs Range, and polymetallic veins in the Harmony Mining District in the northern Sonoma Range (fig. 2). Valmy Formation hosts distal disseminated silver-gold deposits in the Battle Mountain Mining District (Doebrich and others, 1995; Doebrich and Theodore, 1996), polymetallic veins in the Harmony Mining District and mesothermal low-sulfide gold-quartz veins in the Dun Glen Mining District in the East Range (fig. 2).

Late Paleozoic Overlap Assemblage

Rocks of the late Paleozoic overlap assemblage are represented by the Pennsylvanian and Permian Antler sequence of Roberts (1964). These rocks are exposed only in the Osgood Mountains, at Edna Mountain, and at Battle Mountain and are represented by map unit *lPPa* on the geologic map of Nevada (Stewart and Carlson, 1978) (figs. 2, 4).

The Antler sequence consists of calcareous siliciclastic sedimentary rocks and limestone. At Battle Mountain and Edna Mountain, the Antler sequence is divided into three formations, Middle Pennsylvanian Battle Formation, overlain by Pennsylvanian and Permian Antler Peak Limestone, which in turn is overlain by Permian Edna Mountain Formation (Roberts, 1964; Erickson and Marsh, 1974b, c). At Edna Mountain, a unit known as Highway Limestone is interpreted as an off-shore marine facies of the Battle Formation (Erickson and Marsh, 1974b, c). In the Osgood Mountains, the Antler sequence consists of Battle Formation overlain by either Pennsylvanian and Permian Adam Peak Formation or Pennsylvanian and Permian Etchart Limestone (Hotz and Willden, 1964), which are equivalent to Antler Peak Limestone, and represent different facies of a time stratigraphic interval.

The Antler sequence was derived from erosion of rocks of the Roberts Mountains allochthon along the Antler highland and was deposited in a shallow marine environment along the margin of the highland (Roberts and others, 1958; Roberts, 1964). Thicknesses of the formations are extremely variable, such that strata comprising individual formations are completely absent from some stratigraphic sections. Rocks of the Antler sequence lie unconformably on rocks of the Roberts Mountains allochthon and early Paleozoic autochthonous rocks. At Edna Mountain, however, rocks of the Antler sequence are apparently in both depositional and thrust fault contact with Cambrian Preble Formation (Erickson and Marsh, 1974b, c). The Antler sequence is structurally overlain by rocks of the Golconda allochthon along the regionally extensive Golconda thrust (Silberling and Roberts, 1962).

Rocks of the Antler sequence host a variety of epigenetic mineral deposits. At Battle Mountain, porphyry copper deposits, and related copper skarn, gold-silver skarn, and distal disseminated silver-gold deposits are all hosted in chemically reactive limestone and other calcareous clastic rocks of the Antler sequence (Doebrich and others, 1995; Doebrich and Theodore, 1996). In the Potosi Mining District in the Osgood Mountains (fig. 2), rocks of the Antler sequence host tungsten skarn deposits related to the Cretaceous Osgood Mountains stock and Carlin-type gold ore at the Chimney Creek deposit at the Twin Creeks Mine (Osterberg and Guilbert, 1991).

Late Paleozoic Allochthonous Rocks

Late Paleozoic rocks of the Golconda allochthon are present in several ranges in the eastern and southeastern parts of the WSRAA. These include the northern parts of the Hot Springs Range and Osgood Mountains, Edna Mountain, Buffalo Mountain, the western part of Battle Mountain, the southern part of the Sonoma Range, the Tobin Range, and scattered localities in the East Range (figs. 2, 4). Rocks of the Golconda allochthon are represented by map unit *PMh* on the geologic map of Nevada (Stewart and Carlson, 1978) (fig. 4).

The Golconda allochthon is comprised of rocks of the Havallah sequence of Silberling and Roberts (1962) and consists of a Devonian, Mississippian, Pennsylvanian, and Permian tectonostratigraphic assemblage of chert, argillite, shale, siltstone, sandstone, conglomerate, and limestone. Much of the siliciclastic rock is calcareous. At Battle Mountain, the Havallah sequence also contains two chemically distinct suites of volcanic rock. These are (1) Mississippian basalt and basaltic andesite, and (2) Pennsylvanian and (or) Permian basaltic trachyandesite and trachyandesite. The former have chemical affinities with plume-type or enriched mid-ocean ridge basalt (MORB) whereas the latter have affinities with within-plate alkali basalt and within-plate tholeiites (Doebrich, 1995; T.G. Theodore, unpub. data, 1995).

The presence of volcanogenic massive sulfide and manganese deposits in association with Late Devonian to Mississippian pillow basalt and radiolarian chert of the Havallah sequence (Snyder, 1978; Rye and others, 1984; Doebrich, 1995) indicates that the Late Devonian-Mississippian was a time of active seafloor fumarolic activity in a plume-type MORB environment (fig. 3). These associations indicate that rocks of the Havallah sequence were deposited in an oceanic or marginal rift basin west of the North American craton at the same time that the Antler highlands were being eroded and overlap assemblage materials were being deposited along the margin of the highland.

During the Late Permian to Early Triassic Sonoma orogeny (Silberling and Roberts, 1962) rocks of the Havallah sequence were folded and transported eastward on the Golconda thrust and emplaced over rocks of the overlap assemblage (Antler sequence) (fig. 3). This structural relation, Havallah sequence over Antler sequence along the Golconda thrust, represents a very important tectonostratigraphic control on the distribution of ore deposits in the area, particularly in the Battle Mountain Mining District (Doebrich and others, 1995; Doebrich and Theodore, 1996). Structural fabric within the Havallah sequence, as a result of this orogeny, is largely north-striking (N. 20° W. to N. 20° E.) manifested by east vergent folds and numerous imbricate faults bounding structurally interleaved units (Miller and others, 1982; Brueckner and Snyder, 1985; Stewart and others, 1986; Doebrich, 1995). At Battle Mountain, the Havallah sequence has been divided into two lithotectonic units separated by a major imbricate thrust in the Golconda allochthon, the Willow Creek thrust (Murchey, 1990; Theodore, 1991 a, b; Doebrich, 1995) (fig. 3). The lower lithotectonic unit of the Havallah sequence consists of Pennsylvanian and Permian slope deposits, and the upper lithotectonic unit contains Devonian, Mississippian, Pennsylvanian and Permian basinal rocks and turbidites. Abundant calcareous siltstone and sandstone, and limestone are present in the upper lithotectonic unit. The lower and upper lithotectonic units correspond to the Reese River and Tobin assemblages of Tomlinson (1990), and generally correspond to the Pennsylvanian(?) Pumpernickel and Pennsylvanian and Permian Havallah Formations of Roberts (1964), respectively.

The Havallah sequence hosts several types of syngenetic and epigenetic mineral deposits in the WSRAA. Volcanogenic manganese deposits are found in association with Late Devonian to Mississippian chert units in the northern Hot Springs Range (Poverty Peak Mining District), at Buffalo Mountain, on the west side of Battle Mountain, and most notably at the Black Diablo Mine on the east side of the Sonoma Range (fig. 2). Cyprus-type volcanogenic massive sulfide ore was mined from metabasalt and metasedimentary rocks belonging to the Havallah sequence at the Big Mike deposit (Rye and others, 1984) on the west side of the Tobin Range (fig. 2). Porphyry copper, porphyry molybdenum and distal disseminated silver-gold deposits are hosted by calcareous siliciclastic rocks of the Havallah sequence at Battle Mountain (Doebrich and others, 1995; Doebrich and Theodore, 1996), whereas hot-spring type deposits are hosted in Havallah sequence in the Poverty Peak (Hot Springs Range), Tobin (Tobin Range), and Goldbanks (East Range) Mining Districts (fig. 2).

Late Paleozoic Rocks of Uncertain Affinity

Three late Paleozoic rocks units in the WSRAA are lithologically distinct such that their relationship to other units of similar age is uncertain. These are the Mississippian Inskip Formation exposed on the west side of the East Range, the Mississippian Goughs Canyon Formation found in the Osgood Mountains and Hot Springs Range, and the Early Mississippian and Early Pennsylvanian Farrel Canyon Formation in the Osgood Mountains (figs. 2, 4). Rocks of the Inskip and Goughs Canyon Formations are included in map unit *Msv* on the geologic map of Nevada (Stewart and Carlson, 1978) whereas rocks of the Farrel Canyon Formation are included with rocks of the Havallah sequence (map unit *PMh,* geologic map of Nevada) (fig. 4).

The Inskip Formation (Ferguson and others, 1951; Muller and others, 1951; Whitebread, 1994) consists of phyllite, quartzite, wacke, and conglomerate with some limestone and metavolcanic rock. It is interpreted as being in depositional contact with Ordovician Valmy Formation (Whitebread, 1978, 1994; Sando, 1993). The Inskip Formation may represent a post-orogenic unit, possibly an offshore facies of the Antler sequence, deposited on the west side of the Antler highland, and resting unconformably on rocks of the Roberts Mountains allochthon (Stewart, 1980; Sando, 1993).

The Goughs Canyon Formation (Hotz and Willden, 1964) consists of interbedded pillowed metabasalt and limestone with lesser amounts of sandstone, shale, and chert. Its upper and lower contact relationships are uncertain. Hotz and Willden (1964) mapped contacts with underlying Cambrian Harmony Formation and overlying Farrel Canyon Formation as thrust faults. McCollum and McCollum (1991) interpret both contacts to be depositional. In the Hot Springs Range, Jones (in press a) has mapped a unit that she equates with Goughs Canyon Formation as being in thrust fault contact both with an underlying phyllite and shale unit that may be Harmony Formation and with overlying Havallah sequence. Metabasalt of the Goughs Canyon Formation hosts feeder zones to Carlin-type gold ore at the Chimney Creek deposit at the Twin Creeks Mine (Osterberg and Guilbert, 1991).

The Farrel Canyon Formation (Hotz and Willden, 1964) consists of sandstone with interbedded shale, siltstone, chert, and metavolcanic rock. It was originally designated as Pennsylvanian to Permian in age but since has yielded Early Mississippian and Early Pennsylvanian conodonts and radiolarians (McCollum and McCollum, 1991). This unit is temporally and lithologically similar to the Havallah sequence and has been included with the Havallah sequence by Stewart and Carlson (1978; map unit *PMh,* geologic map of Nevada) and Stewart (1980). However, its lower contact is not exposed and the nature of its upper contact is disputed as mentioned above.

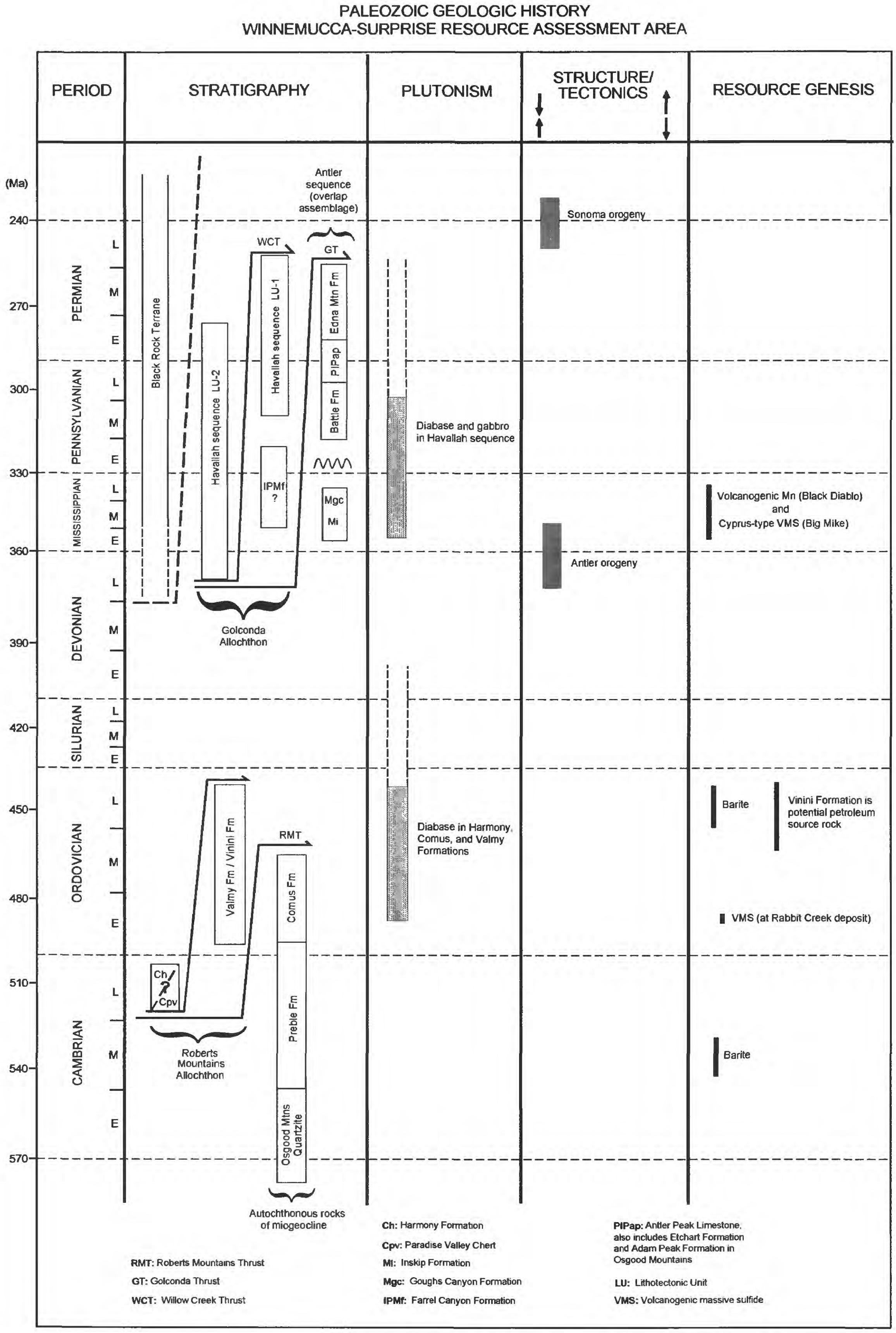

Figure 3. Chart summarizing Paleozoic geologic history of the Winnemucca-Surprise Resource Assessment Area, illustrating temporal relations between deposition of strata, plutonism, tectonic events, and resource genesis. Shaded columns indicate where ages are relatively well constrained; dashed lines indicate uncertainty. Arrows at top of structure/tectonics column indicate compressive and extensional events.

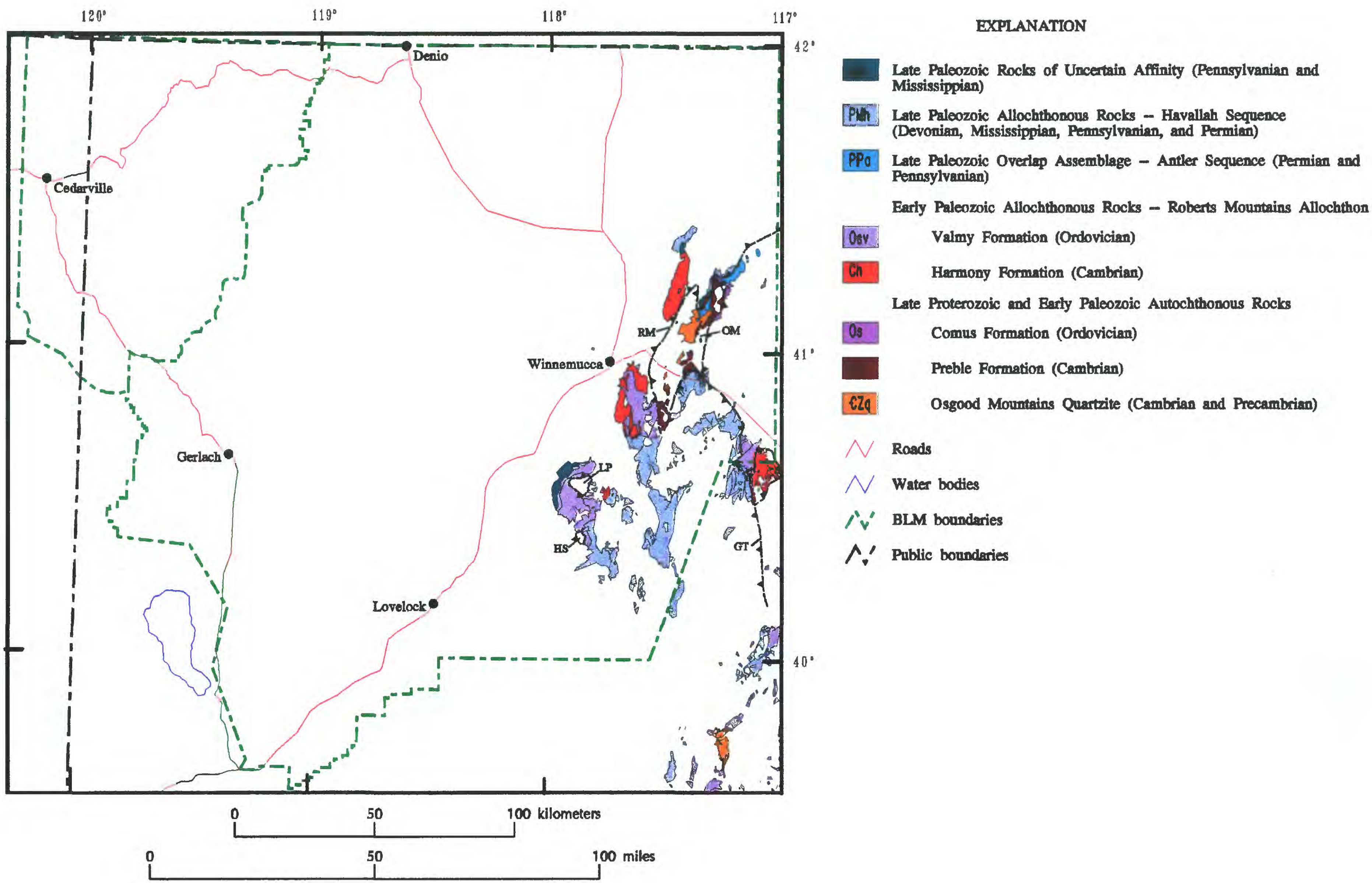

Figure 4. Distribution of Paleozoic rocks in the Winnemucca-Surprise Resource Assessment Area. Map unit labels are the same as used on the geologic map of Nevada (Stewart and Carlson ,1978), from which the geology was modified. See figure 2 for additional location information. **OM**, Osgood Mountains window; **LP**, Lee Peak window; **HS**, Hot Springs Window; **GT**, trace of Golconda thrust; **RM**, trace of Roberts Mountains thrust.

Mesozoic Geologic History

Mesozoic rocks are most abundant in the south, central, and northeast parts of the WSRAA and consist of autochthonous and allochthonous terranes as well as suites of intrusive rock (figs. 5, 6, 7). These include (1) a Triassic autochthonous volcanic-arc, shelf, and platform sequence (Koipato and Star Peak Groups, and part of the Auld Lang Syne Group)(Silberling and Roberts, 1962; Silberling and Wallace, 1969; Burke and Silberling, 1973; Nichols and Silberling, 1977; Speed, 1977, 1978b), (2) a Late Triassic to Early Jurassic allochthonous basinal terrane (most of the Auld Lang Syne Group; Jungo terrane; Fencemaker allochthon) (Burke and Silberling, 1973; Speed, 1978a; Oldow, 1984; Oldow and others, 1986, 1990; Silberling and others, 1987, 1992; Elison and Speed, 1988; Heck, 1991), and (3) a Devonian(?)to Jurassic allochthonous magmatic arc terrane (Black Rock terrane) (Silberling and others, 1987, 1992). Mesozoic plutonism was most prevalent during the period 105-70 Ma, during which granodioritic and monzogranitic stocks related to the Sierra Nevada batholith were emplaced (fig. 5) (Evernden and Kistler, 1970; Silberman and McKee, 1971; Smith and others, 1971). Plutonism also occurred in the Middle and Late Jurassic. The emplacement of the Fencemaker allochthon during the Jurassic and formation of north-striking shear zones in the Late Cretaceous represent two important Mesozoic tectonic events that occurred in the WSRAA (fig. 5) (Oldow, 1984; Oldow and others, 1986). Resource genesis during the Mesozoic was largely related to tectonic and plutonic events. Cretaceous plutonism resulted in porphyry and porphyry-related deposits of molybdenum, tungsten and copper (e.g., Theodore and others, 1992) (fig. 5). Late Cretaceous shear zones host low-sulfide gold-quartz veins. The age of Carlin-type gold deposits remains uncertain though some evidence suggests they formed either in the Middle to Late Jurassic (S.G. Peters, unpub. data) and (or) during the early Cretaceous (Arehart and others, 1993). Favorable petroleum source and reservoir rocks were deposited in the Triassic and heat for hydrocarbon generation was produced throughout the Mesozoic during accretionary and plutonic events (fig. 5; see also Doebrich and others, 1994).

Triassic Autochthonous Rocks

Triassic autochthonous rocks are exposed in the southeast part of the WSRAA, in the Humboldt, East, Sonoma, Tobin, and Stillwater Ranges and in the Augusta Mountains (figs. 2, 6) and include map units *TRc, TRk,* and *TRlgr* on the geologic map of Nevada (Stewart and Carlson, 1978). In the East Range, rocks mapped previously as Triassic autochthonous carbonate rock in the Lee Peak area (Whitebread, 1978) has been reinterpreted, based on new microfossil age determinations, as Early Paleozoic miogeoclinal rock exposed through a structural window in the Roberts Mountains allochthon (Whitebread, 1994) (fig. 3).

The Triassic autochthon consists of a lower sequence of volcanic and volcaniclastic rocks and an upper sequence of carbonate and terrigenous clastic rocks. The lower sequence, known as the Koipato Group (Silberling and Roberts, 1962), contains andesitic and rhyolitic flows, tuffs, and breccias intruded by coeval rhyolite porphyry and leucogranite. In the Humboldt Range, the Koipato Group has been subdivided into the Limerick Greenstone, Rochester Rhyolite, and Weaver Rhyolite (Silberling and Wallace, 1967; Wallace and others, 1969a, b). The upper part of the Koipato Group is Early Triassic in age (Silberling, 1973) whereas the age of the lower part is uncertain and may be as old as Late Permian (Silberling and Roberts, 1962). The Koipato Group lies with marked angular unconformity on folded and faulted late Paleozoic rocks of the Havallah sequence. This relationship is best exposed in the Tobin Range (Ferguson and others, 1952), and is used to assign an upper age constraint (Late Triassic) on the Sonoma orogeny (Silberling and Roberts, 1962). The Koipato Group is believed to represent a short-lived volcanic-arc (Speed, 1977, 1978b) that formed along the western margin of the North American continent and was partly emergent, such that much of the Koipato was deposited subaerially (Stewart, 1980).

The upper sequence of the Triassic autochthon consists of carbonate and terrigenous detrital rocks that lie depositionally on rocks of the Koipato Group and that belong to the Star Peak Group (Nichols and Silberling, 1977) and locally to the Auld Lang Syne Group (Burke and Silberling, 1973; Speed, 1978a, b; Whitebread, 1994). Stratigraphic nomenclature for the upper sequence of the autochthon varies geographically through the WSRAA. In general ascending order, the sequence includes the Tobin, Dixie Valley, Favret, Panther Canyon, Prida, Natchez Pass, Augusta Mountain, Cane Springs, Osobb, Grass Valley, Dun Glen, and Winnemucca Formations (Muller and others, 1951; Ferguson and others, 1951, 1952; Silberling and Roberts, 1962; Silberling and Wallace, 1967; Wallace and others, 1969a, b; Nichols and Silberling, 1977; Elison and Speed, 1988; Whitebread, 1994). The rocks of the upper sequence of the autochthon are Early to Late Triassic in age (Nichols and Silberling, 1977) and represent primarily shelf and platform environments, and locally slope, deltaic, and basinal environments, along the western margin of the North American craton (Nichols and Silberling, 1977; Speed, 1978b).

Rocks of the Triassic autochthon are host to a variety of types of epigenetic mineral deposits. Two active mines (1995) are producing gold and silver from ore deposits hosted in rocks of the autochthon in the Humboldt Range. The Rochester silver-gold deposit (Coeur D'Alene Mines, 1993) in the southern Humboldt Range is a silver-rich variety of a mesothermal low-sulfide gold-quartz vein deposit hosted in metavolcanic rock of the Koipato Group. The Florida Canyon deposit (Hastings and others, 1988) is a Tertiary hot-spring gold deposit in the northern Humboldt Range that is hosted by clastic rocks of the Grass Valley Formation. The Standard Mine, also in the Humboldt Range and active during the 1940s, has been classified as a Carlin-type gold deposit (Ronkos, 1986) and is hosted by shaly limestone of the Prida Formation. tungsten-skarn and polymetallic vein occurrences are also hosted in rocks of the Triassic autochthon.

Triassic-Jurassic Allochthonous Sedimentary and Plutonic Rocks (Jungo Terrane/ Fencemaker Allochthon)

A sequence of allochthonous Triassic to Jurassic basinal sedimentary and mafic plutonic rocks, referred to as the Jungo terrane (Silberling and others, 1987, 1992) or the Fencemaker allochthon (Speed, 1978b; Elison and Speed, 1988; Oldow and others, 1990), is exposed in a broad northeast-striking belt through the WSRAA, from the Fox, Trinity, West Humboldt, and Stillwater Ranges in the southwest to the Santa Rosa Range in the northeast (figs. 2, 6). The allochthon includes map units *JTRs* and *Jgb* on the geologic map of Nevada (Stewart and Carlson, 1978). However, rocks labeled as *JTRs* in the Pine Forest, Fox, and Selenite Ranges (figs. 2, 6; Stewart and Carlson, 1978; Stewart, 1980) in the western part of the WSRAA are assigned to the middle(?) and late Paleozoic and Mesozoic magmatic arc terrane (figs. 2, 6) (Silberling and others, 1987, 1992) which is described in a later section.

The Triassic-Jurassic allochthon consists of Late Triassic and Early Jurassic pelitic sedimentary rocks, quartzose sandstone, and some limestone that are intruded locally by a Middle

Jurassic mafic complex, the Humboldt lopolith of Speed (1976), in the West Humboldt and Stillwater Ranges (figs. 2, 6). The great volume of pelite in the sequence has led to use of the term "mud pile" when referring to these rocks (Burke and Silberling, 1973). Stratigraphic nomenclature for rocks of the allochthon varies geographically through the WSRAA. All of the sedimentary rocks of the allochthon are assigned to the Auld Lang Syne Group (Burke and Silberling, 1973). As defined by Burke and Silberling (1973), the Auld Lang Syne Group includes a lower carbonate-rich shelf sequence and an upper pelitic basinal sequence (Speed, 1978a). The lower carbonate-rich shelf sequence, which consists of the Grass Valley, Dun Glen, and Winnemucca Formations (Burke and Silberling, 1973) is now considered part of the Triassic autochthon, described above, and the upper pelitic basinal sequence of the Auld Lang Syne Group constitutes the Triassic to Jurassic Fencemaker allochthon (Speed, 1978a; Elison and Speed, 1988). The pelitic basinal sequence of the Auld Lang Syne Group includes the O'Neil, Singas, Adorno, and Mullinix Formations in the southern Santa Rosa Range (Compton, 1960), the Raspberry Formation in the Krum Hills and northern East Range (Ferguson and others, 1951), the Nightingale sequence of Bonham (1969) in the Fox Range, and the Pershing Ridge group (Oldow and others, 1990) in the southern Humboldt Range.

Most rocks of the Fencemaker allochthon represent pelagic and hemipelagic deposits and terrigenous and calcareous flysch that were deposited in a subsiding basin (Speed, 1978a; Elison and Speed, 1988; Oldow and others, 1990). Triassic deeper water facies, probably distal turbidites from a submarine fan environment, were overlain by Jurassic shallow-marine slope or carbonate bank deposits, including gypsum deposits, and subaerial deposits (Speed, 1974; Oldow, 1984; Elison and Speed, 1988; Oldow and others, 1990).

The base of the Fencemaker allochthon is the regionally extensive Fencemaker thrust (fig. 5, 6) (Speed, 1978b; Oldow, 1984) which separates basinal rocks of the allochthon from generally coeval platform rocks of the Triassic autochthon described above. Emplacement of the Fencemaker allochthon was generally eastward and occurred from the Middle Jurassic through the Early Cretaceous (Oldow, 1984). During this orogeny, the allochthon underwent polyphase deformation resulting in numerous imbricate thrusts and several orientations of folding. A generalized sequential development of northwest-striking folds followed by east-west-striking folds is recognized in the allochthon (Oldow, 1984). The emplacement of the Humboldt mafic complex was interpreted by Speed (1976) as being syntectonic because it intrudes and truncates large folds and thrusts.

Rocks of the Fencemaker allochthon are host to a variety of types of syngenetic (gypsum) and epigenetic mineral deposits. The most significant deposits hosted in these rocks are the tungsten-skarn deposits in the Mill City Mining District in the Eugene Mountains (fig. 2) (Johnson, 1977) and the iron-endoskarn(?) or volcanic-plutonic-hosted magnetite(?) deposits in the Mineral Basin Mining District, hosted by the Humboldt mafic complex, in the northern Stillwater Range (fig. 2) (Reeves and Kral, 1955; Moore, 1969). Rocks of the allochthon are also host to low-sulfide gold-quartz veins in the Awakening (Slumbering Hills), Mill City (Eugene Mountains), and Antelope (Antelope Range) Mining Districts, polymetallic veins in the Rebel Creek Mining District (Santa Rosa Range), and epithermal gold-silver and antimony veins in the Rebel Creek (Santa Rosa Range), Antelope (Antelope Range), Arabia (Trinity Range), and Willard (Humboldt Range) Mining Districts (fig. 2).

Middle(?) and Late Paleozoic and Mesozoic Allochthonous Magmatic-Arc Rocks (Black Rock Terrane)

A middle(?) and late Paleozoic and Mesozoic allochthonous magmatic-arc-related volcano-sedimentary sequence is exposed northwest of the Triassic-Jurassic allochthon described above. Exposures of this sequence are most abundant in the Jackson Mountains and Jungo Hills but also are present in the Pine Forest Range, the northern Selenite Range, the Granite Range, the southern Bilk Creek Mountains, and the Pueblo Mountains (figs. 2, 6). Rocks of this allochthonous terrane are represented by map unit *TRPvs* and parts of map unit *JTRs* (exposures in the Pine Forest, Fox, and Selenite Ranges only) on the geologic map of Nevada (Stewart and Carlson, 1978). Rocks of this magmatic-arc-related sequence were originally divided into two allochthonous terranes, the Black Rock and Jackson terranes (Silberling and others, 1987). Rocks of these terranes have since been shown to be in depositional contact (Wyld, 1990), eliminating the need for such a division. All rocks of the magmatic-arc sequence now constitute the Black Rock terrane (Silberling, 1991).

The stratigraphically lower part of the Black Rock terrane consists of variably metamorphosed pelitic volcanogenic clastic rock, chert, andesite flows, and limestone and includes the McGill Canyon Unit (Russell, 1984) or McGill Canyon Formation (Maher, 1989) in the Jackson Mountains. In the Pine Forest Range, these rocks are at least as old as Mississippian, possibly Devonian, and extend into the Late Triassic (Wyld, 1990). These rocks represent pelagic, hemipelagic, and turbiditic facies deposited in basin, slope, and distal shelf environments that developed in a intraoceanic magmatic-arc setting along the western margin of the North American continent (Silberling and others, 1987; Russell, 1984; Maher, 1989).

The stratigraphically upper part of the Black Rock terrane largely constitutes the volcano-plutonic part of the magmatic arc and consists of Late Triassic to Late Jurassic andesitic volcanic and volcanogenic sedimentary rocks. The upper volcano-plutonic part of the Black Rock terrane, known as the Happy Creek igneous complex (Russell, 1984), is composed of basaltic andesite, andesite, diorite, and quartz diorite as flows, volcanic breccia, and intrusions. Maher (1989) claims that the volcanic rocks of the arc were erupted in subaerial environments indicating emergent conditions.

As with basinal rocks of the Triassic to Jurassic allochthon described in the previous section, rocks of the Black Rock terrane were deformed during a period from the Middle Jurassic through the Early Cretaceous. During this deformation, a pervasive northeast-striking set of folds was developed, and considerable imbricate thrusting occurred as a result of crustal shortening in an approximately NW-SE direction (Russell, 1984). Intermountain basins that formed in response to this deformational event, and possibly related to intra-arc wrench faulting (Maher, 1989), acted as sites of deposition for Cretaceous fluvial and lacustrine deposits described in a later section.

Rocks of the Black Rock terrane are host to several types of epigenetic mineral deposits. These include tungsten skarns in the Pine Forest Range (fig. 2), low-sulfide gold-quartz veins in the Pine Forest Range and Jackson Mountains (fig. 2), and volcanic-hosted magnetite deposits in the Jackson Mountains (fig. 2).

Jurassic Intrusive Rocks

Jurassic intrusive rocks in the WSRAA can be divided into three general suites. These are (1) the Humboldt mafic complex, of middle Jurassic age, exposed in the West Humboldt and northern Stillwater Ranges (map unit *Jgb*, geologic map of Nevada), (2) Early to Late Jurassic granitic to gabbroic stocks, dikes, and sills that are part of the Happy Creek igneous complex (part of map unit *TRPvs*, geologic map of Nevada) exposed in the Jackson Mountains, and (3) isolated plutons of quartz monzonite, granodiorite, and syenite in the southeast part of the WSRAA (map units *Jgr* and *TJgr,* geologic map of Nevada) (Stewart and Carlson, 1978) (figs. 5, 6, 7). The Humboldt mafic complex (Speed, 1976) and plutonic rocks associated with the Happy Creek igneous complex (Russell, 1984; Maher, 1989) are part of the Triassic-Jurassic Fencemaker allochthon and middle(?) and late Paleozoic and Mesozoic Black Rock magmatic-arc terrane, respectively, and were described in previous sections. This section describes the isolated Jurassic plutons exposed in the East, Sonoma, and Tobin Ranges, and at Buffalo Mountain (figs. 2, 7).

The isolated Jurassic plutons in the southeast part of the WSRAA range in age from approximately 165 to 146 Ma (Silberman and McKee, 1971; Morton and others, 1977) and generally are quartz monzonite or granodiorite, though syenite porphyry phases are widespread in the plutonic complex at Buffalo Mountain (Neff, 1969; Silberman and McKee, 1971). All Jurassic plutons of this suite intrude rocks of the Havallah sequence, with the exception of the Lee Peak pluton in the East Range, which intrudes early Paleozoic autochthonous rocks exposed in a structural window (Lee Peak window) through the Roberts Mountains allochthon.

The geologic environment into which these plutons were emplaced is somewhat enigmatic because they are distal to areas of arc-related magmatism of similar age. Because, however, of the similarity in age and composition of these plutons with plutons of the Jurassic intrusive epochs of the Sierra Nevada batholith (Evernden and Kistler, 1970), these pluton may be related to distal early phases of the Sierra Nevada batholith.

Mineral deposit types known to be associated with Jurassic plutons in the southeast part of the WSRAA primarily include polymetallic veins and copper skarns. In the Fish Creek Mountains, however, outside the southeast border of the WSRAA (fig. 2), the 157 Ma McCoy pluton intruded limestone-bearing strata of the Triassic autochthon (Osobb and Cane Springs Formations) and formed magnetite skarn deposits in dolomite beds in the Osobb Formation (Shawe and others, 1962; Emmons and Eng, 1995).

Cretaceous Fluvial and Lacustrine Rocks

Early Cretaceous fluvial and lacustrine rocks of the King Lear Formation (map unit *Ks*, geologic map of Nevada) are exposed only in the Jackson Mountains (figs. 2, 6). The King Lear Formation (Willden, 1958, 1963, 1964) consists of locally-derived conglomerate, siltstone, mudstone, and limestone that were deposited in fluvial and lacustrine environments in intermountain basins that formed during deformation of the Happy Creek igneous complex (Russell, 1984). Willden (1958, 1963, 1964) and Russell (1984) interpreted rocks of the King Lear Formation as everywhere resting unconformably on rocks of the Late Triassic to Middle Jurassic Happy Creek igneous complex. Maher (1989), however, states that the nature of the contact between the Happy Creek igneous complex and the King Lear Formation is variable, and locally it may be conformable, unconformable, or structural. Maher (1989) also extends the base of the King Lear Formation downward to Middle Jurassic in age. Rocks of the King Lear Formation are imbricated and folded, similar to rocks of the Happy Creek igneous complex, indicating that deformation was ongoing to the middle Cretaceous.

The King Lear Formation is not known to host any significant occurrences of minerals. The formation is, however, considered to contain potential oil and gas source and reservoir rock where buried in Neogene basins (fig. 5; see also Doebrich and others, 1994).

Overlying the King Lear Formation and Happy Creek igneous complex, in the Jackson Mountains, and the Auld Lang Syne Group (Raspberry Formation) in the Krum Hills is the Cretaceous or Tertiary Pansy Lee Conglomerate (map unit *TKs*, geologic map of Nevada) (Willden, 1964; Stewart and Carlson, 1978). The unit consist of conglomerate, sandstone, and siltstone that post-dates folding in the King Lear Formation and pre-dates late Tertiary volcanic rocks.

Cretaceous Plutonic Rocks

Cretaceous granitic rocks in the WSRAA are most abundant in a 125-km wide northeast-striking corridor, from the Shawave and Nightingale Mountains in the southwest to the Santa Rosa Range and Montana Mountains in the northeast (figs. 2, 7). They are, by far, the most voluminous of all plutonic rock groups in the WSRAA and include map units *Kgr, MZgr*, and *KJd* on the geologic map of Nevada (Stewart and Carlson, 1978).

Cretaceous plutonism in the WSRAA occurred during the period 105-70 Ma (fig. 5) (Silberman and McKee, 1971; Smith and others, 1971). This period corresponds to the Huntington Lake and Cathedral Range intrusive epochs of the Sierra Nevada batholith as defined by Evernden and Kistler (1970), north-central Nevada plutonic epochs II and III of Silberman and McKee (1971), and the Lovelock intrusive epoch of Smith and others (1971). Cretaceous plutonic rocks have a wide range of compositions, ranging from gabbro to alaskite, though most large plutons are medium to coarse-grained equigranular biotite±hornblende granite and granodiorite (Smith and others, 1971; John, 1992; John and others, 1994). In a comparison of Cretaceous and Jurassic plutons for a region immediately south and west of the WSRAA, John and others (1994) determined that Jurassic plutons are mildly alkaline and Cretaceous plutons calc-alkaline in composition. In addition, Cretaceous plutons appear to represent deeper paleodepths than Jurassic plutons which locally intrude cogenetic volcanic rocks. These relationships also apply to similar rocks in the WSRAA.

The Cretaceous granitic rocks in the WSRAA represent the continuation of the Sierran magmatic arc into northwest Nevada. Smith and others (1971) propose that the northeast-striking corridor of Cretaceous granitic rock in the WSRAA corresponds to a bend in the Cordillera and is a link between the Sierra Nevada and Idaho batholiths.

Several types of mineral deposits related to porphyry molybdenum and porphyry copper mineral systems are associated with Cretaceous granitic rocks in and adjacent to the WSRAA (fig. 5). These include low-fluorine porphyry molybdenum systems in the Battle Mountain Mining District (Theodore and others, 1992; Doebrich and Theodore, 1996) and at Gregg Canyon in the Sonoma Range (Wendt and Albino, 1992) (fig. 2), tungsten skarn deposits in the Mill City Mining District in the Eugene Mountains (Johnson, 1977), in the Potosi Mining District in the Osgood Mountains (Silberman and others, 1974) and in the Nightingale Mountains (fig. 2), and a porphyry copper system in the northern Fish Creek Mountains (Miller and Silberman, 1977) (fig. 2).

Late Cretaceous Shear Zones

Broad north-striking shear zones that transect the WSRAA are inferred from the alignment of mining districts and other areas that contain low-sulfide gold-quartz veins. These shear zones are delineated on the low-sulfide gold-quartz vein tract map for the WSRAA (see Doebrich and others, 1994) and consist of a western zone that trends north from the Trinity Range to the Pueblo Mountains and an eastern zone that trends east-northeast from the Humboldt Range to the Santa Rosa Range (fig.2). Both of these regional zones appear to merge or emanate at their south ends in the vicinity of the Humboldt Range.

The low-sulfide gold-quartz veins are mesothermal and mesozonal in character, and are associated with the development of ductile fabrics in the host rocks. In the Humboldt Range, the shear zone contains mylonitic fabric and dumortierite- and andalusite-bearing quartz-sericite schist (Wallace and others, 1969b; S.G. Peters, unpub. data, 1996).

These shear zones may be the youngest pre-Tertiary features in the area (fig. 5) because they locally cut across allochthon boundaries and late Cretaceous granitic plutons (S.G. Peters, unpub. data, 1996). However, the eastern zone somewhat parallels the trace of the Fencemaker thrust. These structures presumably formed in a compressional tectonic environment and may document a previously unrecognized Late Cretaceous or Early Tertiary tectono-thermal compressive event in northern Nevada.

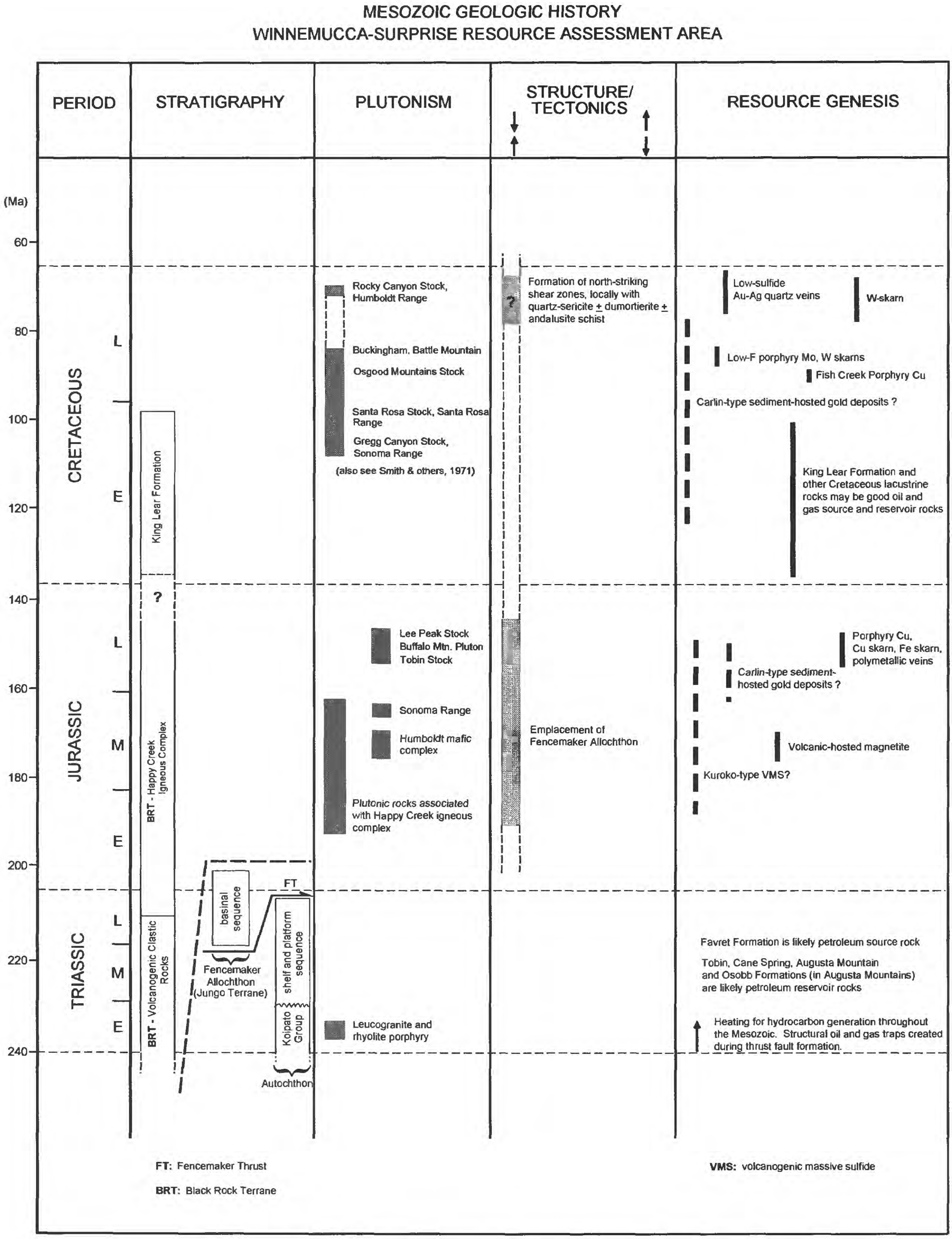

Figure 5. Chart summarizing Mesozoic geologic history of the Winnemucca-Surprise Resource Assessment Area, illustrating temporal relations between deposition of strata, plutonism, tectonic events, and resource genesis. Shaded columns indicate where ages are relatively well constrained; dashed lines indicate uncertainty. Arrows at top of structure/tectonics column indicate compressive and extensional events.

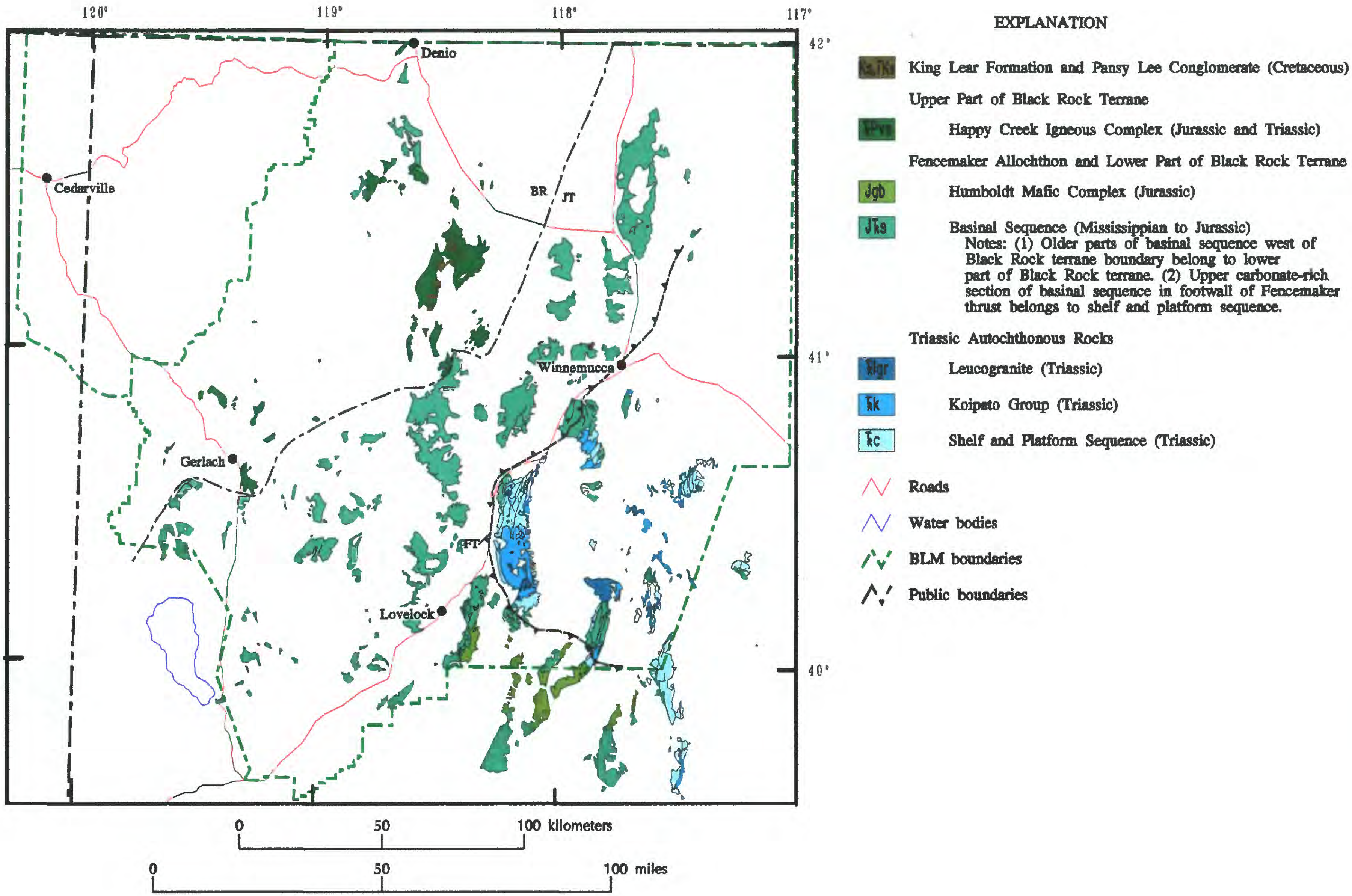

Figure 6. Distribution of Triassic and Jurassic autochthonous and allochthonous volcanic, sedimentary, and plutonic rocks in the Winnemucca-Surprise Resource Assessment Area. Map unit labels are the same as used on the geologic map of Nevada (Stewart and Carlson ,1978), from which the geology was modified. See figure 2 for additional location information. **FT**, Fencemaker thrust; **JT**, Jungo terrane (Fencemaker allochthon); **BR**, Black Rock terrane.

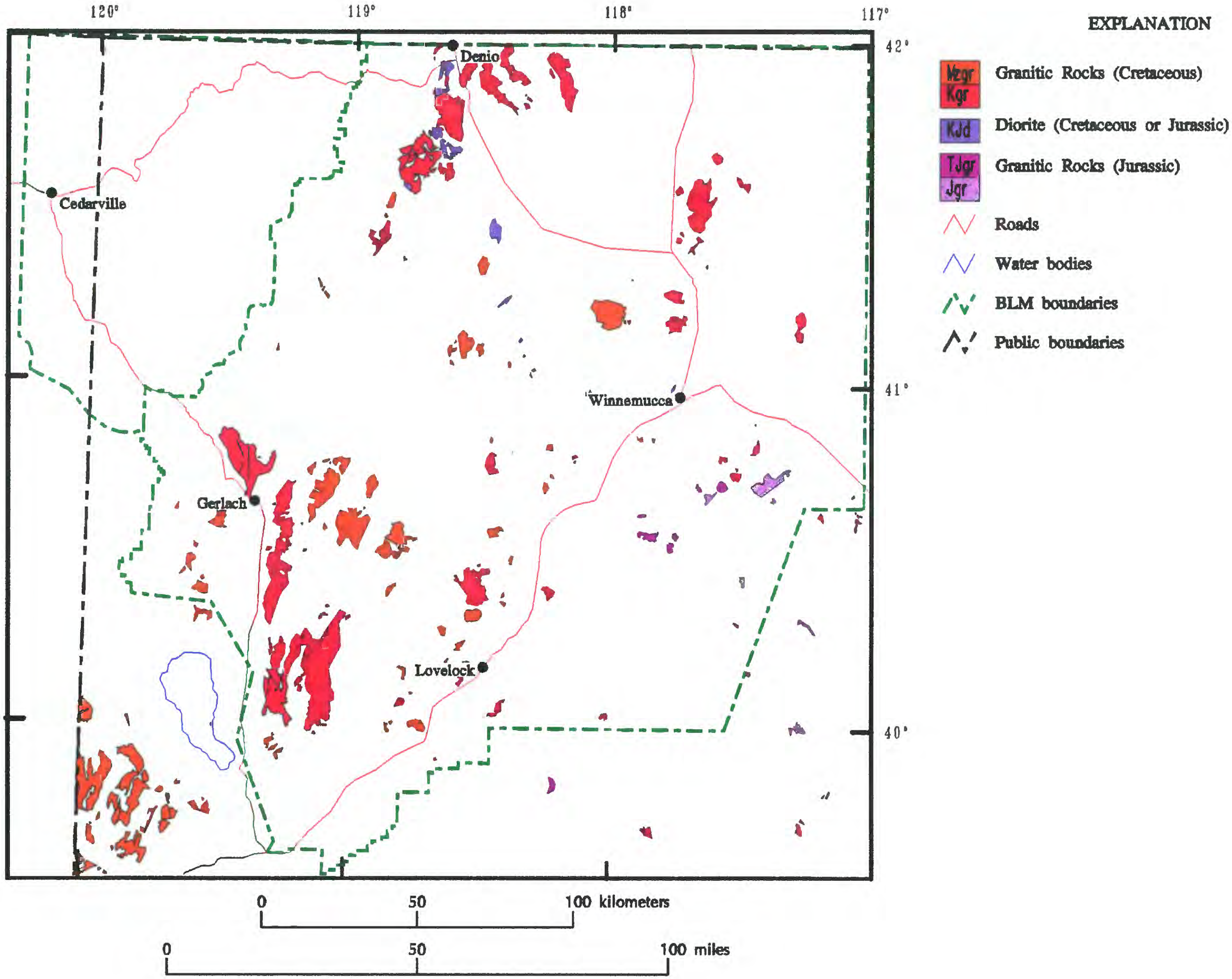

Figure 7. Distribution of Mesozoic granitic rocks in the Winnemucca-Surprise Resource Assessment Area. Map unit labels are the same as used on the geologic map of Nevada (Stewart and Carlson ,1978), from which the geology was modified. See figure 2 for additional location information.

Cenozoic Geologic History

Tectonics and magmatism during the Cenozoic in the northern Great Basin were vastly different from what had preceded in the Paleozoic and Mesozoic. The tectonic regime changed from one of compression to one of extension with related volcanism and plutonism (fig. 8). The Cenozoic can be divided into several tectono-magmatic episodes based on time-space patterns of volcanism and tectonism in the western United States (Armstrong and others, 1969; McKee, 1971; Christiansen and Lipman, 1972; Noble, 1972; Christiansen and others, 1992). In Nevada, these include (1) a late Eocene to early Miocene episode of calc-alkalic silicic and intermediate volcanism and plutonism (interior andesite-rhyolite assemblage) associated with a continental arc, (2) an early and middle Miocene episode of calc-alkalic intermediate composition magmatic-arc-related volcanism (western andesite assemblage), and (3) a middle Miocene to Holocene episode of continental extension and subalkaline and peralkaline bimodal volcanism (bimodal basalt-rhyolite assemblage) (fig. 8) (Cox and others, 1991; Christiansen and others, 1992; Ludington and others, 1993). In addition, Pleistocene pluvial sedimentation affected a large part of the WSRAA.

Resource development in the WSRAA during the Cenozoic was largely related to plutonism during the late Eocene and Oligocene and high regional heat flow during Miocene to Holocene extensional tectonism (fig. 8). Large deposits of copper, gold, and silver, related to late Eocene to early Oligocene plutonism, have been, and continue to be, mined in the Battle Mountain area (Roberts and Arnold, 1965; Theodore and Blake, 1975, 1978; Wotruba and others, 1988; Theodore and others, 1990; Doebrich and others, 1995). The change from calc-alkalic volcanism during the Oligocene to early Miocene to subalkaline and peralkaline bimodal volcanism in the middle Miocene is mimicked by a corresponding change in the type of epithermal gold-silver deposits produced; subvolcanic quartz-adularia-type (Comstock-type) deposits are associated with the former whereas shallower hot-spring and sub-hot-spring type deposits are associated with the latter (fig. 8) (Noble and others, 1988; Cox and others, 1991). Neogene block faulting resulted in burial of Triassic petroleum source rocks and hydrocarbon generation. Elevated regional heat flow created by Neogene extensional tectonics has also resulted in the generation of geothermal resources to the present day (fig. 8).

Late Eocene to Early Miocene Magmatism and Tectonics

Interior Andesite-Rhyolite Assemblage

Late Eocene to early Miocene volcanic and plutonic rocks in the WSRAA are assigned to the interior andesite-rhyolite assemblage (fig. 8) (Cox and others, 1991; Christiansen and others, 1992; Ludington and others, 1993). This assemblage includes map units Tr_2, Tt_2, *Tgr*, and *TJgr* (in the Battle Mountain area only) on the geologic map of Nevada (Stewart on Carlson, 1978) (fig. 9). These rocks are most abundant in the Black Rock Range with scattered localities in the Pine Forest Range and Montana Mountains in the north part of the area and in the West Humboldt Range, northern Stillwater Range, southern Tobin Range, and Battle Mountain in the south part of the WSRAA (figs. 2, 9). Regionally, rocks of the interior andesite-rhyolite assemblage are most voluminous in a NW-SE-striking belt extending southeastward from the southeast margin of the WSRAA (Stewart and Carlson, 1976; Stewart and others, 1977b).

Volcanic Rocks

Volcanic rocks of the interior andesite-rhyolite assemblage in the WSRAA range in age from approximately 34 to 20 Ma and consist of calc-alkalic silicic ash-flow tuffs and subordinate rhyolite, dacite, and andesite lava flows (Noble, 1972; Stewart, 1980; Best and others, 1989; Ludington and others, 1993). In the WSRAA, this assemblage includes the early Oligocene Caetano Tuff and the late Oligocene Fish Creek Mountains Tuff (McKee, 1970) exposed in the southern Tobin Range (Johnson, 1977) and the Oligocene or Miocene Bates Mountain Tuff (McKee, 1968) the extent of which has recently been expanded to include the west and north sides of Battle Mountain (Doebrich and Theodore, 1996). In the Washoe, Storey and Churchill county areas to the south and west of the WSRAA, this assemblage includes the abandoned Miocene Hartford Hill Rhyolite (Bingler, 1978), which has been divided into the tuff of Whiskey Springs, the tuff of Coyote Spring, the Nine Hill Tuff, the tuff of Chimney Spring and other tuff units with names of local derivation (e.g. John, 1995) (McKee and Stewart, 1971; Bingler, 1978; Deino, 1985; 1989; Best and others, 1989; Garside and Bonham, 1992).

Volcanic rocks of the interior andesite-rhyolite assemblage were erupted along a continental arc considerably inboard of the continental margin as it existed during the late Eocene to early Miocene. Various hypotheses have been put forth to explain the evolution of the time-space pattern of volcanism, most of which deal with the geometry of the subducting slab and (or) the rate of convergence of the North American and Farallon plates (Lipman and others, 1971; Noble, 1972; Snyder and others, 1976; Coney, 1987; Christiansen and others, 1992).

Volcanic rocks of the interior andesite-rhyolite assemblage do not host any significant mineral deposits in the WSRAA, though volcanogenic uranium occurrences are found locally in basal non-welded ash-flow tuffs. In the Pyramid Mining District in the Pah Rah Range, however, outside the southwest border of the WSRAA (fig. 2), rocks of this assemblage host Cu-Ag-Au-bearing quartz-alunite-enargite veins, presumably related to an Oligocene to early Miocene porphyry copper system (Wallace, 1975). In the Olinghouse Mining District, also in the Pah Rah Range, gold-bearing dacite porphyry dikes intrude rocks of the interior andesite-rhyolite assemblage and thus are considerably younger than the volcanic host rocks of the assemblage (Garside and Bonham, 1992).

Plutonic Rocks

Plutonism during the Cenozoic was most prevalent during late Eocene to early Miocene time (fig. 8). Late Eocene to early Miocene plutonic rocks in the WSRAA include several stocks in the Battle Mountain Mining District, the Kennedy stock in the southern East Range, and the Majuba Hill stock at Majuba Mountain on the east side of the Antelope Range (figs. 2, 9).

In the Battle Mountain Mining District, several late Eocene to early Oligocene granodiorite porphyry intrusions were emplaced into Paleozoic rocks (Theodore and others, 1973). Intrusive centers in the Copper Canyon, Upper Paiute Canyon, and Buffalo Valley areas developed porphyry copper and molybdenum-copper systems and related copper skarn, gold-silver skarn, and distal disseminated silver-gold deposits (Theodore and Blake, 1975, 1978; Doebrich and others, 1995; Doebrich and Theodore, 1996; Ivosevic and Theodore, 1996; Theodore, 1996).

The Kennedy stock is a 30-Ma east-west elongated composite intrusion on the north flank of Granite Mountain in the southern East Range (Silberman and McKee, 1971; Wallace, 1977).

It is composed of a border phase of gabbro that grades inward into diorite, quartz monzonite, and finally granite in the center of the stock (Thurber, 1982). It intrudes volcanic rocks and coeval leucogranite of the Triassic Koipato group and late Paleozoic rocks of the Havallah sequence. A porphyry copper-molybdenum system developed in association with emplacement of the stock (Thurber, 1982; Juhas, 1982).

The Majuba Hill stock consists of a 24- to 25-Ma subvolcanic intrusive complex emplaced into Triassic argillites of the Fencemaker allochthon (MacKenzie and Bookstrom, 1976; Silberman and Dockter, 1977). The complex consists of several intrusive phases including rhyolite and latite porphyries and intrusive breccias (Trites and Thurston, 1958; MacKenzie and Bookstrom, 1976). Porphyry molybdenum-copper-tin mineralization was related to the evolution of the intrusive complex.

Outside the southwest border of the WSRAA in the Pah Rah Range, the 24.0$\pm$0.7 Ma (recalculated; Wallace, 1975) Guanomi quartz monzonite intrudes nearly coeval volcanic rocks of the interior andesite-rhyolite assemblage. A porphyry copper-molybdenum system developed in association with emplacement of this stock (Wallace, 1975; Satkoski and Berg, 1982).

Volcanic Troughs and Calderas

During the Oligocene and early Miocene, many volcanic troughs and calderas developed in association with the eruption of volcanic rocks of the interior andesite-rhyolite assemblage and were filled with rocks of this assemblage. The troughs and calderas are present throughout the northwest-striking belt of late Eocene to early Miocene volcanism in central and southern Nevada (Stewart and Carlson, 1976). Two large east-west elongated volcanic troughs formed at the northwest end of this belt of volcanism.

The northern of the two volcanic troughs extends into the southeast part of the WSRAA, in the southern parts of the Tobin and East Ranges (figs. 2, 9) (Burke and McKee, 1979; Wallace, 1978). The Fish Creek caldera in the Fish Creek Mountains (McKee, 1970) is a major volcanic center within this trough, and the east-west elongated Kennedy stock is postulated to represent the west end of the trough (Wallace, 1978).

The southern of the two volcanic troughs is located south of the WSRAA and extends from the Shoshone Mountains on the east to the southern Stillwater Range on west (Stewart and Carlson, 1976; Burke and McKee, 1979). The 23- to 29-Ma Stillwater caldera complex in the southern Stillwater Range (John, 1995) is a major volcanic center that coincides with the west end of this trough.

Early and Middle Miocene Magmatism and Tectonics

Western Andesite Assemblage

Early and middle Miocene andesitic and dacitic volcanic rocks in the WSRAA are assigned to the western andesite assemblage (fig. 8) (Cox and others, 1991; Christiansen and others, 1992; Ludington and others, 1993). This rock assemblage includes map units Ta_2 and *Tob* on the geologic map of Nevada (Stewart and Carlson, 1978) (fig. 9). These rocks are found primarily in the west part of the WSRAA, including the Granite Range, Calico Mountains, and Hays Canyon Range, and also at scattered localities in the Black Rock, Pine Forest and southern Tobin Ranges (figs. 2, 9).

Rocks of the western andesite assemblage range in age from approximately 20 to 12 Ma and consist of thick sequences of andesite and dacite flows and volcanic breccia. In and near the WSRAA this assemblage includes rocks of the Alta and Kate Peak Formations (Gianella, 1936; Bonham, 1969). Rocks of the assemblage are correlated with the Miocene Cascade magmatic arc and believed to represent coalescing stratovolcanoes that existed along the southern extent of the arc (Cox and others, 1991; Christiansen and others, 1992). The magmatic arc is believed to have formed along the North American continental margin above a steeply dipping subduction zone (Coney, 1987).

Rocks of the western andesite assemblage are host to very few mineral occurrences in the WSRAA. The Leadville Mining District in the Calico Mountains (fig. 2) contains polymetallic vein deposits that are hosted in rocks of the western andesite assemblage and are overlain by approximately 15-Ma rhyolitic volcanic and sedimentary rocks.

Middle Miocene to Holocene Magmatism and Tectonics

Bimodal Basalt-Rhyolite Assemblage

Middle Miocene to Pleistocene basaltic and rhyolitic volcanic rocks and lacustrine tuffaceous sedimentary rocks in the WSRAA are assigned to the bimodal basalt-rhyolite assemblage (fig. 8) (Cox and others, 1991; Christiansen and others, 1992; Ludington and others, 1993). Volcanic and shallow intrusive rocks of the assemblage include map units *Tb, Tba,* Ta_3, Tr_3, *QTb, QTa,* and *Qtr* on the geologic map of Nevada (Stewart and Carlson, 1978) and map units *Tv* and *Qv* on the geologic map of California (Jennings, 1977) (fig. 10). Volcaniclastic and tuffaceous sedimentary rocks of the assemblage include map units Tt_3, *Tts*, and Ts_3 on the geologic map of Nevada (Stewart and Carlson, 1978) (fig. 10). Rocks of this assemblage are, by far, the most voluminous of the three Cenozoic volcano-sedimentary assemblages present in the WSRAA and are most abundant in the northern and western parts of the WSRAA (fig. 10). Exposures of these rocks in the northeast part of the WSRAA, in the Bilk Creek Mountains, the Montana Mountains, and the northern Santa Rosa Range, constitute the southern part of the Owyhee plateau and (or) the southern extent of the Snake River plain (fig. 2). Exposures of rocks of the bimodal basalt-rhyolite assemblage in the northwest part of the WSRAA, northwest of the Black Rock Desert, constitutes the southeastern extent of the Modoc plateau (fig. 2).

Volcanic rocks of the bimodal basalt-rhyolite assemblage range in age from approximately 17 to 1 Ma, though most are middle Miocene in age. These rocks are coeval with rocks of the Steens Mountains basalt and the Columbia River basalt (Noble and others, 1973; McKee and Noble, 1986). The assemblage consists of alkali-olivine and tholeiitic basalt, basaltic andesite, and subalkaline to peralkaline rhyolite. Rhyolitic rocks are present as flows, flow breccias, tuffs, domes, and shallow intrusions. Several calderas formed in response to the eruption of rhyolitic ash-flow tuffs. Basaltic rocks are present as flows, breccias, and laharic units that often form flat to shallow-dipping plateaus and mesa.

Sedimentary rocks of the bimodal basalt-rhyolite assemblage consist of lacustrine and fluvial facies, and include light-colored conglomerate, sandstone, siltstone, mudstone, limestone, and locally abundant diatomite (Van Houten, 1956; Gilbert and Reynolds, 1973; Stewart, 1980). These rocks contain continental fauna and flora as well as generally large amounts of tuffaceous material derived from contemporaneous volcanic deposits. Lava flows and ash-flow tuffs locally are interstratified with the sedimentary sequences.

Regional and local nomenclature for rocks of the bimodal basalt-rhyolite assemblage is varied for the WSRAA and vicinity. Some map units contain both volcanic and sedimentary rocks, whereas other units have been named for specific volcanic or sedimentary sequences. Bonham (1969) defines the 16-12 Ma Pyramid sequence as a volcanic and sedimentary rock sequence at the base of the bimodal basalt-rhyolite assemblage in southern Washoe and Storey counties. In northern Washoe county, the middle Miocene Cañon Rhyolite (Bonham, 1969) consists of rhyolite flows and flow dome complexes, and the middle Miocene High Rock sequence (Bonham, 1969) consists of mixed tuffaceous sedimentary rocks and diatomite, as well as, rhyolite and basalt lava flows. In Humboldt county, Willden (1964) uses the nomenclature of Merriam (1907, 1910) to define sedimentary rock sequences in the Virgin Valley and Thousand Creek areas (Virgin Valley beds of Merriam, 1907; Thousand Creek beds of Merriam, 1910) and a basalt unit in the Charles Sheldon Antelope Range (Mesa basalt of Merriam, 1910).

The bimodal compositional nature of volcanic rocks of this assemblage is a function of the extensional tectonic regime that has prevailed in the region since middle Miocene time (Christiansen and Lipman, 1972; Noble, 1972, 1988). During extension and resultant block faulting, basaltic magmas from deep sources were tapped, rhyolitic magmas were produced from partial melting of crustal rocks, and sedimentary basins, which formed as grabens, collected tuffaceous lacustrine and fluvial deposits. Many basins that formed during middle and late Miocene block faulting appear to have been precursors of modern-day basins, though some were quite different (Stewart, 1980). The present orientation of basins began to develop sometime after 9 Ma, at which time extension direction changed from a WSW-ENE direction to a WNW-ESE direction (Zoback and others, 1981). The northwest part of the Great Basin, including the WSRAA, has not been documented to have experienced periods of significant or extreme extension as other area of the Great Basin have (Seedorff, 1991). In the Fireball Ridge area on the east side of the Truckee Range, however, 25-Ma tuffs have nearly vertical dips, probably reflecting large magnitude extension, at least on a local scale (D.A. John, written commun., 1995). The lack of documented significant or extreme extension in the WSRAA may be due to the lack of exposure of appropriate age rocks that would document such events.

The onset of regional extension in the middle Miocene was accompanied by a change in the type of mineral deposits that developed. The preceding late Eocene to early Miocene and early and middle Miocene magmatic-tectonic episodes produced porphyry copper-molybdenum and related deposits, and subvolcanic quartz-adularia-type (Comstock-type) deposits. The middle Miocene to Holocene episode of extension and bimodal volcanism produced many higher-level hot-spring and sub-hot-spring type deposits and volcanogenic uranium deposits (fig. 8) (Noble and others, 1988; Cox and others, 1991). Most of these deposits are hosted in volcanic and sedimentary rocks of the bimodal basalt-rhyolite assemblage, although some, for example the Florida Canyon hot-spring gold-silver deposit (Hastings and others, 1988), are hosted in older Tertiary or pre-Tertiary rocks. Hot-spring type deposits generally are gold-silver or mercury producers. Important hot-spring gold-silver deposits in the WSRAA include the Crofoot/Lewis deposit in the Sulphur Mining District (Ebert and others, 1996), the Hog Ranch deposit north of the Granite Range (Bussey, 1996), the Wind Mountain deposit on the west side of the northern Lake Range (Wood, 1991), the Florida Canyon deposit in the northern Humboldt Range (Hastings and others, 1988), and the Sleeper deposit on the northwest flank of the Slumbering Hills (Nash and others, 1991) (fig. 2). The most significant hot-spring mercury deposits in the WSRAA are found in the Disaster and Opalite Mining Districts surrounding the McDermitt caldera complex in the Montana Mountains (figs. 2, 10). Significant volcanogenic uranium deposits are hosted by sedimentary and volcanic rocks of the bimodal basalt-rhyolite assemblage that form the moat sequence of the McDermitt caldera complex (Rytuba and Glanzman, 1979).

Several types of non-metallic mineral resources developed in association with rocks of the bimodal basalt-rhyolite assemblage. These include diatomite deposits in lacustrine sedimentary rock sequences (Nash, 1995), perlite in hydrated obsidian units, sulfur at hydrothermal hot-spring deposits (for example, Sulphur Mining District), precious opal in hydrothermally altered sedimentary and volcanic rocks (for example, Virgin Valley) and pumice associated with young volcanic units.

Neogene extension, block faulting, and anomalously high regional geothermal gradients all developed together beginning in about the early to middle Miocene. In addition to generating the volcanism, sedimentary basins, and mineral resources mentioned above, these processes also were responsible for generating geothermal resources and petroleum resources (fig. 8). Geothermal resources are currently being exploited in and around the WSRAA and are a direct result of deep circulating meteoric waters, convected by a high regional geothermal gradient, and subsequently channeled by basin-and-range normal faults. Petroleum generation during the Neogene has been the result of burial of pre-Tertiary source rocks by block faulting and infilling of grabens. Lacustrine sedimentary rocks of the bimodal basalt-rhyolite assemblage may also be good fossil-fuel reservoir rocks (fig. 8; see also Doebrich and others, 1994).

Volcanic Centers

Several known and inferred volcanic centers in the WSRAA were developed during the middle Miocene in association with the eruption and deposition of rocks of the bimodal basalt-rhyolite assemblage. These include the McDermitt caldera complex, the Ragged Top caldera, the Cottonwood Creek volcanic center, the Badger Mountain caldera, and the Goosey Lake depression (fig. 10). With the exception of the Ragged Top caldera (Heggeness, 1982), the existence of which has been questioned (G.V. Albino, oral commun., 1993), all middle Miocene volcanic centers in the WSRAA are located near the margins of the Modoc and Owyhee plateaus (figs. 2, 10). Rytuba (1989) suggests that the boundary between the Modoc and Owyhee plateaus and the Paleozoic and Mesozoic terranes to the east and south, respectively, correspond to major fault zones that have displaced the Paleozoic and Mesozoic terranes as much as 1 km downward. The northeast-striking Black Rock Structural Boundary bounds the southeast margin of the Modoc plateau and the northwest-striking Orevada Rift bounds the southwest margin of the Owyhee plateau. Caldera complexes are aligned parallel to these major structures in each of the volcanic plateaus (Rytuba, 1989).

The McDermitt caldera complex (McKee, 1976; Rytuba and McKee, 1984) and the Goosey Lake depression (Vikre, 1985a, b) are located on the Owyhee plateau (figs. 2, 10). The 45-km-wide McDermitt caldera complex consists of four nested calderas in the Montana Mountains along the Nevada-Oregon border. Large volumes of peralkaline rhyolitic ash-flow tuffs were erupted from the complex, and rhyolite ring domes were emplaced along the western margin of the complex. The caldera complex contains significant hot-spring mercury deposits in moat-filling tuffaceous sedimentary rocks, volcanogenic uranium deposits associated with rhyolite ring domes and shallow intrusive bodies, and lithium occurrences in moat-filling tuffaceous sedimentary rocks (Rytuba and Glanzman, 1979). The Goosey Lake depression is a shallow, 24 by 32 km, volcanic basin located southeast of McDermitt and north of Paradise Valley. The northwest rim of the Goosey Lake depression coincides with intrusions and eruptive centers in the National Mining District where hot-spring and sub-hot-spring gold-silver type mineral deposits are present (Vikre, 1985a).

The Cottonwood Creek volcanic center and the inferred Badger Mountain caldera are located on the Modoc plateau (figs. 2, 10). The Cottonwood Creek volcanic center lies north of the Granite Range and is defined by a shallow basin rimmed by middle Miocene peralkaline rhyolite and filled with middle Miocene tuffaceous lacustrine sedimentary rocks (Harvey and others, 1986). The Hog Ranch hot-spring gold-silver deposit is on the southeast margin of the Cottonwood Creek volcanic center (Bussey, 1996). The Badger Mountain caldera is north of the Calico Mountains in the Charles Sheldon Antelope Refuge. Its existence is inferred on the basis of coinciding gravity and aeromagnetic anomalies (Greene and Plouff, 1981). Other possible concealed calderas are inferred by additional gravity and aeromagnetic anomalies south and northeast of the Badger Mountain caldera (fig. 10) (Greene and Plouff, 1981). Southeast of the Badger Mountain caldera, eruptive centers for middle Miocene peralkaline rhyolite ash-flow tuffs and lava flows define north-striking linear vents that parallel range front structures, implying control by basin-and-range extension (Korringa, 1973).

Northern Nevada Rift

The northern Nevada rift, originally defined as the Oregon-Nevada lineament (Stewart and others, 1975), is a N. 20° W. -striking regional structure that transects the northeast corner of the WSRAA, northeast of the Osgood Mountains, Hot Springs Range, and Santa Rosa Range (figs. 2, 10). The rift is defined by basalt dike swarms, graben-filling volcanic rocks, and a prominent positive regional aeromagnetic anomaly that suggests the rift is a much as 500 km long, extending from the Oregon-Nevada border to central Nevada (Robinson, 1970; Blakely and Jachens, 1991; Zoback and others, 1994).

The age of dikes and graben-filling volcanic rocks range from 17 to 12 Ma, indicating that the formation of the rift was coeval with the inception of basin-and-range extension in northern Nevada (fig. 8). Basaltic dikes of the northern Nevada rift are also equivalent in age, orientation, and composition to feeder dikes that fed the main eruptive pulse of the Columbia River flood basalts in northeast Oregon and southeast Washington (Zoback and Thompson, 1978; Zoback and others, 1994). Because of these similarities, Zoback and others (1994) propose that both regions are part of a major lithospheric rift that propogated south-southeast and north-northwest from a central mantle plume. The site of initial breaching of the North American plate by this mantle plume may have been the McDermitt Caldera complex (Parsons and others, 1994; Zoback and others, 1994).

Midas Trough

At about 9 Ma, the extension direction in northern Nevada changed to NNW-SSE and resulted in the formation of the Midas trough and related ENE-striking normal faults and grabens (Zoback and Thompson, 1978; Wallace, 1991) (fig. 8). The Midas trough is located on the east-central margin of the WSRAA, east of the Osgood Mountains (figs. 2, 10). Here, ENE-striking normal faults and grabens cut NNW-striking faults and basalt dikes of the northern Nevada rift. The ENE-striking normal faults are most widespread throughout a 240-km-wide segment of the northern Nevada rift that extends from the Midas trough on the north to the Cortez fault (northwest flank of Cortez Mountains) on the south (Zoback and others, 1994). This zone appears to extend southwest through the southeast part of the WSRAA, where young ENE-striking normal faults are present, and may have influenced the orientation of some of basins and ranges in this area.

The late Miocene ENE-striking normal faults are post-mineral in most mining districts and have affected the exposure of earlier mineral deposits and mineral systems (Wallace, 1991; Doebrich and Theodore, 1996). The Florida Canyon hot-spring gold-silver deposit in the northern Humboldt Range, however, is postulated to have formed at or near the intersection of a ENE-striking fault and a north-striking range-front normal fault zone (Hastings and others, 1988).

Quaternary Normal Faults

Quaternary normal faults bound most of the major basins and ranges in the WSRAA. Present-day extension directions are approximately east-west along the east and west margins of the Great Basin, and northwest to N. 60° W in the interior of the Great Basin (Zoback, 1989). This is reflected in the generally more northeast orientations of ranges in the east part of the WSRAA. Quaternary displacement on many of these faults is exhibited by fault scarps in Quaternary alluvial sediments in the basins. Many Quaternary-age range-bounding normal faults may be reactivated older Tertiary faults (for example see Doebrich, 1995; Doebrich and Theodore, 1996). Some of these faults are conduits for geothermal fluids and have previously been conduits for hydrothermal fluids at hot-spring-type mineral deposits (e.g. Sulphur Mining District, Florida Canyon deposits, Dixie-Comstock Mine).

Pleistocene Pluvial Deposits

Pleistocene Lake Lahontan was a large inland lake that filled most of the large basins in the WSRAA. The valleys between the Selenite Range and the Trinity Range in the south part of the WSRAA, and Grass Valley, Buffalo Valley, and Pumpernickel Valley, all in the east part of the WSRAA (figs. 2, 11) were the only basins that did not floor Lake Lahontan (Russell, 1885; Snyder and others, 1964). The most significant natural water-filled remnants of Pleistocene Lake Lahontan are Pyramid Lake and Walker Lake. Pleistocene lakes also filled Long Valley and Surprise Valley in the northwest corner of the WSRAA (figs. 2, 11) (Snyder and others, 1964).

Beach terraces of Lake Lahontan are visible on many of the ranges in the WSRAA, and the highest stand of the lake was at 4,380-ft (1,348-m) elevation. Playa deposits in the Black Rock Desert, Desert Valley, Winnemucca Lake, and the Carson Sink (figs. 2, 11), represent little modified bottom sediments of Lake Lahontan. Because the lake had no outlet, it collected all material supplied by streams and springs. Material in suspension was deposited as lacustrine deposits including conglomerate, sandstone, siltstone, mudstone, and limestone. Material in solution formed calcareous tufa when the lake evaporated (Russell, 1885; Cartwright, 1961). Sand and gravel beach and bar deposits formed along the shores of Lake Lahontan. In areas where the shoreline coincided with major channels of material influx, rounded fluvial sand and gravel deposits were sorted, and finer materials were winnowed out to produce high-quality sand and gravel deposits that locally are exploited commercially (J. C. Yount, oral commun., 1995).

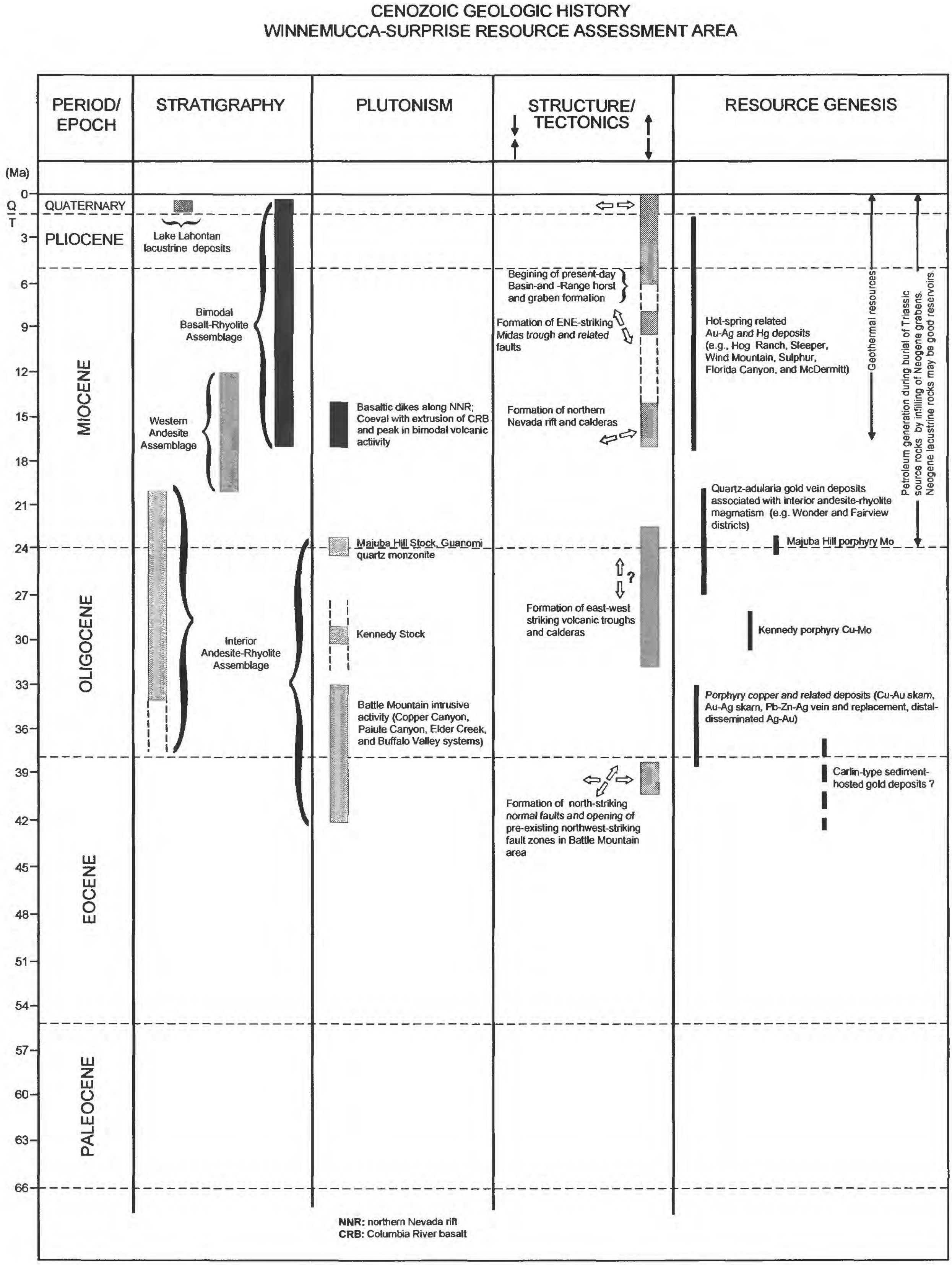

Figure 8. Chart summarizing Cenozoic geologic history of the Winnemucca-Surprise Resource Assessment Area, illustrating temporal relations between deposition of strata, plutonism, tectonic events, and resource genesis. Shaded columns indicate where ages are relatively well constrained; dashed lines indicate uncertainty. Arrows at top of structure/tectonics columns indicate compressive and extensional events; additional arrows in column indicate direction of extension through time.

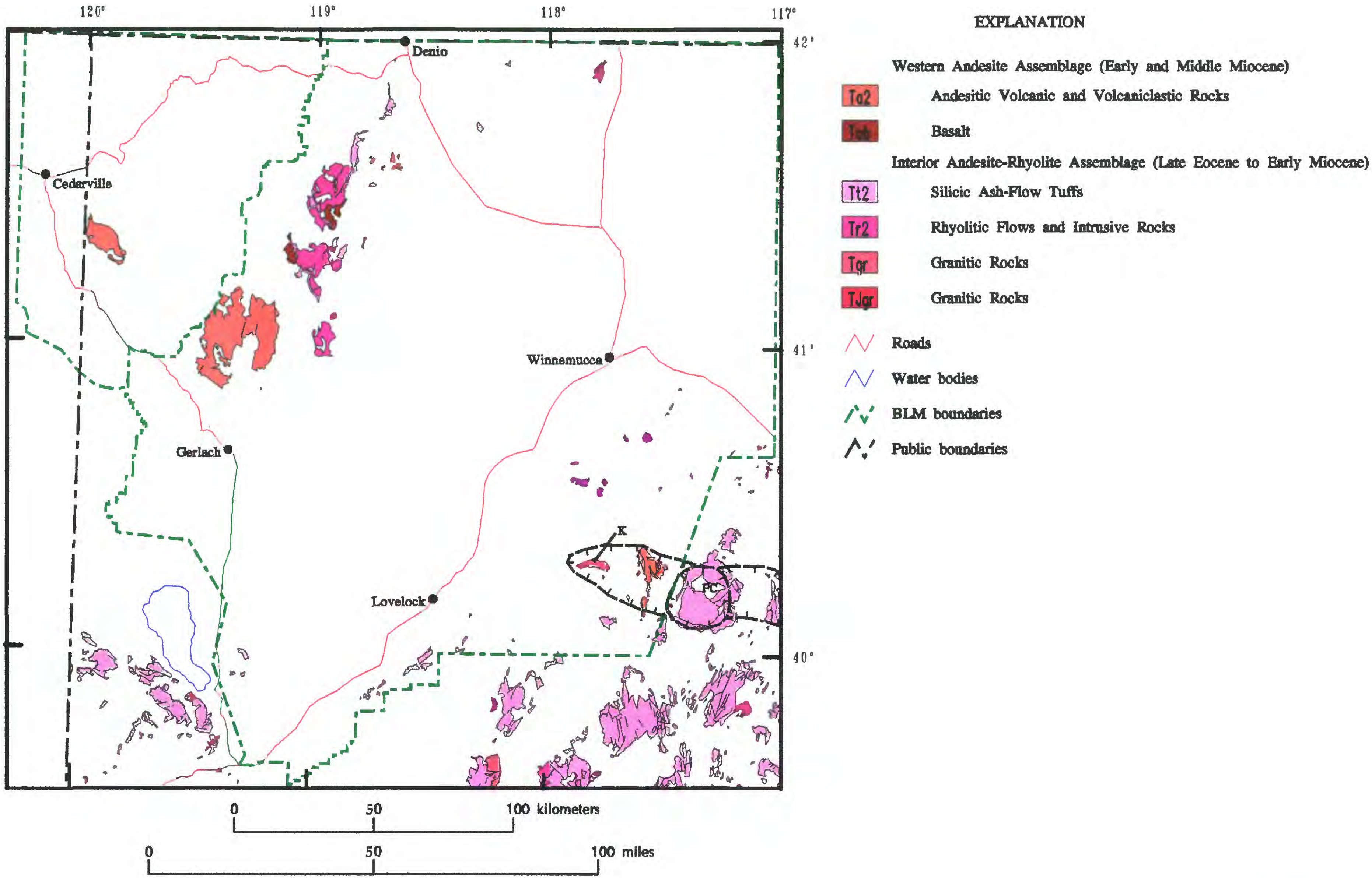

Figure 9. Distribution of rocks of the late Eocene to early Miocene interior andesite-rhyolite assemblage and rocks of the early and middle Miocene western andesite assemblage (Cox and others, 1991; Christiansen and others, 1992; Ludington and others, 1993) in the Winnemucca-Surprise Resource Assessment Area. Map unit labels are the same as used on the geologic map of Nevada (Stewart and Carlson ,1978), from which the geology was modified. See figure 2 for additional location information. Hatchured line is extent of proposed volcanic trough, modified from Stewart and Carlson (1976). **K**, Kennedy stock; **FC**, Fish Creek caldera.

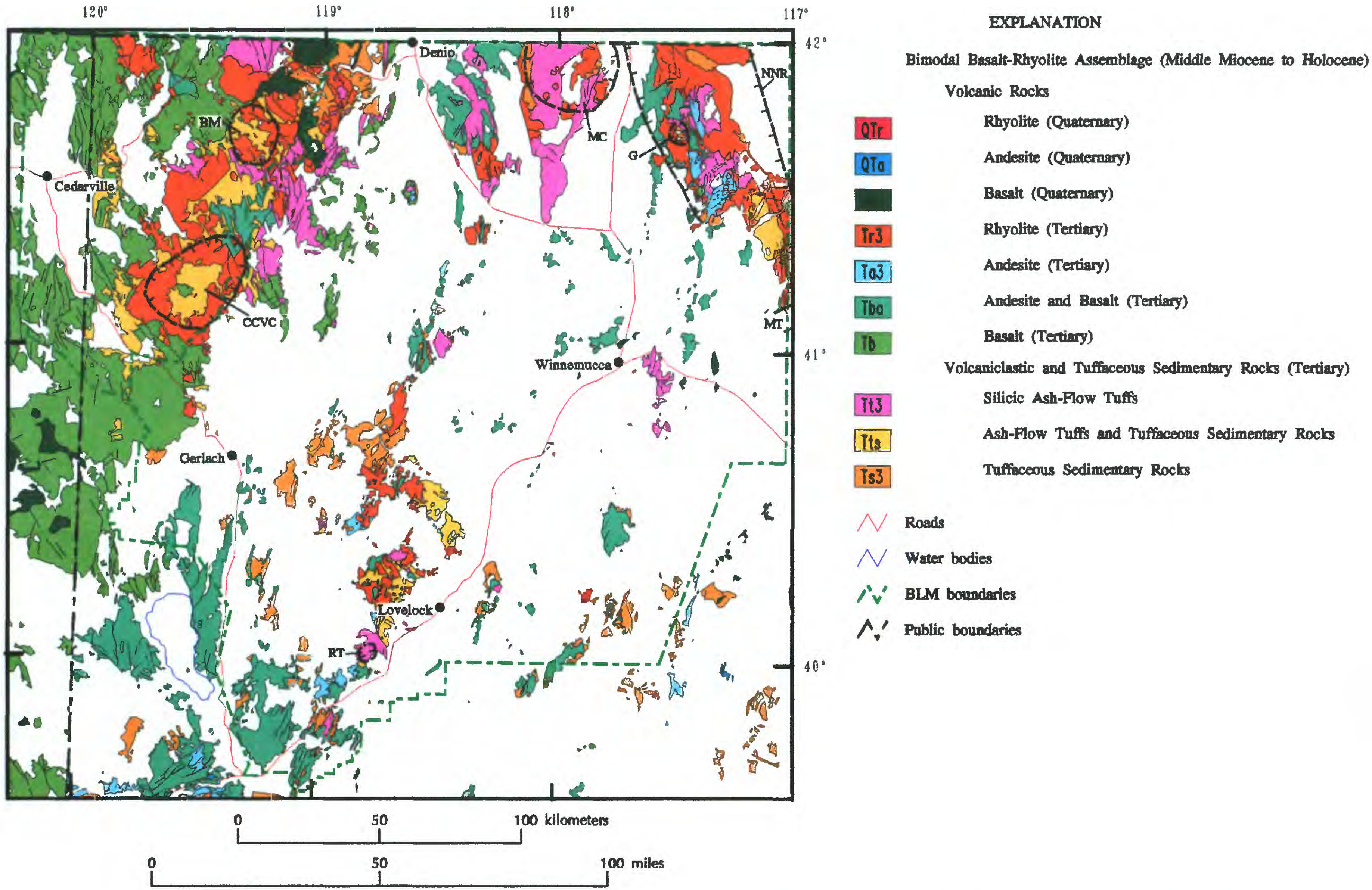

Figure 10. Distribution of rocks of the middle Miocene to Holocene bimodal basalt-rhyolite assemblage (Cox and others, 1991; Christiansen and others, 1992; Ludington and others, 1993) in the Winnemucca-Surprise Resource Assessment Area. Map unit labels are the same as used on the geologic map of Nevada (Stewart and Carlson ,1978), from which the geology was modified. Map units *Tb* and *QTb* have been equated with map units *Tv* and *Qv*, respectively, on the geologic map of California (Jennings, 1977). See figure 2 for additional location information. **CCVC**, Cottonwood Creek volcanic center; **BM**, Badger Mountain caldera; **MC**, McDermitt caldera complex; **G**, Goosey Lake depression; **NNR**, northern Nevada rift; **MT**, Midas trough.

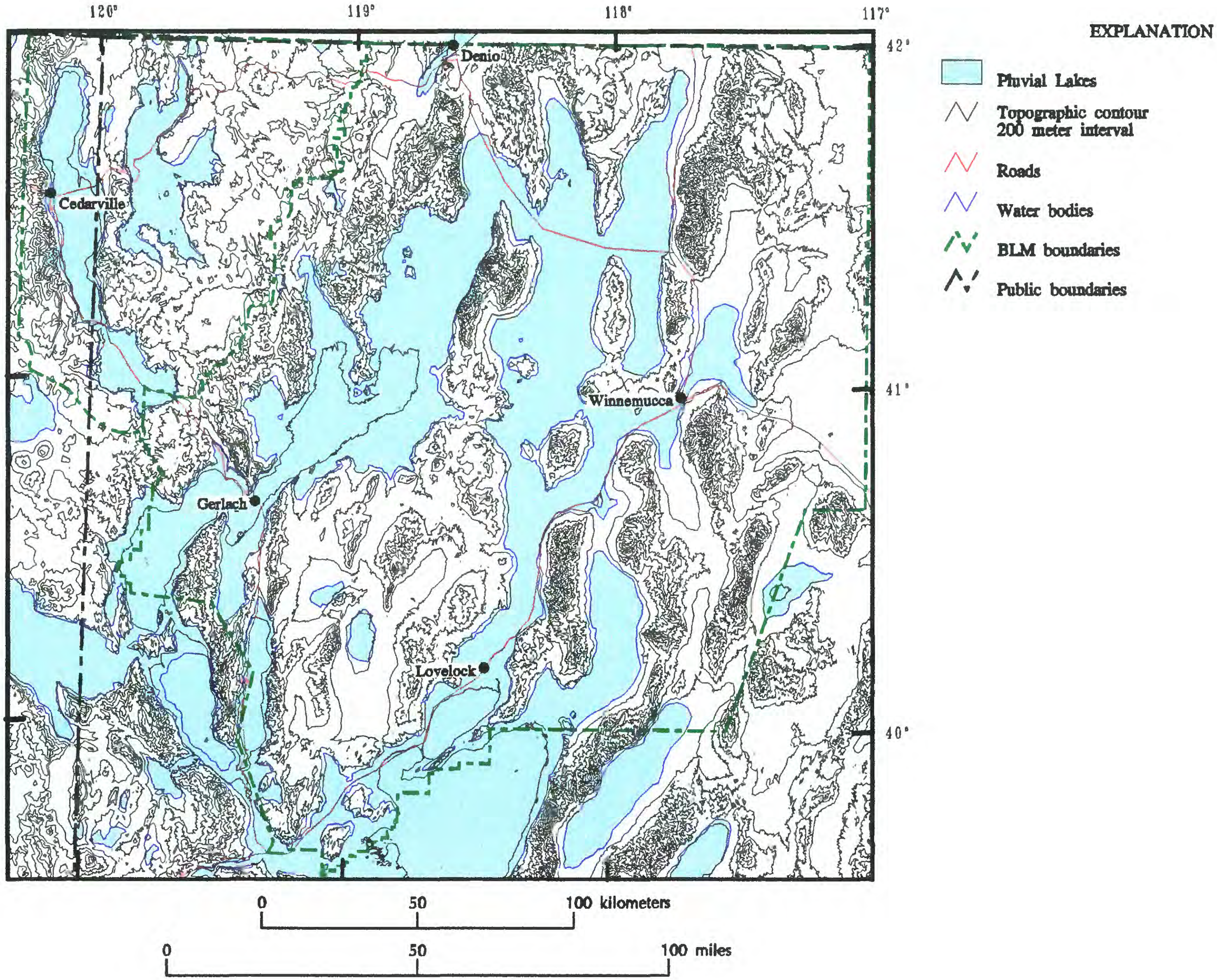

Figure 11. Map showing the maximum extent of Pleistocene Lake Lahontan and other Pleistocene lakes in the Winnemucca-Surprise Resource Assessment Area (modified from Snyder and others, 1964).

References Cited

Arehart, G.B., Foland, K.A., Naeser, C.W., and Kesler, S.E., 1993, 40Ar/39Ar, K/Ar, and fission track geochronology of sediment-hosted disseminated gold deposits at post-Betze, Carlin Trend, northeastern Nevada: Economic Geology, v. 88, no. 3, p. 622-646.

Armstrong, R.L., Ekren, E.B., McKee, E.H., and Noble, D.C., 1969, Space-time relations of Cenozoic silicic volcanism in the Great Basin of the western United States: American Journal of Science, V. 267, p. 478-490.

Berger, B.R., 1985, Geological and geochemical relationships at the Getchell mine and vicinity, Humboldt County, Nevada, *in* Hollister, V.F.M, ed., Case Histories of Mineral Discoveries, Volume I, discoveries of Epithermal Precious Metal Deposits: Society of Mining Engineers of the American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., New York, New York, p. 51-60.

Best, M.G., Christiansen, E.H., Deino, A.L., Grommé, C.S., McKee, E.H., and Noble, D.C., 1989, Excursion 3A: Eocene through Miocene volcanism in the Great Basin of the western United States: New Mexico Bureau of Mines and Mineral Resources Memoir 47, p. 91-33.

Bingler, E.C., 1978, Abandonment of the name Hartford Hill Rhyolite Tuff and adaption of new formation names for middle Tertiary ash-flow tuffs in the Carson City-Silver City area, Nevada: U.S. Geological Survey Bulletin 1457-D, 19 p.

Blakely, R.J., and Jachens, R.C., 1991, Regional study of mineral resources in Nevada: Insights from three-dimensional analysis of gravity and magnetic anomalies: Geological Society of America bulletin, v. 103, p. 795-803.

Bloomstein, E.I., and Clark, J.B., 1990, Geochemistry of the Ordovician high-calcium black shales hosting major gold deposits of the Getchell Trend in Nevada, *in* Grauch, R.I., and Huyck, H.L.O., eds., Metalliferous black shales and related ore deposits, proceedings, International Geological Correlation Program Project 254, U.S. Geological Survey Circular 1058, p. 1-5.

Bloomstein, E.I., Massingill, G.L., Parrat, R.L., and Peltonen, D.R., 1991, Discovery, geology, and mineralization of the Rabbit Creek gold deposit, Humboldt County, Nevada, *in* Raines, G.L., Lisle, R.W., Schafer, R.W., and Wilkinson, W.H., eds., Geology and Ore Deposits of the Great Basin, Symposium Proceedings: Reno, Geological Society of Nevada, v. 2, p. 821-843.

Bonham, H.F., 1969, Geology and mineral deposits of Washoe and Storey Counties, Nevada, with a section on Industrial rock and mineral deposits by K.G. Papke: Nevada Bureau of Mines and Geology Bulletin 70, 107 p., 2 maps, scale 1:250,000.

Brueckner, H.K., and Snyder, W.S., 1985, Structure of the Havallah sequence, Golconda allochthon, Nevada: Evidence for prolonged evolution in an accretionary prism: Geological Society of America Bulletin, v. 96, p. 1113-1130.

Burke, D.B., and McKee, E.H., 1979, Mid-Cenozoic volcano-tectonic troughs in central Nevada: Geological -Society of America Bulletin, v. 90, no. 2, p. 181-184.

Burke, D.B., and Silberling, N.J., 1973, The Auld Lang Syne Group of Late Triassic and Jurassic (?) age, north-central Nevada: U.S. Geological Survey Bulletin B-1394-E, p. E1-E14.

Bussey, S.D., 1996, Gold mineralization and associated rhyolitic volcanism at the Hog Ranch mine, northwest Nevada, *in* Coyner, A.R., and Fahey, P.L., eds., Geology and Ore Deposits of the American Cordillera: Geological Society of Nevada Symposium, Reno/Sparks, Nevada, April, 1995, Proceedings, in press.

Cartwright, K., 1961, A study of the Lake Lahontan sediments in the Winnemucca area, Nevada: Reno, Nevada, University of Nevada, M.Sc. thesis, 52 p.

Christiansen, R.L., and Lipman, P.W., 1972, Cenozoic volcanism and plate tectonic evolution of the Western United States - II, Late Cenozoic: Royal Society of London Philosophical Transactions, v. 271, p. 249-284.

Christiansen, R.L., Yeats, R.S., Graham, S.A., Niem, W.A., Niem, A.R., Snavely, P.D., Jr., 1992, Post-Laramide geology of the U.S. Cordilleran region, *in*, Burchfield, B.C., Lipman, P.W., and Zoback, M.L., eds., The Cordilleran Orogen, conterminous U.S., Geological Society of Nevada, The Geology of North America, v. G-3, p. 261-406.

Coeur D'Alene Mines, 1993, Coeur Rochester, *in* Struhsacker, E. ed., Gold and Silver Deposits of Western Nevada, Geological Society of Nevada Special Publication #18.

Compton, R.R., 1960, Contact Metamorphism in Santa Rosa Range, Nevada: Geological Society America Bulletin, vol. 71, pp. 1383-1416.

Coney, P.J., 1987, The regional tectonic setting and possible causes of Cenozoic extension in the North American Cordillera, *in* Coward, M.P., Dewey, J.F., and Hancock, P.L., eds., Continental extensional tectonics: Geological Society of London Special Publications 28, p. 177-186.

Cookro, T.M., and Theodore, T.G., 1989, Geology and geochemistry in the vicinity of the Adelaide Crown Mine, Humboldt County, Nevada, *in* Schindler, K.S., ed., USGS Research on Mineral Resources--1989, Program and Abstracts, U.S. Geological Survey Circular C-1035, p. 10

Cox, D.P., Ludington, S., Sherlock, M.G., Singer, D.A., Berger, B.R., and Tingley, J.V., 1991, Mineralization patterns in time and space in the Great Basin of Nevada: Geology and Ore Deposits of the Great Basin Symposium Proceedings, Reno, Nev., Geological Society of Nevada, p. 193-198.

Deino, A.L., 1985, I--Stratigraphy, chemistry, K-Ar dating, and paleomagnetism of the Nine Hill Tuff, California-Nevada, II-- Miocene/Oligocene ash-flow tuffs of Seven Lakes Mountain, California-Nevada, III--Improved calibration methods and error estimates for ^{40}K-^{40}Ar dating of young rocks: Berkeley, California, University of California, Ph.D. dissertation, 498 p.

Deino, A.L., 1989, Single crystal $^{40}Ar/^{39}Ar$ dating as an aide in correlation of ash flows: Examples from the Chimney Spring/New Pass Tuffs and the Nine Hill/Bates Mountain Tuffs of California and Nevada [abs.]: New Mexico Bureau of Mines and Mineral Resources Bulletin 131, p. 70.

Doebrich, J.L., 1994, Preliminary geologic map of the Galena Canyon quadrangle, Lander County, Nevada: U.S. Geological Survey Open-File Report 94-664, scale 1:24,000.

Doebrich, J.L., 1995, Geology and mineral deposits of the Antler Peak 7.5-minute quadrangle, Lander County, Nevada: Nevada Bureau of Mines and Geology Bulletin 109, 44 p., 2 plates, scale 1:24,000.

Doebrich, J.L., Albino, G.V., Barker, C.E., Duffield, W.A., Dunn, V.C., Hanna, W.F., McFarlan, J.P., McGuire, D.J., Miller, M.S., Peters, S.G., Plouff, D., Raines, G.L., Sawatzky, D.L., and Spanski, G.T., 1994, Resource assessment of the Bureau of Land Management's Winnemucca district and Surprise resource area, northwest Nevada and northeast California - An interim project status report: U.S. Geological Survey open-file report OF-94-712, 101 p.

Doebrich, J.L., and Theodore, T.G., 1996, Geologic history of Battle Mountain mining district, Nevada, and regional controls on the distribution of mineral systems, *in* Coyner, A.R., and Fahey, P.L., eds., Geology and Ore Deposits of the American Cordillera: Geological Society of Nevada Symposium, Reno/Sparks, Nevada, April, 1995, Proceedings, in press.

Doebrich, J.L., Wotruba, P.R., Theodore, T.G., McGibbon, D.H., and Felder, R.P., 1995, Field Guide for geology and ore deposits of the Battle Mountain Mining District, Humboldt and Lander Counties, Nevada, Field

Trip H: Geology and Ore Deposits of the American Cordillera Symposium, Geological Society of Nevada, April 10-13, 1995, Reno, 92 p.

Ebert, S.W., Groves, D.I., and Jones, J.K., 1996, Geology, alteration, and ore controls of the Crofoot/Lewis mine, Sulphur, Nevada: A well preserved epithermal hot-spring gold-silver deposit, *in* Coyner, A.R., and Fahey, P.L., eds., Geology and Ore Deposits of the American Cordillera: Geological Society of Nevada Symposium, Reno/Sparks, Nevada, April, 1995, Proceedings, in press.

Elison, M.W., and Speed, R.C., 1988, Triassic flysch of the Fencemaker allochthon, East Range, Nevada--Fan facies and provenance: Geological Society of America Bulletin, v. 100, no. 2, p. 185-199.

Emmons, D.L., and Eng, T.L., 1995, Geologic map of the McCoy mining district, Lander County, Nevada: Nevada Bureau of Mines and Geology Map 103, scale 1:12,000.

Erickson, R.L., and Marsh, S.P., 1974a, Paleozoic tectonics in the Edna Mountain Quadrangle, Nevada: Journal of Research, U.S. Geological Survey, v. 2, no. 3, p. 331-337.

Erickson, R.L., and Marsh, S.P., 1974b, Geologic quadrangle map of the Iron Point quadrangle, Humboldt County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-1175, scale 1:24,000.

Erickson, R.L., and Marsh, S.P., 1974c, Geology of the Golconda quadrangle, Humboldt County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-1174, scale 1:24,000.

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

Evernden, J.F. and Kistler, R.W., 1970, Chronology of emplacement of Mesozoic batholithic complexes in California and western Nevada: U.S. Geological Survey Professional Paper 623, 43 p.

Ferguson, H.G., Muller, S.W., and Roberts, R.J., 1951, Geology of the Winnemucca quadrangle, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-11, scale 1:125,000.

Ferguson, H.G., Roberts, R.J., and Muller, S.W. ,1952, Geology of the Golconda quadrangle, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-15, scale 1;125,000.

Foster, J.M., and Kretschmer, E.L., 1991, Geology of the Mag deposit, Pinson Mine, Humboldt County, Nevada, *in* Raines, G.L., Lisle, R.W., Schafer, R.W., and Wilkinson, W. H., eds., Geology and Ore Deposits of the Great Basin, Symposium Proceedings: Reno, Geological Society of Nevada, v. 2, p. 845-856.

Gabrielse, H., Snyder, W.S., and Stewart, J.H., 1983, Sonoma orogeny and Permian to Triassic tectonism in western North America: Geology, v. 11 p. 484-486.

Gilluly, J., 1967, Geologic Map of the Winnemucca quadrangle, Pershing and Humboldt Counties, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-656, scale 1:62,500.

Garside, L.J., and Bonham, H.F., Jr., 1992, Olinghouse mining district, Washoe County, Nevada, *in* Craig, S.D., ed., Structure, Tectonics and Mineralization of the Walker Lane, Symposium Proceedings, April 24, 1992, Reno, Nevada, Geological Society of Nevada, p. 227-238.

Gianella, V.P., 1936, Geology of the Silver City district and the southern portion of the Comstock Lode, Nevada: Nevada University Bulletin, v. 30, no. 9, p.

Gilbert, C.M., and Reynolds, M.W., 1973, Character and chronology of basin development, western margin of the Basin and Range province: Geological Society of America Bulletin, v. 84, no. 8, p. 2489-2509.

Greene, R.C., and Plouff, Donald, 1981, Location of a caldera source for the Soldier Meadow Tuff, northwestern

Nevada, indicated by gravity and aeromagnetic data: Geological Society of America Bulletin, Part I, vol. 92, p. 4-6 and Part II, vol. 92, p. 39-56.

Harvey, D.S., Noble, D. C., and McKee, E. H., 1986, Hog Ranch gold property, northwestern Nevada: age and genetic relation of hydrothermal mineralization to coeval peralkaline silicic and associated basaltic magmatism: Isochron/West, no. 47, p. 9-11.

Hastings, J.S., Burkart, T.H., and Richardson, R.W., 1988, Geology of the Florida Canyon gold deposit, Pershing County, Nevada, *in* Schafer, R.W., Cooper, J.J., and Vikre, P.G., Bulk mineable precious metal deposits of the western United States, Symposium Proceedings: Reno, Geological Society of Nevada, p. 433-452.

Heck, F.R., 1991, Depositional setting and regional relationships of basinal assemblages, Pershing Ridge Group and Fencemaker Canyon Sequence in northwestern Nevada--Alternative interpretation: Geological Society of America Bulletin, v. 103, no. 6, p. 842-846.

Heggeness, J.O., 1982, The geology of Ragged Top caldera: Reno, Nevada, University of Nevada, M.Sc. thesis, 107 p.

Hotz, P.E., and Willden, R., 1964, Geology and Mineral Deposits of the Osgood Mountains quadrangle, Humboldt County, Nevada: U.S. Geological Survey Professional Paper 431, 128 p.

Ivosevic, S.W., and Theodore, T.G., 1996, Weakly developed porphyry system at upper Paiute Canyon, Battle Mountain mining district, Nevada, *in* Coyner, A.R., and Fahey, P.L., eds., Geology and Ore Deposits of the American Cordillera: Geological Society of Nevada Symposium, Reno/Sparks, Nevada, April, 1995, Proceedings, in press.

Jennings, C.W., 1977, Geologic map of California: California Division of Mines and Geology, Geologic Data Map 2, scale 1:750,000.

John, D.A., 1992, Chemical analyses of granitic rocks in the Reno 1 degrees by 2 degrees Quadrangle and in the northern Pine Nut Mountains, west-central Nevada: U.S. Geological Survey Open-File Report OF-92-246, 35 p.

John, D.A., 1995, Tilted middle Tertiary ash-flow calderas and subjacent granitic plutons, southern Stillwater Range, Nevada: Cross sections of an Oligocene igneous center: Geological Society of America Bulletin, v. 107, no. 2, p. 180-200.

John, D.A., Schweickert, R.A., and Robinson, A.C., 1994, Granitic rocks in the Triassic-Jurassic magmatic arc of western Nevada and eastern California: U.S. Geological Survey Open-File Report 94-148, 61 p.

Johnson, M.G., 1977, Geology and mineral resources of Pershing County, Nevada: Nevada Bureau of Mines and Geology Bulletin 89, 115 p.

Jones, A. E., in press a, Geologic map of the Hot Springs Peak 7.5-minute quadrangle, Humboldt County, Nevada: Nevada Bureau of Mines and Geology Field Studies Map FS-#, scale 1:24,000.

Jones, A. E., in press b, Geologic map of the Delvada Spring 7.5-minute quadrangle, Humboldt County, Nevada: Nevada Bureau of Mines and Geology Field Studies Map FS-#, scale 1:24,000.

Joralemon, Peter, 1951, The Occurrence of Gold at the Getchell Mine, Nevada: Economic Geology, vol. 46, p. 267-310.

Juhas, A.P., 1982, Preliminary geology of the Kennedy porphyry molybdenum copper district, Pershing County, Nevada: Global Tectonics and Metallogeny, vol. 1, no. 4, p. 356-372.

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, p. 251-258.

Ketner, K.B., 1983, Strata-bound, silver-bearing iron, lead and zinc sulfide deposits in Silurian and Ordovician rocks of allochthonous terranes, Nevada and northern Mexico: U.S. Geological Survey Open-File Report 83-792, 6 p.

Ketner, K.B., Ehman, K.D., Repetski, J.E., Stamm, R.G., and Wardlaw, B.R., 1993, Paleozoic stratigraphy and tectonics in northernmost Nevada: Implications for the nature of the Antler orogeny, Geological Society of America Abstracts with Programs, v. 25, n. 5, p. 62-63.

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

Korringa, M.K., 1973, Linear vent area of the Soldier Meadow tuff, an ash-flow sheet in northwestern Nevada: Geological Society of America Bulletin, vol. 84, p. 3849-3866.

Kretschmer, E.L., 1984a, Geology of the Pinson and Preble gold deposits, Humboldt County, Nevada: Arizona Geological Society Digest, vol. 15, p. 59-66.

Kretschmer, E.L., 1984b, Geology of the Pinson mine, Humboldt County, Nevada, *in* Tingley, J.V., and Bonham, H.F., eds., sediment-hosted precious-metal deposits of northern Nevada: Nevada Bureau of Mine and Geology, Report 40, p. 52-55.

Lahren, M.M., Schweickert, R.A., Connors, K.A., and Ludington, S., 1995, Allochthonous tectonic units of the central and western Great Basin [abs]: Geology and Ore Deposits of the American Cordillera, Reno/Sparks, Nevada, 1995, Program with Abstracts, p. A45.

Lipman, P.W., Prostka, H.J., and Christiansen, R.L., 1971, Evolving subduction zones in the western United States, as interpreted from igneous rocks: Science, v. 174, p. 821-825.

Ludington, S.D., Cox, D.P., Singer, D.A., Sherlock, M.G., Berger, B.R., and Tingley, J.V., 1993, Spatial and temporal analysis of precious-metal deposits for a mineral resource assessment of Nevada, *in* Kirkham, R.V., Sinclair, W.D., Thorpe, R.I., and Duke, J.M., eds., Mineral Deposit Modeling: Geological Association of Canada, Special Paper 40, p. 31-40.

MacKenzie, W.B., and Bookstrom, A.A., 1976, Geology of the Majuba Hill Area, Pershing County, Nevada: Nevada Bureau of Mines and Geology Bulletin 86.

Madden-McGuire, D.J., 1991, Stratigraphy of the limestone-bearing part of the Lower Cambrian to Lower Ordovician Preble Formation near its type locality, Humboldt County, north-central Nevada, *in* Raines, G.L., Lisle, R.W., Schafer, R.W., and Wilkinson, W. H., eds., Geology and Ore Deposits of the Great Basin, Symposium Proceedings: Reno, Geological Society of Nevada, vol. 2, p. 875-893.

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

Maher, K.A., 1989, Geology of the Jackson Mountains, Northwest Nevada: Pasadena, California, California Institute of Technology, Ph.D. dissertation, 526 p.

McCollum, L.B., and McCollum, M., 1991, Paleozoic rocks of the Osgood Mountains, Nevada, *in* Raines, G.L., Lisle, R.E., Schafer, R.W., Wilkinson, W.H., eds., Geology and Ore Deposits of the Great Basin, Reno, NV, April 1-5, 1990 Symposium Proceedings, p. 735-738.

McKee, E.H., 1968, The Bates Mountain Tuff in central Nevada: Geological Society of America and Associated Societies Annual Meetings, Tucson, 1968, Abstracts with Programs, p. 81.

McKee, E.H., 1970, Fish Creek Mountains Tuff and volcanic center, Lander County, Nevada: U.S. Geological Survey Professional Paper 681.

McKee, E.H., 1971, Tertiary igneous chronology of the Great Basin of Western United States -- Implications for tectonic models: Geological Society of America Bulletin, v. 82, p. 3497-3502.

McKee, E.H., 1976, Origin of the McDermitt caldera in Nevada and Oregon: Transactions of the Society of Mining Engineers, v. 260, p. 196-199.

McKee, E.H., and Noble, D.C., 1986, Tectonic and magmatic development of the Great Basin during late Cenozoic time: Modern Geology, v. 10, p. 39-49.

McKee, E.H., and Silberman, M.L., 1970, Geochronology of Tertiary igneous rocks in central Nevada: Geological Society of America Bulletin, v. 81, p. 2317-2328.

McKee, E.H., and Stewart, 1971, Stratigraphy and potassium-argon ages of some Tertiary tuffs from Lander and Churchill Counties, central Nevada: U.S. Geological Survey Bulletin 1311-B, p. B1-B28.

Merriam, J.C., 1907, The occurrence of middle Tertiary mammal-bearing beds in northwestern Nevada: Science, v., 26 p. 380-382.

Merriam, J.C., 1910, Tertiary mammal beds of Virgin Valley and Thousand Creek in northwestern Nevada, part I, geologic history: University of California Publications, Bulletin of the Department of Geology, v. 6, no. 2, p. 21-53.

Miller, B.W., and Silberman, M.L., 1977, Cretaceous K-Ar age of hydrothermal alteration at the north Fish Creek porphyry copper prospect, Fish Creek Mountains, Lander County, Nevada: Isochron/West, no. 18, p. 7.

Miller, E.L., Kanter, L.R., Larue, D.K., Turner, R.J., Murchey, B., and Jones, D.L., 1982, Structural fabric of the Paleozoic Golconda allochthon, Antler Peak quadrangle, Nevada: Progressive deformation of an oceanic sedimentary assemblage: Journal of Geophysical Research, vol. 87, no. B5, p. 3795-3804.

Moore, J.G., 1969, Geology and mineral resources of Lyon, Douglas, and Ormsby Counties, Nevada: Nevada Bureau of Mines and Geology, Bulletin 75, 45 p.

Morton, J.L., Silberman, M.L., Bonham, H.F., Garside, L.J., and Noble, D.C., 1977, K-Ar ages of volcanic rocks and ore deposits in Nevada and eastern California -- Determinations run under the USGS-NBMG cooperative program: Isochron/West, no. 20, p. 19-29.

Muller, S.W., Ferguson, H.G., and Roberts, R.J., 1951, Geology of the Mount Tobin quadrangle, Nevada: U.S. Geological Survey Geological Quadrangle Map GQ-7, scale 1:125,000.

Murchey, B.L., 1990, Age and depositional setting of siliceous sediments in the upper Paleozoic Havallah sequence near Battle Mountain, Nevada: Implications for the paleogeography and structural evolution of the western margin of North America, *in* Harwood, D.S., and Miller, M.M., eds., Paleozoic and early Mesozoic paleogeographic relations; Sierra Nevada, Klamath Mountains, and related terranes: Geological Society of America Special paper 255, p. 137-155.

Nash, J.T., 1995, Reconnaissance geology and resources of Miocene diatomite, Trinity Pass area, Pershing County, Nevada: U.S. Geological Survey Open-File Report 95-84, 16 p.

Nash, J.T., Utterback, W.C., and Saunders, J.A., 1991, Geology and geochemistry of the Sleeper gold deposits, Humboldt County, Nevada an interim report, *in* Raines, G.L., Lisle, R.W., Schafer, R.W., and Wilkinson, W. H., eds., Geology and Ore Deposits of the Great Basin, Symposium Proceedings: Reno, Geological Society of Nevada, vol. 2, p. 1063-1084.

Neff, T.R., 1969, Petrology and structure of the Buffalo mountain pluton (probably Late Permian), Humboldt County, Nevada: Stanford, California, Stanford University, Ph.D. dissertation, 210 p.

Nichols, K.M., and Silberling, N.J., 1977, Stratigraphy and depositional history of the Star Peak Group (Triassic), northwestern Nevada: Geological Society of America Special Paper 178, 73 p.

Noble, D.C., 1972, Some observations on the Cenozoic volcano-tectonic evolution of the Great Basin, western United States: Earth and Planetary Science Letters, v. 17, p. 142-150.

Noble, D.C., 1988, Cenozoic volcanic rocks of the northwestern Great Basin: an overview, *in* Buffa, R., Cuffney, R., and Seedorff, E., (editors), Hot-spring gold deposits of northwestern Nevada and southeastern Oregon: Geological Society of Nevada 1988 Spring Field Trip Guidebook, Special Publication No. 7, p. 31-42.

Noble, D.C., Hedge, C. E., McKee, E. H., and Korringa, M. K., 1973, Reconnaissance study of the strontium isotope composition of Cenozoic volcanic rocks in the northwestern Great Basin: Geological Society of America Bulletin, v. 84, p. 1393-1406.

Noble D.C., McCormick, J.K., McKee, E.H., Silberman, M.L., and Wallace, A.B., 1988, Time of mineralization in the evolution of the McDermitt Caldera Complex, Nevada-Oregon, and the relation of middle Miocene mineralization in the northern Great Basin to coeval regional magmatic activity: Economic Geology, vol. 83, p. 859-863.

Noble, D.C., McKee, E.H., Smith, J.G., and Korringa, M.K., 1970, Stratigraphy and geochronology of Miocene volcanic rocks in northwestern Nevada: U.S. Geological Survey Professional Paper 700-D, p. D23-D32.

Oldow, J.S., 1984, Evolution of a late Mesozoic back-arc fold and thrust belt, western Great Basin, U.S.A.: Tectonophysics, v. 102, p. 245-274.

Oldow, J.S., Bartel, R.L., and Gelber, A.W., 1986, Structure and sedimentology of early Mesozoic basinal rocks of the Fencemaker Allochthon, Pershing District, southern Humboldt Range, Nevada: Geological Society of America, Abstracts with Programs, v. 18, no. 2, p. 166-167.

Oldow, J.S., Bartel, R.L., and Gelber, A.W., 1990, Depositional setting and regional relationships of basinal assemblages, Pershing Ridge Group and Fencemaker Canyon Sequence in northwestern Nevada with Suppl. Data 90-03: Geological Society of America Bulletin, v. 102, no. 2, p. 193-222.

Osterberg, M.W., and Guilbert, J.M., 1991, Geology, wall-rock alteration and new exploration techniques at the Chimney Creek sediment-hosted gold deposit, Humboldt County, Nevada, *in* Raines, G.L., Lisle, R.W., Schafer, R.W., and Wilkinson, W. H., eds., Geology and Ore Deposits of the Great Basin, Symposium Proceedings: Reno, Geological Society of Nevada, vol. 2, p. 805-819.

Parsons, T., Thompson, G.A., and Sleep, N.H., 1994, Mantle plume influence on the Neogene uplift and extension of the U.S. western Cordillera?: Geology, v. 22, p. 83-86.

Peters, S.G., and Evans, J.G., 1995, Megascopic and mesoscopic fabric geometries in parts of the Carlin trend, Eureka and Elko Counties, Nevada [abs]: Geology and Ore Deposits of the American Cordillera, Reno/Sparks, Nevada, 1995, Program with Abstracts, p. A61-A62.

Reeves, R.G., and Kral, V.E., 1955, Iron ore deposits of Nevada--Part A: Geology and iron ore deposits of the Buena Vista Hills, Churchill and Pershing Counties, Nevada: Nevada Bureau of Mines and Geology Bulletin 53a, p. 1-32.

Roberts, R.J., 1964, Stratigraphy and structure of the Antler Peak quadrangle, Humboldt and Lander Counties, Nevada: U.S. Geological Survey Professional Paper 459-A, 93 p.

Roberts, R.J., and Arnold, D.C., 1965, Ore deposits of the Antler Peak quadrangle, Humboldt and Lander Counties, Nevada: U.S. Geological survey Professional Paper 459-B, 93 p.

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

Roberts, R.J., and Thomasson, M.R., 1964, Comparison of late Paleozoic depositional history of northern Nevada and central Idaho: U.S. Geological Survey Professional Paper 475-D, p. D1-D6.

Robinson, E.S., 1970, Relation between geological structure and aeromagnetic anomalies in central Nevada: Geological Society of America Bulletin, v. 81, p. 2045-2060.

Ronkos, C.J., 1986, Geology and interpretation of geochemistry at the Standard Mine, Humboldt County, Nevada: Journal of Geochemical Exploration, v. 25, nos. 1-2, p. 129-137.

Russell, B.J., 1984, Mesozoic geology of the Jackson Mountains, northwestern Nevada: Geological Society of America Bulletin, v. 95, p. 313-323.

Russell, I.C., 1885, Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U.S. Geological Survey Monograph XI, 288 p.

Rye, R.O., Roberts, R.J., Snyder, W.S., Lahusen, G.L., and Motica, J.E., 1984, Textural and stable isotope studies of the Big Mike cupriferous volcanogenic massive sulfide deposit, Pershing County, Nevada: Economic Geology, vol. 79, p. 124-140.

Rytuba, J.J., 1989, Volcanism, extensional tectonics, and epithermal mineralization in the northern Basin and Range province, California, Nevada, Oregon, and Idaho, *in* Schindler, K.S., ed., U.S. Geological Survey research on mineral deposits-program and abstracts-Fifth Annual V.E. McKelvey Forum on Mineral and Energy Resources: U.S. Geological Survey Circular 1035, p. 59-61.

Rytuba, J.J. and McKee, E.H., 1984, Peralkaline ash-flow tuff and calderas of the McDermitt volcanic field, southeast Oregon and north-central Nevada: Journal of Geophysical Research, v. 89, no. B10, p, 8616-8628.

Rytuba, J.J., and Glanzman, R.K., 1979, Relation of mercury, uranium, and lithium deposits to the McDermitt caldera complex, Nevada-Oregon: Nevada Bureau of Mines and Geology Report 33, p. 109-118.

Saller, A.H., and Dickinson, W.R., 1982, Alluvial to marine facies transition in the Antler overlap sequence, Pennsylvanian and Permian of North-central Nevada: Journal of Sedimentary Petrology, v. 52, no. 3, p. 925-940.

Sando, W.J., 1993, Coralliferous carbonate shelves of Mississippian age, west side of Antler Orogen, central Nevada: U.S. Geological Survey Bulletin B-1988-F, p. F1-F29.

Satkoski, J.J., and Berg A.W., 1982, Field inventory of mineral resources, Pyramid Lake Indian Reservation, Nevada: U.S. Bureau of Mines Report BIA No. 38-II, 47 p.

Seedorff, C.E., 1991, Magmatism, extension, and ore deposits of Eocene to Holocene age in the Great Basin -- Mutual effects and preliminary proposed genetic relationships, *in* Raines, G.L., Lisle, R.W., Schafer, R.W., and Wilkinson, W. H., eds., Geology and ore deposits of the Great Basin Symposium Proceedings: Reno, NV, Geological Society of Nevada, p. 133-178.

Shawe, F.R., Reeves, R.G., and Kral, V.E., 1962, Iron ore deposits of Nevada, part C, Iron ore deposits of northern Nevada: Nevada Bureau of Mines and Geology Bulletin 53c, 125 p.

Silberling, N.J., 1973, Geologic events during Permian-Triassic time along the Pacific margin of the United States, *in* Logan, A., and Hills, L.V., eds., The Permian and Triassic Systems and their mutual boundary: Alberta

Society of Petroleum Geologists, Calgary, Alberta, Canada, p. 345-362.

Silberling, N.J., 1991, Allochthonous terranes of western Nevada -- Current status, *in* Raines, G.L., Lisle, R.W., Schafer, R.W., and Wilkinson, W. H., eds., Geology and Ore Deposits of the Great Basin, Symposium Proceedings: Reno, NV, Geological Society of Nevada, p. 101-102.

Silberling, N.J., Jones, D.L., Blake, M.C., Jr., and Howell, D.G., 1984, Lithotectonic terrane map of the western conterminous United States, Pt. C of Silberling, N.J. and Jones, D.L., eds., Lithotectonic maps of the North American Cordillera: U.S. geological Survey Open-File Report 84-523, 43 p.

Silberling, N.J., Jones, D.L., Blake, M.C., Jr., and Howell, D.G., 1987, Lithotectonic terrane map of the western conterminous United States: U.S. Geological Survey Miscellaneous Field Studies Map MF-1874-C.

Silberling, N.J., and Roberts, R.J., 1962, Pre-Tertiary stratigraphy and structure of northwestern Nevada: Geological Society of America Special Paper 72, 58 p.

Silberling, N.J., and Wallace, R.E., 1967, Geologic map of the Imlay Quadrangle, Pershing County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-666, scale 1:62,500.

Silberling, N.J., and Wallace, R.E., 1969, Stratigraphy of the Star Peak Group, Triassic, and overlying lower Mesozoic rocks, Humboldt Range, Nevada: U.S. Geological Survey Professional Paper 592.

Silberman, M.L., Berger, B.R., and Koski, R.A., 1974, K-Ar age relations of granodiorite emplacement and tungsten and gold mineralization near the Getchell mine, Humboldt County, Nevada: Economic Geology, vol. 69, p. 646-656.

Silberman, M.L., and Dockter, R.D., 1977, Age of emplacement and mineralization of the Majuba Hill intrusive complex, Pershing County, Nevada: Isochron/West, n. 18, p. 5-6.

Silberman, M.L., and McKee, E.H., 1971, K-Ar ages of granitic plutons in north-central Nevada: Isochron/West no. 1, p. 15-22.

Smith, J.G., McKee, E.H., Tatlock, D.B., and Marvin, R.F., 1971, Mesozoic granitic rocks in northwestern Nevada: A link between the Sierra Nevada and Idaho Batholiths: Geological society of America Bulletin, vol. 82, p. 2935-2944.

Snyder, C.T., Hardman, G., and Zdenek, F.F., 1964, Pleistocene lakes in the Great Basin: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-416, scale 1:1,000,000.

Snyder, W.S., 1978, Manganese deposited by submarine hot springs in chert-greenstone complexes, western United States: Geology, v. 6, p. 741-744.

Snyder, W.S., Dickinson, W.R., and Silberman, M.L., 1976, Tectonic implications of space-time patterns of Cenozoic magmatism in the western United States: Earth and Planetary Science Letters, v. 32, p. 91-106.

Speed, R.C., 1974, Evaporite-carbonate rocks of the Jurassic Lovelock Formation, West Humboldt Range, Nevada: Geological Society of America Bulletin, v. 85, no. 1, p. 105-118.

Speed, R.C., 1976, Geologic map of the Humboldt Lopolith and surrounding terrane, Nevada: Geological Society of America Map-Chart Series, MC-14, 4 p.

Speed, R.C., 1977, Island-arc and other paleogeographic terranes of late Paleozoic age in the western Great Basin, *in* Stewart, J. H., Stevens, C. H., Fritsche, A. E., eds., Paleozoic Paleogeography of the Western United States, Pacific Coast Paleogeography Symposium 1, p. 349-362.

Speed, R.C., 1978a, Basinal terrane of the early Mesozoic marine province of the western Great Basin, *in* Howell, D.

G., McDougall, K.A., eds., Mesozoic paleogeography of the western United States. Pacific Coast Paleogeography Symposium, no. 2, p. 237-252.

Speed, R.C., 1978b, Paleogeographic and plate tectonic evolution of the early Mesozoic marine province of the western Great Basin, *in* Howell, D. G., McDougall, K.A., eds., Mesozoic paleogeography of the western United States. Pacific Coast Paleogeography Symposium, no. 2, p. 253-270.

Speed, R.C., and Sleep, N.H., 1982, Antler orogeny and foreland basin: A model: Geological Society of America Bulletin, v. 93, p. 815-828.

Stanley, K.O., Chamberlain, C.K., and Stewart, J.H., 1977, Depositional setting of some eugeosynclinal Ordovician rocks and structurally interleaved Devonian rocks in the Cordilleran mobile belt, Nevada Stewart, J.H., Stevens, C.H., and Fritche, A. E., eds., Paleozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 1, p. 259-274.

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

Stewart, J.H., and Carlson, J.E., 1976, Cenozoic rocks of Nevada: Nevada Bureau of Mines and Geology Map 52, scale 1:1,000,000.

Stewart, J.H., and Carlson, J.E., compilers, 1978, Geologic map of Nevada: U.S. Geological Survey Map, 1:500,000 scale.

Stewart, J.H., MacMillan, Nichols, K.M., Stevens, C.H., 1977a, Deep-water upper Paleozoic rocks in north-central Nevada--A study of the type area of the Havallah Formation, *in* Stewart, J.H., Stevens, C.H., and Fritsche, A.E., eds., Paleozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 1, p. 337-348.

Stewart, J.H., Moore, W.J., and Zietz, I., 1977b, East-west patterns of Cenozoic igneous rocks, aeromagnetic anomalies, and mineral deposits, Nevada and Utah: Geological Society of America Bulletin, v. 88, p. 67-77.

Stewart, J.H., Murchey, B., Jones, D.L., and Wardlaw, B.R., 1986, Paleontologic evidence for complex tectonic interlayering of Mississippian to Permian deep-water rocks of the Golconda allochthon in Tobin range, north-central Nevada: Geological Society of America Bulletin, v. 97, p. 1122-1132.

Stewart, J.H., Walker, G.W., and Kleinhampl, F.J., 1975, Oregon-Nevada lineament: Geology, v. 3, no. 5, p. 265-268.

Suczek, C.A., 1977, Tectonic relations of the Harmony Formation, northern Nevada: Stanford, Calif., Stanford University, Ph.D. thesis, 96 p.

Theodore, T.G., 1991a, Preliminary geologic map of the North Peak quadrangle, Humboldt and Lander Counties, Nevada: U.S. Geological Survey Open-File Report 91-429, scale 1:24,000.

Theodore, T.G., 1991b, Preliminary geologic map of the Valmy quadrangle, Humboldt County, Nevada: U.S. Geological Survey Open-File Report 91-430, scale 1:24,000.

Theodore, T.G., 1994, Preliminary geologic map of the Snow Gulch quadrangle, Humboldt and Lander Counties, Nevada, *with a section on* Radiolarians in the Ordovician Valmy Formation and Devonian Scott Canyon Formation by B. L. Murchey, *and a section on* Helicoprion sp. from the Pennsylvanian and Permian Antler Peak Limestone, Lander County, Nevada, by R.A. Hanger, E.E. Strong, and R.T. Ashinhurst: U.S. Geological Survey Open-File Report 94-436, scale 1:24,000.

Theodore, T.G., 1996, Geology and implications of silver:gold ratios of the Elder Creek porphyry copper system, Battle Mountain mining district, Nevada, *in* Coyner, A.R., and Fahey, P.L., eds., Geology and Ore Deposits of the American Cordillera: Geological Society of Nevada Symposium, Reno/Sparks, Nevada, April, 1995, Proceedings, in press.

Theodore, T.G., and Blake, D.W., 1975, Geology and geochemistry of the Copper Canyon Porphyry copper deposit and surrounding area, Lander County, Nevada: U.S. Geological Survey Professional Paper 798-B, 86 p.

Theodore, T.G., and Blake, D.W., 1978, Geology and geochemistry of the West ore body and associated skarns, Copper Canyon porphyry copper deposits, Lander County, Nevada: U.S. Geological Survey Professional Paper 798-C, 85 p.

Theodore, T.G., Blake, D.W., Loucks, T.A., and Johnson, C.A., 1992, Geology of the Buckingham stockwork molybdenum deposit and surrounding area, Lander County, Nevada, *with a section on:* Potassium-argon and $^{40}Ar/^{39}Ar$ geochronology of selected plutons in the Buckingham area by E.H. McKee, *and a section on* Economic geology *by* T.A. Loucks and C.A. Johnson, *and a section on* Supergene copper deposits at Copper Basin *by* D.W. Blake, *and a section on* Mineral chemistry of Late Cretaceous and Tertiary skarns *by* J.M. Hammarstrom: U.S. Geological Survey Professional Paper 798-D, p. D1-D307.

Theodore, T.G., Howe, S.S., and Blake, D.W., 1990, The Tomboy-Minnie gold deposits at Copper Canyon, Lander County, Nevada, *in* Shawe, D.R., Ashley, R.P., and Carter, L.M.H., eds, Geology and Resources of Gold in the United States, Chapter E - Gold in Porphyry Copper Systems: U.S. Geological Survey Bulletin 1857-E, p. E43-E55.

Theodore, T.G., Silberman, M.L., and Blake, D.W., 1973, Geochemistry and K-Ar ages of plutonic rocks in the Battle Mountain mining district, Lander County, Nevada: U.S. Geological Survey Professional Paper 798-A, 24 p.

Thurber, J. E., 1982, Petrology and Cu-Mo mineralization of the Kennedy stock, East Range, Pershing County, Nevada: Fort Collins, Colorado, Colorado State University, M.Sc. thesis.

Tomlinson, A.J., 1990, Biostratigraphy, stratigraphy, sedimentary petrology, and structural geology of the upper Paleozoic Golconda allochthon, north-central Nevada: Stanford, Calif., Stanford University, Ph.D. dissertation, 491 p.

Trites, A.F., and Thurston, R. H., 1958, Geology of Majuba Hill, Pershing County, Nevada: U.S. Geological Survey Bulletin 1046-I, p. 183-203.

Van Houten, F.B., 1956, Reconnaissance of Cenozoic sedimentary rocks of Nevada: American Association of Petroleum Geologists Bulletin, v. 40, p. 2801-2825.

Vikre, P.G., 1985a, Precious-metal vein systems in the National district, Humboldt County, Nevada: Economic Geology, vol. 80, p. 360-393.

Vikre, P.G., 1985b, Geologic map of the Buckskin Mountain quadrangle, Humboldt County , Nevada: Nevada Bureau of Mines and Geology Map 88, scale 1:24,000.

Wallace, A.B., 1975, Geology and mineral deposits of the Pyramid district, southern Washoe County, Nevada: Reno, Nevada, University of Nevada, Ph.D. thesis, 162 p.

Wallace, A.B., 1979, Possible signatures of porphyry-copper deposits in middle to late Tertiary volcanic rocks of western Nevada: Nevada Bureau of Mines and Geology Report 33, p. 69-76.

Wallace, A.R., 1977, Geology and ore deposits, Kennedy mining district, Pershing County, Nevada: Boulder, Colorado, University of Colorado, M.Sc. thesis.

Wallace, A.R., 1978, Relationship between the Kennedy Stock and mid-Cenozoic fault troughs, West-central Nevada: Geological Society of America, Abstracts with Programs, v. 10, no. 3, p. 152.

Wallace, A.R., 1991, Effect of Late Miocene extension on the exposure of gold deposits in north central Nevada, *in* Raines, G.L., Lisle, R.W., Schafer, R.W., and Wilkinson, W. H., eds., Geology and Ore Deposits of the Great Basin, Symposium Proceedings: Reno, Geological Society of Nevada, v. 2, p. 179-184.

Wallace, R.E., Silberling, N.J., Irwin, W.P., and Tatlock, D.B., 1969a, Geologic map of the Buffalo Mountain Quadrangle, Pershing and Churchill Counties, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-821, scale 1:62,500.

Wallace, R.E., Tatlock, D.B., Silberling, N.J., and Irwin, W.P., 1969b, Geologic map of the Unionville quadrangle, Pershing County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-820, scale 1:62,500.

Wendt, C.J., and Albino, G.V., 1992, Porphyry copper and related occurrences in Nevada: Nevada Bureau of Mines and Geology Map 100.

Whitebread, D.H., 1978, Preliminary geologic Map of the Dun Glen quadrangle, Pershing County, Nevada: U.S. Geological Survey Open-File Report 78-407, scale 1:48,000.

Whitebread, D.H., 1994, Geologic Map of the Dun Glen quadrangle, Pershing County, Nevada: U.S. Geological Survey Miscellaneous Investigations Map I-2409, scale 1:48,000.

Willden, C.R., 1958, Cretaceous and Tertiary orogeny in the Jackson Mountains, Humboldt County, Nevada: American Association of Petroleum Geologists Bulletin, v. 42. no. 10, p. 2378-2398.

Willden, R., 1961, Preliminary map of Humboldt County, Nevada: U.S. Geological Survey Mineral Investigations Field Studies Map MF-236.

Willden, R., 1963, General geology of the Jackson Mountains, Humboldt County, Nevada: U.S. Geological Survey Bulletin 1141-D, 65 p.

Willden, R., 1964, Geology and mineral deposits of Humboldt County, Nevada: Nevada Bureau of Mines and Geology Bulletin 59, 154 p.

Willden, R., and Speed, R. C., 1974, Geology and Mineral Deposits of Churchill County, Nevada: Nevada Bureau of Mines and Geology Bulletin 83.

Wood. J.D., 1991, Geology of the Wind Mountain Gold deposit, Washoe, County, Nevada, *in* Raines, G.L., Lisle, R.W., Schafer, R.W., and Wilkinson, W. H., eds., Geology and Ore Deposits of the Great Basin, Symposium Proceedings: Reno, Geological Society of Nevada, v. 2, p. 1051-1061.

Wotruba, P.R., Benson, R.G., and Schmidt, K.W., 1988, Geology of the Fortitude gold-silver skarn deposit, Copper Canyon, Lander County, Nevada, *in* Schafer, R.W., Cooper, J.J., and Vikre, P.G., eds., Bulk Mineable precious metal deposits of the Western United States: Reno, Geological Society of Nevada, p. 159-171.

Wrucke, C.T., Churkin, M., Jr., and Heropoulos, C., 1978, Deep-sea origin of Ordovician pillow basalt and associated sedimentary rocks, northern Nevada: Geological Society of America Bulletin, v. 89, no. 8, p. 1272-1280.

Wyld, S.J., 1990, Paleozoic and Mesozoic rocks of the Pine Forest Range, northwest Nevada, and their relation to volcanic arc assemblages of the western U.S. Cordillera, *in* Harwood, D.S., and Miller, M.M., eds., Paleozoic and early Mesozoic paleogeographic relations; Sierra Nevada, Klamath Mountains, and related terranes: Geological Society of America Special paper 255, p. 219-237.

Zoback, M.L., 1989, State of stress and modern deformation of the northern Basin and Range province: Journal of Geophysical Research, B, v. 94, p. 7105-7128.

Zoback, M.L., Anderson, R.E., and Thompson, G.A., 1981, Cainozoic evolution of the state of stress and style of tectonism of the Basin and Range province of the western United States: Philosophical Transactions of the Royal Society of London, A 300, p. 407-434.

Zoback, M.L., McKee, E.H., Blakely, R.J., and Thompson, G.A., 1994, The northern Nevada rift--Regional tectonomagmatic relations and middle Miocene stress direction: Geological Society of America Bulletin, v. 106, no. 3, p. 371-382.

Zoback, M.L., and Thompson, G.A., 1978, Basin and range rifting in northern Nevada--clues from a mid-Miocene rift and its subsequent offsets: Geology, v. 6, no. 2, p. 111-116.