CHAPTER 5

CENOZOIC VOLCANIC GEOLOGY OF NEVADA

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INTRODUCTION

In order to delineate permissive areas that include Cenozoic volcanic rocks that are buried by as much as 1,000 m of younger deposits, we analyzed their surface and subsurface distribution. The result of this analysis is shown on plate 5-1, which depicts the Cenozoic volcanic rocks of Nevada in a way specifically designed to support this resource analysis. The primary sources of information were Stewart and Carlson (1976 and 1978) and Stewart (1980), but concepts and data from more recent studies, especially Sargent and Roggensack (1984) and Best and others (1989b), were also incorporated.

ORGANIZATION OF MAP UNITS

This map is designed specifically to support the resource analysis. Therefore, rocks are grouped into thematic map units that depict similar environments of formation for mineral deposits. Most epithermal precious-metal deposits are in volcanic rocks, and the focus of this map is on Cenozoic volcanic rocks, both exposed and concealed. The outcropping volcanic and volcaniclastic rocks are grouped into three map units, which we term assemblages, and which represent different petrogenetic suites. These assemblages were defined using the concepts presented by Christiansen and Yeats (1992). This scheme was selected after we discovered that many volcanic-hosted mineral deposit types show distribution patterns in Nevada that are much more closely related to age and petrotectonic affinity of the associated volcanic rocks than to their lithology. These relationships are discussed in detail in the parts of this study entitled Delineation of resource assessment tracts and Estimation of number of undiscovered deposits.

Geologic features that mark the eruptive source for volcanic rocks have implications for the occurrence of mineral deposits, and thus, are depicted differently on plate 5-1. The intrusions which are the sources of lava flows, particularly rhyolitic ones, may serve as relatively long-lived heat sources that may drive hydrothermal systems. Although each intrusive body could be classified into one of the assemblages, we lacked the detailed information necessary to make such assignations. Thus, we grouped felsic intrusions (unit Tri of Stewart and Carlson, 1978), mafic intrusions (unit Tmi of Stewart and Carlson, 1978), and the somewhat deeper-seated holocrystalline intrusions (unit Tg of Stewart and Carlson, 1978) into a single map unit, Cenozoic intrusive rocks. Calderas, which mark the source of the overwhelming majority of the volume of volcanic rocks of Nevada, are also portrayed, and are discussed below, in the section on volcanic structures.

Sedimentary rocks of Cenozoic age are widespread in Nevada, and many of them are contemporary with and/or composed largely of detritus derived from the erosion of volcanic rocks. We were unable to separate the volcanogenic part of these rocks, and chose not to include them on our map of specifically volcanic rocks, even though in some cases, they may serve as hosts for mineral deposits.

Subsurface volcanic rocks could not be assigned to assemblages, and are depicted as a single map unit. Exposed pre-Cenozoic rocks are also depicted as a single map unit, primarily to aid readability of the map.

VOLCANIC ROCKS IN THE SUBSURFACE

The special analysis of aeromagnetic data that is described in chapter 3 provided most of the information used to infer the subsurface extent of the volcanic rocks in the upper kilometer of the crust. While direct application of Blakely's analysis was sufficient to locate subsurface volcanic rocks in the majority of cases, two major types of complications arise in making subsurface projections of volcanic rocks. First, the magnetic methods are insensitive to age, and cannot distinguish between shallowly buried Cenozoic volcanic rocks and older (pre-Tertiary) magnetic igneous rocks. Particularly in western Nevada, where much of the basement is composed of older volcanic rocks, a generous dose of interpretation and intuition was used to delineate the subsurface Cenozoic volcanic rocks, and the map is probably least reliable in that area.

Second, some Cenozoic volcanic rocks are only weakly magnetized, and do not yield a magnetic signal strong enough to indicate their presence. In these cases too, the interpretation is less reliable. Examples are found scattered throughout the map area; one is the Caetano Tuff (Stewart and McKee, 1977), which, in much of its outcrop area, does not yield a strong magnetic signal. Though Stewart and McKee (1977) do not give details of the opaque mineralogy of this Oligocene low-silica rhyolite ash-flow tuff, biotite is the predominant mafic mineral and perhaps the tuff's non-magnetic nature is primary. However, they also report that large parts of the tuff are hydrothermally altered, and contain abundant nonmagnetic limonite.

CALDERAS

Calderas are the structural depressions that form when a catastrophic explosive eruption of magma results in the collapse of the roof of the pre-eruptive magma chamber. After formation, they are surrounded by the outflow facies of the erupted ash-flow tuff. Frequently, only part of the underlying magma chamber vents to the surface, and they may be the site of renewed volcanism and intrusion. Calderas are commonly the site of extensive brittle fracturing, due to upward movement of magma and explosive volcanism. They are also often the sites of long-lived heat sources that may drive hydrothermal circulation systems. For these reasons, mineral deposits may be associated with calderas, which are depicted in red on the map. They are also important because they are depressions filled with volcanic rocks and are unlikely to preserve any of the basement in the upper kilometer of the crust. Areas depicted as calderas are assumed to contain a section of volcanic and volcaniclastic rock at least a kilometer thick, and thus, are not permissive for mineral deposits hosted in pre-Tertiary rocks, even when the gravity data do not directly support such an interpretation.

Not all calderas in Nevada have been identified, and there remains controversy about some of those which have been identified and inferred. The number of distinct ash-flow tuff outflow sheets considerably outnumbers the identified calderas, and so, in some cases, calderas are known to exist, yet their location may be unknown because they have been disrupted by younger events, or they are buried by younger rocks. Best and others (1989b), without which our compilation effort would have been immeasurably more difficult, depict about 60 calderas that lie at least partially within Nevada. We depict 70 on plate 5-1 and figure 5-1, and list them, by numbers keyed to the map, in table 5-1. In some cases, discrepancies in numbers arise because several nested calderas that erupted successive ash-flow sheets are grouped together, or are as yet not amenable to discrimination. For example, we, as did Best and others (1989b) list the Indian Peak Caldera (Best and Grant, 1987) and the Caliente caldron complex (Ekren and others, 1977) as single entities even though each was the source of several ash-flow tuffs, and may, therefore, consist of several discrete calderas.

The detailed gravity analysis in chapter 3 has permitted us to suggest the location of several previously unknown, but suspected, calderas. West of Lovelock, in the Trinity Range, is a well defined circular depression in the basement rocks (Caldera #9, plate 5-1, fig. 5-1, table 5-1), inferred on the basis of gravity data, to be several kilometers deep, that is filled with volcaniclastic sedimentary rocks and rhyolite flows of Miocene age. The depression's curvilinear northeastern margin is nearly coincident with a curvilinear contact of the younger volcanic rocks with Mesozoic sedimentary and granitoid rocks. Although the surface geology is not indicative of an intracaldera environment, the surface rocks may be younger, and this area would seem to be an excellent candidate for a totally concealed caldera. We emphasize that this and similar calderas are conjectured entirely on the basis of geophysical evidence and geologic inference; we are unable to suggest that they are the source of any specific ash-flow tuffs. Other conjectural calderas include #13, northeast of Tuscarora, #16, in the Midas area of north central Nevada, and #29, southwest of Ely.

In addition, there are some calderas whose general location is well-known, and whose outflow-facies ash-flow tuffs are well-known, but whose precise outlines, particularly the structural boundaries, are not known. In some cases, geophysics, both gravity and magnetics have allowed us to suggest the outline of the caldera where none was known before. Examples of this type include #'s 1, 2, and 3, in northwestern Nevada, and #50, east of Warm Springs.

VOLCANIC ASSEMBLAGES

The landmark paper by Dickinson and Hatherton (1967) relating chemistry of eruptive volcanic rocks to depth of underlying subductions zones set the stage for attempts to explain compositional differences of suites of igneous rocks throughout western North America using the emerging theory of plate tectonics. Notable early examples include the studies of Armstrong and others (1969), Lipman and others (1972) and Christiansen and Lipman (1972), which were the first attempts to explain the volcanism of western interior North America. Since then, numerous other scenarios have been proposed, and the depth-alkalinity theory is popular enough that information and interpretations of this sort are successfully marketed as an exploration tool in mineral exploration.

As used here, a volcanic assemblage is a group of rocks that share similar chemical compositions that are indicative of formation in a particular tectonic environment. Classification of volcanic fields is a complex matter, and it is often nearly impossible to assign an individual volcanic rock unit unequivocally to an assemblage. For example, Lipman and others (1972) pointed out that high-silica rhyolites were characteristic of bimodal volcanic assemblages, related to an extensional tectonic regime and yet, rhyolites with more than 75% silica are not uncommon in continental volcanic fields associated with compressional tectonic environments, and perhaps related to subduction. Topaz rhyolites (Christiansen and others, 1986) are also associated with bimodal volcanism, but are not unknown in other petrotectonic environments.

Successful strategies rely on the delineation of compositional groups that are also grouped coherently in time and space, without direct reference to genetic models. As the important role of continental crustal material and of the mantle in the formation of onshore melts has been demonstrated (Smith, 1979; Hildreth, 1981), there has been less emphasis on the subducting slab, and a re-emphasis on empirical classification of volcanic rocks, based on physical and chemical characteristics. Recent papers by Gans and others (1989) and Mutschler and others (1987) argue persuasively that much calc-alkaline volcanism is the result of an injection of heat, fluids, and basaltic magma from the mantle into the lower crust.

It has also been recognized for a long time that tectonic controls on magma chemistry appear to influence the distribution of mineral deposit types (Ludington, 1978; Keith and others, 1991). In this study, we have made an attempt to incorporate our information about the distribution of various types and ages of volcanic rocks into a classification scheme for Nevada that we hope will prove useful in support of this mineral resource analysis.

Recent syntheses of Cenozoic geology in the Cordilleran region (Noble, 1988; Christiansen and Yeats, 1992) provide a framework for subdividing the volcanic and plutonic rocks of Nevada into three assemblages: (1) an interior andesite-rhyolite assemblage, found primarily in central Nevada, and dominated by ash-flow tuffs erupted from large calderas, (2) a western andesite assemblage, confined to western Nevada, composed mainly of intermediate-composition stratovolcanoes, and (3) a bimodal basalt-rhyolite assemblage

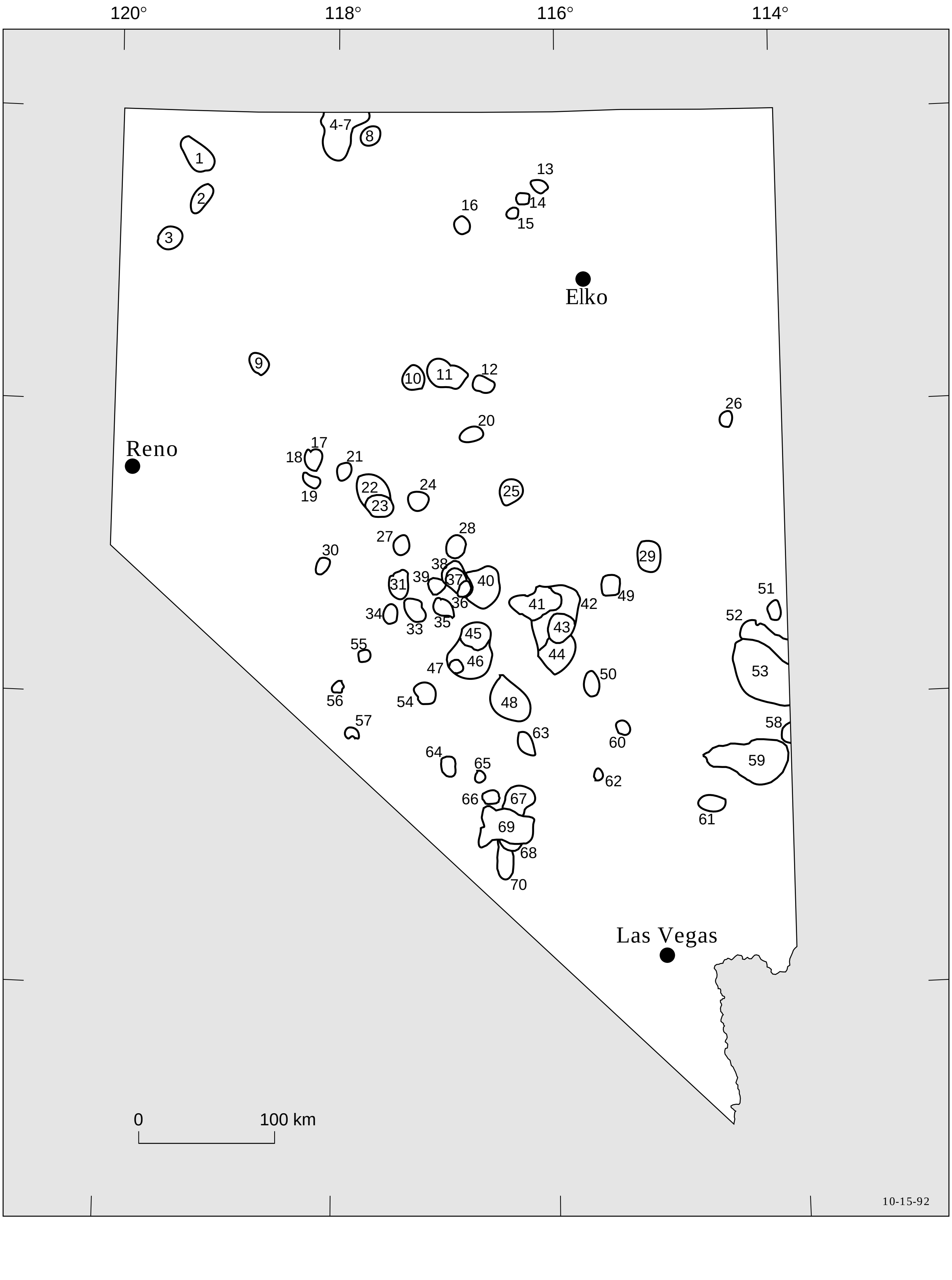

Figure 5-1. Calderas of Nevada. Identifying numbers are keyed to table 5-1.

Table 5-1. Known and speculative calderas of Nevada

No.	Name	Tuff	Age (Ma)	Source
1	Virgin Valley	Idaho Canyon	16	Noble (1988)
2	unnamed	Ashdown	25	Noble (1988)
3	Highrock	Soldier Mdw, Summit Lk	16–15	Noble (1988)
4	Jordan Meadow	Long Ridge	16	Rytuba and McKee (1984)
5	Long Ridge	Long Ridge	16	Rytuba and McKee (1984)
6	Calavera	Double H	16	Rytuba and McKee (1984)
7	Washburn	Oregon Canyon	16	Rytuba and McKee (1984)
8	Hoppin Peaks	Hoppin Peaks	16	Rytuba and McKee (1984)
9	unnamed	?	—	[1]
10	Fish Creek Mountains	Fish Creek Mountains	25	Stewart and McKee (1977)
11	unnamed	Caetano	33	[2]
12	Cortez	Caetano	33	[2], Rytuba and others (1984)
13	unnamed	?	—	[1]
14	Big Cottonwood Cyn.	Tuscarora	38?	Berger and others (1991)
15	Toe Jam Creek	unnamed	38?	Berger and others (1991)
16	unnamed	?	—	[3]
17	Job Canyon	Job Canyon	29	John (1995)
18	Poco Canyon	Poco Canyon, New Pass, Chimney Sprgs	25	John (1995)
19	Elevenmile Canyon	Elevenmile Canyon	25	John (1995)
20	unnamed	Hall Creek	36–33	[4]
21	unnamed	—	30–24?	[4], Hardyman and others (1987); Riehle and others (1972)
22	unnamed	Desatoya	24	[4], McKee and others (1987)
23	unnamed	—	28?	[4], McKee and others (1987
24	unnamed	—	25?	[4], Burke and McKee (1979)
25	unnamed	—	35?	[4]
26	unnamed	Kalamazoo	35	[5]
27	Arc Dome	Arc Dome	25	Brem and others (1991)
28	Northumberland	Northumberland	33	McKee (1974); Hardyman (written commun.)
29	unnamed	?	35?	[1]
30	unnamed	Gabbs Valley	25	John (1992), Ekren and Byers (1986)
31	Toiyabe	Toiyabe, Copper Mountain	23–21	John (1992)
32	Darrough	Darrough Felsite	K?	Brem and others (1991)
33	Peavine	Peavine Canyon	25	Shawe and others (1986); Hardyman (written commun.)
34	unnamed	?	—	[1]
35	Manhattan	Diamond King, Round Rock	25	Shawe (1987)
36	Trail Canyon	Trail Canyon	24	Boden (1986)
37	Mt. Jefferson	Mt. Jefferson	26	Boden (1986)
38	Moores Creek	Moores Creek	27	Boden (1986)
39	Round Mountain	Round Mountain	27	Henry and others (1995)
40	Table Mountain	Haystack Canyon	27	Hardyman (written commun.)
41	Hot Creek Valley	Hot Creek Canyon	30	Hardyman (written commun.)
42	Williams Ridge	Williams Ridge–Morey Pk, Windous Butte	32	Hardyman (written commun.)
43	Lunar Lake	Lunar Cuesta, Monotony	27–26	Ekren and others (1974); Hardyman (written commun.);
44	Pancake Range	Black Rock Summit, Halligan Mesa Palisade Mesa	31–30	Hardyman (written commun.)
45	Big Ten Peak	Big Ten Peak	25	Hardyman (written commun.)
46	Unnamed	—	—	Hardyman (written commun.)
47	Unnamed	—	—	Hardyman (written commun.)
48	Kawich	White Blotch Spring	26–24	Hardyman (written commun.)
49	unnamed	Stone Cabin	35	Best and others (1989b)
50	Quinn Canyon Range	Shingle Pass?	26	Best and others (1989b)
51	unnamed	Cottonwood Wash	31	Best and others (1989b)
52	Indian Peak	Wah Wah Springs	30	Best and others (1989a)
53	White Rock	Lund	28	Best and others (1989a)
54	Fraction	Fraction	21–18	Bonham and Garside(1979)
55	Monte Cristo	Castle Peak	>15	Best and others (1989a)
56	unnamed	Candeleria Hills sequence	25	Robinson and Stewart (1984)
57	Silver Peak	?	6	Robinson (1972)
58	unnamed	Leach Canyon, Condor Canyon	24–22	Best and others (1989b)
59	Caliente	Bauers, Harmony Hills, Hiko, Racer	23–19	Ekren and others (1977)
60	Unnamed	Hancock Summit	26	Best and others (1989b)
61	Kane Springs Wash	Kane Wash	15	Novak (1984)
62	Bald Mountain	Bald Mountain	25	Ekren and others (1977)
63	Cathedral Ridge	-	17	Ekren and others (1971); Bonham and Garside(1979)
64	Stonewall Mountain	Stonewall Flat	8	Weiss and Noble (1989), Hausback and others (1990)
65	Mount Helen	Tolicha Peak	<14	Ekren and others (1971)
66	Silent Canyon	Belted Range	14	Byers and others (1989)
67	Black Mountain	Thirsty Canyon	8	Byers and others (1989)
68	Claim Canyon	Paintbrush	13	Byers and others (1989)
69	Timber Mountain	Timber Mountain	11	Byers and others (1989)
70	Crater Flat-Prospector Pass	Crater Flat	14	Byers and others (1989)

1. Speculative caldera boundary drawn on the basis of gravity signature coincident with volcanic rocks.
2. Depiction of two separate source areas for Caetano Tuff based on consultations with Jim Rytuba and E. H. McKee.
3. Speculative caldera boundary drawn in collaboration with Alan Wallace, USGS, who has mapped in the area.
4. Speculative caldera boundaries drawn in collaboration with E.H. McKee, USGS.
5. Speculative caldera boundary drawn in collaboration with Jon Hegstrom, USGS.
6. In addition to the sources listed, the compilation of Sargent and Roggensack (1984) was extremely valuable in the construction of this table.

in northern and south-central Nevada, composed of flows, domes, and ash-flow tuff sheets. These assemblages are distinctive with regard to petrology, geochemistry, eruptive style, and their associated mineral deposits. The distribution of rocks of these assemblages is shown on plate X, and, in generalized form, in figure 5-2.

Interior Andesite-rhyolite Assemblage

The most voluminous volcanic deposits in Nevada belong to the interior andesite-rhyolite assemblage and extend from Elko and White Pine Counties southwestward to Lyon, Mineral, and northern Nye Counties. Rocks assigned to this assemblage include those in the Tuscarora belt of Christiansen and Yeats (1992) and include such representative rock units as the Caetano Tuff (Stewart and McKee, 1977), Cottonwood Wash Tuff (Best and others, 1989a), Fraction Tuff (Bonham and Garside, 1979), Monotony Tuff (Best and others, 1989b), and Isom Formation (Best and others, 1989b).

Rocks assigned to this assemblage range in age from 43 Ma in northeast Nevada to about 22 Ma in Lyon and Mineral Counties, and as young as 19 Ma in the Tonopah district. A progression in age from northeast to southwest has been noted by several authors (Snyder and others, 1976; Best and others, 1989b). During any one time interval, there appears to have been a nearly continuous belt of volcanism extending from central Nevada east to the Wasatch Range in Utah (Stewart and Carlson, 1976). The magmatism that formed these volcanic deposits is thought to be related to the early stages of subduction of the Farallon Plate, and the southwestward younging is explained by the steepening and collapse of an earlier, gently inclined, subduction zone (Zoback and others, 1981). Other workers question the role of subduction and point out that this magmatism shows a close time and space association with localized crustal extension, as well as that the origin of the volcanic rocks can be explained using only mantle and continental crustal sources (Gans and others, 1989).

The interior andesite-rhyolite assemblage comprises voluminous ash-flow tuffs and flow-dome complexes, and lesser amounts of andesitic lava flows. Basalts are rare. Large caldera complexes are characteristic of this assemblage in central Nevada. Ash-flow tuff is primarily dacite to rhyolite; lava flows are more mafic (andesite to dacite) (Best and others, 1989b). Sr and Nd isotope and trace element geochemistry indicates a dominant crustal component in the generation of some the magmas (Gans and others, 1989). Locally, near Mount Hope in Eureka County, high-fluorine rhyolites are found that resemble topaz rhyolites. Rock names used here are those used by others; no attempt was made to assemble a petrochemical database and apply rock names systematically.

Ash-flow tuffs of this assemblage were, in general, deposited on a regionally extensive erosion surface of low relief (McKee, 1988). Locally, however, the prevolcanic basement displayed considerable relief. For example, Sibbett (1982) described faults with displacements of 900 m cutting the basement and lowermost volcanic beds near Tuscarora. Cook (1965) described a subdued topography formed by erosion of moderately inclined Paleozoic strata deformed in the Sevier Orogeny.

Plutonic rocks coeval with rocks of the andesite-rhyolite assemblage are associated with important, but widely spaced centers of mineralization. The most important of these centers are the Bingham and Tintic districts where the assemblage extends into Utah. In northern Nevada, subvolcanic intrusions and granitic plutons presumably related to this volcanic episode contain Climax molybdenum deposits (Mount Hope) and copper, tungsten, and gold skarns (Battle Mountain, McCoy, Cherry Creek, and Kinsley districts). These plutons and related deposits range from 39 to 36 Ma and are distributed in southeast- to east-trending belts. Some sediment-hosted gold deposits spatially associated with the Roberts Mountain thrust fault in east-central Nevada have been associated with volcanism, and are believed to have been formed during this time interval, but their ages and the genetic link to igneous activity require clarification. In southern Nevada, a more dispersed belt of plutons ranging in age from 35 to 23 Ma are associated with the Pioche and Bristol districts and scattered tungsten skarn, base-metal skarn, and polymetallic vein and replacement deposits.

Volcanic rocks of this assemblage host hot-spring and epithermal quartz-adularia vein deposits. In Elko County, Oligocene ash-flow tuff hosts the Tuscarora district, dated at 38 Ma. But to the south, in Lander, Eureka, and White Pine Counties, volcanic rocks of this assemblage between 38 and 28 Ma in age apparently contain no important deposits. Between 28 and 19 Ma, large multistage calderas formed across Churchill, and northern Nye and Lincoln Counties, and the epithermal mineral deposits in the Wonder, Fairview, Bruner, Round Mountain, Tonopah, Eagle Valley, Stateline, and Atlanta districts were formed. The reason for this apparent hiatus in epithermal mineralization is not well understood.

Western Andesite Assemblage

In Washoe, Storey, Lyon, Douglas, Mineral, and Esmeralda Counties and in Carson City, flows, breccias, lahars, and tuffs of hornblende andesite, minor basalt and felsic tuffs are found that are believed to be a southern extension of the Cascade volcanic arc (Christiansen and Yeats, 1992). In addition, andesites occupy the southern tip of the state and extend south and east into Arizona and southern California. These rocks are intruded by locally abundant dikes and small stocks that range in composition from andesite to rhyolite. Map units representative of this assemblage include the Kate Peak Formation (Gianella, 1975), Pyramid sequence (Bonham and Papke, 1969), Mizpah Formation (Bonham and Garside, 1979), and the Patsy Mine Volcanics (Anderson and others, 1972).

Rocks of the western andesite assemblage range from about 20 Ma near Tonopah to 17 Ma near Pyramid Lake to 12 Ma at Aurora. Andesite in northern Washoe County is as old as 31 Ma. In southernmost Nevada, the ages range in age from 16 to 12 Ma.

The western andesite assemblage is characterized by the remnants of large composite volcanoes. Large ash-flow tuff units and their caldera sources are essentially absent. Volcanic rocks along the Walker Lane Belt (John, 1992)

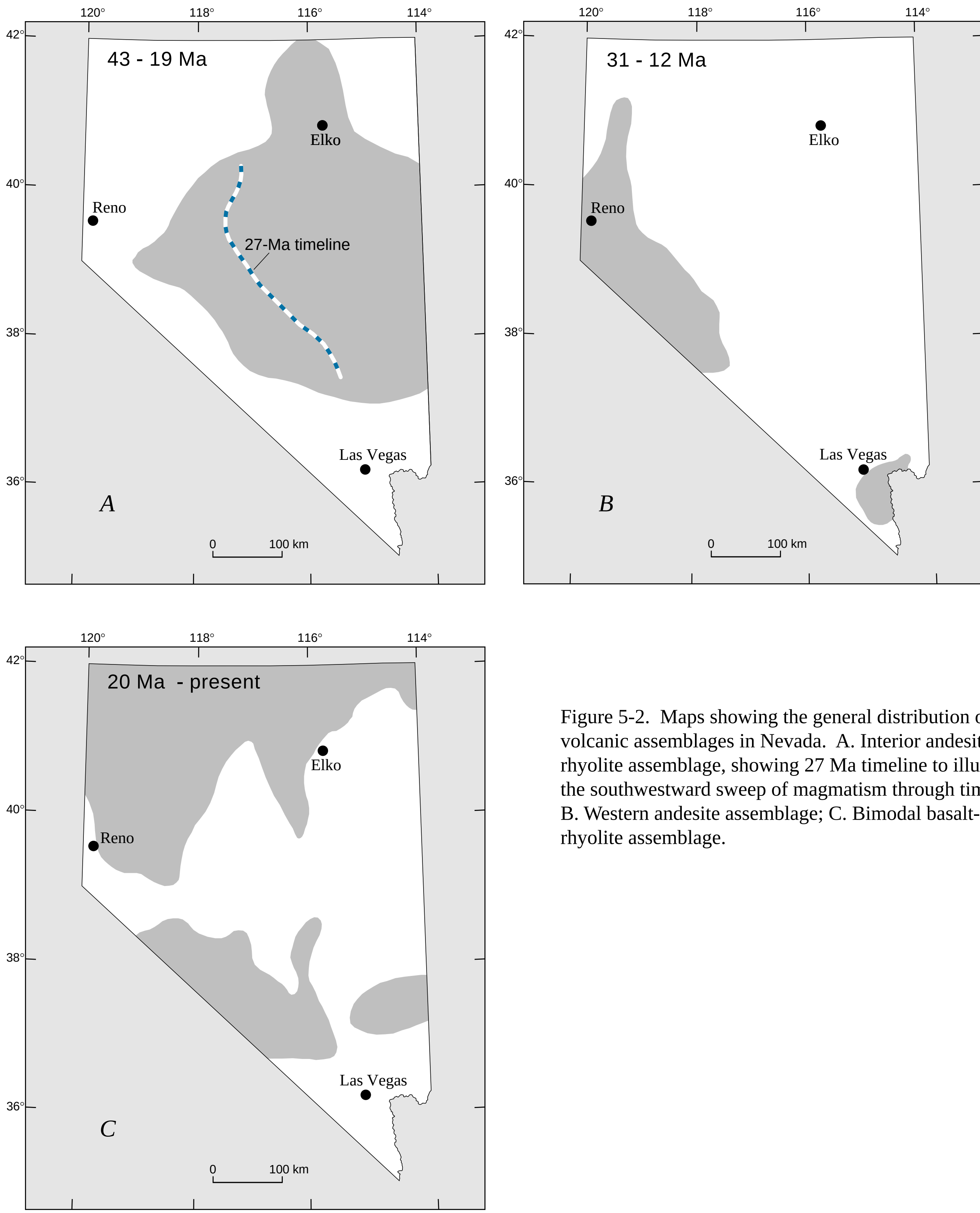

Figure 5-2. Maps showing the general distribution of volcanic assemblages in Nevada. A. Interior andesite-rhyolite assemblage, showing 27 Ma timeline to illustrate the southwestward sweep of magmatism through time; B. Western andesite assemblage; C. Bimodal basalt-rhyolite assemblage.

were deposited simultaneously with steep normal and strike-slip faulting caused by pre-20 Ma extension with a NE-SW orientation of the least principal stress (Zoback and others, 1981).

Hydrothermal alteration is a widespread and distinctive feature of the western andesite assemblage. A small low-F porphyry Mo system (Guanomi) is related to a subvolcanic intrusion coeval with this assemblage. Epithermal ores are hosted by rocks of the western andesite assemblage in the Comstock, Olinghouse, Rawhide, Paradise Peak, Gilbert, Aurora, Borealis, Goldfield, Nelson, and Searchlight districts in Nevada, and the Oatman district in Arizona.

Bimodal Basalt-rhyolite Assemblage

The youngest volcanic rocks in Nevada form the bimodal basalt-rhyolite assemblage. This is typically composed of olivine basalt, pyroxene andesite, and extensive rhyolite flow-dome complexes and ash-flow tuff. These rocks occur in two regions, one covering large parts of Washoe, Humboldt and Elko Counties, with extensions southward, represented by such rock units as the Steens Basalt (Hart and Carlson, 1985), Summit Lake Tuff (Noble and others, 1970), Soldier Meadow Tuff (Korringa, 1973), and an older (early Miocene and Oligocene) group of basalts and related rhyolite tuffs (Ashdown Tuff) in the Black Rock, Pine Forest, and surrounding ranges (Noble and others, 1970). A second area, extending across southern Nevada in Esmeralda, southern Nye, and Lincoln Counties is represented by the ash-flow tuffs and calderas of the southwestern Nevada volcanic field (Christiansen and others, 1977; Noble and others, 1991), volcanic rocks in the Castle Mountains (Ausburn, 1991), and the rocks of the Kane Springs Wash volcanic center (Novak, 1984).

In northern Nevada, rocks of this assemblage range from 23 Ma to 12 Ma, although most formed between 17 and 12 Ma. Bimodal volcanic rocks in south-central Nevada are most voluminous from 16 to 10 Ma. Younger rocks, primarily basalt and basaltic andesite, are found throughout the state; they may be as young as Holocene. Generation of the magmas of this assemblage has been related to extension of the crust in a back-arc environment (Noble, 1988); the youngest rocks were erupted in an extensional environment unrelated to subduction.

Rhyolites of this assemblage have higher sodium contents than earlier rocks of the interior andesite-rhyolite assemblage; some are peralkaline and some are highly evolved (Best and others, 1989b). Caldera-forming eruptions of ash-flow tuff were common, but generally smaller in volume than those of the interior andesite-rhyolite assemblage.

In northern Nevada, vents for the bimodal basalt-rhyolite assemblage are found in NNW-trending belts, associated with dike swarms and linear magnetic anomalies that suggest extension with a NE-SW orientation of the least principal stress. At 10 Ma, this stress field rotated 45° west, and, with the inception of modern basin-range faulting, the episode of voluminous bimodal volcanism came to a close (Zoback and others,1981), although minor activity continues into the Holocene.

Epithermal deposits associated with this assemblage in northern Nevada are at Hog Ranch, National, Cordero, Buckskin, Sleeper, Midas, Cornucopia, Ivanhoe, Jarbidge, Rosebud, Seven Troughs, Fire Creek, and Buckhorn. In southern Nevada, these rocks host deposits in the Silver Peak, Cuprite, and Bullfrog districts. Hot-spring mercury and volcanogenic uranium deposits are also numerous in areas underlain by rocks of this assemblage. Highly evolved rhyolites, often topaz- or cassiterite-bearing, are common in this assemblage; they are delineated on plate 5-1 (see Christiansen and others, 1986). Examples include Izzenhood (Fries, 1942) and the Toano Range (Price and others, 1992). A rhyolitic intrusive-extrusive complex belonging to the southern part of this assemblage, where it extends into Utah, hosts the Pine Grove Climax-type molybdenum deposit (Keith and others, 1986). In northern Nevada, the Majuba Hill tin-molybdenum-copper deposit is hosted by rhyolite related to the bimodal assemblage in the Black Rock Range (MacKenzie and Bookstrom, 1976).

AREAS OF OVERLAP AND INTERFINGERING

Along boundaries between volcanic rock assemblages, overlap and interfingering of rocks belonging to two and locally three assemblages is common. In the Tonopah district, for example, rocks described and dated by Bonham and Garside (1979) can be assigned as follows: ash-flow tuffs older than 21 Ma belong to the interior andesite-rhyolite assemblage; the Mizpah Andesite (20.5 Ma) represents the western andesite assemblage and is overlain by the Fraction tuff. We assigned the Fraction tuff (20-18 Ma) to the interior andesite-rhyolite assemblage, although Christiansen and Yeats (1992) suggest it is one of the earliest representatives of the bimodal rocks. It is overlain by several trachyandesite units that we assign to the western andesite assemblage. The bimodal basalt-rhyolite assemblage is represented by the olivine-rich trachyandesite of Red Mountain (15 Ma) and by numerous younger rhyolite dome complexes.

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