U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

GRANITIC ROCKS IN THE TRIASSIC-JURASSIC MAGMATIC ARC OF WESTERN NEVADA AND EASTERN CALIFORNIA

by

David A. John[1] , Richard A. Schweickert[2], and Allen C. Robinson[1]

Open-File Report

94-148

---

[1]U.S. Geological Survey, Menlo Park, California

[2]Mackay School of Mines, University of Nevada, Reno, Nevada

Introduction

This paper is a chapter from a longer report that describes the geology and geophysics of part of the Triassic and Jurassic magmatic arc of western Nevada and eastern California. A summary of the report has been released in abstract form (Schweickert, 1993), but because of the length and complexity of the report and the long review process, this chapter is being released as an open-file report to make the data and interpretations contained in it available.

The part of the Triassic and Jurassic arc that is the focus of this study is an irregular area in western Nevada and eastern California centered at the latitude of Lake Tahoe (fig. 1). Granitic rocks are widely distributed in the study area, forming more than 75 percent of the exposed pre-Cenozoic basement rocks. These rocks, which probably include more than 100 separately emplaced plutons, can be broadly divided into seven groups on the basis of age, chemical composition, and regional distribution. These groups are: (1) Middle or earliest Late Triassic in the northern Wassuk Range, (2) latest Early Jurassic in the Pine Grove Hills-Wassuk Range-Gillis Range, (3) Middle Jurassic in the Yerington area, (4) Middle or earliest Late Jurassic in the northern Sierra Nevada, (5) earliest Late Jurassic in the West Walker River area, (6) Cretaceous, and (7) late Tertiary (fig. 2). Although the absence of reliable isotopic age data and lack of detailed field and petrologic studies hinders assignment of many plutons to these groups, the division of granitic rocks shown in figure 2 represents our best estimation based on presently available data. This section summarizes geologic, geochronologic, geochemical, petrographic, and metallogenic data for each group of plutons and discusses some of the differences between groups of plutons. Because the focus of this study is on Triassic and Jurassic rocks, only brief summaries of the Cretaceous and Tertiary granitoids are included for completeness and comparison.

This study is primarily a compilation and interpretation of existing data. New field studies were limited to the southwest part of the Reno 1° by 2° quadrangle exclusive of the Sierra Nevada and were undertaken as part of the Reno CUSMAP project (John and others, 1993). Samples collected during this field work were studied petrographically and chemically analyzed (John, 1992). Additional petrographic studies were made as part of this study of samples collected by R.A. Schweickert (1972, 1976) in the southwest corner of the study area and of samples collected by J.H. Stewart and others (Stewart and others, 1981, 1989; Stewart and Johannesen, 1981; Stewart and Reynolds, 1987) in the Wassuk Range, Pine Nut Mountains, Pine Grove Hills, and southwestern Gillis Range.

Sources of chemical data used in this study include about 80 analyses of samples collected by D.A. John, primarily in the Reno 1° by 2° quadrangle (John, 1992), about 30 unpublished analyses of samples collected by D.A. John and R.A. Armin in the northwestern part of the Walker Lake 1° by 2° quadrangle, about 70 unpublished analyses of various plutons in western Nevada from the files of MagmaChem (S.B. Keith, written commun., 1990), about 50 unpublished analyses of samples collected in the southwest and south-central parts of the study area by A.C. Robinson, analyses of five samples collected by D.S. Harwood in the Donner Pass area, and data from Armin and John (1983), Agüe and Brimhall (1988), Thompson and White (1964), Lee (1984), Schweickert (1976), Dilles (1984), Bingler (1978), Hudson (1977), and Wallace (1975). All chemical analyses are recalculated to 100 percent on a volatile-free basis. Rubidium and strontium concentrations and isotopic ratios were measured and whole-rock Rb-Sr isochron ages calculated by A.C. Robinson for many plutons using samples collected primarily by A.C. Robinson and D.A. John (table 1).

Middle or earliest Late Triassic granitoids in the northern Wassuk Range

Distribution. Granitic rocks of Triassic or inferred Triassic age are limited to small exposures in the northern Wassuk Range and in the low hills about 10 km south-southeast of Yerington (fig. 2). Two bodies of plutonic rocks are included in this group: (1) dioritic dikes and stocks in the northern Wassuk Range (Wassuk Range Diorite) that intrude and are locally complexly intermixed with Triassic metavolcanic rocks, and (2) a composite quartz monzonite to diorite pluton south of Yerington (Strosnider Ranch pluton). The Wassuk Range Diorite is associated with a sequence of broadly bimodal metavolcanic rocks that probably are correlative with the McConnell Canyon Volcanics (J.H. Dilles, written commun., 1991) in the Singatse Range. These metavolcanic rocks consist of silicic ignimbrites that are overlain by andesite and rhyolite lavas (Dilles and Wright, 1988). The Wassuk Range Diorite intrudes the silicic ignimbrites and an andesite lava flow near the base of the upper part of the volcanic section. Dilles and Wright (1988) suggest that the diorite may be comagmatic with the andesite that it intrudes. The Strosnider Ranch pluton is a composite pluton consisting of a mafic dioritic border phase petrographically similar to the Wassuk Range Diorite and an interior, quartz-rich quartz monzonite to granodiorite phase (Proffett and Dilles, 1984).

Age. Dilles and Wright (1988) obtained a concordant zircon U-Pb age of 232.7±2.9 Ma on a sample of the Wassuk Range Diorite collected in the northern Wassuk Range. They also obtained a U-Pb age of 232.2±2.3 Ma on a quartz porphyry dike in the northern Wassuk Range that they interpret as a feeder for some of the metavolcanic rocks associated with the Wassuk Range Diorite. The Strosnider Ranch pluton is undated but intrudes metavolcanic rocks possibly correlative to the Middle Triassic or older McConnell Canyon Volcanics and is intruded by Jurassic(?) andesite and rhyolite dikes (Proffett and Dilles, 1984).

Chemistry, modal composition, and petrography. Only limited chemical and modal data are available for the Triassic granitoids. The Wassuk Range Diorite is medium- to coarse-grained, equigranular biotite-hornblende quartz diorite and diorite that contains about 40 to 50 percent plagioclase, 10 to 20 percent combined quartz and orthoclase, 20 percent hornblende, and 10 percent biotite (Bingler, 1978). Bingler (1978) and Dilles (1984) each report one chemical analysis of the Wassuk Range Diorite suggesting that it ranges from about 53 to 59 percent SiO_2 and is somewhat less alkali-rich than Middle Jurassic granitoids in the Yerington area (figs. 3 and 4). The Strosnider Ranch pluton is medium- to coarse-grained and locally porphyritic containing small potassium feldspar phenocrysts. It ranges from a dioritic border phase that contains 25 to 50 percent ragged hornblende which replaces clinopyroxene to a granodioritic or granitic interior phase that contains 30 to 35 percent quartz and 10 to 15 percent shreddy biotite which replaces mafic minerals (Proffett and Dilles, 1984). No chemical analyses are available for the Strosnider Ranch pluton.

Depth of emplacement. The Triassic granitoids are thought to intrude coeval and cogenetic volcanic rocks (Dilles and Wright, 1988), and thus they appear to have been emplaced at shallow depths. One hornblende analysis reported by Dilles (1984) for the Wassuk Range Diorite yields a pressure of 0.9 kbar using the hornblende geobarometer of Johnson and Rutherford (1989). This pressure is equivalent to about 3 km depth.

Hydrothermal alteration. Most exposures of the Triassic granitoids are metamorphosed and strongly altered. They contain abundant epidote, white mica, albite, and chlorite (Bingler, 1978; Proffett and Dilles, 1984). Hornblende is commonly replaced by shreddy, fine-grained biotite. In addition, these rocks commonly are tectonically deformed and locally have a secondary foliation.

Mineralization. No mineral deposits are known to be related to the Triassic granitoids.

Latest Early Jurassic plutons in the Pine Grove Hills and Wassuk Range

This group of granitic plutons includes several poorly dated, composite plutons in the Pine Grove Hills and in the central and southern parts of the Wassuk Range—granodiorite of Lobdell Summit (no. 4, fig. 2), granite of Baldwin Canyon, granitic rocks of Cottonwood Creek, and granitic rocks of Babbitt (no. 5, fig. 2)—that are inferred to be Early Jurassic in age on the basis of whole-rock Rb-Sr isochrons (table 1; Robinson and Kistler, 1986).

Distribution. Late Early Jurassic plutons are exposed in the Pine Grove Hills, in the central and southern parts of the Wassuk Range, and possibly in the southwestern Gillis Range (fig. 2). The largest pluton is the granodiorite of Lobdell Summit (no. 3, fig. 2) which is extensively exposed in several large masses in the Pine Grove Hills (Stewart and others, 1981; Stewart and Reynolds, 1987). The granite of Baldwin Canyon (no. 4, fig. 2) crops out in the southern Wassuk Range about 5 km southeast of the southernmost exposure of the granodiorite of Lobdell Summit. The granitic rocks of Babbitt and the granitic rocks of Cottonwood Creek (no. 5, fig. 2) consist of scattered exposures in the central Wassuk Range on the south and north sides of Mt. Grant, respectively. Several other plutons including the granite of Thorne (no. 6, fig. 2) and monzodiorite (no. 7, fig. 2) in the southwestern Gillis Range are Early or Middle Jurassic in age on the basis of petrographic characteristics or strontium isotope data (see below).

Age. Ten samples of the granodiorite of Lobdell Summit have yielded a whole-rock Rb-Sr isochron of 186.9±8.5 Ma (table 1). This new age is similar to the 186.5±7.7-Ma whole-rock Rb-Sr age reported by Robinson and Kistler (1986) that was calculated from seven samples of the granodiorite of Lobdell Summit combined with two samples of the granite of Baldwin Canyon. K-Ar ages on hydrothermal minerals in the granodiorite of Lobdell Summit are 80.8±2.4 (biotite) and 85.9±2.0 (muscovite) (table 2; Robinson and Kistler, 1986).

Robinson and Kistler (1986) obtained a four-point whole-rock Rb-Sr isochron age of 188.2±5.5 Ma from combined samples of the mafic pillow breccia of Ashby and the granitic rocks of Cottonwood Creek and the granitic rocks of Babbitt and a five-point isochron of 186.4±5.1 Ma for the metavolcanic rocks of Mt. Grant and the Dunlap Formation. Although the latter isochron has a somewhat lower intercept, it was suggested that the granitic rocks of Babbitt and the granitic rocks of Cottonwood Creek might represent caldera-rim plutons associated with Early Jurassic metavolcanic rocks in the Walker Lake area. However, a zircon U-Pb age of about 242 Ma on a rhyolite tuff collected at the top of Mt. Grant obtained as part of this project (D.M. Unruh, written commun., 1991) makes this suggestion extremely unlikely.

Chemistry, modal composition, and petrography. The granodiorite of Lobdell Summit is a heterogeneous, probably composite, pluton that has not been mapped in detail. It is composed of medium-grained hornblende-biotite or biotite granodiorite and biotite granite. The main (northern) part of the granodiorite phase generally contains about 10 to 20 percent shreddy, fine-grained biotite, which is in part pseudomorphous after hornblende. Unaltered hornblende is uncommon and subordinate in abundance to biotite. The granite phase mostly consists of graphic intergrowths of quartz and perthitic potassium feldspar with only trace amounts of interstitial biotite. The southeasternmost exposures of this pluton as shown on existing maps (Stewart and others, 1981; John, 1983) are more mafic and more hornblende-rich than other parts of the pluton and contain 10 to 30 percent hornblende, only minor biotite, and prominent crystals of sphene (Nowak, 1979; Stewart and others, 1981). Rb-Sr element concentration and isotopic data suggest that these exposures probably are not comagmatic with the main part of pluton exposed further north (Robinson and Kistler, 1986); however, the Rb-Sr data for these exposures are similar to Rb-Sr concentration and isotopic data for samples of the nearby Middle Jurassic granodiorite of Chipmunk Spring (see section on "Middle Jurassic plutons in the Yerington area"). Seven chemical analyses indicate that SiO_2 content of the main part of the granodiorite of Lobdell Summit ranges from about 65 to 74.5 percent and that the potassium and total alkali contents are notably less than in the Middle Jurassic granitoids (compare figs. 3 and 4).

The granite of Baldwin Canyon is a medium-grained, equigranular to porphyritic, leucocratic granite that generally contains less than 5 percent shreddy biotite and minor hornblende (Stewart and others, 1981). Only one chemical analysis from the southwest part of this pluton is available and may be atypical of most of the pluton. The analyzed sample contains only about 63 weight percent SiO2 and has a much lower Rb/Sr ratio (approx. 0.09) than analyses reported by Robinson and Kistler (1986) (Rb/Sr=0.96-1.09), although it has relatively high potassium and total alkali contents (fig. 3).

The granitic rocks of Babbitt mostly consist of medium- to coarse-grained biotite-hornblende quartz monzodiorite. Mafic minerals, consisting of hornblende and less abundant fine-grained, shreddy biotite, average about 20 to 30 percent. Other rock types in this pluton include medium-grained, sparsely porphyritic granite, quartz monzonite, and granodiorite that may be dikes in the main phase of the pluton (Stewart and Johannesen, 1981). No chemical data are available for the granitic rocks of Babbitt.

The granitic rocks of Cottonwood Creek comprise a heterogeneous pluton consisting of medium-grained equigranular hornblende-biotite granodiorite and medium- to coarse-grained biotite granite that contains about 5 percent fine-grained, shreddy biotite. Both rock types include intermixed diorite and mafic dikes, leucocratic zones, and border zones consisting of irregular masses of intimately intermixed granitic rocks and metavolcanic wall rocks (Stewart and others, 1981). The granite phase rarely contains small (0.2 mm) garnets. No chemical data are available for this pluton.

The granite of Thorne is a somewhat heterogeneous pluton mostly composed of fine- to medium-grained biotite granite or granodiorite (Stewart and Johannesen, 1981). The texture of the pluton ranges from medium-grained porphyry containing 1 to 5 mm plagioclase phenocrysts set in a fine-grained graphic textured groundmass to medium-grained seriate. Primary mafic mineral content ranges from about 3 to 10 percent, but these minerals are mostly replaced by fine-grained green biotite. High-salinity fluid inclusions are common in igneous quartz crystals. Three chemical analyses of this pluton suggests that it contains about 72-74 weight percent SiO_2, has relatively high K_2O and total alkali contents, and is weakly to strongly peraluminous (fig. 3).

Depth of emplacement. Depths of emplacement of these plutons can not be precisely estimated from available data. However, relatively shallow depths are inferred on the basis of fluid-inclusion populations in quartz, which commonly contain high-salinity (halite-bearing) fluid inclusions suggesting paleodepths $\leq$5 km (John, 1989). No other depth estimates can be made with existing data.

Hydrothermal alteration. Shreddy, fine-grained biotite that is interstitial or forms small clots and locally replaces hornblende is common in all these plutons. The origin of most of this biotite is unclear, although much of it may be hydrothermal. Parts of the granite of Thorne are cut by microveins of potassium feldspar and biotite. Weak to moderate deuteric or propylitic alteration is common in most plutons and manifested by partial replacement of biotite by chlorite and alteration of plagioclase to sericite and (or) epidote. Biotitic and sericitic alteration of the granodiorite of Lobdell Summit is associated with Cretaceous granite porphyry and rhyolite dikes in the Wilson (Pine Grove) district.

Mineralization. No significant mineral deposits related to the Early Jurassic plutons are known. Gold-silver mineralization at the Wheeler, Wilson, and Rockland Mines in the Wilson district is present in quartz veins and stringers in shear zones in the granodiorite of Lobdell Summit associated with altered granite porphyry or rhyolite dikes (Moore, 1969). Hydrothermal biotite and sericite from these mines have Late Cretaceous ages (80.8±2.4 and 85.9±2.0 Ma, respectively, Robinson and Kistler, 1986), which are approximately the same age as the nearby granodiorite of Nye Canyon (88-92 Ma, tables 1 and 2). The Cowboy tungsten mine is located in a septum of metamorphic rocks between the granodiorite of Lobdell Summit and the granodiorite of Nye Canyon. Here, tungsten minerals are present in irregular skarn that replaces marble

(Moore, 1969; Schilling, 1968). Small amounts of lead and silver have also been produced (Moore, 1969). It is not known which pluton formed the mineralized skarn.

Middle Jurassic plutons in the Yerington area

Middle Jurassic (ca. 170-165 Ma) plutonic rocks centered on the Yerington district in the middle part of the study area are the most well-studied group of granitic rocks due to their genetic ties to porphyry copper and copper and iron skarn deposits (Bingler, 1978; Proffett and Dilles, 1984; Dilles, 1984, 1987; Dilles and Wright, 1988; Dilles and Einaudi, 1992; Carten, 1986; Hudson and Oriel, 1979; Hudson, 1983; Castor, 1972; Battles, 1991). This group of granitoid plutons includes the Yerington and Shamrock (Mt. Siegel) batholiths, the Gray Hills pluton, and the granitic rocks of Butler Mountain (probably the eastern parts of the Shamrock batholith), the Sunrise Pass pluton, quartz monzodiorite porphyry dikes, numerous dioritic bodies in the northern Pine Nut Mountains, the granodiorite of Chipmunk Spring in the East Walker River area, and small plutons near Weber Reservoir (Afterthought pluton) and near the Dayton iron deposit (Iron Blossom pluton) (fig. 2). The Ivy Ranch pluton along the East Walker River also has many characteristics similar to these Middle Jurassic plutons; however, Rb-Sr whole-rock isotopic data suggest that it is Late Cretaceous in age. Several of the plutons, notably the Yerington and Shamrock batholiths, appear to be closely associated with coeval volcanic rocks (Artesia Lake Volcanics and Fulstone Spring Volcanics, respectively; Dilles, 1987; Dilles and Wright, 1988).

Distribution. Middle Jurassic and inferred Middle Jurassic granitoids are exposed in a west-northwest-trending belt across the central part of the study area with major exposures in the Pine Nut Mountains, the Singatse, Buckskin, and northern Wassuk Ranges, and the East Walker River area (fig. 2). The granitoids extend from the vicinity of Carson City in the northern Pine Nut Mountains east to the northern Wassuk Range. Farther east, small exposures of Middle Jurassic porphyry dikes in the Wildhorse Canyon area of the Gillis Range, of Jurassic(?) granitic rocks between the Calico Hills and the east side of Weber Reservoir (Afterthought pluton), the 172-Ma granodiorite of Hidden Wash (no. 17, fig. 2) (D.M. Unruh, written commun.), and of the earliest Late Jurassic (approx. 161 Ma) granodiorite of Copper Mountain just east of the study area suggest that this belt of granitoids is about 100 km long and 25 to 40 km wide (fig. 2); exposures of Middle Jurassic(?) metavolcanic rocks in the Carson Range extend this belt of igneous rocks to about 130 km long. Present exposures of individual plutons also are strongly elongated in a west-northwest direction (notably the Yerington and Shamrock batholiths and quartz monzodiorite porphyry dikes; fig. 2). Although much of the elongation is due to 100+ percent east-west extension across the area during the late Cenozoic (Proffett, 1977; Proffett and Dilles, 1984; Geissman and others, 1982), Proffett and Dilles (1984) and Dilles and Wright (1988) have suggested that several of these plutons were emplaced into an extensional environment and that the quartz monzodiorite porphyry dikes intrude east-west trending faults formed during Middle Jurassic extension. Present exposures of the Shamrock and Yerington batholiths cover more than 1,000 km^2 and 400 km^2, respectively.

Age. The Yerington and Shamrock batholiths have been dated using zircon U-Pb methods which indicate that the Yerington batholith was emplaced between about 169-168 Ma, the Shamrock batholith is about 166 Ma in age, and that volcanic rocks possibly cogenetic with the Shamrock batholith (Fulstone Spring Volcanics) are about 167-166 Ma in age (table 2; Dilles and Wright, 1988). The U-Pb ages on the Yerington and Shamrock batholiths and porphyry intrusions in the Fulstone Spring Volcanics are significantly older than published K-Ar ages which range from 81 to 148 Ma for the Yerington batholith, 103 to 158 Ma for the Shamrock batholith, and approximately 127 Ma for an intrusion in the Fulstone Spring Volcanics (table 2). A hornblende K-Ar age for the Gray Hills pluton (157.4±5 Ma) is virtually identical to the hornblende K-Ar age of the Shamrock batholith supporting the possible correlation of these plutons. A hornblende quartz monzodiorite porphyry dike in the northern Buckskin Range has a U-Pb age of approximately 165 Ma (Dilles and Wright, 1988), and a megascopically similar dike in the Gillis Range also has a U-Pb age of about 165-171 Ma (D.M. Unruh, written commun., 1991). Dilles and Wright (1988) also obtained an imprecise zircon Pb-Pb age of 172±5 Ma on the Sunrise Pass pluton; in comparison, this pluton has yielded a hornblende K-Ar age of 149.3±8 Ma (Krueger and Schilling, 1971; Castor, 1972). The granodiorite of Hidden Wash has yielded a U-Pb age of 172±4 Ma as part of this study (D.M. Unruh, written commun., 1991). The granodiorite of Copper Mountain, located just east of the study area, has hornblende and biotite K-Ar ages of 158±7 and 161±4 Ma, respectively (table 2). The granodiorite of Chipmunk Spring has a ten-point whole-rock Rb-Sr isochron age of 168.6±7.2 Ma (table 1). The Afterthought and Iron Blossom plutons and diorite bodies in the Pine Nut Mountains are undated but inferred to be Middle Jurassic in age on the basis of chemistry, metallogeny, and (or) hydrothermal alteration.

Chemistry, modal composition, and petrography. The Yerington batholith (Dilles, 1984, 1987; Castor, 1972) and parts of the Shamrock batholith and the Sunrise Pass pluton (Castor, 1972) are the only plutons that have been studied in detail, although abundant chemical and petrographic data are available for many of the other plutons.

The Yerington batholith constitutes the most compositionally diverse Middle Jurassic plutonic unit in the study area, ranging from cumulate gabbro to granite porphyry (Dilles, 1984, 1987). The Yerington batholith consists of 3 major intrusive phases which successively decrease in volume (from about 75 to 19 to 6 volume percent) and increase in silica content (average of 60, 66, and 68 weight percent SiO_2) and depth of emplacement (<1, 1.5, and 2.5-5 km) from the oldest to the youngest phases. The three successive intrusive phases are: (1) the informally named McLeod Hill quartz monzodiorite of Carten (1986), (2) the informally named Bear quartz monzonite of Carten (1986), and (3) the informally named Luhr Hill granite of Carten (1986). The Luhr Hill granite grades into granite porphyry dikes that are temporally and spatially associated with porphyry copper mineralization that immediately overlies granite cupolas in the batholith (Dilles, 1987). Textures of the Yerington batholith vary from fine- to medium-grained hornblende gabbro, containing about 50 percent hornblende, to augite-bearing, fine- to medium-grained, equigranular biotite-hornblende quartz monzodiorite, containing 15 to 25 percent mafic minerals, to medium-grained porphyritic hornblende-biotite granite and granite porphyry, containing scattered potassium feldspar megacrysts as long as 2 cm and about 5 to 10 percent mafic minerals (Dilles, 1987). High-salinity (halite-bearing) fluid inclusions are ubiquitous in igneous quartz crystals in the Yerington batholith.

The silica content of the Yerington batholith ranges from about 55 to 69 weight percent exclusive of gabbroic segregations (Dilles, 1987). The batholith is characterized by very high Sr contents (generally >1,000 ppm; Dilles, 1987; Robinson and Kistler, 1986) and low Rb/Sr ratios (fig. 4). It is similar to other Middle Jurassic plutons in the Yerington area, in having relatively high K_2O and Ba contents compared to the other groups of granitoids in the study area. Rocks of the Yerington batholith form a coherent compositional series that is similar to calc-alkaline suites of high-K orogenic (arc) andesites and dacites (Dilles, 1987).

Numerous small bodies of diorite and quartz diorite crop out in the northern Pine Nut Mountains (fig. 2; J.H. Stewart, unpub. mapping, 1989) and at the Dayton iron deposit (Reeves and others, 1958; Roylance, 1966). These rocks have fine-grained, hypidomorphic granular textures and contain about 25 to 35 percent mafic minerals dominantly composed of hornblende. Clinopyroxene, which is partially replaced by hornblende, and (or) biotite, which partially replaces hornblende, are present in small abundances. The diorites are recrystallized to biotite hornfels where they are intruded by Cretaceous(?) plutons, notably along the west side of the Pine Nut Mountains just southeast of Carson City. Diorite at the Dayton iron deposit predates iron skarn mineralization (Roylance, 1966). The diorites are commonly cut by epidote or actinolite veins that locally have narrow, bleached albite(?) selvages. The silica content of three diorite samples from the northern Pine Nut Mountains ranges from about 56 to 58 weight percent, and they have notably high alkali contents compared to nearby Triassic and Cretaceous plutons with similar silica contents; in general, their chemical compositions are very similar to mafic parts of the Yerington batholith (fig. 4). The diorites are believed to be Middle Jurassic in age on the basis of their chemical compositions and the types of hydrothermal alteration present in them.

Most of the Shamrock (Mt. Siegel) batholith is a seriate, medium-grained hornblende or biotite-hornblende granodiorite or granite. These rocks generally contain about 10 to 20 percent combined hornblende and biotite with hornblende commonly being more abundant than biotite. Potassium feldspar crystals have a conspicuous pink coloration and are highly turbid in thin section. Quartz porphyry dikes are locally present in the Singatse Range (Proffett and Dilles, 1984) and in the Pine Nut Mountains, but apparently do not form swarms of dikes similar to the dike swarms that are present in the Yerington batholith. The compositional variation of the Shamrock batholith apparently is less than that shown by the Yerington batholith with the SiO_2 content of ten relatively unaltered samples of the Shamrock batholith ranging from 61.3 to 69.7 weight percent (fig. 4). Potassium and total alkali contents are high as they are in the Yerington batholith, but Sr and Ba contents are markedly lower and Rb/Sr ratios higher than those in the Yerington batholith and in the Sunrise Pass pluton. High-salinity fluid inclusions in igneous quartz appear to be ubiquitous in this pluton.

The Gray Hills pluton is a medium-grained, (biotite) hornblende granodiorite that is petrographically and compositionally similar to the Shamrock batholith (fig. 4). Bingler (1978) describes widespread albitization of the Gray Hills pluton that is similar to hydrothermal alteration that is widespread in the Shamrock batholith (see section on hydrothermal alteration below). A strontium isotope analysis of an unaltered sample of the Gray Hills pluton is also similar to isotopic analyses of samples from the Shamrock batholith. On the basis of similarities in composition, petrography, Sr isotopic data, and hydrothermal alteration, and nearly identical younger hornblende K-Ar ages (table 2), we believe that the Shamrock batholith and the Gray Hills pluton probably are parts of the same major intrusion.

Northern exposures of the granitic rocks of Butler Mountain (the area that includes Butler Mountain; Stewart and others, 1981; fig. 2) are also megascopically, petrographically, and isotopically similar to the Shamrock batholith and the Gray Hills pluton. These rocks are medium-grained, sparsely porphyritic granodiorite that contain about 15 percent mafic minerals composed of hornblende and lesser biotite, and scattered, small (<1 cm), pink-colored potassium feldspar phenocrysts. Much of the biotite is chloritized, and chlorite-epidote-sericite alteration zones are common (Stewart and others, 1981). High-salinity fluid inclusions are abundant in igneous quartz crystals. No chemical analyses are available, but Rb-Sr element concentration and isotopic compositions are nearly identical to those of nearby samples of the Shamrock batholith and the Gray Hills pluton. On the basis of the petrographic and isotopic similarities of these three plutons and a remarkably linear west-northwest-trending southern boundary of the Shamrock batholith, the Gray Hills pluton, and the northern part of the granitic rocks of Butler Mountain (fig. 2), we believe that these plutons represent a single large batholith that is now exposed across an area covering about 1,000 km^2.

The Sunrise Pass pluton consists of two textural phases of (biotite-) hornblende granodiorite and granite: a medium-grained, equigranular phase and a medium- to coarse-grained, coarsely porphyritic phase that contains 10 to 20 percent white to pink potassium feldspar megacrysts as long as 3 cm (Castor, 1972; J.H. Stewart, oral commun., 1989). Modal mineralogy and chemical composition of both phases are similar and contacts between the two phases are largely gradational suggesting that both phases are part of a single major intrusion (Castor, 1972; J.H. Stewart, oral commun., 1989). Both textural phases generally contain 5 to 10 percent hornblende and only minor biotite. Fine-grained sphene is abundant and conspicuous. A satellite body exposed in Sullivan Canyon about 4 km northwest of the main exposures of the

Sunrise Pass pluton (fig. 2) includes outcrops of both textural phases that are megascopically, petrographically, and compositionally similar to other parts of the pluton. Chemical analyses of eleven samples of relatively unaltered rock indicate that there is little compositional variation in the Sunrise Pass pluton; SiO_2 content ranges from about 62 to 68 weight percent with most samples clustering around 66 percent (fig. 4). Potassium, total alkali, and barium contents are high similar to other Middle Jurassic plutons in the Yerington area (fig. 4). There are no consistent compositional differences between porphyritic and equigranular phases. High-salinity fluid inclusions are ubiquitous in igneous quartz crystals.

Hornblende quartz monzodiorite porphyry dikes (Proffett and Dilles, 1984; Dilles and Wright, 1988) [granodiorite porphyry units of Castor (1972) and of Bingler (1978)] contain about 40 to 50 percent phenocrysts consisting mostly of plagioclase that forms tabular crystals as much as 1.5 cm long, less abundant hornblende, biotite, and resorbed quartz, and sparse potassium feldspar megacrysts as long as 6 cm in a microcrystalline (0.1 mm) groundmass of the same minerals (Castor, 1972; Bingler, 1978; Proffett and Dilles, 1984). Rounded inclusions of fine-grained hornblende andesite are abundant locally (Proffett and Dilles, 1984). Chemical analyses of three samples collected from the east side of the Pine Nut Mountains, from near Yerington, and from the northern Wassuk Range are nearly identical and contain about 60 weight percent SiO_2 and about 2.5 weight percent K_2O (fig. 4). Trace-element analyses for two of the samples are also nearly identical (fig. 4). High-salinity fluid inclusions are present in quartz phenocrysts.

The granodiorite of Chipmunk Spring is a medium-grained, seriate to sparsely porphyritic biotite-hornblende granodiorite. It contains about 10 percent mafic minerals consisting of partially chloritized hornblende and biotite; hornblende generally is about twice as abundant as biotite. Much of the pluton is moderately altered with sericite replacing plagioclase, chlorite replacing mafic minerals, and abundant epidote. Pinkish potassium feldspar crystals are highly turbid. High-salinity fluid inclusions are present in igneous quartz in most samples. No chemical data are available for this pluton. Stewart and others (1981) mapped several sets of altered, northeast-trending dikes that intrude the pluton, and that they thought were related to it. These dikes include propylitized, fine- to medium-grained hornblende-plagioclase porphyry and sericitized, fine- to medium-grained leucocratic granite porphyry.

The Afterthought pluton is a composite intrusion consisting of five or more textural phases ranging from diorite or gabbro to granite that are discontinuously exposed from the low hills east of Weber Reservoir to the Calico Hills and were encountered in drill holes beneath the Calico Hills (Lawrence and Redmond, 1967; Lawrence, 1969; Satkoski and others, 1985). Quartz diorite and granodiorite phases evidently constitute most of the pluton. Only surface exposures of the pluton in the southern part of the low hills east of Weber Reservoir were examined in this study. These exposures consist of fairly uniform fine- to medium-grained, seriate biotite-hornblende granodiorite containing about 10 to 15 percent hornblende and 5 percent biotite. These rocks contain about 65 to 68 weight percent SiO_2 and have very high Sr contents (1,600-1,790 ppm, fig. 4). High-salinity fluid inclusions are abundant in igneous quartz crystals. The Afterthought pluton is inferred to be Middle Jurassic in age on the basis of its composition, associated hydrothermal alteration and mineralization (see below), and presence of high-salinity fluid inclusions.

The Iron Blossom pluton (no. 15, fig. 2) crops out between the Iron Blossom (iron skarn) prospect and U.S. Highway 50 and probably was encountered in drill holes at the Dayton iron deposit (Roylance, 1966). Surface exposures near the Iron Blossom Prospect consist of medium-grained, seriate biotite-hornblende granodiorite that contains about 20 percent mafic minerals dominantly composed of hornblende. Rocks similar in appearance to this granodiorite are present in drill holes underlying and near the Dayton iron deposit and were inferred to be the source of mineralizing fluids that formed the iron skarn (Roylance, 1966). A Jurassic age is inferred for this pluton based on its relatively high K_2O and Zr contents (fig. 4) and apparent genetic relation to iron skarn mineralization (see following section on mineralization).

The granodiorite of Copper Mountain (no. 18, fig. 2) crops out in several fault blocks at Copper Mountain just east of the study area on the east side of the Gillis Range. The pluton is a medium-grained biotite-hornblende granodiorite containing about 3 percent biotite and 13 percent hornblende (Ekren and Byers, 1986). Chemical analyses of this pluton are similar to other Middle Jurassic plutons in the Yerington area with relatively high K_2O, total alkali, and Zr contents (fig. 4).

The Ivy Ranch pluton (16, fig. 2) is a medium-grained, porphyritic hornblende biotite granite that contains small (≤1 cm) plagioclase and pinkish-colored potassium feldspar phenocrysts, about 10 percent biotite + hornblende in approximately equal abundances, and abundant sphene. Three chemical analyses suggest that there is little compositional variation in this pluton with SiO_2 content ranging from 67.6 to 69.8 weight percent and relatively high K_2O and Zr contents similar to the known Middle Jurassic plutons (figs. 4). High-salinity fluid inclusions are locally present in igneous quartz crystals. The Ivy Ranch pluton is undated, but its chemical composition and petrographic features are very similar to the Middle Jurassic plutons. However, relatively low measured $^{87}Sr/^{86}Sr$ ratios of samples of this pluton suggest that it is no older than late Early Cretaceous (<120 Ma) in age.

Depth of emplacement. Geologic, petrologic, and petrographic data indicate that many of the Middle Jurassic plutons were emplaced at relatively shallow depths (≤5 km), although quantitative estimates for depths of emplacement are available only for the Yerington batholith. Geologic reconstructions based on detailed studies in the Yerington district suggest that the Yerington batholith was emplaced in three major pulses with successively younger phases emplaced at progressively greater depths (Dilles, 1984, 1987). Initial intrusion of the Yerington batholith may have reached depths <1 km, whereas the youngest phase was emplaced at depths ≥2.5 km. Due to late Cenozoic extension, present exposures of the Yerington batholith have been tilted approximately 90° from their original orientation and are structural cross sections that represent paleodepths ranging from <1 to >8 km (Dilles, 1987). Pressure/depth estimates for the Yerington batholith can also be made using amphibole compositions reported by Dilles (1984) and the hornblende geobarometer (Hammarstrom and Zen, 1986; Johnson and Rutherford, 1989). Calculated pressures for 9 samples using the Johnson and Rutherford (1989) calibration range from about 1.4 kbar to slightly negative pressures, which are generally in accord with depths estimated from geologic reconstructions (1 kbar equals approximately 3.5 km paleodepth). Two hornblende analyses reported by Dilles (1984) for the Shamrock batholith yield negative pressures (-0.16 and -0.76 kbars) using the hornblende geobarometer of Johnson and Rutherford (1989).

Precise estimates for depths of emplacement of other Middle Jurassic plutons can not be made with existing data. Middle Jurassic igneous rocks in this group range from consisting entirely of volcanic rocks on the west side of the belt (Carson Range) to consisting entirely of plutonic rocks on the east side (northern Wassuk Range and eastern Gillis Range). Exposures in the central part of the belt (Buckskin and Singatse Ranges) consist of both volcanic and plutonic rocks. This change suggests that deeper exposures are present on the east side of the belt. High-salinity fluid inclusions are virtually ubiquitous in igneous quartz crystals in these intrusions regardless of proximity to veins or other evidence of hydrothermal alteration. John (1989) described similar phenomenon in Tertiary granitic intrusions in the central Wasatch Mountains, Utah, and showed that high-salinity fluid inclusions were limited to intrusions emplaced at depths less than approximately 5 km. The presence of extensive areas of hydrothermal alteration apparently not related to younger intrusions also suggest relatively shallow emplacement levels.

Hydrothermal alteration. Strong hydrothermal alteration is present throughout large parts of the Middle Jurassic plutons but has not been systematically mapped and described except in the Yerington district (Dilles, 1984; Dilles and Einaudi, 1992; Carten, 1986; Battles, 1991), in the southern Buckskin Range (Hudson, 1983), and in the Gray Hills (Bingler, 1978). Hydrothermal alteration is most pronounced in the Singatse Range, particularly in the vicinity of porphyry copper deposits in the Yerington district (Dilles, 1984; Dilles and Einaudi, 1992; Carten, 1986) and along the northern margin of the Shamrock batholith (Battles, 1991), in the southern Buckskin Range (Hudson, 1983), in the Gray Hills (Bingler, 1978), near Butler Mountain (Stewart and others, 1981), and in the northern Pine Nut Mountains (John and others, 1993; D.A. John, unpub. data, 1990). Numerous types of hydrothermal alteration and alteration assemblages are present in the Yerington and Shamrock batholiths and in the Gray Hills pluton including propylitic, potassic (biotite and (or) potassium feldspar), sericitic (quartz-sericite-pyrite), argillic, advanced argillic, clinopyroxene, and scapolite assemblages; however, the most common and characteristic types of alteration in these plutons are sodic and sodic-calcic alteration (Carten, 1986; Dilles, 1984; Battles, 1991). Sodic alteration consists of albite replacement of potassium feldspar and chlorite replacement of biotite, whereas sodic-calcic alteration consists of replacement of potassium feldspar by oligoclase and replacement of biotite by actinolite (Carten, 1986; Battles, 1991). In porphyry copper systems in the Yerington batholith, sodic-calcic and sodic alteration formed at relatively deep levels as early and late types of alteration, respectively, which proxied for early potassic and late quartz-sericite-pyrite alteration that formed at shallower levels (Carten, 1986; Dilles and Einaudi, 1992).

Hydrothermal alteration in other Middle Jurassic plutons generally is much weaker and less widespread. The southern margin of the Sunrise Pass pluton is bleached and mafic minerals are altered to clinopyroxene near its contact with a dike-like mass of the Yerington batholith. Other parts of the pluton are relatively unaltered except for narrow bleached zones around widely scattered actinolite joint coatings. The Afterthought pluton is relatively fresh in surface exposures, although narrow quartz-pyrite and thicker actinolite-epidote veins with bleached albite(?) selvages are present. In addition, albite, scapolite, and epidote alteration of granitic rocks is reported in drill holes at the Calico (Fe-Cu skarn) prospect (Satokski and others, 1985). Diorite bodies in the northern Pine Nut Mountains commonly have narrow actinolite and (or) epidote veins with thin bleached albite(?) selvages. The granodiorite of Chipmunk Spring is commonly partially altered to sericite and chlorite. The Ivy Ranch pluton is little altered except for weak to moderate deuteric alteration consisting of sericite±epidote alteration of plagioclase and chlorite alteration of biotite.

Mineralization. Large copper and iron deposits are related to the Middle Jurassic plutons of this group. The Yerington batholith is the most highly mineralized plutonic system in the study area with three porphyry copper systems and numerous copper and copper-iron skarn deposits genetically related to it (Knopf, 1918; Einaudi, 1982). The Minnesota Iron Mine (iron exoskarn deposit) apparently is also genetically related to the Yerington batholith (Dilles and Wright, 1988). Copper- and gold-bearing quartz veins in strongly altered Middle Jurassic metavolcanic rocks in the southern Buckskin Range (Buckskin gold deposit) also may be related to the upper parts of the Yerington batholith (J.L. Doebrich, oral commun., 1991; Hudson, 1983). Other base- and precious-metals are notably absent in the Yerington batholith and mineral deposits associated with it (Wilson, 1963; Hudson, 1983). Iron-copper skarn and polymetallic vein mineralization in the Calico Hills and on the east side of Weber Reservoir are apparently related to the Afterthought pluton (Lawrence and Redmond, 1967; Satkoski and others, 1985; John and others, 1993). The Dayton iron deposit and the Iron Blossom Prospect are apparently related to the granodioritic Iron Blossom pluton (Roylance, 1966; John and others, 1993). No economic mineralization is associated with the Shamrock batholith, although specular hematite-bearing endoskarn zones that locally contain copper oxide minerals are common in this pluton in the Pine Nut Mountains. A small polymetallic vein deposit (Cu-Pb-Zn-Ag) is present at the Bidwell Mine in the northwestern part of the Sunrise Pass pluton in the northern Pine Nut Mountains. No mineralization is known to be associated with the granodiorite of Chipmunk Spring or the Ivy Ranch pluton. Copper skarns are present in Triassic carbonate rocks along the margins of and disseminated copper sulfides are present in the granodiorite of Copper Mountain.

Other intrusions of Early or Middle Jurassic age

Several other plutons in the Wassuk and Gillis Ranges are undated but have chemical and (or) petrographic features that are similar to the Middle Jurassic plutons in the Yerington area. These plutons include the granite of Thorne and hornblende monzodiorite (unit KJd of Stewart and Johannesen, 1981) in the Ryan Canyon area of the southern Gillis Range, hornblende-biotite granodiorite (nos. 6 and 7, fig. 2) in the central Wassuk Range, and granodiorite (unit Jgd of Ekren and Byers, 1985) in the southeastern Gillis Range (fig. 2). As discussed above in the section on Early Jurassic granites, the granite of Thorne might be Early Jurassic in age.

Middle or Late Jurassic plutons in northern Sierra Nevada

Distribution. Plutonic rocks of Middle or Late Jurassic age that range in composition from peridotite to granodiorite form four intrusive complexes in the northern Sierra Nevada near the northwest edge of the study area. These intrusive complexes include the Emigrant Gap pluton (no. 20, fig. 2), the metadiorite of Lacey Creek (no. 21, fig. 2), French Lake pluton (no. 22, fig. 2), and plutonic rocks in the Haypress Creek area (the informally named Haypress Creek granodiorite of Schweickert and others, 1984) (no. 23, fig. 2).

The Emigrant Gap pluton is a heterogeneous, mafic to intermediate intrusive complex that underlies an area of about 35 km^2 in the southern part of the Emigrant Gap 15-minute quadrangle. The pluton has been mapped by James (1971), Harwood and others (in press), and Schweickert and others (in press). The emplacement and petrology of the intrusive complex have been discussed by James (1967, 1971). It is intruded along its northern margin by intermediate to silicic rocks of the French Lake pluton. Snoke and others (1982) proposed that the Emigrant Gap pluton is one of a number of mafic intrusive bodies that formed magma chambers for widespread Jurassic volcanic rocks. The similarity of the age of the intrusive complex (discussed below) to the age of the Tuttle Lake Formation, together with the occurrence of a large number of mafic dikes related to the intrusive complex between the two rock units, suggests that the Emigrant Gap pluton could represent one of the principal magma chambers for the Tuttle Lake Formation (Harwood and others, in press; Schweickert and others, in press).

The metadiorite of Lacey Creek crops out over an area of about 8 km^2 along the south side of Lacey Valley and southwest Perazzo Canyon in the Webber Peak 7.5-minute quadrangle. Its full areal extent is concealed beneath Miocene volcanic and sedimentary rocks, but scattered exposures suggest the pluton may underlie most of the northern third of the Webber Peak quadrangle. Similar rocks occur near Meadow and Fordyce Lakes in the southwestern parts of the quadrangle. The metadiorite body discordantly intrudes metasedimentary strata assigned to the Lower and Middle Jurassic Sailor Canyon Formation. Along its northeastern margin southwest of Perazzo Canyon, the contact of the pluton cuts sharply across northeast-trending folds developed within metaconglomerate and tuffaceous sandstone of the Sailor Canyon Formation. The body in the southwestern corner of the quadrangle appears to truncate the southern limb of a northwest-trending anticline developed within the Sailor Canyon Formation.

The French Lake pluton is a large discordant intrusion underlying about 70 km^2 in the eastern and central parts of the Emigrant Gap 15-minute quadrangle (Lahren and others, 1988; Schweickert and others, 1984, in press). It is elongate in a northeasterly direction and contains a central unit of granodiorite to quartz diorite and several smaller masses of dioritic and gabbroic rocks. Along its western edge, it intrudes Paleozoic rocks of the Shoo Fly Complex and overlying Devonian through Jurassic strata. Along its northern boundary, the pluton intrudes the Lower and Middle Jurassic Sailor Canyon Formation and the Middle Jurassic Tuttle Lake Formation along a sharp, planar contact that dips 1-2° to the west. Bedding and cleavage in the Jurassic units dip steeply into this contact and are truncated by it. Near Interstate 80, the southern part of the French

Lake pluton intrudes Middle Jurassic rocks of the Emigrant Gap pluton. The eastern parts of the pluton are either intruded by Cretaceous granodiorite or are concealed beneath Miocene volcanic and sedimentary rocks.

Plutonic rocks in the Haypress Creek area form a large, elliptical mass covering approximately 250 km^2 in the eastern part of the Sierra City 15-minute quadrangle and part of the adjoining Sierraville 15-minute quadrangle. These plutonic rocks, which have previously been referred to informally as the Haypress Creek granodiorite and the Haypress Creek pluton by Schweickert and others (1984), have not been mapped or studied in detail, but sampling, megascopic characteristics, and Rb-Sr whole-rock concentration and isotopic data indicate that there are at least 5 intrusive phases that show considerable variation in composition and texture and probably range in age from about 157 to 105 Ma (fig. 5, tables 1 and 2). The approximate distribution of the 5 phases, herein called the Yuba Pass, Haypress Creek, Bald Ridge, Pass Creek, and Henness Pass intrusions, are shown in figure 5. On its western and southwestern edges, the plutons intrude metasedimentary rocks of the Lower and Middle Jurassic Sailor Canyon Formation. The southeastern and eastern boundaries of the plutons are concealed beneath Cenozoic volcanic and sedimentary deposits. Possibly related granitic rocks crop out north of Calpine along California Highway 89, but their relation to intrusions in the Haypress Creek area is unknown. Conspicuous northeast-trending second-generation folds developed within the Sailor Canyon Formation near the southwestern margin of the plutonic mass are truncated by the intrusion. This relation was cited by Schweickert and others (1984) as evidence for the timing of Nevadan orogeny deformation.

Age. Drake and others (1975) obtained K-Ar ages of 174-152 Ma from gabbroic to dioritic rocks of the Emigrant Gap pluton (table 2). Snoke and others (1982) reported a U-Pb age of 163 Ma from two-pyroxene diorite near Lake Valley Reservoir. From what appears to be the same locality, Saleeby and others (1989) reported an internally concordant U-Pb age of 164 Ma from the main pyroxene diorite phase of the pluton. No U-Pb ages have been obtained on older phases of the pluton. The available data suggests that at least part of this body is about the same age as the Shamrock batholith in the Yerington district, but the mafic and ultramafic phases are probably somewhat older. We infer that some of the older phases may be approximately the same age as metavolcanic rocks of the Tuttle Lake Formation (see also, Harwood and others, in press).

No isotopic age data are available for the metadiorite of Lacey Creek itself, although a single sample of an apparently penecontemporaneous metadacite, discussed below, combined with two samples of metadiorite from the Meadow Lake area yield a three-point Rb-Sr whole-rock isochron age of 165.2 Ma with an intercept of 0.70411 which suggests a late Middle Jurassic age. Previous maps of the region regarded the metadiorite as a mass of Triassic or Jurassic metavolcanic rocks. However, on the basis of field relations, its age is inferred to be Jurassic, because it intrudes the Lower and Middle Jurassic Sailor Canyon Formation and is metamorphosed to greenschist grade, in contrast to the fresh, unaltered appearance of nearby Cretaceous plutons. Locally, the pluton contains an incipient schistosity, suggesting it experienced part of the deformation recorded in the metasedimentary rocks. Certain lithologic features, described below, suggest that the metadiorite may be a shallow intrusion similar to the Emigrant Gap pluton and related to the Middle Jurassic Tuttle Lake Formation, exposed 8 km west (on English Mountain) and 20 km south of Perazzo Canyon, but this relation is speculative.

No isotopic ages have previously been published for the French Lake pluton. During this study, a sample collected from the granodiorite-quartz diorite unit at the Excelsior mine, near the eastern contact of the pluton yielded hornblende and biotite K-Ar ages of 151±4.5 and 139.0±4.0 Ma, respectively (table 2; Garside and others, 1992). We interpret the hornblende age as a minimum age; an older age limit is provided by the 162- to 163-Ma ages of Wracher and others (1991).

The only published isotopic ages for plutonic rocks in the Haypress Creek area were reported by Evernden and Kistler (1970) from several samples collected along California Highway 49, near and east of Yuba Pass. One sample of the Yuba Pass intrusion collected 4 km from the western margin of the pluton west of Yuba Pass yielded recalculated K-Ar ages of 157 and 154 Ma from biotite and hornblende, respectively. A sample collected from just east of Yuba Pass yielded a recalculated biotite K-Ar age of 101.5 Ma, and another collected 3 km farther east yielded several recalculated biotite K-Ar ages of 99.9-104 Ma and a recalculated hornblende K-Ar age of 128 Ma. New strontium isotope studies of intrusions in the Haypress Creek area yielded the following whole-rock isochrons ages for the five intrusions (table 1): Bald Ridge intrusion, 157 Ma; Yuba Pass intrusion, 154 Ma; Haypress Creek intrusion,153 Ma; Pass Creek intrusion, 119 Ma; and, Henness Pass intrusion, 105 Ma.

Chemistry, modal composition, and petrography. The Emigrant Gap pluton has been described by James (1971), who reported that it consists of an east-northeast-trending core zone of peridotite and dunite near its southern contact which are enclosed by two-pyroxene gabbros that in turn grade outward into dioritic and granodioritic rocks. Contacts between ultramafic and mafic rocks are sharp, whereas other contacts are gradational. The ultramafic rocks include dunite, wehrlitic peridotite, olivine clinopyroxenite, and clinopyroxenite. All units contain inclusions of the others. Most rocks contain igneous foliations and lineations, but the dunite contains a strong tectonite fabric. Brecciated dunite, in which subangular blocks of dunite occur in a matrix of olivine-rich peridotite, is common locally. Gabbroic rocks form both irregular intrusive masses that cut across the ultramafic core units and also tabular bodies subparallel to the eastern margin of the pluton. The gabbros are heterogeneous, and include two-pyroxene gabbro, norite, and hornblende gabbro, that locally form the matrix of brecciated ultramafic rocks. Dioritic to granodioritic rocks include two pyroxene-biotite-diorite, tonalite, two-pyroxene granodiorite, and hornblende granodiorite. During emplacement of the Emigrant Gap pluton, wallrocks including the Shoo Fly Complex and Devonian to Mississippian strata underwent very strong deformation in shear zones bordering the pluton. This deformation has been interpreted to have resulted from expansion and forceful emplacement of the mafic parts of the pluton (James, 1971; Schweickert and others, 1984, in press; Harwood and others, in press).

Wracher (1991) reported chemical data for the Emigrant Gap pluton. Disregarding the ultramafic units, the pluton has a silica content ranging from about 53 to 70 weight percent and forms a subalkalic, medium-K series that is generally less enriched in total alkalis and K_2O than Cretaceous parts of the Sierra Nevada batholith and other Middle to Late Jurassic plutons in the study area (compare figs. 4, 6, 7, and 8). The pluton is metaluminous (fig. 6), and, in general, silica contents are lower than most Cretaceous plutons in the Sierra Nevada batholith within the study area. Rubidium and Sr contents and Rb/Sr ratios are relatively low, but Sr slightly increases with increasing SiO_2 over the entire compositional range, in contrast to plutons in the Yerington and West Walker River areas and to the Sierra Nevada batholith where Sr decreases with increasing silica.

The metadiorite of Lacey Creek is an extremely heterogeneous body. Most outcrops are igneous breccias consisting of angular to rounded fragments of diorite and diorite porphyry in a greenish matrix consisting of pyroxene diorite. Local areas are underlain by more homogeneous pyroxene diorite. The diorite breccia contains a wide variety of clast types, including pyroxenite, pyroxene gabbro, diorite porphyry, quartz diorite, andesite porphyry, and dacite. Sparse xenoliths of metasiltstone also occur locally. Despite the wide range of textures and compositions of igneous fragments, most appear to have been characterized by pyroxene and (or) plagioclase phenocrysts. Fragments generally are angular to subangular, and range from about 0.5 to 40 cm in long dimension. Clasts commonly are also greater than 50 percent of the rock. No chemical data are available for the metadiorite.

The diorite shows abundant evidence of metamorphic recrystallization. The rocks are generally dark green, and mafic minerals have been replaced by irregular patches of fibrous amphibole. Epidote is widespread as a replacement of feldspar. Outlines of fragments in diorite breccia are indistinct.

Near the south end of Lacey Valley, a small mass of metadacite appears to have been intruded penecontemporaneously with the metadiorite. The contact between the two rock types is highly irregular, with angular fragments of dacite appearing to have spalled off into the diorite. Dikes of dacite are also injected into diorite breccia. The dacite locally has prominent flow layering that defines disharmonic flow folds. Both rock units probably were emplaced at relatively shallow levels. Both the diorite and the dacite locally contain a schistosity that trends north to northeast, suggesting both rock units have experienced some of the deformation of their host rocks.

The French Lake pluton (as defined in this report) consists of at least seven phases, of which a central granodiorite-quartz diorite mass is most extensive. No chemical data are available for this pluton. Four smaller masses of hornblende diorite and related rocks are present within and along the periphery of the main mass: one body crops out along the western edge of the pluton, southwest of Spaulding Lake; another crops out east of Spaulding Lake; an elongate body crops out along much of the eastern margin of the pluton; and one crops out in the central part of the pluton in the Black Buttes area. Several small mafic bodies, referred to as the mafic complex of Beyers Lakes (Schweickert and others, in press), occur south of the Black Buttes. Northwest of the Black Buttes, a body of biotite quartz diorite extends west of the main pluton and cuts across the Paleozoic section.

The granodiorite-quartz diorite mass is heterogeneous and consists mostly of light-gray, medium- to coarse-grained hornblende-biotite granodiorite and quartz diorite. Mafic minerals are subhedral to anhedral, and mafic enclaves are common. Locally, darker patches of quartz diorite occur within lighter granodiorite; contacts are sharp in some areas and gradational in others. Some rocks are tonalite and quartz monzodiorite.

The smaller dioritic phases are also heterogeneous and include hornblende diorite, pyroxene-biotite diorite, tonalite, and granodiorite. The pyroxene-bearing rocks lithologically resemble the dioritic rocks of the Emigrant Gap pluton to the south and could be considerably older than the granodiorite. Dikes of granodiorite and quartz diorite of the central mass typically intrude the dioritic phases, suggesting that the more mafic rocks predate the granodioritic rocks. One of the dioritic bodies, near Summit City, consists of diorite breccia that shows signs of metamorphic recrystallization. This unit closely lithologically resembles the metadiorite of Lacey Creek (described above), and could be a related intrusion.

Biotite quartz diorite forms a distinct phase of the French Lake pluton between Island Lake and Sand Ridge. The rock is dark gray, medium grained, contains >20 percent quartz, and has 5-10 percent subhedral biotite. It intrudes the hornblende diorite body of the Black Buttes, but intrusive relations with the granodiorite-quartz diorite unit are unclear.

The mafic complex of Beyers Lakes (Schweickert and others, in press) consists of gabbro, pyroxene-biotite diorite, diorite porphyry, and plagioclase porphyry. Dikes related to this complex intrude the hornblende diorite of Black Buttes and are, in turn, intruded by granodiorite-quartz diorite of the French Lake pluton. The gabbro is very dark gray, coarse-grained, and consists of subequal amounts of calcic plagioclase and mafic minerals, which include both clinopyroxene and hornblende. The pyroxene-biotite diorite is coarse-grained and consists of calcic plagioclase, biotite, clinopyroxene, orthopyroxene, and minor quartz. Diorite porphyry appears to be a phase of the pyroxene-biotite diorite and consists of dark calcic plagioclase phenocrysts as much as 2 cm long, and smaller phenocrysts of clino- and orthopyroxene in a fine-grained groundmass of quartz, plagioclase, and biotite. Plagioclase porphyry forms dark green dikes up to 10 m thick containing megacrystic plagioclase phenocrysts up to 3 cm in length in a fine grained, granular groundmass of quartz, plagioclase, and hornblende. The dikes appear to originate from the hornblende-pyroxene gabbro.

In summary, the dioritic and gabbroic phases of the French Lake pluton predate, and could be significantly older than, the main granodiorite-quartz diorite phase. Some could represent remnants of a once-more-extensive Emigrant Gap pluton. The main granodiorite-quartz diorite phase discordantly truncates steeply dipping bedding and cleavage in Jurassic units to the north and northwest, and therefore appears to postdate Late Jurassic Nevadan orogeny deformation.

As discussed above, plutonic rocks in the Haypress Creek area have not been studied in detail, but megascopic and isotopic data indicate that there are at least five major intrusions with diverse characteristics and ages: Yuba Pass, Haypress Creek, Bald Ridge, Pass Creek, and Henness Creek intrusions (fig. 5, table 1).

The Yuba Pass intrusion forms the northernmost part of the mass of plutonic rocks in the Haypress Creek area. This intrusion is a light-gray, fine-grained, sparsely porphyritic biotite-hornblende granodiorite. Mafic minerals composed about 12 to 15 percent of the rock and consist of subequal abundances of subhedral to anhedral biotite that forms locally larger flakes and subhedral hornblende that locally forms small phenocrysts (≤3 mm) and is partially replaced by fine-grained biotite. Fine-grained quartz is abundant and more conspicuous than in the other intrusions. The easternmost exposures of the Yuba Pass intrusion are more leucocratic, somewhat coarser grained, and contain sparse potassium feldspar oikocrysts as much as 1 cm across. Most exposures of the Yuba Pass intrusion appear very fresh.

The Haypress Creek intrusion forms the central part of the plutonic mass and is the most mafic intrusion. It ranges from a medium-grained, porphyritic biotite-hornblende diorite along its outer margins to a coarse-grained, biotite-hornblende-pyroxene gabbro in the central part of the intrusion. The porphyritic phase contains abundant tabular to equidimensional, poikilitic plagioclase phenocrysts as much as 1 cm across in a medium-grained, seriate groundmass. Mafic minerals compose about 15 to 20 percent of the rock and consist of tabular hornblende crystals as long as 5 mm and fine-grained biotite flakes. This porphyritic phase appears to grade texturally into a coarse-grained gabbroic phase with local cumulate texture. The cumulate is composed of about 70 percent dark-gray, tabular plagioclase crystals as long as 2 cm with irregular clots of mafic minerals filling interstices between plagioclase crystals. Clots of mafic minerals compose about 25 to 30 percent of the rock and consist of hornblende crystals with pyroxene cores and small flaky biotite crystals.

The Bald Ridge intrusion crops out on the southwest side of the mass. This intrusion is a medium-grained, porphyritic biotite-hornblende monzodiorite(?). It contains small (<5 mm) tabular plagioclase phenocrysts and sparse, irregularly-shaped potassium feldspar(?) oikocrysts as much as 1 cm across. Mafic minerals, consisting of small biotite flakes, anhedral to subhedral hornblende, and sparse pyroxene(?) phenocrysts, constitute about 25 to 30 percent of the rock.

The Pass Creek intrusion is a dark-gray, fine-grained porphyritic hornblende-pyroxene(?) diorite that crops out in the southern part of the pluton. Mafic minerals form about 20 to 25 percent of the rock and mostly consist of fine-grained hornblende and (or) pyroxene with sparse hornblende phenocrysts as long as 7 mm. Plagioclase crystals are very dark gray colored.

The Henness Pass intrusion crops out along the southeast side of the plutonic mass. It is a medium-grained, equigranular, hornblende-biotite granodiorite containing about 8 to 12 percent mafic minerals consisting of subhedral biotite flakes and less abundant hornblende as much as 5 mm long. Quartz is conspicuous. The outer(?) part of the intrusion is finer-grained and more mafic containing about 15 to 17 percent mafic minerals. The Henness Pass intrusion appears notably fresher than most of the other intrusions.

Depth of emplacement. Depths of emplacement for these plutons are poorly constrained. James (1971) interpreted the ultramafic and two-pyroxene bearing rocks of the Emigrant Gap pluton to have been emplaced as high-temperature magmas and magmatic crystal mushes. The concentrically zoned mafic complex was suggested to have been formed by crystal fractionation and flowage differentiation of a single gabbroic magma. Field relations within the Emigrant Gap 15-minute and Duncan Peak 7.5-minute quadrangles suggest that the body is tilted eastward together with Jurassic metasedimentary and metavolcanic rocks. If the pluton is genetically related to the Tuttle Lake Formation, as suggested by Harwood and others (in press), it probably solidified beneath no more than about two to five km of cover.

The assortment of clast types, textural variability, and apparent shallow level of emplacement all suggest that the metadiorite of Lacey Creek represents a shallow subvolcanic magma chamber for eruptive rocks. The Tuttle Lake Formation is a unit compositionally similar to intermediate volcanic rocks that overlies the Sailor Canyon Formation on English Mountain, 8 km west of Lacey Creek, and in areas to the south. No exposures of the Tuttle Lake Formation are present in the immediate vicinity of the metadiorite of Lacey Creek, however. Conceivably, the metadiorite of Lacey Creek represents part of a subvolcanic magma chamber for units like the Tuttle Lake Formation.

No estimates of depth of emplacement can be made for the French Lake pluton and plutonic rocks in the Haypress Creek area using available data.

Hydrothermal alteration. Hydrothermal alteration has not been studied or systematically noted in these plutons except for parts of the French Lake pluton between French Lake and Meadow Lake, where quartz-tourmaline veins and shear zones marked by dark-colored crush breccia and pseudotachylyte are widely developed (Doebrich and others, in press).

Mineralization. The only significant known mineralization spatially associated with the Jurassic plutons in the northern Sierra Nevada is in the Meadow Lake district along the edge of the French Lake pluton. Here, the French Lake pluton and surrounding Jurassic metavolcanic wallrocks host a swarm of west-northwest trending quartz-tourmaline veins that locally contain copper and gold. These veins were mined for their gold content. Mineral deposits in the Meadow Lake district are described in detail by Doebrich and others (in press).

Late Jurassic plutons in West Walker River area

Distribution. Several intrusions of Late Jurassic age (approx. 160-150 Ma) are exposed in the Sweetwater Mountains and along their northern and western slopes in the West Walker River area on the east side of the Sierra Nevada (hereafter called the West Walker River area) near the southwest corner of the study area. These Late Jurassic intrusions include the granite of East Fork (no. 24, fig. 2) and the ntrusive suite of Wild Horse Mountain, which is composed of the dioritic to quartz dioritic West Walker pluton (no. 25, fig. 2), other diorites and silicic differentiates, the granite of Desert Creek (no. 26, fig. 2), and related porphyries (fig. 2). The granodiorite of Log Cabin Creek (no. 27, fig. 2), which crops out just southwest of the study area, is also Late Jurassic in age. In addition to the West Walker pluton, the granite of Desert Creek, the granodiorite of East Fork, and the granodiorite of Log Cabin Creek, Schweickert (1976) also included the nearby, informally named Swauger Creek mafic complex (no. 28, fig. 2) and the China Garden pluton (no. 29, fig. 2) in a group of shallow-level plutonic complexes in the West Walker River area that he inferred to be of Late Triassic to Middle Jurassic age. Although the field interpretation of Brem (1984), that the Swauger Creek mafic complex is older than the granodiorite of East Fork, would make it Late Jurassic or older, K-Ar ages and a Rb-Sr whole-rock isochron are concordantly Late Cretaceous (tables 1 and 2; Schweickert, 1972, 1976; Robinson and Kistler, 1986). Strontium whole-rock isochrons also indicate a Late Cretaceous age for the China Garden pluton, a nearby dacitic tuff, and an adjacent rhyolitic tuff intruded by the pluton (table 1; Robinson, 1985).

Age. Schweickert (1972, 1976) reported thirteen hornblende and biotite K-Ar ages from five intrusive units in the West Walker River area, of which two, the Devils Gate and Mack Canyon plutons, have since been combined (Brem, 1984). All thirteen of the K-Ar ages are Late Cretaceous (table 2). Because Schweickert considered three of the units, the Swauger Creek mafic complex, the China Garden pluton, and the granite of Desert Creek, to be of Late Triassic to Middle Jurassic age, he argued that their Late Cretaceous K-Ar ages were reset by reheating and hydrothermal alteration induced by intrusion of the Late Cretaceous plutons scattered among them. Subsequent Rb-Sr whole-rock isotopic dating of all of the intrusive rocks, both Late Cretaceous and older, in the West Walker River area (table 1; Robinson, 1985; Robinson and Kistler, 1986) has shown that the Swauger Creek mafic complex and the China Garden pluton are Late Cretaceous in age and the granite of Desert Creek is Late Jurassic.

Careful comparison of the K-Ar and Rb-Sr ages (tables 1 and 2), taking into consideration the geography of the plutons and the sample locations, indicates considerable coherency that includes both concordancy and some resetting. In the Swauger Creek mafic complex, hornblende K-Ar ages of 95.3±3.5 and 93.7±2.6 Ma in two samples are concordant with a 12-point strontium whole-rock isochron of 93.3±1.6 Ma. In another sample, a biotite K-Ar age of 81.0±1.6 Ma and a hornblende K-Ar age of 85.6±1.7 Ma agree well with biotite K-Ar ages of 85.5±1.7 and 80.8±1.6 Ma in two samples of the adjacent granite of Devils Gate–Mack Canyon pluton–Murphy Creek pluton set and with a 7-point strontium whole-rock isochron of 85.8±3.0 Ma from this unit.

A 36-point strontium whole-rock isochron yields an age of 91.2±1.3 Ma for the China Garden pluton (table 1). The rhyolitic tuff intruded by the pluton forms a 12-point strontium whole-rock isochron of 89.7±5.3 Ma with an $^{87}Sr/^{86}Sr$ intercept 0.001 higher than the intercept yielded by the isochron for the pluton. Three samples of the dacitic tuff plot along but slightly above the isochron for the pluton, while other dacitic tuff samples plot nearer the midpoint between the two isochrons, depending upon their relative abundance of included rhyolite clasts. Biotite K-Ar ages of 82.3±1.6, 82.3±1.6, and 77.7±1.5 Ma from three samples in the China Garden pluton, agree with a 7-point strontium whole-rock isochron of 82.5±1.2 Ma in the adjacent granite of Rock Creek. Two splits of low-potassium hornblende from the sample with the 77.7-Ma biotite yield K-Ar ages of 61.3±6.0 and 63.2±2.1 Ma.

Various phases of the intrusive suite of Wild Horse Mountain yield the following strontium whole-rock isochrons (table 1): northern diorite and silicic differentiates, 8-point, 155.3±4.0 Ma; other diorite and silicic differentiates, 6-point, 151.0±3.3 Ma; relatively unaltered granite, 12-point, 152±14.3 Ma; relatively unaltered aplite, one point paired with granite initial $^{87}Sr/^{86}Sr$, 157.5 Ma; three different groups of silicic porphyries, 5-point, 155.9±7.0 Ma, 7-point, 156.8±8.6 Ma, 10-point, 153.9±7.4 Ma. A hornblende K-Ar age of 88.5±2.1 Ma from one locality in the granite of Desert Creek agrees well with a 9-point strontium whole-rock isochron of 87.7±1.7 Ma from the adjacent granite of Taylor Valley. From another locality, a hornblende K-Ar age of 83.3±4.4 Ma agrees with the 7-point strontium whole-rock isochron of 82.5±1.2 Ma from the nearby granite of Rock Creek.

Because the blocking temperature for argon retention in hornblende is substantially greater than that of argon in biotite, hornblende K-Ar ages in Sierran granitoids are usually concordant with primary strontium whole-rock isochron ages even when younger K-Ar ages of paired biotite indicate argon loss from the biotite during simple reheating (A.C. Robinson, unpub. data). In the granite of Desert Creek, it may be that recrystallization of hornblende (Schweickert, 1972, 1976) during Late Cretaceous albitic alteration, as indicated by rotated strontium whole-rock isochrons (Robinson, 1985), rather than outgassing of argon during simple reheating accounts for the argon loss in the hornblende. There is also textural evidence for hornblende recrystallization in the China Garden pluton (Schweickert, 1972, 1976), though it is not known when the alteration occurred, because the K-Ar ages of the low-potassium hornblendes are probably not reliable. Two of the three hornblende K-Ar ages from the Swauger Creek mafic complex are concordant with its strontium whole-rock isochron. The K-Ar age of the third hornblende matches the K-Ar ages and strontium whole-rock isochron of the granite of Devils Gate-Mack Canyon pluton-Murphy Creek pluton set that intrudes it. It is not known whether this apparent resetting resulted from thermal outgassing or from recrystallization of the hornblende.

The granite of East Fork and its associated porphyry phase are very similar in composition, texture, and alteration to the granite and porphyries of the intrusive suite of Wild Horse Mountains. Five relatively unaltered granite and porphyry samples yield a strontium whole-rock isochron of 151.3±10.3 Ma. Other moderately to strongly albitized granite, porphyry, and aplite samples of this unit form secondary Late Cretaceous isochrons rotated from the primary isochron.

Sixteen whole-rock samples of granodiorite and leucocratic dikes from the Log Cabin Creek pluton form a strontium isochron of 160.1±4.1 Ma.

Chemistry, modal composition, and petrography. Jurassic plutons in the West Walker River area are characterized by hypabyssal textures and alkaline affinities as emphasized by Schweickert (1972, 1976). These characteristics are also present in the China Garden pluton but are absent in nearby Cretaceous plutons of the Sierra Nevada batholith (fig. 7).

The intrusive suite of Wild Horse Mountain includes the granite of Desert Creek, local porphyry margins and dikes, large bodies of diorite, quartz diorite, and differentiates on the north and west periphery, and internal dikes and masses of aplite and alaskite. Chemical analyses indicate that SiO_2 content is about 61 weight percent in the quartz diorite, 64 to 69 weight percent in the granite and 68 to 71 weight percent in the porphyries. Potassium content is uniformly high in all samples, and the intrusive suite is borderline alkaline (fig. 7).

Schweickert (1972, 1976) referred to the most southerly of the diorite to quartz diorite bodies of the Desert Creek intrusive suite as the West Walker pluton, and described it in detail. It is a medium- to coarse-grained, seriate, hornblende-biotite quartz diorite that contains 25 to 45 percent mafic minerals and 50 to 60 percent plagioclase in crystals as long as 1 cm. Much of the plagioclase appears to have cumulate textures with mafic minerals, quartz, and potassium feldspar filling interstices between plagioclase crystals (Schweickert, 1976). Hornblende forms pale blue-green oikocrystic crystals that commonly replace clinopyroxene. Biotite forms ragged, fine-grained flakes. Fine-grained biotite and hornblende locally fill fractures in plagioclase phenocrysts. The textures of the mafic minerals suggest that the pluton has been thermally recrystallized (Schweickert, 1976). Only one chemical analysis is available for the West Walker pluton; this analysis suggests that the pluton is relatively enriched in alkalis compared to the Triassic and Early Jurassic granitoids, but has markedly lower alkali contents than Middle Jurassic rocks in the Yerington area (figs. 3, 4, and 7).

There is an abrupt transition in texture of the West Walker pluton from a uniform medium- to coarse- grained, hypidiomorphic granular quartz diorite to a hypabyssal–appearing, fine-grained diorite along the west margin of the pluton, where the pluton intrudes andesitic metavolcanic rocks. The suggestion of Schweickert (1976) that the West Walker pluton may have intruded its own volcanic cover along this contact is supported by the Rb-Sr concentration and isotopic similarity between two whole-rock samples each of the intrusive and extrusive rocks.

Most of the granite of Desert Creek consists of a medium-grained, coarsely porphyritic hornblende granite (quartz monzonite) and granodiorite. Mafic mineral content averages about 10 percent and commonly consists of fibrous pale blue-green hornblende that partially replaces clinopyroxene and local minor biotite. Highly turbid, pink colored potassium feldspar megacrysts as long as 1 cm are scattered throughout the pluton, and potassium feldspar rims on plagioclase crystals are common (Schweickert, 1972). Much of the pluton appears to be thermally metamorphosed (Brem, 1984), and Robinson (1985; Stewart and others, 1989) reports a 6-point rotated whole-rock Rb-Sr isochron age of 87.4±1.9 Ma apparently resulting from local progressive albitization of the pluton by hydrothermal fluids associated with the adjacent Late Cretaceous granite of Taylor Valley. Fluid inclusions in igneous quartz crystals are extremely abundant in many samples and include high-salinity (halite-bearing) inclusions (D.A. John, unpub. data, 1991).

The granite of East Fork is a medium-grained porphyritic granite that contains 1 to 15 percent, 0.4 to 1.5 cm long pink to purple potassium feldspar megacrysts and about 10 percent fine-grained biotite and blue-green actinolite (Stewart and others, 1989). Brem (1984) also describes a porphyritic granite phase that has a fine-grained groundmass and contains fewer mafic minerals. No chemical, modal, or petrographic data are available for this pluton.

Most of the Log Cabin Creek pluton is a medium-grained porphyritic biotite-hornblende granite or granodiorite containing 1 to 2 cm long dark-gray potassium feldspar megacrysts (Chesterman, 1975; Keith and Sietz, 1981). This phase contains about 10 to 15 percent mafic minerals dominantly composed of fine-grained biotite that replaces hornblende and abundant euhedral sphene crystals as large as 2 mm long. Chesterman (1975) describes the granodiorite phase as grading into medium-grained, porphyritic quartz diorite that contains about 30 to 35 percent hornblende which is partially replaced by biotite, dark gray potassium feldspar megacrysts as long as 2 cm, and smaller (0.5-1.0 cm) plagioclase phenocrysts. The main phase of the pluton contains about 68 to 70 weight percent SiO_2 and has high K_2O and Na_2O contents similar to other Jurassic plutons in the West Walker River area (fig. 7). No modal or petrographic data are available for this pluton.

Because many aspects of the composition, texture, and recrystallization of the China Garden pluton are more like the Jurassic plutons than other nearby Cretaceous plutons, a summary description from Schweickert (1972, 1976) is included here. Most of this pluton is a medium-grained seriate hornblende-biotite granite (quartz monzonite) that contains about 8 to 12 percent anhedral mafic minerals. Schweickert describes evidence for extensive subsolidus recrystallization including partial replacement of plagioclase by potassium feldspar, formation of large quartz crystals by replacement of plagioclase and potassium feldspar, replacement of clinopyroxene by fibrous blue-green amphibole, and local replacement of hornblende by fine-grained biotite. Fluid inclusions, including high-salinity inclusions, are extremely abundant in igneous quartz crystals (D.A. John, unpub. data, 1991).

Schweickert (1972, 1976) describes several marginal phases along the western edge of the China Garden pluton including porphyritic, granophyric, granophyric porphyry, and foliated schistose phases. He interprets the marginal phases of the pluton to represent conduits for magma that erupted to the surface, and he suggests that a body of metamorphosed, welded dacitic tuff exposed on the north side of Little Antelope Valley just north of the China Garden pluton may be the extrusive equivalent of the China Garden pluton. Subsequent Rb-Sr concentration and isotopic analyses (Robinson, 1985) not only support this suggestion, but indicate that a rhyolite underlying the dacitic tuff and intruded by the China Garden pluton is also of the same Late Cretaceous age as the pluton. Conglomerates in the West Antelope sequence of Schweickert (1976) that he assumed were older than the rhyolite are actually parts of the dacitic tuff containing clasts of the rhyolite. The Late Cretaceous age for these volcanic rocks is the youngest yet determined for Mesozoic volcanic rocks in the Sierra Nevada region.

The silica content of the China Garden pluton ranges from about 60 to 70 weight percent. Relatively high alkali contents are more like those of the Jurassic plutons in the West Walker River and Yerington areas than the alkali contents of other Late Cretaceous plutons of the Sierra Nevada and its eastern flank (fig. 7).

Depth of emplacement. The Jurassic plutons and the China Garden pluton are inferred to be shallowly-emplaced, hypabyssal intrusions on the basis of textural and petrographic features and proximity of some of the intrusions to apparently coeval and cogenetic volcanic rocks (Schweickert, 1972, 1976; Robinson, 1985). Hypabyssal textures, including chilled margins, roof breccias, and porphyry phases, are common features in these plutons. Field relations and Rb-Sr concentration and isotopic data suggest that the West Walker and China Garden plutons intrudes their own volcanic cover rocks (Schweickert, 1972, 1976; Robinson, 1985). High-salinity fluid inclusions are also common in igneous quartz in the granite of Desert Creek, the China Garden pluton, and in the more felsic parts of the West Walker pluton (D.A. John, unpub. data, 1991), which also suggests relatively shallow depths of emplacement.

Hydrothermal alteration. Although textural features indicating thermal recrystallization, bleaching and albitic alteration, and local biotitization are common in the Jurassic plutons in the West Walker River area and in the China Garden pluton (Schweickert, 1972, 1976; Brem, 1984; Robinson, 1985; Stewart and others, 1989), hydrothermal alteration has not been systematically mapped or studied. Recrystallization of primary mafic minerals and (or) replacement of these minerals by shreddy, fine-grained biotite and fibrous amphibole are common features in the West Walker pluton, the granite of Desert Creek, and the China Garden pluton (Schweickert, 1972, 1976). Discordant K-Ar ages and rotated Rb-Sr whole-rock isochrons suggest that at least some of this alteration may be related to emplacement of nearby Late Cretaceous plutons (Robinson, 1985). Much of the granite of Desert Creek has been bleached and albitized. Because Rb-Sr concentration and isotopic analyses and some X-ray diffractometer studies (A.C. Robinson, unpub. data) indicate that most aplite dikes in the granite of Desert Creek are variably albitized, even in relatively unaltered granite host rock, and that the most strongly albitized zones of the granite are associated with the most strongly albitized aplite dikes, it appears likely that the albitizing hydrothermal fluids gained access to the granite through aplite dikes. One local suite of progressively albitized granite associated with a strongly albitized aplite dike yields a 6-point rotated Rb-Sr whole-rock isochron age of 87.4±1.2 Ma that matches the 9-point Rb-Sr whole-rock isochron age of 87.5±1.2 Ma from the adjacent granite of Taylor Valley (Robinson, 1985). Rb-Sr isotope systematics clearly indicate that the aplite dikes that underwent albitization belong to the intrusive suite of Wild Horse Mountain, and are not themselves Late Cretaceous in age.

The granite of East Fork is altered to quartz-sericite-pyrite assemblages containing small amounts of molybdenite and copper minerals in the Sweetwater Mountains (Brem, 1984; Brem and others, 1983); however, sericite yielded a Late Cretaceous alteration age (Brem, 1984).

Related mineralization. Relatively little mineralization of known Jurassic age is present in the West Walker River area. Several mines and prospects, including the Lilly and Arrowhead Mines, are present between Risue and Blackwell Canyons near the northwestern margin of the granite of Desert Creek. Mineralization at the Lilly mine consists of tungsten- and molybdenum-bearing skarn in metavolcanic rocks near a fault contact with quartz diorite associated with the granite of Desert Creek (Stewart and others, 1989). The age of mineralization is unknown, however, because the skarns are faulted against the granitic rocks. Small copper-iron skarns are present about 1 km south of Blackwell Canyon in Triassic carbonate rocks along the edge of the quartz diorite. These skarns are undated but may be Jurassic in age. Copper sulfide minerals and scheelite are present in skarn at the Arrowhead Mine in Risue Canyon. Gold reportedly is also present (Moore, 1969). The Arrowhead Mine is in Mesozoic metavolcanic rocks that are equidistant from the granite of Desert Creek and the Late Cretaceous granite of Taylor Valley (Stewart and others, 1989); the source and age of mineralizing fluids are unknown. Another prospect of possible Jurassic age is the Iron Cap prospect in Sweetwater Canyon in the Sweetwater Mountains. The Iron Cap prospect is a magnetite skarn body in Mesozoic calc-silicate rocks (Brem and others, 1983). The nearest granitic intrusion is the granite of East Fork, although a large landslide about 1 km across separates the pluton from the skarn, and a genetic relationship between the two is unclear. Quartz-sericite alteration, quartz veins, and associated molybdenum mineralization are present in the granite of East Fork in the Sweetwater Mountains (Brem and others, 1983); however, sericite alteration has been dated at about 72 Ma (Brem and others, 1983; Brem, 1984). Most other precious- and base-metal occurrences in the area underlain by these granitoids are Tertiary in age (Brem and others, 1983).

Cretaceous plutons of the Sierra Nevada batholith and related rocks

Distribution. Granitic plutons of Cretaceous or inferred Cretaceous age are scattered across most of the study area forming much of its southwestern, northern, and southern parts. For example, the southern part of the Carson Range and the Sierra Nevada south and southwest of Lake Tahoe are underlain by nearly continuous exposures of late Early to Late Cretaceous plutons of the Sierra Nevada batholith (fig. 1). Most other exposures of Cretaceous plutons in the study area probably are related to the Sierra Nevada batholith, although east of the Sierran crest large areas are covered by Tertiary volcanic rocks and Quaternary surficial deposits and there is a general decrease in the overall proportion of granitic rocks exposed east of the main exposures of the batholith (John, 1983; Greene and others, 1991). Large areas of Cretaceous and Cretaceous(?) plutons north and northwest of Reno are poorly mapped and many plutons are undated; these plutons tend to be more mafic than most of Cretaceous plutons in the main part of the batholith (see below). Within the study area, dozens of individual plutons have been mapped in areas that have been studied in detail (for example, see Armin and John, 1983; Armin and others, 1984; John, 1983; Loomis, 1983).

Age. The K-Ar and Rb-Sr isotopic age data in tables 1 and 2 represent less than half the volume of Cretaceous plutons in the study area; however, within major exposures of the Sierra Nevada batholith, the relative ages of many other plutons are constrained by field relations (for example, see Armin and John, 1983; Loomis, 1983; Armin and others, 1984). Also, for many localities, routine sampling of leucocratic dikes cross-cutting granitoid rocks sampled to obtain regional initial $^{87}Sr/^{86}Sr$ data provide age control in the form of reconnaissance 2 or 3 point whole-rock isochrons commonly with sufficient variation in Rb/Sr to be within ten percent of the true age (A.C. Robinson, unpub. data).

The ages of most of the Cretaceous plutons in the study area fall within the range of 120 to 80 Ma, with an asymmetric normal distribution centered around 95 to 90 Ma. Cretaceous plutons older than about 110 Ma are constrained to the Sierra Nevada, whereas plutons between 110 to 80 Ma are scattered throughout western Nevada as well as along the crest and east flank of the Sierra Nevada. In the study area, Cretaceous plutons older than 100 Ma are generally found within a relatively narrow zone near its western edge, extending from the middle of Plumas County in the north, southward through the Donner Pass area and an area slightly west of Lake Tahoe to the southwest edge of the study area, where the zone passes through the vicinity of Caples and Silver Lakes west of Carson Pass. Scattered within this zone are a number of plutons with ages clustered tightly between 120 and 117 Ma, and a few more with ages around 112-110 Ma. Plutons between 105 and 110 Ma in age are particularly common north of Henness Pass, and another group between Donner Pass and Carson Pass is close to 100 Ma in age (for example, fig. 8). Outside of this zone, the quartz monzonite of Garfield Hills (111±4.1 Ma, table 1) and the granodiorite of Huntoon Valley (104.4±2 Ma, table 2) are both east of the Wassuk Range in the southeastern part of the study area. On the west side of the Wassuk Range, discordant K-Ar ages of 97.5±0.6 and 107.8±0.7 Ma for biotite and hornblende, respectively, (Robinson and Kistler, 1986) were obtained from a rock that we now believe is part of the Middle Jurassic Shamrock batholith. Another pair of discordant K-Ar ages of 83.5±3 and 109.3±4 Ma for biotite and hornblende, respectively, were obtained by Noble and others (1973) for the granodiorite of Bullionville in the southern Pine Nut Mountains.

Eastward of the relatively narrow zone of Early Cretaceous plutons predominantly older than 100 Ma, Early to Late Cretaceous plutons ranging in age from 100 to 77 Ma scatter broadly across the study area. With decreasing age, however, there is a gradual eastward shift in the western limit of plutons of comparable age. The locus of the shift is near the east flank of the Sierra Nevada, and the youngest pluton along this subtle age gradient is the 82.5±1.2-Ma granite of Rock Creek in the West Walker River area. Farther east in the southern Wassuk Range, the granodiorite of Alum Creek (77.2±2 Ma) and the granite of Corey Creek (77.3±2 Ma) are the youngest Cretaceous plutons in the study area.

Chemistry, modal composition, and petrography. Cretaceous granitic plutons have a wide range of chemical and modal compositions ranging from diorite to leucogranite, although most large plutons are medium- to coarse-grained biotite±hornblende granite and granodiorite that have 60 to 75 percent SiO_2 (fig. 9; Parker, 1959; Loomis, 1983; Armin and John, 1983; John, 1983, 1992; Ague and Brimhall, 1988a). A number of plutons, especially in the southwestern part of the study area, are coarsely porphyritic containing potassium feldspar megacrysts as much as several cm long (for example, the granodiorite of Topaz Lake, granite of Taylor Valley, and granite of Nye Canyon). Hornblende/biotite ratios generally are less than one even in relatively mafic rocks (John, 1983). In contrast, hornblende generally is more abundant than biotite in the Middle and Late Jurassic plutons of the Yerington and West Walker River areas.

Cretaceous plutons in the Sierra Nevada, the Pine Grove Hills, the Wassuk and Gillis Ranges, the West Walker River area, and the southwestern part of the Reno 1° by 2° quadrangle are notably less potassium-rich and more aluminous than the Jurassic plutons (fig. 9). They average about 1 weight percent less K_2O at a similar silica content, and virtually all rocks containing more than 70 weight percent SiO_2 are peraluminous. Limited Zr data suggest that the Cretaceous plutons tend to have lower Zr content than the Middle Jurassic plutons of the Yerington group (compare figs. 4 and 9). Cretaceous(?) plutons exposed north of Reno and east of Emigrant Gap and principal exposures of the Sierra Nevada batholith tend to be more mafic (most have $SiO_2 \leq 65$ weight percent) and have slightly higher K_2O and Zr contents than other Cretaceous plutons at similar SiO_2 contents and are similar to the Middle Jurassic plutons of the Yerington group (compare figs. 4 and 9).

Depth of emplacement. Depths of emplacement of most Cretaceous plutons can only be crudely approximated using existing data. Metamorphic mineral assemblages in metasedimentary rocks intruded by Late Cretaceous plutons in the Hope Valley area in the Sierra Nevada about 25 km south of Lake Tahoe are estimated to have formed at approximately 2 kbars (Kerrick and others, 1973), although these pressure estimates are not well constrained. Two kbars pressure is equivalent to about 7 km depth. Pressures calculated using hornblende compositions reported by Ague and Brimhall (1988a,b) for Late Cretaceous plutons in the Sierra Nevada batholith along the southwest edge of the study area and the hornblende geobarometer (Hammarstrom and Zen, 1986; Johnson and Rutherford, 1989) generally are about 2 kbars (16 samples, mean=1.89 kbars, standard deviation=1.00 kbars). However, nine of these samples are from a single pluton (granodiorite of Topaz Lake) that has an unreasonably large range in calculated pressures of 0.0-2.1 kbars. Three samples from the Donner Lake area yielded lower pressures (0.1-0.9 kbars) and are referred to by Ague and Brimhall (1988b) as the Donner Lake low pressure zone. High-salinity fluid inclusions in igneous quartz have not been identified in Late Cretaceous plutons in the Sierra Nevada batholith in the southwestern part of the study area or in Cretaceous plutons in the southwestern part of the Reno 1° by 2° quadrangle (D.A. John, unpub. data, 1991) suggesting depths of emplacement greater than about 5 km (John, 1989). Quantitative estimates for depths of emplacement of other Cretaceous plutons in the study area cannot be made with existing data.

Hydrothermal alteration. Hydrothermal alteration in the Cretaceous plutons is generally weak and has been studied in detail only in a few areas. Large areas of nearly continuous exposures of Cretaceous plutons of the Sierra Nevada batholith in the southwest part of the study area are virtually unaltered, except where late Tertiary alteration (mostly propylitic alteration) has been superimposed (for example, the Ebbetts Pass–Markleeville area, Wilshire, 1957). Elsewhere, several areas of Cretaceous alteration in granitic rocks include the Ryan Canyon area in the southwestern Gillis Range (Luethe, 1974; Hudson, 1983), the Sweetwater Mountains (Brem and others, 1983), the northern Garfield Hills, the Pine Grove Hills (Wilson district) (Moore, 1969), the Virginia City district (Vikre and others, 1988; Vikre, 1989), and the Santa Fe district just southeast of the study area (Clark, 1922). Hydrothermal alteration associated with Pine Nut porphyry molybdenum deposit in the southern Pine Nut Mountains is undated but is likely Cretaceous in age (Doebrich and others, in press). Hydrothermal alteration in these areas is mostly sericitic alteration associated with stockwork quartz veining (Moore, 1969; Brem and others, 1983; Vikre, 1989). Pyrite and molybdenite are the most common sulfide minerals associated with the quartz veins. Alteration in the Ryan Canyon area is somewhat different consisting of both massive pyritic alteration and aluminous (advanced argillic) alteration in different areas that are probably related to different Cretaceous intrusions (Luethe, 1974; Hudson, 1983).

Related mineralization. Mineral deposits thought to be related to Cretaceous plutons in the study area is mostly limited to tungsten skarn, low-fluorine porphyry molybdenum, and polymetallic vein deposits. In addition, several areas of Cretaceous hydrothermal alteration possibly related to porphyry copper systems are present in the southeastern part of the area (Ryan Canyon, Gillis Range, and northern Garfield Hills) and copper skarn and porphyry copper mineralization are present in the Gabbs Valley Range (Santa Fe district) about 6 km southeast of the study area (Clark, 1922; Kleinhampl and others, 1983), suggesting that the metallogeny and (or) levels of exposure may change near the southeastern edge of the study area.

Small tungsten skarn deposits are present on the margins of Cretaceous plutons in the Hope Valley area, McTarnahan Hill (Delaware district), Churchill Butte, southern Pine Nut Mountains (Gardnerville district), Olinghouse district, and elsewhere in the study area. Low-fluorine porphyry molybdenum systems of Cretaceous or suspected Cretaceous age are present in the Sweetwater Mountains (Brem and others, 1983), the southern Pine Nut Mountains (Westra and Keith, 1981; Doebrich and others, in press), and the Garfield Hills (Kleinhampl and others, 1983). Copper skarn and disseminated copper mineralization associated with the quartz monzonite of Giroux Mountain in the Santa Fe district just east of the study area is undated but is probably Cretaceous in age (John, 1983).

Tertiary granitic plutons

Distribution. Tertiary granitoid plutons form several small bodies scattered in the north-central and northeast parts of the study area. Tertiary granitoid plutons include the Davidson Granodiorite in the Virginia City area, dioritic intrusions on Peavine Peak, and granitic dikes in the Olinghouse district. In addition, the granodioritic Guanomi stock is about 6 km northeast of the study area on the southwest shore of Pyramid Lake. Numerous hypabyssal porphyry intrusions are also associated with Tertiary volcanic rocks in the study area, but they generally lack phaneritic textures.

Age. The Davidson Granodiorite is the only pluton directly dated by K-Ar methods and is middle Miocene in age, approximately 17 to 14 Ma (table 2). Dioritic intrusions on Peavine Peak are approximately the same age based on the ages of rocks that they intrude and rocks that overlie them (Hudson, 1977). In addition, granitic dikes in the Olinghouse district are inferred to be about

13 Ma in age based on regional age relations (Geasan, 1980). The Guanomi stock, situated just east of the study area, is about 24 Ma in age based on the age of hydrothermal alteration associated with it (Wallace, 1975).

Chemistry, modal composition, and petrography. Intrusive rocks on Peavine Peak are fine-grained pyroxene diorite and quartz diorite porphyry containing 53 to 61 percent SiO_2 (fig. 10; Hudson, 1977). The Davidson Granodiorite is a medium-grained pyroxene-biotite granodiorite containing about 61 to 65 weight percent SiO_2 and relatively high K_2O contents relative to the Cretaceous plutons (fig. 10). Orthopyroxene and clinopyroxene are partially replaced by fibrous amphibole (Thompson, 1959). Intrusive rocks in the Olinghouse district have been variably described as granodiorite porphyry (Bonham, 1969) and dacite porphyry (Geasan, 1980). Bonham (1969) notes that the porphyry contains sodic plagioclase, biotite, and hornblende phenocrysts set in a fine-grained groundmass of quartz, potassium feldspar, and opaque minerals. No chemical data are available for these rocks. The Guanomi stock grades from a medium-grained quartz monzonite in the central part of its exposures outwards into quartz monzonite porphyry (Bonham, 1969). Chemical analyses reported by Wallace (1975) of "propylitized" samples suggest that the stock contains about 67 to 68 weight percent SiO_2 and has a relatively high K_2O content compared to the Cretaceous plutons (fig. 9).

Depth of emplacement. The Tertiary plutons intrude approximately coeval volcanic rocks and are thought to have been emplaced at very shallow depths, probably mostly ≤ 1 km. Vikre (1989, p. 1576) states that "Contact relations and intrusive textures of Davidson Granodiorite as well as vein temperatures indicate that several thousand feet of Alta rocks covered Davidson apophyses ..." No other estimates for depth of emplacement can be made using available data.

Hydrothermal alteration. Most exposures of Tertiary granitoids in the study area are weakly to strongly hydrothermally altered. Alteration ranges from propylitic assemblages, which are common in all exposures, to quartz-sericite-pyrite which is well developed in the Guanomi stock (Bonham, 1969; Wallace, 1975), to argillic and advanced argillic assemblages which are present locally in the Peavine district (Hudson, 1977). Pyrite is common in all exposures.

Related mineralization. Hudson (1977) suggested that porphyry copper mineralization may underlie the Peavine and Wedekind districts at depth. This suggestion was based on comparison of hydrothermal alteration in these districts to alteration found in the upper parts of known porphyry copper systems. Gold-copper mineralization is locally present in and adjacent to the dioritic intrusions in the Peavine district (Bonham, 1969; Hudson, 1977). The Guanomi stock contains a low-grade porphyry copper-(molybdenum) system (Bonham, 1969; Wallace, 1975; Satkoski and Berg, 1982). Epithermal gold-silver veins (adularia-sericite type) in the Olinghouse district are spatially associated with and commonly hosted by granodiorite porphyry dikes (Bonham, 1969). Both the intrusive dikes and the veins occupy northeast-trending faults that cut Miocene volcanic rocks. No mineralization is known to be directly related to the Davidson Granodiorite (Vikre, 1989).

Discussion and Summary

There are notable similarities and differences between various groups of granitoids in the study area. Many attributes, including composition, depths of emplacement, and metallogeny, vary between different groups of granitoids. These differences are particularly evident when comparing Jurassic plutons in the Yerington area (group 3), the northern Sierra Nevada (group 4), and the West Walker River area (group 5) to Cretaceous plutons of the Sierra Nevada batholith (group 6). In this section, we describe the regional framework of the plutons, contrast major attributes of the different groups of plutons, and discuss some of the possible implications of these features and their bearing on Triassic and Jurassic metallogenesis.

Regional setting

Granitic plutons in the study area represent an amalgamation of arc-related magmas of varying age and composition that formed broad bands of magmatic rocks across the western Cordillera throughout the Mesozoic. In the study area, granitic plutons are found in two different provinces: the Sierra Nevada and the Great Basin. Although these provinces are late Cenozoic physiographic features, they also correspond to overall changes in the nature of the pre-Cenozoic basement rocks. The Sierra Nevada, which forms the western third of the study area, is underlain almost entirely by Mesozoic granitic rocks of the Sierra Nevada batholith and was the focus of magmatic activity throughout most of the Mesozoic. In contrast, the proportion of Mesozoic granitoids that form basement rocks progressively decreases from west to east across the Great Basin (for example, Barton and others, 1988), and within the study area, Mesozoic volcanic and sedimentary rocks are inferred to underlie a much larger part of the Great Basin than the Sierra Nevada (Schweickert, this volume).

Plutonic rocks in the Sierra Nevada batholith generally form relatively coherent northwest- to north-northwest-trending belts of broadly age-equivalent plutons that represent superposition of magmatic arcs of various ages (for example, Evernden and Kistler, 1970; Kistler and others, 1971; Stern and others, 1981; Kistler, 1990; Chen and Tilton, 1991). Kistler (1990, fig. 2) has divided these belts into Triassic (240-200 Ma), Middle Jurassic (180-165 Ma), latest Jurassic and Early Cretaceous (152-127 Ma), Early Cretaceous (123-100 Ma), and Late Cretaceous (92-77 Ma) groups. Within the study area, most of plutons of the Sierra Nevada are part of the Early or Late Cretaceous belts, and Middle Jurassic plutons are exposed only in the Emigrant Gap area (fig. 2, tables 1 and 2). Regular compositional variations in the central part of the Sierra Nevada batholith south of the study area (between latitudes 36°45'-38° N.), which are most obviously manifested by general west to east increases in K_2O and potassium feldspar and decreases in MgO, CaO, FeO, and mafic minerals, have long been known and appear independent of pluton age (for example, Lindgren, 1915; Moore, 1959; Bateman and Dodge, 1970; Bateman, 1992). However, more recent regional petrologic studies by Ague and Brimhall (1987, 1988a,b), which are primarily based on biotite and hornblende compositions, suggest that compositional variations in the batholith, which are reflected in both mineralogical and whole-rock chemical data, are more complex and irregularly distributed than previously recognized, although Ague and Brimhall suggest a general west to east increase in the amount of contamination of magmas derived from melting of upper mantle or subducted oceanic slabs by continentally-derived crustal components. Other studies of radiogenic (Sr, Nd, and Pb) and stable (O) isotopes, primarily at latitudes south of the study area, indicate several magma sources for the Sierra Nevada batholith (for example, Kistler and Peterman, 1973, 1978; Kistler and others, 1986; Kistler, 1990; DePaolo, 1981; Saleeby and others, 1987; Chen and Tilton, 1991; Masi and others, 1981), and many plutons, particularly on the east side of the batholith, appear to have incorporated a significant component of Precambrian supracrustal material (Chen and Tilton, 1991). Unfortunately, most plutons in the study area have not undergone detailed petrologic study.

In contrast to the Sierra Nevada batholith, age and compositional patterns of Mesozoic granitoids in the western Great Basin are more poorly defined, in part due to the paucity of exposure, lack of isotopic dating, and lack of detailed petrologic study of most plutons. However, one of the more striking features is the west-northwest-trending belt of Middle Jurassic magmatism centered in the Yerington area that is oriented at a high angle to the major age belts in the Sierra Nevada batholith. This belt is about 25-40 km wide and extends for a distance of about 130 km from the Carson Range to the northern Gillis Range, although its length may have been nearly doubled by late Cenozoic extension. This belt of Middle Jurassic magmatism approximately parallels the east-west bend in the Precambrian continental margin and in the 0.706 isopleth in initial strontium ratio, but it is situated about 50 km north of these features.

Compositional, modal, and strontium isotopic data for Cretaceous plutons throughout the study area suggest that they are similar to Cretaceous parts of the Sierra Nevada batholith (fig. 11). The plutons are quartz-bearing, calc-alkaline rocks similar to Cretaceous plutons that are well characterized farther south in the central Sierra Nevada (Bateman and Dodge, 1970; Bateman and Chappell, 1979; Bateman, 1992; Dodge and others, 1982; Kistler and Peterman, 1978; Kistler and others, 1986; Ague and Brimhall, 1988a).

In contrast, Jurassic plutons in the Yerington and West Walker River areas differ both from Late Jurassic plutons on the west side of the Sierra Nevada batholith (for example, the western foothills rocks, Bateman and Dodge, 1970; Bateman, 1992) and Middle to Late Jurassic plutons further east in the central Great Basin (for example, the Austin, Northumberland, and Clipper Gap plutons in the Toiyabe and Toquima Ranges; Lee, 1984). Late Jurassic plutons in the western Sierra Nevada and in central Nevada are less enriched in potassium than the Jurassic plutons in the Yerington and West Walker River areas. Jurassic plutons in central Nevada are more aluminous (borderline peraluminous) and tend to be more silica rich, whereas Late Jurassic plutons in the western Sierra Nevada have a wide range of silica contents (approx. 56-73 weight percent) but have uniformly low potassium contents.

Depths of emplacement

Middle Jurassic plutons in the Yerington area and in the northern Sierra Nevada and Late Jurassic plutons in the West Walker River area appear to have been emplaced at relatively shallow depths with present exposures commonly representing paleodepths less than about 5 km. Relatively shallow depths of emplacement are reflected in textures of the intrusions, style of emplacement, extent of hydrothermal alteration, fluid-inclusion populations, and types of mineral deposits associated with the intrusions. Coeval, possibly cogenetic volcanic rocks are preserved for several of these plutons in the Yerington and West Walker River areas, and the Emigrant Gap pluton may be the source of some of the volcanic rocks in the Tuttle Lake Formation.

In contrast to the Jurassic plutons, present exposures of most Cretaceous plutons in the Sierra Nevada batholith and in other parts of the study area appear to represent somewhat greater depths, with most exposures probably representing paleodepths greater than about 5-7 km (pressure >1.5-2 kbars). Coeval volcanic rocks are generally absent in the vicinity of the Cretaceous plutons with the notable exception of the China Garden pluton. Two other areas of possible low pressure (<1 kbar) Cretaceous plutons defined by Ague and Brimhall (1988b, fig. 7) are present near Donner Lake and along the southwest edge of the study area (Bridgeport low pressure zone). However, many of the samples in the Bridgeport zone are from a single pluton (granodiorite of Topaz Lake) that shows unreasonably(?) large scatter in pressure estimates (0.0–2.1 kbars) calculated from hornblende compositions

The change in the types of mineral deposits from porphyry copper and copper-iron skarn deposits related to the Middle Jurassic plutons to tungsten skarn deposits associated with the Cretaceous plutons also suggests greater paleodepths for the Cretaceous plutons as porphyry copper deposits typically form at depths <5 km, whereas tungsten skarns commonly form at depths >5 km (Newberry and Einaudi, 1981; Barton and others, 1988).

Compositional variations

Notable compositional differences between the Middle Jurassic plutons of the Yerington area, Late Jurassic plutons of the West Walker River area, and Cretaceous plutons are manifested both in chemical and modal compositions. The average silica content of the Jurassic plutons tends to be lower than in the Cretaceous plutons. At similar silica contents, Middle Jurassic plutons have higher K_2O, total alkalis, Ba, and Zr, and lower Al_2O_3 and total iron than the Cretaceous plutons (figs. 4, 7, and 9). The Peacock (alkali-lime) index for the Middle Jurassic plutons is about 56 (borderline between alkali-calcic and calc-alkalic) and about 56.5 for the West Walker River plutons (calc-alkalic) compared to about 59 for the Cretaceous plutons (calc-alkalic). The aluminum saturation index (A/CNK= molar $Al_2O_3/(CaO+Na_2O+K_2O)$ is lower in the Middle Jurassic plutons with all Middle Jurassic plutons being metaluminous (A/CNK<1), whereas many of the more silica-rich Cretaceous plutons are peraluminous (A/CNK>1) (figs. 4 and 9). Late Jurassic plutons in the West Walker River area have A/CNK ratios similar ratios in the Middle Jurassic plutons, whereas A/CNK ratios are higher in the China Garden pluton than in the Jurassic plutons but are similar to A/CNK ratios in the Cretaceous plutons (fig. 7). Strontium content is much greater (≥1,000 ppm) in several of the Middle Jurassic plutons than in the Cretaceous plutons, but Late Jurassic plutons in the West Walker River area have relatively low strontium contents (fig. 7). No zirconium or barium data are available for the West Walker River plutons. Hornblende/biotite ratios in both the Middle and Late Jurassic plutons are commonly greater than one, which are higher than ratios in Cretaceous plutons that generally are less than one.

Middle Jurassic plutons of the Yerington area (group 3) and Late Jurassic plutons of the West Walker River area (group 5) have some compositional similarities to Triassic and Jurassic alkaline plutons that form scattered bodies throughout the length of the Cordillera from British Columbia to the Sonoran Desert (early Mesozoic alkalic magmatic province, Miller, 1978, fig. 1). Schweickert (1972, 1976) also noted that the Late Jurassic plutons in the West Walker River area had alkaline affinities somewhat similar to Middle Jurassic monzonitic plutons in the White and Inyo Mountains, California (Sylvester and others, 1978; Miller, 1978). The alkaline plutons are characterized by high K_2O, total alkalis, Ba, Sr, and Rb, moderate silica, generally low normative and modal quartz (Miller, 1977, 1978), although alkaline plutons in the Bristol and Providence Mountains, California, have relatively lower strontium contents (<800 ppm; Fox and Miller, 1990). The alkaline plutons are commonly homogeneous, although the Mt. Lowe intrusion in the San Gabriel Mountains, California, and alkaline plutons in the Bristol and Providence Mountains are more compositionally heterogeneous (Barth and Ehlig, 1988; Fox and Miller, 1990). Many of the alkaline plutons appear to have been emplaced at relatively shallow depths with comagmatic(?) volcanic rocks preserved locally (Fox and Miller, 1990). Magnetite skarns and extensive areas of albitic alteration are associated with several of these plutons in the Mojave Desert (Hall and others, 1988; Fox and Miller, 1990). Miller (1977, 1978) suggested that alkaline plutons in the Mojave Desert formed by small amounts of melting of alkali-enriched eclogite in the upper mantle, whereas Sylvester and others (1978) suggested that the alkaline plutons in the White Mountains formed from initial melting of undepleted upper mantle. Fox and Miller (1990) concluded that heterogeneous alkali-rich plutons in the Providence and Bristol Mountains may have formed by extensive hornblende fractionation but specified no particular magma source.

Christe and Hannah (1990, fig. 8) suggested that the early Mesozoic alkaline plutons were part of a larger zone of potassium-rich volcanic and plutonic rocks that they called the "high potassium magmatic province". They noted that potassium-rich, mildly alkaline igneous rocks in this province included Mesozoic volcanic sequences on Peavine Peak, in the Pine Nut Mountains, and in the Yerington district that range in age from late Early Jurassic to late Middle Jurassic.

Jurassic plutons of the Yerington and West Walker River area groups are mildly alkaline but significantly differ from the alkaline plutons in the White and Inyo Mountains and elsewhere in the Cordillera in several ways (fig. 11). These Jurassic plutons in the study area have relatively high potassium contents, but the potassium content is notably less than in most of the alkaline plutons elsewher (fig. 11*A*). Only a few plutons in the study area (parts of the Desert Creek pluton and diorite bodies in the northern Pine Nut Mountains) would be classified as alkaline using the Irvine and Baragar (1971) total alkali-silica diagram (figs. 4, 7, and 11*B*). Also, only a few of the Jurassic plutons (notably the Yerington batholith and the Sunrise Pass pluton) have high barium, strontium, and rubidium concentrations that are similar to the high concentrations of these elements in the alkaline plutons; however, absolute strontium and rubidium concentrations are generally lower at any given Rb/Sr ratio than in the alkaline plutons (fig. 11*C*). Most of the Jurassic plutons in the study area contain abundant modal quartz and are granodiorite, quartz monzodorite, and granite in the IUGS classification (for example, Dilles, 1987; John, 1983). In contrast, many of the alkaline plutons are quartz-poor monzonites and feldspathoidal-bearing rocks (for example, those in the White and Inyo Mountains, Sylvester and others, 1978).

The compositional and modal differences between Jurassic plutons of the Yerington and West Walker River groups and alkaline plutons elsewhere in the Cordillera and between these Jurassic plutons and Cretaceous plutons within the study area suggest different magma origins and (or) interaction with the upper crust during ascent and crystallization. Dilles (1987) suggested that mafic parts of the Yerington batholith (the informally named McLeod Hill quartz monzodiorite) were derived by crystal fractionation of mantle-derived basaltic magma combined with assimilation of as much as 50 percent Triassic volcanic-arc rocks. Ague and Brimhall (1987, 1988a,b) suggested that F/OH ratios in biotite are sensitive indicators of contamination of magmas derived from the upper mantle by continentally-derived crustal rocks, with higher F/OH ratios indicating greater amounts of contamination. Using biotite compositions reported by Dilles (1987) and the classification scheme of Ague and Brimhall (1987, 1988a), the Yerington batholith is a moderately to strongly contaminated I-type granitic body (I-MC and I-SC types) with the amount of contamination generally increasing with increasing silica content and from early to late phases of the batholith. A single biotite analysis of the Shamrock batholith from the southern Singatse Range is moderately contaminated (I-MC type), whereas a single analysis of the Triassic Wassuk Range Diorite is weakly contaminated (I-WC type) according to the Ague and Brimhall classification (data from Dilles, 1987). Biotite compositions for Cretaceous plutons in the Sierra Nevada batholith in the study area range from weakly contaminated to strongly contaminated according to the Ague and Brimhall classification (Ague and Brimhall, 1988a, fig. 3). Ague and Brimhall (1988b) suggest that plutons showing moderate or strong contamination are underlain by continental crust, which they defined as Precambrian rocks or derivative sedimentary rocks. Thus, they infer that most of the study area is underlain by continental crust (fig. 12). In contrast, Kistler (1990; Kistler and Peterman, 1973, 1978) infers that plutons with initial strontium ratios less than 0.706 indicate the absence of continental (Precambrian) crust. Most plutons in the study area, including Middle Jurassic plutons, have initial strontium ratios less than 0.706 (fig. 12) implying an absence of Precambrian continental crust beneath most of the study area. In addition, Dilles (1987) noted that the low initial strontium ratio of the Yerington batholith (approx. 0.704) only allows assimilation of trace amounts of radiogenic Precambrian crust despite petrologic modelling which suggested assimilation of as much as 50 weight percent crustal materials.

Common Pb and additional Sr isotopic data (Wright and Wooden, 1991; J.L. Wooden, oral commun., 1991) also suggest that there are few differences in inferred source and amount of continental crust contamination between Jurassic and Cretaceous plutons in the northwestern Great Basin and northeastern Sierra Nevada, an area which includes the study area. Their data suggest either that Cretaceous plutons contain slightly more radiogenic strontium for equivalent isotopic lead and (or) that Jurassic plutons contain slightly more radiogenic lead for equivalent isotopic strontium, but the differences are minor compared to isotopic differences between Jurassic to Early Cretaceous and Late Cretaceous plutons in the northeastern Great Basin (Wright and Wooden, 1991).

Christe and Hannah (1990) suggested that potassium-rich Early Jurassic volcanic rocks in the northern Sierra Nevada formed in an extensional environment in an island arc that was undergoing a complex transition from orogenic (compressional) to extensional tectonics. They further suggested that the high potassium magmatic province of the Cordillera formed during a long-lived (Late Triassic to Late Jurassic) extensional event following the Sonoma orogeny. Proffett and Dilles (1984) and Dilles and Wright (1988) noted that emplacement of the Shamrock batholith closely followed formation of major east-west-striking normal faults that bound and downdrop the Yerington batholith >1 km on its north and south sides. These faults, presumably related to extension, represent a change from a compressional (folding) environment, which was present during emplacement of the Yerington batholith, although they suggest that this folding episode may be a local event related to emplacement of the Yerington batholith. Barton (1990) also suggested that Jurassic plutons in the Great Basin may have more primitive compositions (more alkalic), because they were emplaced into an extensional environment (at least locally) and underwent less interaction with the crust than the Cretaceous plutons, which were emplaced into a compressional environment (constant subduction). The somewhat more primitive compositions and possibly thinner crust due to extension may have allowed the Jurassic plutons to rise to shallower depths in the crust than the Cretaceous plutons.

In summary, there are significant compositional differences between Middle to Late Jurassic plutons in the Yerington and West Walker River areas and Cretaceous plutons. The Middle to Late Jurassic plutons are mildly alkaline but not as strongly alkaline as Triassic and Jurassic alkaline plutons elsewhere in the Cordillera.

It is not obvious from the available data that varying amounts of assimilation of Precambrian continental crust can account for the compositional variations shown between different age groups of plutons in central part of the study area. Alternatively, the compositional variations between the Middle Jurassic plutons in the Yerington area and Cretaceous plutons of the Sierra Nevada may reflect differences in the depth of magma generation and (or) the tectonic environment of magma generation and emplacement. The more alkaline Jurassic plutons may represent slightly greater depths of melting, which could enrich the melts in alkalis, Rb, Sr, and Ba, or melting of an enriched or less depleted upper mantle source, which would also enrich the magma in these elements. Subsequent Cretaceous magmas might have formed either at shallower depths or have melted more depleted upper mantle. The Cretaceous magmas also may have assimilated more highly evolved crust (Triassic and Jurassic volcanic-arc rocks) than the Jurassic magmas.

Metallogeny

Mineral deposits associated with the Middle Jurassic plutons are generally different than that those associated with the Cretaceous plutons within the study area. Most mineralization related to the Middle Jurassic plutons are porphyry copper, copper-iron, and iron skarn deposits associated with the Yerington batholith. Other areas of copper-iron mineralization of inferred Middle Jurassic age include iron-copper skarn and copper-bearing polymetallic veins in the Calico Hills, iron skarn at the Dayton iron deposit, and skarn and disseminated copper mineralization at Copper Mountain, just east of the study area. Other types of mineralization known to be related to the Middle Jurassic plutons include copper- and gold-bearing quartz-tourmaline veins and copper- and molybdenum-bearing skarn in and adjacent to the French Lake pluton in the northern Sierra Nevada.

In contrast to the copper-iron mineralization related to the Middle Jurassic plutons, most mineralization associated with Cretaceous plutons in the study area is tungsten skarn and porphyry molybdenum. Tungsten skarns are the most common type of deposit and are present around numerous Cretaceous plutons where they intrude carbonate rocks. The Pine Nut porphyry molybdenum system in the southern Pine Nut Mountains is undated but likely to be Cretaceous in age, because the composition of the nearby Shamrock batholith is dissimilar to compositions of plutons genetically associated with low fluorine porphyry molybdenum deposits elsewhere (fig. 11*D*). Several other prospects for porphyry molybdenum systems are present in the study area including Cretaceous mineralization in the Sweetwater Mountains and in the Garfield Hills, both of which were drilled in the early 1980s. Aluminous (advanced argillic) and pyritic alteration possibly related to porphyry copper systems are present in the Ryan Canyon area, southern Gillis Range, in the southeastern part of the study area (Luethe, 1974; Hudson, 1983). This alteration is Late Cretaceous (~95-90 Ma) in age. Further to the southeast in the Santa Fe district, copper skarn and possible porphyry copper mineralization are associated with Cretaceous(?) intrusions (quartz monzonite of Giroux Mountain). The change from Mo-W to Cu-Fe deposits spatially associated with Cretaceous plutons suggests that the metallogeny of the Cretaceous plutons may change across the study area from west to east. This change also may indicate that more shallowly emplaced Cretaceous plutons are preserved near the southeastern edge of the study area.

The Yerington batholith is the source of largest known mineral deposits of Triassic or Jurassic age in the study area. Several petrologic features separate the Yerington batholith from other plutons of similar age in the study area (for example, the Shamrock batholith) and may explain its apparent uniqueness in terms of mineralization among Triassic and Jurassic plutons. These features include: (1) more compositional diversity (expanded compositional series) with more highly differentiated compositions (granite porphyries), (2) multiple intrusions that were very rapidly emplaced (<1 m.y., Dilles and Wright, 1988), (3) possibly a more primitive or deeper magma source reflected in higher K, Sr, and Ba contents, and (4) a high potassium nature that may indicate more water-rich magmas (Gill, 1981), which are important in the formation of porphyry and skarn deposits.

Conclusions

Granitic plutons in the Reno study area record a diversity of discontinuous arc-related magmatic activity from Late Triassic to late Tertiary time. The plutons can be separated into seven broad groups on the basis of age, distribution, composition, and metallogenesis. These groups are: small Late Triassic plutons in the center of the study area, Early Jurassic plutons in the southeast and south-central parts of study area, Middle Jurassic plutons in the Yerington area, latest Middle to Late Jurassic plutons in the northern Sierra Nevada, Late Jurassic plutons in the West Walker River area, Cretaceous plutons concentrated in the Sierra Nevada but spread throughout the study area, and late Tertiary plutons scattered in the northeast part of the study area. Present exposures of most Jurassic plutons represent shallower paleodepths than exposures of most Cretaceous plutons, and several Jurassic plutons probably intrude cogenetic volcanic cover.

Jurassic plutons in the Yerington and West Walker River areas tend to have mildly alkaline compositions that are notably different from calc-alkaline compositions typical of Cretaceous plutons of the Sierra Nevada batholith. The compositional differences include generally higher K_2O, Sr, Ba, and Zr contents and Sr/Rb ratios, lower SiO_2 and Al_2O_3 contents, and higher modal hornblende/biotite ratios. However, despite the many compositional differences between these groups of plutons, radiogenic isotopes (Sr, Pb) only differ slightly. The origins of the compositional variations are unclear but may reflect differences in depths of melting and magma genesis, differences in the nature of the intruded crust (Triassic volcanic-arc rocks versus Jurassic volcanic-arc rocks), and (or) differences in the tectonic setting of magmatism (possibly an extensional environment for at least part of the Jurassic magmatism).

No mineralization is known to be genetically associated with Late Triassic plutonism in the study area. Middle Jurassic plutons in the Yerington area, particularly the Yerington batholith, formed large porphyry copper and copper-iron skarn deposits. Relatively little mineralization is known to be associated with other groups of Jurassic plutons. Tungsten skarn and low-fluorine porphyry molybdenum deposits are the main types of mineral deposits associated with Cretaceous plutons within the study area, although copper skarn deposits and porphyry copper-type alteration are associated with Cretaceous(?) plutons near the southeast corner of the study area. The differences in metallogenesis between the Middle Jurassic and Cretaceous plutons probably reflect generally greater paleodepths of present exposures of the Cretaceous plutons and compositional differences between the groups of plutons. The Yerington batholith has several characteristics, including more compositional diversity, larger volume, and emplacement in several closely spaced (temporally) pulses, that separate it from other Middle Jurassic plutons in the study area and may help explain its apparent uniqueness in terms of the formation of large metallic mineral deposits.

References cited

Ague, J.J., and Brimhall, G.H., 1987, Granites of batholiths of California: Products of local assimilation and regional scale contamination: Geology, v. 15, p. 63-66.

———1988a, Regional variations in bulk chemistry, mineralogy, and the compositions of mafic and accessory minerals in the batholiths of California: Geological Society of America Bulletin, v. 100, p. 891-911.

———1988b, Magmatic arc asymmetry and distribution of anomalous plutonic belts in the batholiths of California: Effects of assimilation, crustal thickness, and depth of crystallization: Geological Society of America Bulletin, v. 100, p. 912-927.

Armin, R.A., and John, D.A., 1983, Geologic map of the Freel Peak 15-minute quadrangle, California and Nevada, *with* Quaternary geology by J.C. Dohrenwend: U.S. Geological Survey Miscellaneous Investigations Map I-1424, scale 1:62,500.

Armin, R.A., John, D.A., and Moore, W.J., 1984, Geologic map of the Markleeville 15-minute quadrangle, Alpine County, California, *with* Quaternary geology by J.C. Dohrenwend: U.S. Geological Survey Miscellaneous Investigations Map I-1474, scale 1:62,500.

Barth, A.P., and Ehlig, P.L., 1988, Geochemistry and petrogenesis of the marginal zone of the Mount Lowe Intrusion, central San Gabriel Mountains, California: Contributions to Mineralogy and Petrology, v. 100, p. 192-204.

Barton, M.D., 1990, Cretaceous magmatism, metamorphism, and metallogeny in the east-central Great Basin, *in* Anderson, J.L., ed., The nature and origin of Cordilleran magmatism: Boulder, Colorado, Geological Society of America Memoir 174, p. 283-302.

Barton, M.D., Battles, D.A., Debout, G.E., Capo, R.C., Christensen, J.N., Davis, S.R., Hanson, R.B., Michelsen, C.J., and Trim, H.E., 1989, Mesozoic contact metamorphism in the western United States, *in* Ernst, W.G., ed., Metamorphism and crustal evolution of the western United States, Rubey volume VII: Englewood Cliffs, New Jersey, Prentice Hall, p. 110-178.

Bateman, P.C., 1992, Plutonism in the central part of the Sierra Nevada Batholith, California: U.S. Geological Survey Professional Paper 1483, 186 p.

Bateman, P.C., and Chappell, B.W., 1979, Crystallization, fractionation, and solidification of the Tuolumne Intrusive Series, Yosemite National Park, California: Geological Society of America Bulletin, part 1, v. 90, p. 465-482.

Bateman, P.C., and Dodge, F.C.W., 1970, Variations of major chemical constituents across the central Sierra Nevada batholith: Geological Society of America Bulletin, v. 81, p. 409-420.

Battles, D.A., 1991, Metasomatic alteration within a tilted batholith, Yerington district, Nevada: *in* Raines, G.L., Lisle, R.E., Schafer, R.W., and Wilkinson, W.H., eds., Symposium on the geology and ore deposits of the Great Basin, Proceedings: Reno, Geological Society of Nevada and U.S. Geological Survey, p. 351-353.

Bell, J.W., and Garside, L.J., 1987, Geologic map of the Verdi Quadrangle, Nevada: Nevada Bureau of Mines and Geology Urban Series Map 4Gg, scale 1:24,000.

Bingler, E. C., 1978, Geologic map of the Schurz quadrangle: Nevada Bureau of Mines and Geology Map No. 60, scale 1:48,000.

Bonham, H.F., Jr., 1969, Geology and mineral deposits of Washoe and Storey Counties, Nevada: Nevada Bureau of Mines and Geology, Bulletin 70, 140 p.

Brem, G.F., 1984, Geologic map of the Sweetwater Roadless Area, Mono County, California, and Lyon and Douglas Counties, Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-1535-B, scale 1:62,500.

Brem, G.F., Chaffee, M.A., Plouff, Donald, Lambeth, R.H., Campbell, H.W., Scott, D.F., and Spear, J.M., 1983, Mineral resource potential of the Sweetwater Roadless Area, Mono County, California and Lyon and Douglas Counties, Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-1535-A, scale 1:62,500.

Carten, R.P., 1986, Sodium-calcium metasomatism; chemical, temporal, and spatial relationships at the Yerington, Nevada, porphyry copper deposit: Economic Geology, v. 81, p. 1495-1519.

Castor, S.B., 1972, Geology of the Central Pine Nut and northern Buckskin Ranges, Nevada: A study of Mesozoic intrusive activity: Reno, University of Nevada, Ph.D. dissertation, 270 p.

Chen, J.H., and Tilton, G.R., 1991, Applications of lead and strontium isotopic relationships to the petrogenesis of granitoid rocks, central Sierra Nevada batholith, California: Geological Society of America Bulletin, v. 103, p. 439-447.

Chesterman, C.W., 1975, Geology of the Matterhorn Peak 15-minute quadrangle, Mono and Tuolumne Counties, California: California Division of Mines & Geology, Map Sheet 22, scale 1:62,500.

Christe, Geoff, and Hannah, J.L., 1990, High-K, continental-arc volcanism in the Kettle Rock sequence of the eastern Mesozoic belt, northern Sierra Nevada, California; Implications for lower Mesozoic Cordilleran tectonics, *in* Anderson, J.L., ed., The nature and origin of Cordilleran magmatism: Boulder, Colorado, Geological Society of America Memoir 174, p. 315-330.

Clark, C.W., 1922, Geology and ore deposits of the Santa Fe district, Mineral County, Nevada: University of California Publications in the Geological Sciences, v. 14, p. 10-74.

DePaolo, D.J., 1981, A neodynium and strontium isotopic study of the Mesozoic calc-alkaline granitic batholiths of the Sierra Nevada and Penisular Ranges, California: Journal of Geophysical Research, v. 86, p. 10470-10488.

Dilles, J.H., 1984, The petrology and geochemistry of the Yerington batholith and the Ann-Mason porphyry copper deposit, western Nevada: Stanford, California, Stanford University Ph.D. dissertation, 389 p.

——— 1987, Petrology of the Yerington batholith, Nevada: Evidence for evolution of porphyry copper ore fluids: Economic Geology, v. 82, p. 1750-1789.

Dilles, J.H., and Einaudi, M.T. 1992, Wall-rock alteration and hydrothermal fluid flow paths about the Ann-Mason porphyry copper deposit, Nevada—a 6-km vertical reconstruction: Economic Geology, v. 87, p. 1963-2001.

Dilles, J.H., and Wright, J.E., 1988, The chronology of early Mesozoic arc magmatism in the Yerington district, Nevada, and its regional implications: Geological Society of America Bulletin, v. 100, p. 644-652.

Dodge, F.C.W., Millard, H.T., and Elsheimer, H.N., 1982, Compositional variations and abundances of selected elements in granitoid rocks and constituent minerals, central Sierra Nevada batholith, California: U.S. Geological Survey Professional Paper 1248, 24 p..

Doebrich, J.L., Garside, L.J., and Shawe, D.Triassic-Jurassic magmatic arc of western Nevada and eastern California--Part II: Mineral deposits: U.S. Geological Survey Bulletin (in press).

Drake, R.E., Bowman, H.R., and Herbert, A.J., 1975, Chronology of the O.B. James pluton: Nuclear Chemistry Annual Report, Lawrence Berkeley Laboratory, p. 358.

Ekren, E.B., and Byers, F.M., Jr., 1985, Geologic map of Win Wan Flat, Kinkaid NW, Kinkaid, and Indian Head Peak quadrangles: U. S. Geological Survey Miscellaneous Investigations Series Map I-1578, scale 1:48,000.

——— 1986, Geologic map of the Murphys Well, Pilot Cone, Copper Mountain, and Poinsettia Spring quadrangles, Mineral County, Nevada: U. S. Geological Survey Miscellaneous Investigations Series Map I-1576, scale 1:48,000.

Einaudi, M.T., 1977, Petrogenesis of the copper-bearing skarn at the Mason Valley Mine, Yerington district, Nevada: Economic Geology, v. 72, p. 769-795.

——— 1982, Description of skarns associated with porphyry copper plutons: southwestern North America, in Titley, S. R., ed., Advances in the Geology of Porphyry Copper Deposits, Southwestern North America: Tucson, University of Arizona Press, p. 139-184.

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, 42 p.

Fox, L.K., and Miller, D.M., 1990, Jurassic granitoids and related rocks of the southern Bristol Mountains, southern Providence Mountains, and Colton Hills, Mojave Desert, California, *in* Anderson, J.L., ed., The nature and origin of Cordilleran magmatism: Boulder, Colorado, Geological Society of America Memoir 174, p. 111-132.

Garside, L.J., Bonham, H.F., Jr., and McKee, E.H., 1992, Potassium-argon ages of plutonic rocks and associated vein and alteration minerals, northeast Sierra Nevada, California and Nevada: Isochron/West, no. 58, p. 13-15.

Geasan, D.L., 1980, The geology of a part of the Olinghouse mining mining district, Washoe County, Nevada: Reno, University of Nevada, M.S. thesis, 118 p.

Geissman, J.W., Van der Voo, R., and Howard, K.L., Jr., 1982, A paleomagnetic study of structural deformation in the Yerington district, Nevada: 2, Mesozoic basement units and their total and pre-Oligocene tectonism: American Journal of Science, v. 282, p. 1080-1109.

Gill, J.B., 1981, Orogenic andesites and plate tectonics: New York, Springer-Verlag, 385 p.

Greene, R.C., Stewart, J.H., John, D.A., Hardyman, R.F., Silberling, N.J., and Sorensen, M.L., 1991, Geologic map of the Reno quadrangle, Nevada and California: U.S. Geological Survey Miscellaneous Field Studies Map MF-2154-A, scale 1:250,000.

Hall, D.J., Cohen, L.H., and Schiffman, P., 1988, Hydrothermal alteration associated with the Iron Hat iron skarn deposit, eastern Mojave Desert, San Bernardino, California: Economic Geology, v. 81, p. 586-605.

Hammarstrom, J.M., and Zen, E-an, 1986, Aluminum in hornblende: An empirical igneous geothermometer: American Mineralogist, v. 71, p. 1297–1313.

Harwood, D.S., Fisher, G.R., and Waugh, in press, Geologic map of the Duncan Peak and southern part of the Cisco Grove quadrangles, Placer and Nevada Counties, California: U.S. Geological survey Miscellaneous Field Investigations Map I-2341, scale 1:24,000.

Hudson, D.M., 1977, Geology and alteration of the Wedekind and part of the Peavine districts, Washoe County, Nevada: Reno, University of Nevada, M.S. thesis, 102 p.

——— 1983, Alteration and geochemical characteristics of the upper parts of selected porphyry systems, western Nevada: Reno, University of Nevada, Ph.D. dissertation, 229 p.

Hudson, D.M., and Oriel, W.M., 1979, Geologic map of the Buckskin Range, Nevada: Nevada Bureau of Mines and Geology, Map 64, scale 1:18,000.

Irvine, T.N., and Baragar, W.R.A., 1971, A guide to the chemical classification of the common volcanic rocks: Canadian Journal of Earth Sciences, v. 8, p. 523-548.

James, O.B., 1967, Origin and emplacement of the ultramafic rocks of the Emigrant Gap area, California: Stanford, Calif., Stanford University, Ph.D. dissertation, 205 p.

———1971, Origin and emplacement of ultramafic rocks of the Emigrant Gap area, California: Journal of Petrology, v. 12, p. 523-560.

John, D.A., 1983, Map showing the distributions, ages, and petrographic characteristics of Mesozoic plutonic rocks in the Walker Lake 1° by 2° quadrangle, California and Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-1382-B, scale 1:250,000.

———1989, Geologic setting, depths of emplacement, and regional distribution of fluid inclusion populations in intrusions of the central Wasatch Mountains, Utah: Economic Geology, v. 84, p. 386-409.

———1992, Chemical analyses of granitic rocks in the Reno 1° by 2° quadrangle and in the northern Pine Nut Mountains, west-central Nevada: U.S. Geological Survey Open-File Report 92-246, 35 p.

John, D.A., Stewart, J.H., Kilburn, J.E., Silberling, N.J., and Rowan, L.C., 1993, Geology and mineral resources of the Reno 1° by 2° quadrangle, Nevada and California: U.S. Geological Survey Bulletin 2019, 65 p.

Johnson, M.C., and Rutherford, M.J., 1989, Experimental calibration of the aluminum-in-hornblende geobarometer with application to Long Valley caldera (California) volcanic rocks: Geology, v. 17, p. 837–841.

Keith, W.J., and Seitz, J.F., 1981, Geologic map of the Hoover Wilderness and adjacent study area, Mono and Tuolumne Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1101-A, scale 1:62,500.

Kerrick, D.M., Crawford, K.E., and Randazzo, A.F., 1973, Metamorphism of calcareous rocks in three roof pendants in the Sierra Nevada, California: Journal of Petrology, v. 14, p. 303-325.

Kistler, R.W., 1990, Two different lithospheric types in the Sierra Nevada, California, *in* Anderson, J.L., ed., The nature and origin of Cordilleran magmatism: Boulder, Colorado, Geological Society of America Memoir 174, p. 271-281.

Kistler, R.W., Chappell, B.W., Peck, D.L., and Bateman, P.C., 1986, Isotopic variation in the Tuolumne Intrusive Suite, central Sierra Nevada, California: Contributions to Mineralogy and Petrology, v. 94, p. 205-220.

Kistler, R.W., Evernden, J.F., and Shaw, H.R., 1971, Sierra Nevada plutonic cycle, Part 1, Origin of granitic batholiths: Geological Society of America Bulletin, v. 82, p. 853-868.

Kistler, R.W., and Peterman, Z.E., 1973, Variations in Sr, Rb, K, Na, and initial $^{87}Sr/^{86}Sr$ in Mesozoic granitic rocks and intruded wall rocks in central California: Geological Society of America Bulletin, v. 84, p. 3489-3512.

———1978, Reconstruction of crustal blocks of California on the basis of initial strontium isotopic compositions of Mesozoic granitic rocks: U.S. Geological Survey Professional Paper 1071, 17 p.

Kleinhampl, F.J., Fiebelkorn, J.B., John, D.A., and Moore, W.J., 1983, Mineral occurrence map and table listing property names, commodities, and production, Walker Lake, California-Nevada 1° x 2° quadrangle: U.S. Geological Survey Miscellaneous Field Studies Map MF-1382-R, scale 1:250,000.

Knopf, Adolph, 1918, Geology and ore deposits of the Yerington district, Nevada: U.S. Geological Survey Professional Paper 114, 68 p.

Krueger, H.W., and Schilling, J.H., 1971, Geochron/Nevada Bureau of Mines K/Ar age determination--List 1: Isochron/West, no. 71-1, p. 9-14.

Lahern, M.M., Schweickert, R.A., and Taranik, J.V., 1988, Analysis of the northern Sierra accreted terrane, California, with airborne thermal infrared multispectral scanner data: Geology, v. 16, p. 525-528.

Lawrence, E.F., 1969, Geological and geophysical investigations of the deposits of the Calico area, Mineral County, Nevada: Riverside, University of California, Ph.D. dissertation, 112 p.

Lawrence, E.F., and Redmond, R.L., 1967, Exploration of the Calico area, Walker River Indian Reservation, Mineral County, Nevada: Society of Mining Engineers of AIME, Preprint No. 67-I-311, 10 p.

Lee, D.E., 1984, Analytical data for a suite of granitoid rocks from the Basin and Range province: U.S. Geological Survey Bulletin 1602, 54 p.

Luethe, R.D., 1974, Petrology of the Ryan Canyon stock, Mineral County, Nevada: Reno, University of Nevada, M.S. thesis, 88 p.

Lindgren, Waldemar, 1915, The igneous geology of the Cordilleras and its problems, *in* Problems of American geology: New Haven, Yale University, Silliman Foundation, p. 234-286.

Loomis, A.A., 1983, Geology of the Fallen Leaf Lake 15-minute quadrangle, El Dorado County, California: California Division of Mines and Geology Map Sheet 32, scale 1:62,500.

Masi, U., O'Neil, J.R., and Kistler, R.W., 1981, Stable isotope systematics in Mesozoic granites of central and northern California and southwestern Oregon: Contributions to Mineralogy and Petrology, v. 76, p. 116-126.

Miller, C.F., 1977, Early alkalic plutonism in the calc-alkalic batholithic belt of California: Geology, v. 5, p. 685-688.

———1978, An early Mesozoic alkalic magmatic belt belt in western North America, *in* Howell, D.G., and McDougall, K.A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 163-174.

Moore, J.G., 1959, The quartz diorite boundary line in the western United States: Journal of Geology, v. 67, p. 197-210.

———1969, Geology and mineral deposits of Lyon, Douglas, and Ormsby Counties, Nevada: Nevada Bureau of Mines and Geology, Bulletin 75, 45 p.

Newberry, R.J., and Einaudi, M.T., 1981, Tectonic and geochemical setting tungsten skarn mineralization in the Cordillera, *in* Dickinson, W.R., and Payne, W.D., eds., Relations of tectonics ore deposits in southern Cordillera: Arizona Geological Society Digest, v. XIV, p. 99-111.

Noble, D.C., McKee, E.H., and Schweickert, R.A., 1973, K-Ar ages on post Early Jurassic granodiorite from the southern Pine Nut Range, western Nevada: Isochron/West, no. 7, p. 3-4.

Nowak, G., 1979, The geology and uranium occurrences of the Washington mining district, Lyon County, Nevada: Reno, University of Nevada, M.S. thesis, 92 p.

Parker, R.W., 1959, Petrology and structure of pre-Tertiary rocks in western Alpine County, California: Berkeley, University of California, Ph.D. dissertation, 162 p.

Proffett, J.M., Jr., 1977, Cenozoic geology of the Yerington district, Nevada, and implications for the nature and origin of the Basin and Range faulting: Geological Society of America Bulletin, v. 88, p. 247-266

Proffett, J.M., Jr., and Dilles, J.H., 1984, Geologic map of the Yerington district, Nevada: Nevada Bureau of Mines and Geology Map 77. scale 1:24,000

Reeves, R.G., Shawe, F.R., and Kral, V.E., 1958, Iron ore deposits of Nevada. Part B. Iron ore deposits of west-central Nevada: Nevada Bureau of Mines andGeology, Bulletin 53, 78 p.

Robinson, A.C., 1985, Whole-rock strontium isotopic ages of Mesozoic plutons in the West Walker River area, east-central California [abs.]: Geological Society of America Abstracts with Programs, v. 17, p. 404.

Robinson, A.C., and Kistler, R.W., 1986, Maps showing isotopic dating in the Walker Lake 1° by 2° quadrangle, California and Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-1382-N.

Roylance, J.G., Jr., 1966, The Dayton iron deposits, Lyon and Storey counties, Nevada: Nevada Bureau of Mines Report 13, p. 125-141.

Saleeby, J.B., Sams, D.B., and Kistler, R.W., 1987, U/Pb zircon, strontium and oxygen isotopic and geochronological study of the southernmost Sierra Nevada batholith, California: Journal of Geophysical Research, v. 92, p. 10443-10466.

Saleeby, J.B., Shaw, H.F., Niemeyer, S., Moores, E.M., and Edelman, S.H., 1989, U/Pb, Sm/Nd, and Rb/Sr geochronological and isotopic study of northern Sierra Nevada ophiolitic assemblages, California: Contributions to Mineralogy and Petrology, v. 102, p. 205-220.

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.

Satkoski, J.J., Lambeth, R.H., White, W.W., III, and Dunn, M.D., 1985, Field inventory of mineral resources and compilation of exploration data, Walker River Indian Reservation, Nevada: U.S. Bureau of Mines Report BIA No. 21-11, 271 p.

Schilling, J.H., 1968, Molybdenum resources of Nevada: Nevada Bureau of Mines and Geology Open-File Report, 195 p.

Schweickert, R.A., 1972, Shallow-level intrusions in the eastern Sierra Nevada, California: Stanford, CA, Stanford University, Ph.D. dissertation, 85 p.

———1976, Shallow-level plutonic complex in the eastern Sierra Nevada, California, and their tectonic implications: Geological Society of America Special Paper 176, 58 p.

———1993, Triassic-Jurassic magmatic arc of western Nevada and eastern California—Part I: Geological evolution [abs.], *in* Craig, S.D., ed., Structure, tectonics and mineralization of the Walker Lane, proceedings volume: Reno, Geological Society of Nevada, p. 62-63.

Schweickert, R.A., Harwood, D.S., Girty, G.H., and Hanson, R.E., 1984, Tectonics of the northern Sierra Nevada—Roadlog, *in* Lintz, Joesph, Jr., ed., Western Geological excursions, v. 4: Geological Society of America and Department of Geological Sciences, University of Nevada, Reno, Guidebook for the 1984 Annual meetings of the Geological Society of America, p. 1-64.

Schweickert, R.A., Harwood, D.S., Girty, G.H., and Hanson, R.E., in press, Geologic map of the Emigrant Gap quadrangle, Sierra and Nevada Counties, California: U.S. Geological Survey Geologic Quadrangle Map GQ-.

Snoke, A., Sharp, W.D., Wright, J.E., and Saleeby, J.B., 1982, Significance of mid-Mesozoic periodititic to dioritic intrusive complexes, Klamath Mountains--western Sierra Nevada: Geology, v. 10, p. 160-166.

Steiger, R.H., and Jager, E., 1977, Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, p. 359-362.

Stern, T.W., Bateman, P.C., Morgan, B.A. Newell, M.F., and Peck, D.L., 1981, Isotopic U-Pb ages of zircon from the granitoids of the central Sierra Nevada, California: U.S. Geological Survey Professional Paper 1185, 17 p.

Stewart, J.H., Brem, G.F., and Dohrenwend, J.C., 1989, Geologic map of Desert Creek Peak quadrangle, Lyon and Douglas Counties, Nevada, and Mono County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-2050, scale 1:62,500.

Stewart, J.H., and Johannesen, D.C., 1981, Geologic map of the Hawthorne quadrangle, Mineral County, Nevada, with Surficial geology by J.C. Dohrenwend: U.S. Geological Survey Miscellaneous Field Studies Map MF-1277, scale 1:62,500.

Stewart, J. H., and Reynolds, M. W., 1987, Geologic map of Pine Grove Hills quadrangle, Lyon County, Nevada: U. S. Geological Survey Open-File Report OF-87-658, scale, 1:62,500.

Stewart, J.H., Reynolds, M.W., and Johannesen, D.C., 1981, Geologic map of the Mount Grant quadrangle, Lyon and Mineral Counties, Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-1278, scale 1:62,500.

Streckeisen, A.L., 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1-33.

Sylvestor, A.G., Miller, C.F., and Nelson, C.A., 1978, Monzonites of the White-Inyo Range, California, and their relation to the calc-alkalic Sierra Nevada batholith: Geological Society of America Bulletin, v. 89, p. 1677-1687.

Thompson, G.A., 1959, Geology of the Virginia City quadrangle, Nevada: U.S. Geological Survey Bulletin 1042-C. p. 45-77.

Thompson, G.A., and White, D.E., 1964, Regional geology of the Steamboat Springs area, Washoe County, Nevada: U.S. Geological Survey Professional Paper 458-A, 52 p.

Vikre, P.G., 1989, Fluid-mineral relations in the Comstock lode: Economic Geology, v. 84, p. 1574-1613.

Vikre, P.G., McKee, E.H., and Silberman, M.L., 1988, Chronology of Miocene hydrothermal and igneous events in the western Virginia Range, Washoe, Storey, and Lyon Counties, Nevada: Economic Geology, v. 83, p. 864-874.

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

———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.

Westra, Gerhard, and Keith, S.B., 1981, Classification and genesis of stockwork molybdenum deposits: Economic Geology, v. 76, p. 844-873.

Wilshire, H.G. 1957, Propylitization of Tertiary volcanic rocks near Ebbetts Pass, Alpine County, California: University of California, Department of Geological Sciences Bulletin, v. 25, no. 6, p. 239-346.

Wilson, J.R., 1963, Geology of the Yerington mine: Mining Congress Journal, v. 49, no. 5, p. 30-34.

Wracher, M.D., 1991, The petrology, geochemistry, and geochronology of the Emigrant Gap composite pluton, and its structural relationship to the Shoo Fly Complex: San Diego, Calif., San Diego State University, MS thesis, 75 p.

Wracher, M.D., Girty, G.H., and Wardlaw, M.S., 1991, Deformation in the Shoo Fly complex and the role of a Middle Jurassic plutonic complex, northern Sierra Nevada, California [abs.]: Geological Society of America Abstracts with Programs, v. 23, p. 111.

Wright, J.E., and Wooden, J.L., 1991, New Sr, Nd, and Pb, isotopic data from plutons in the northern Great Basin: Implications for crustal source and granite petrogenesis in the hinterland of the Seiver thrust belt: Geology, v. 19, p. 457-460.

Table 1. Whole-rock Rb-Sr isochron ages

[To constrain slope by extending the range of $^{87}Rb/^{86}Sr$, most Rb-Sr whole-rock isochrons in this table include samples of cross-cutting aplite and pegmatite dikes as well as typical main phase of the plutons. The ages therefore tend to date the separation of leucocratic phases late in the crystallization of the plutons. Some isochrons in this study supersede isochrons reported by Robinson and Kistler (1986) but incorporate samples used in that study. Isochrons in this study are reported with 2 sigma errors; Robinson and Kistler (1986) report isochrons with 1 sigma errors.]

Unit	Age (Ma)	Number of samples	Reference
Haypress Creek area (see fig. 5)			
Yuba Pass intrusion	153.9±11	7	this study
Haypress Creek intrusion	153.4±21	7	this study
Bald Ridge intrusion	157.3±7.5	8	this study
Henness Pass intrusion	105.2±17	5	this study
Pass Creek intrusion	118.9±17	5	this study
Donner Pass area (see fig. 8)			
White Rock Lake	119.1±3.1	19	this study
Summit Lake	101.3±2.3	23	this study
Castle Valley	112.0±4.4	7	this study
Granite Chief	101.2±3.5	10	this study
Donner Pass	117.5±4.2	9	this study
Cold Creek	102.7±3.7	8	this study
The Cedars	101.8±10.5	8	this study
Forest Hill Divide	97.8±7.9	3	this study
Picayune Valley	99.6±4.0	6	this study
Whiskey Creek	102.2±11.5	8	this study
Sierra Nevada (Lake Tahoe area and south)			
Bryan Meadow Granodiorite[1]	84.4±6.7	5	Robinson and Kistler, 1986
Bryan Meadow Granodiorite and granodiorite of Lovers Leap[2]	99.5±16	7	this study
Carson Pass Tonalite of Parker (1961)	101.4±7.0	3	Robinson and Kistler, 1986
Granodiorite of Kinney Lakes	90.7±0.8	43	this study
Granodiorite of White Mountain	96.4±1.7	13	this study
Granite of Sonora Bridge	96.2±1.4	15	this study
Granodiorite of Kennedy Meadow (outer part)[3]	87.0±0.8	19	this study
Granodiorite of Kennedy Meadow (inner part)[3]	85.6±1.9	6	this study
Granodiorite of Silver King Creek (outer part)[4]	85.5±0.7	12	this study
Granodiorite of Silver King Creek (inner part)[4]	84.5±0.7	15	this study
West Walker River area			
Granodiorite of Slinkard Valley[5]	84.7±1.2	20	this study
Granite of Mill Creek[6]	84.2±0.7	21	this study
Granite of Rock Creek[6]	82.5±1.2	7	this study
China Garden pluton	91.2±1.3	36	this study
Rhyolite tuff[7]	89.7±5.3	12	this study
Intrusive suite of Wild Horse Mountain: granite[7]	152.2±14.3	12	this study
Intrusive suite of Wild Horse Mountain: porphyries A[7]	155.9±7.0	5	this study
Intrusive suite of Wild Horse Mountain: porphyries B[7]	156.8±8.6	7	this study
Intrusive suite of Wild Horse Mountain: porphyries C[7]	153.9±7.4	10	this study

Intrusive suite of Wild Horse Mountain: northern diorites[7]	155.3±4.0	8	this study
Intrusive suite of Wild Horse Mountain: other diorites[7]	151.0±3.3	6	this study
Granite of East Fork	151.3±10.3	5	this study
Granodiorite of Log Cabin Creek	160.1±4.1	16	this study
Granite of Taylor Valley	87.7±1.7	9	this study
Granite of Taylor Valley, leucocratic dikes[8]	83.3±2.0	5	this study
Granite of Devil's Gate and Mack Canyon pluton, undivided	85.8±3.0	7	this study
Swauger Creek mafic complex	93.3±1.6	12	this study
Granodiorite of Eagle Creek	95.9±2.1	16	this study
Porphyritic quartz monzonite of the Masonic district	83.5±1.9	7	this study
Pine Grove Hills—East Walker River—Wassuk Range			
Granite of Nye Canyon	88.2±12.5	8	this study
Granodiorite of Chipmunk Spring	168.6±7.2	10	this study
Granodiorite of Lobdell Summit	186.9±8.5	10	this study
Quartz monzonite of Garfield Hills	111.1±4.1	9	Robinson and Kistler, 1986
Granodiorite of Alum Creek and granite of Cory Creek, undivided	78.7±5.0	8	Robinson and Kistler, 1986
Granite of Walker Lake	96.1±1.2	4	Robinson and Kistler, 1986
Granitic rocks of Babbitt, granitic rocks of Cottonwood Creek, and mafic pillow breccia of Ashby	188.2±5.5	4	Robinson and Kistler, 1986

[1]Freel Peak 15-minute quadrangle (Armin and John, 1983)
[2]Fallen Leaf Lake 15-minute quadrangle (Loomis, 1983)
[3]Southwestern part of the granodiorite of Topaz Lake
[4]Central part of the granodiorite of Topaz Lake
[5]Northeastern part of the granodiorite of Topaz Lake
[6]Eastern part of the granodiorite of Topaz Lake
[7]Extrusive equivalent(?) of China Garden pluton; see text for description of unit
[8]Leucocratic dikes intrusive in northern part of the granite of Taylor Valley may belong to an unexposed unit comparable in age to, and east of, the granodiorite of Slinkard Valley

Table 2. K-Ar, U-Pb, and fission track isotopic ages of granitic rocks in the Reno study area

Unit	Reported age (Ma)[1]	Method dated[2]	Primary reference
Sierra Nevada batholith			
Bryan Meadow Granodiorite	78.1±0.6	K-Ar (hb)	Robinson and Kistler, 1986
Bryan Meadow Granodiorite	82.6±0.6	K-Ar (hb)	Robinson and Kistler, 1986
Bryan Meadow Granodiorite	83.9±0.6	K-Ar (hb)	Robinson and Kistler, 1986
Bryan Meadow Granodiorite	84.1±0.5	K-Ar (bt)	Robinson and Kistler, 1986
Bryan Meadow Granodiorite	86.9±0.5	K-Ar (bt)	Robinson and Kistler, 1986
Bryan Meadow Granodiorite	87.5±0.5	K-Ar (bt)	Robinson and Kistler, 1986
Bryan Meadow Granodiorite	89.3±2	K-Ar (bt)	Evernden and Kistler, 1970
Bryan Meadow Granodiorite	89.6±2	K-Ar (bt)	Evernden and Kistler, 1970
Burnside Lake Adamellite[3]	86.5±0.5	K-Ar (bt)	Robinson and Kistler, 1986
Carson Pass Tonalite[3]	90.9±2	K-Ar (bt)	Evernden and Kistler, 1970
Ebbetts Pass Granodiorite[3]	94.6±2.0	K-Ar (hb)	Armin and others, 1984
Ebbetts Pass Granodiorite[3]	88.3±2	K-Ar (bt)	Evernden and Kistler, 1970
Echo Lake Granodiorite	90.0±2	K-Ar (bt)	Evernden and Kistler, 1970; Loomis, 1983
Echo Lake Granodiorite	93.7±2	K-Ar (hb)	Evernden and Kistler, 1970; Loomis, 1983
Echo Lake Granodiorite	72.8±1	K-Ar (bt)	Robinson and Kistler, 1986
Echo Lake Granodiorite	91.7±0.8	K-Ar (hb)	Robinson and Kistler, 1986
Freel Peak Granodiorite	82.9±1.5	K-Ar (bt)	Armin and John, 1983
Freel Peak Granodiorite	84.4±0.6	K-Ar (hb)	Robinson and Kistler, 1986
Freel Peak Granodiorite	85.4±0.5	K-Ar (bt)	Robinson and Kistler, 1986
Freel Peak Granodiorite	93.2±3.0	K-Ar (hb)	Armin and John, 1983
Granodiorite of Daggett Pass	85.6±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Daggett Pass	88.3±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Daggett Pass	92.1±2	K-Ar (hb)	Evernden and Kistler, 1970
Granodiorite of Kinney Lakes	83.9±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Kinney Lakes	85.1±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Kinney Lakes	85.7±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Kinney Lakes	86.3±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Kinney Lakes	86.3±2	K-Ar (hb)	Evernden and Kistler, 1970
Granodiorite of Kinney Lakes	86.9±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Kinney Lakes	87.7±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Kinney Lakes	87.8±0.6	K-Ar (bt)	Keith and others, 1983
Granodiorite of Lovers Leap	96.0±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Topaz Lake	81.5±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Topaz Lake	83.1±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Topaz Lake	83.5±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Topaz Lake	83.7±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Topaz Lake	83.8±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Topaz Lake	84.0±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Topaz Lake	84.2±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Topaz Lake	84.8±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Topaz Lake	84.9±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Topaz Lake	85.0±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Topaz Lake	86.4±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Wright Lake	95.1±2	K-Ar (bt)	Evernden and Kistler, 1970
Granodiorite of Wright Lake	100.0±2	K-Ar (hb)	Evernden and Kistler, 1970

Jurassic plutons in the Yerington area and the Wassuk Range Diorite

Flow dome in Fulstone Spring Volcanics	166.5±0.4	U-Pb	Dilles and Wright, 1988
Granodiorite of Copper Mountain	158±7	K-Ar (hb)	Marvin and Cole, 1978
Granodiorite of Copper Mountain	161±4	K-Ar (bt)	Marvin and Cole, 1978
Gray Hills pluton	102.3±3	K-Ar (bt)	Bingler, 1978
Gray Hills pluton	143.2±4	K-Ar (hb)	Bingler, 1978
Gray Hills pluton	157.4±5	K-Ar (hb)	Bingler, 1978
Quartz monzodiorite porphyry	≥165	U-Pb	Dilles and Wright, 1988
Quartz porphyry (Yerington area)	232.2±2.3	U-Pb	Dilles and Wright, 1988
Shamrock batholith	103±3	K-Ar (bt)	Bingler and others, 1980
Shamrock batholith	158.5±5	K-Ar (hb)	Bingler and others, 1980
Shamrock batholith	165.8±0.4	U-Pb	Dilles and Wright, 1988
Sunrise Pass pluton	172±5	Pb-Pb	Dilles and Wright, 1988
Sunrise Pass pluton	149.3±8	K-Ar (hb)	Castor, 1972
Wassuk Range Diorite	81.9±2.5	K-Ar (bt)	Bingler and others, 1980
Wassuk Range Diorite	138±4	K-Ar (hb)	Bingler and others, 1980
Wassuk Range Diorite	143.4±3	K-Ar (hb)	Evernden and Kistler, 1970
Wassuk Range Diorite	232.7±2.9	U-Pb	Dilles and Wright, 1988
Yerington batholith	81.0±2.4	K-Ar (bt)	Bingler and others, 1980
Yerington batholith	117±5	K-Ar (hb)	Bingler and others, 1980
Yerington batholith	127±7	K-Ar (hb)	Hudson, 1983
Yerington batholith	138±7	K-Ar (hb)	Hudson, 1983
Yerington batholith	146±4	K-Ar (hb)	Bingler, 1972
Yerington batholith	148±4	K-Ar (hb)	Bingler and others, 1980
Yerington batholith	168.5±0.4	U-Pb	Dilles and Wright, 1988
Yerington batholith	169.4±0.4	U-Pb	Dilles and Wright, 1988

Northern Sierra Nevada plutons

Haypress Creek area	156.7±2	K-Ar (bt)	Evernden and Kistler, 1970
Haypress Creek area	153.6±2	K-Ar (hb)	Evernden and Kistler, 1970
Haypress Creek area	101.5±2	K-Ar (bt)	Evernden and Kistler, 1970
Haypress Creek area	99.6±2	K-Ar (bt)	Evernden and Kistler, 1970
Haypress Creek area	99.9±2	K-Ar (bt)	Evernden and Kistler, 1970
Haypress Creek area	101.0±2	K-Ar (bt)	Evernden and Kistler, 1970
Haypress Creek area	103.5±2	K-Ar (bt)	Evernden and Kistler, 1970
Haypress Creek area	103.5±2	K-Ar (bt)	Evernden and Kistler, 1970
Haypress Creek area	128.0±2	K-Ar (hb)	Evernden and Kistler, 1970
Donner Pass area, site #1512	99.1±2	K-Ar (bt)	Evernden and Kistler, 1970
Donner Pass area, site #1512	100.2±2	K-Ar (hb)	Evernden and Kistler, 1970
Emigrant Gap pluton	174-152	K-Ar	Drake and others, 1975
Emigrant Gap pluton	163	U-Pb	Snoke and others, 1982
Emigrant Gap pluton	164	U-Pb	Saleeby and others, 1989
French Lake pluton	139.0±4.0	K-Ar (bt)	McKee and Garside, in press
French Lake pluton	151.4±4.5	K-Ar (hb)	McKee and Garside, in press

Cretaceous plutons—Wassuk Range and Great Basin

Bald Mountain pluton	82.0±3	K-Ar (bt)	Bingler, 1972
Granite of Cory Creek	77.3±2	K-Ar (bt)	Evernden and Kistler, 1970
Granite of Walker Lake	77.5±0.5	K-Ar (bt)	Robinson and Kistler, 1986
Granitic rocks of Butler Mountain	97.5±0.6	K-Ar (bt)	Robinson and Kistler, 1986
Granitic rocks of Butler Mountain	107.8±0.7	K-Ar (hb)	Robinson and Kistler, 1986

Granodiorite of Alum Creek	77.2±2	K-Ar (hb)	Evernden and Kistler, 1970
Granodiorite of Alum Creek	79.8±2.4	K-Ar (musc)	Robinson and Kistler, 1986
Granodiorite of Bullionville	83.5±3	K-Ar (bt)	Noble and others, 1973
Granodiorite of Bullionville	109.3±4	K-Ar (hb)	Noble and others, 1973
Granodiorite of Nye Canyon	89.2±2.8	K-Ar (bt)	Krueger and Schilling, 1971
Granodiorite of Nye Canyon	92.3±2.8	K-Ar (bt)	Krueger and Schilling, 1971
Granodiorite (Virginia City area)	84.9±4.0	K-Ar (hb)	Vikre and others, 1988
Granodiorite (Verdi area)	90.7±2.9	K-Ar (bt)	McKee and Garside, in press
Peterson Mountain	89.5±3.0	K-Ar (bt)	McKee and Garside, in press
Porphyry of Ryan Canyon (alteration)	91.4±3.4	K-Ar (musc)	Luethe, 1974
Green Talc alteration (Gillis Range)	94.6±1.7	K-Ar (bt)	Hudson, 1983
Green Talc alteration (Gillis Range)	95.4±1.7	K-Ar (musc)	Hudson, 1983
Quartz monzonite of Gillis Range	91.3±2	K-Ar (hb)	Evernden and Kistler, 1970
Quartz monzonite of Gillis Range	92.5±2	K-Ar (bt)	Evernden and Kistler, 1970
Quartz monzonite of Gillis Range	96.1±2	K-Ar (bt)	Evernden and Kistler, 1970
West Walker River area plutons			
China Garden pluton	61.3±6.0	K-Ar (hb)	Schweickert, 1976
China Garden pluton	63.2±2.1	K-Ar (hb)	Schweickert, 1976
China Garden pluton	77.7±1.5	K-Ar (bt)	Schweickert, 1976
China Garden pluton	82.3±1.6	K-Ar (bt)	Schweickert, 1976
China Garden pluton	82.3±1.6	K-Ar (bt)	Schweickert, 1976
Granite of Desert Creek	83.3±4.4	K-Ar (hb)	Schweickert, 1976
Granite of Desert Creek	88.5±2.1	K-Ar (hb)	Schweickert, 1976
Granite of Devils Gate	80.8±1.6	K-Ar (bt)	Schweickert, 1976
Granite of Devils Gate	85.5±1.7	K-Ar (bt)	Schweickert, 1976
Granite of Mill Creek	122±2	K-Ar (bt)	Evernden and Kistler, 1970
Swauger Creek mafic complex	81.0±1.6	K-Ar (bt)	Schweickert, 1976
Swauger Creek mafic complex	85.6±1.7	K-Ar (hb)	Schweickert, 1976
Swauger Creek mafic complex	93.7±2.6	K-Ar (hb)	Schweickert, 1976
Swauger Creek mafic complex	95.3±3.5	K-Ar (hb)	Schweickert, 1976
Tertiary plutons			
Davidson Granodiorite	10.5±0.1 to 17.6±2.1 (3)	Fission track	Vikre and others, 1988
Davidson Granodiorite	10.8±0.8 to 14.7±0.4 (8)	K-Ar	Vikre and others, 1988

[1] All pre-1977 ages recalculated using I.U.G.S. decay constants (Steiger and Jager, 1977).

[2] bt, biotite; hb, hornblende; musc, muscovite.

[3] of Parker (1961)

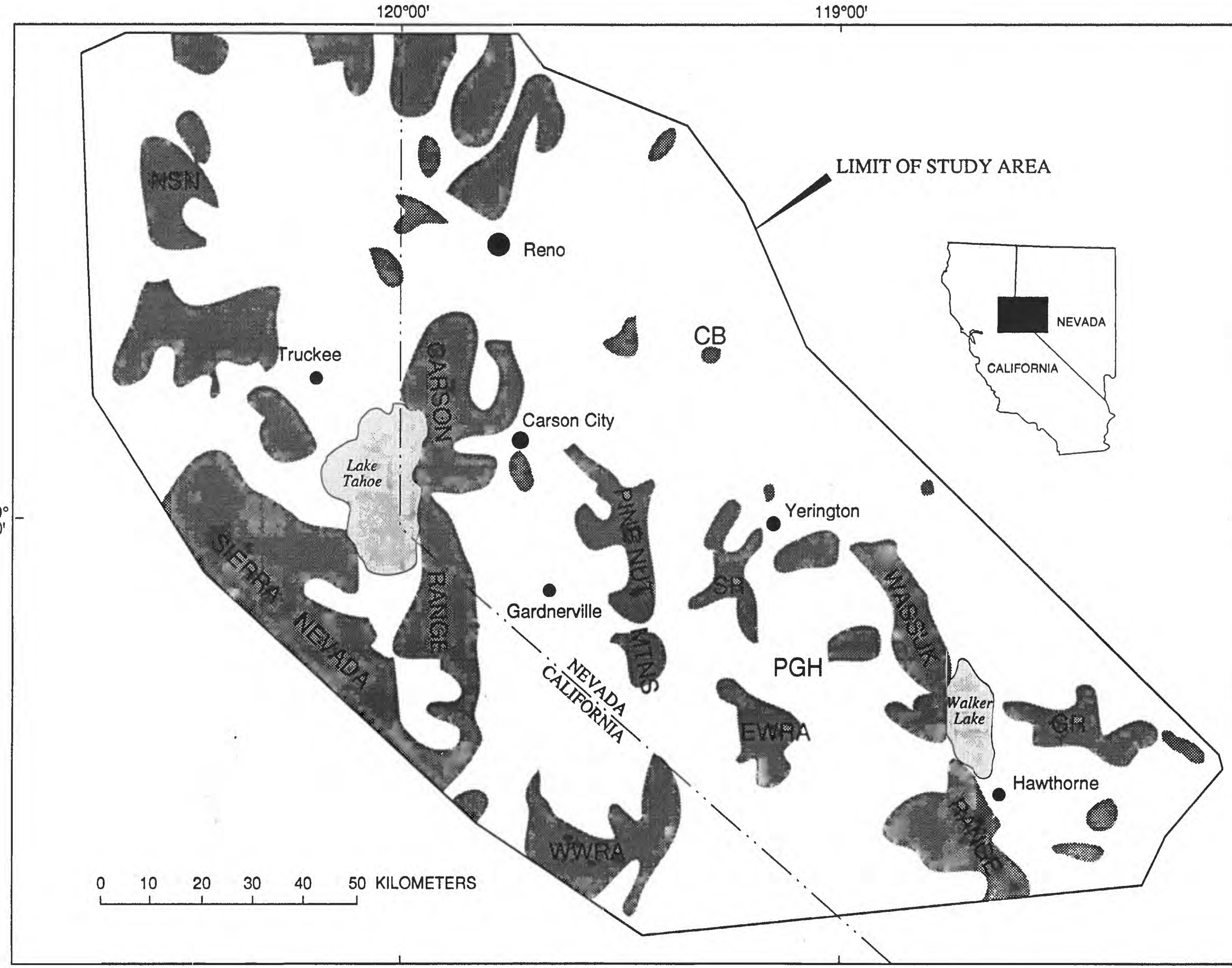


Figure 1. Map showing location of the Reno study area and generalized distribution of granitic rocks (shaded). CB, Churchill Butte; EWRA, East Walker River area; GR, Gillis Range; NSN, Northern Sierra Nevada; PGH, Pine GroveHills, SR, Singatse Range; WWRA, West Walker River area.

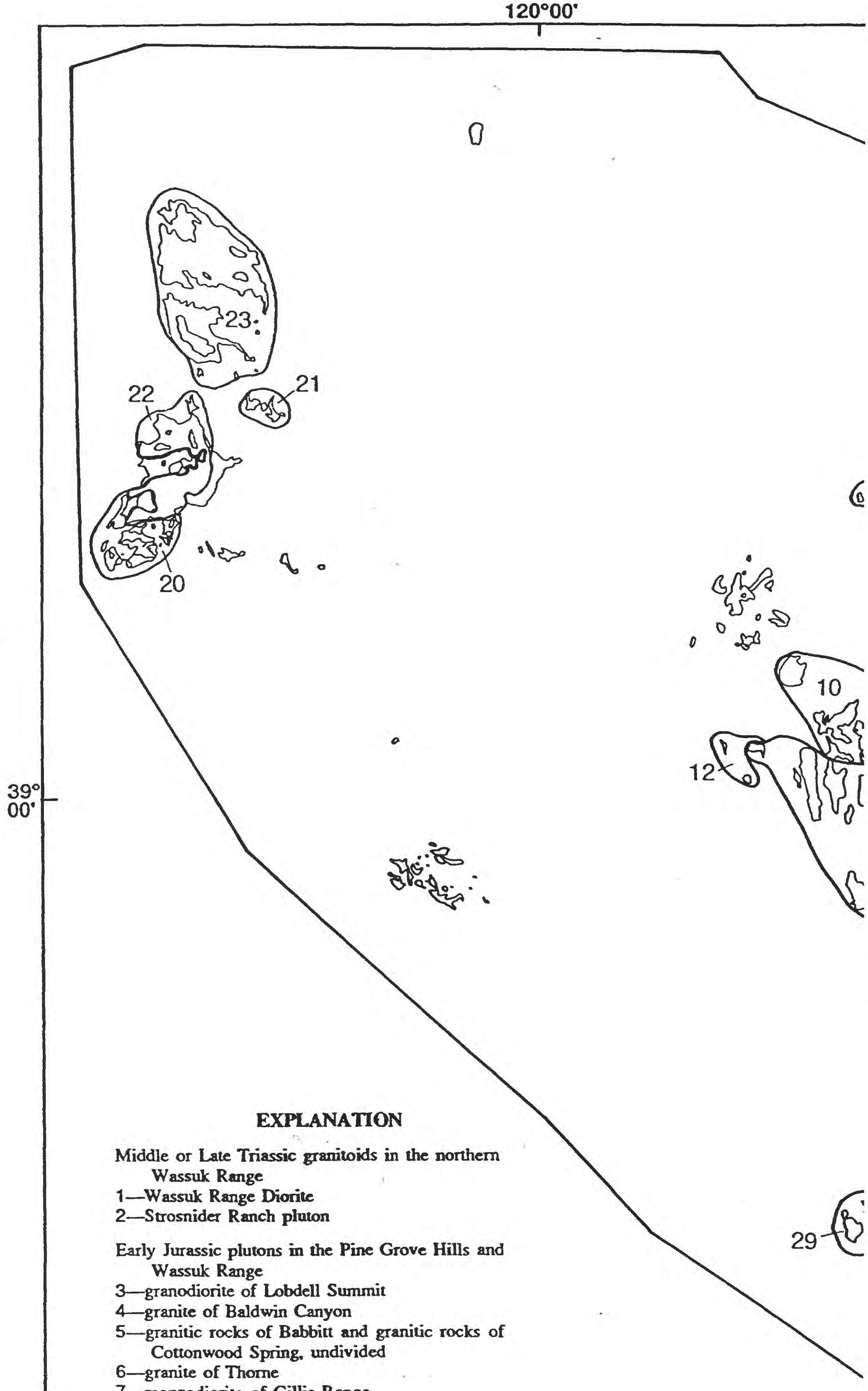
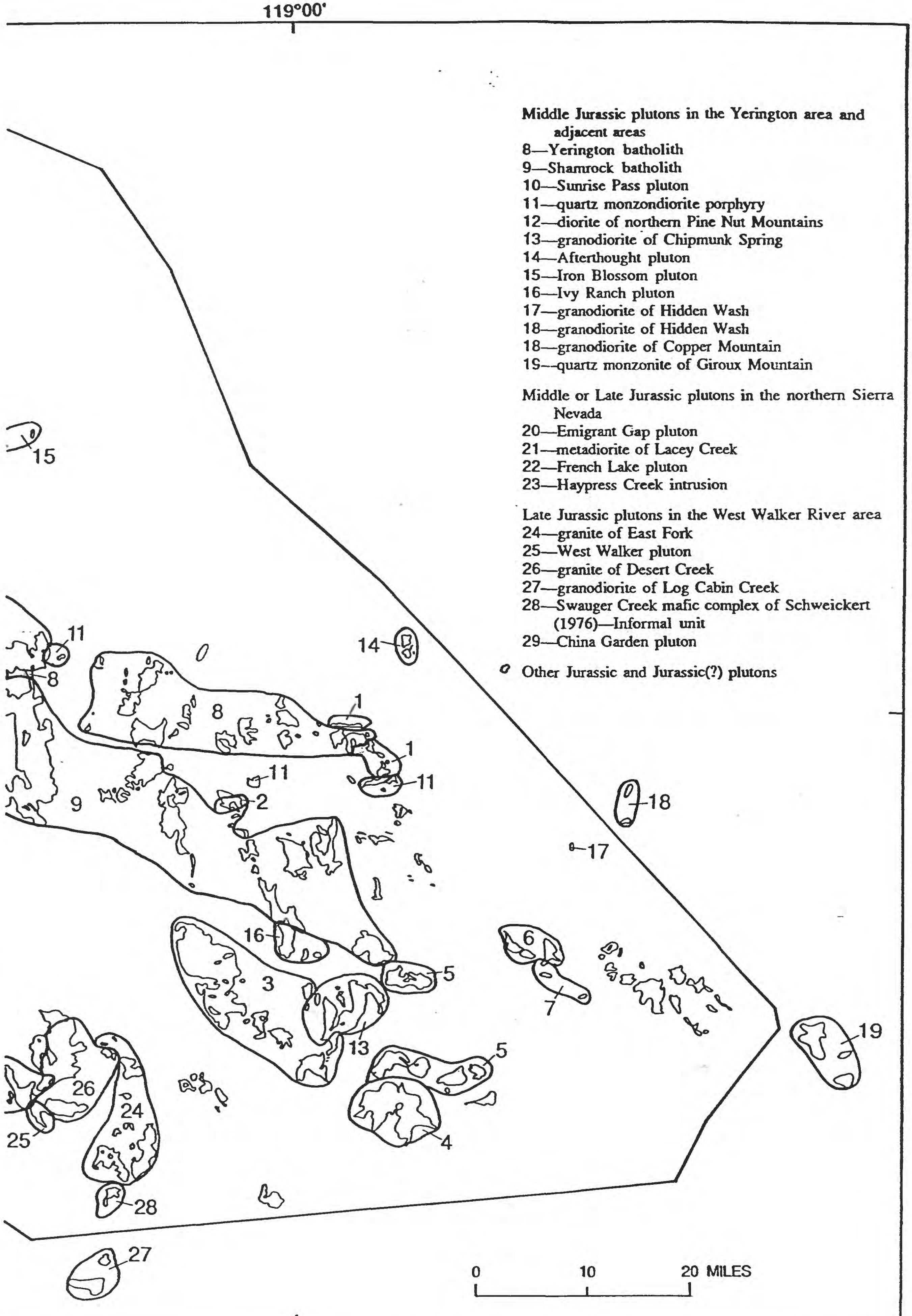


Figure 2. Map showing Triassic and Jurassic plutons discussed in text.


119°00'
Middle Jurassic plutons in the Yerington area and adjacent areas
8—Yerington batholith
9—Shamrock batholith
10—Sunrise Pass pluton
11—quartz monzondiorite porphyry
12—diorite of northern Pine Nut Mountains
13—granodiorite of Chipmunk Spring
14—Afterthought pluton
15—Iron Blossom pluton
16—Ivy Ranch pluton
17—granodiorite of Hidden Wash
18—granodiorite of Hidden Wash
18—granodiorite of Copper Mountain
19—quartz monzonite of Giroux Mountain
Middle or Late Jurassic plutons in the northern Sierra Nevada
20—Emigrant Gap pluton
21—metadiorite of Lacey Creek
22—French Lake pluton
23—Haypress Creek intrusion
Late Jurassic plutons in the West Walker River area
24—granite of East Fork
25—West Walker pluton
26—granite of Desert Creek
27—granodiorite of Log Cabin Creek
28—Swauger Creek mafic complex of Schweickert (1976)—Informal unit
29—China Garden pluton
Other Jurassic and Jurassic(?) plutons
0
10
20 MILES

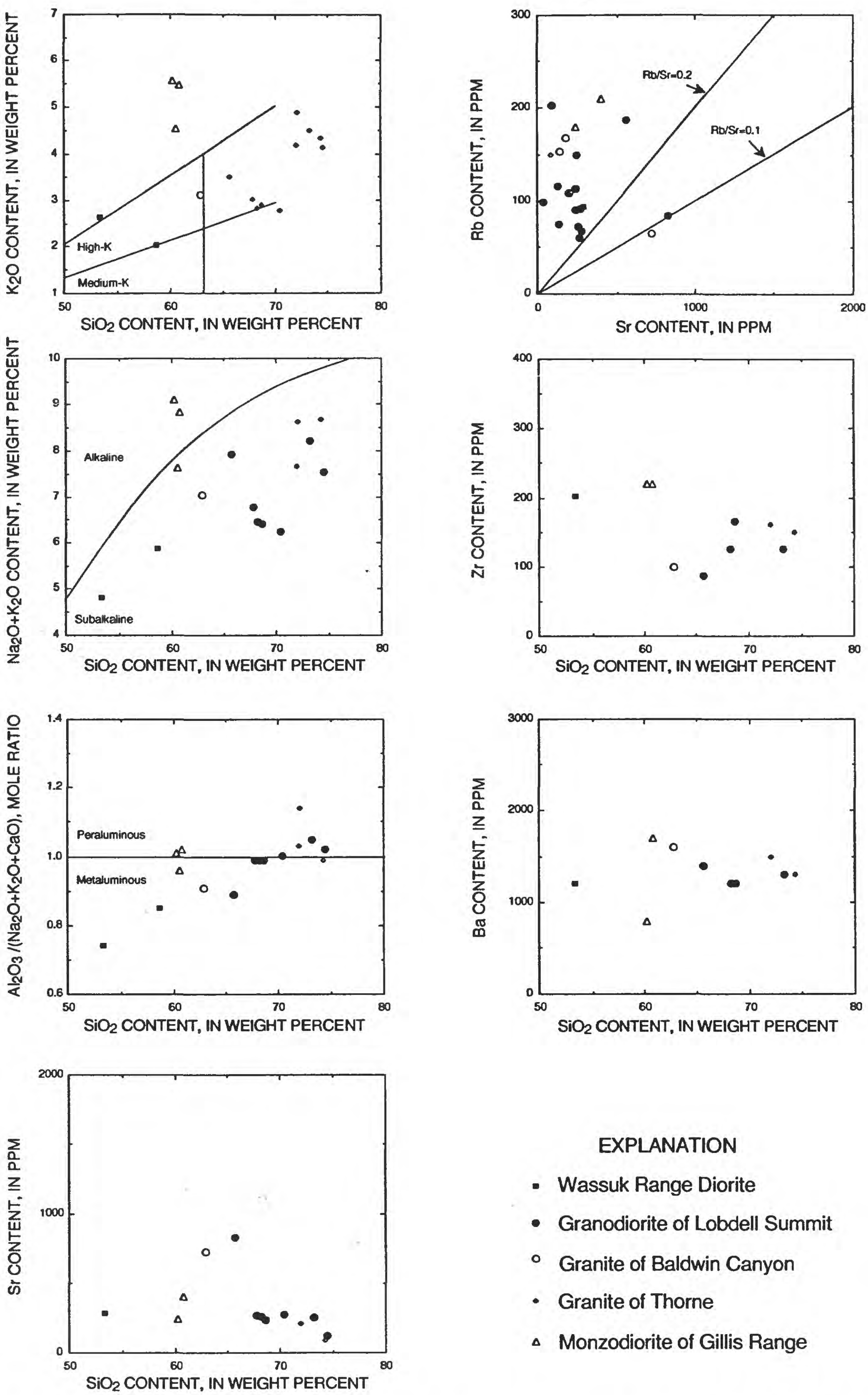


Figure 3. Plots of major and trace-element chemical data for Early Jurassic plutons and the Triassic Wassuk Range Diorite. Alkaline-subalkaline boundary from Irvine and Barager (1971). High-K and medium-K fields are for orogenic andesites as defined by Gill (1981). Data from Bingler (1978), Dilles (1984), John (1992), and S.B. Keith (written commun., 1990).

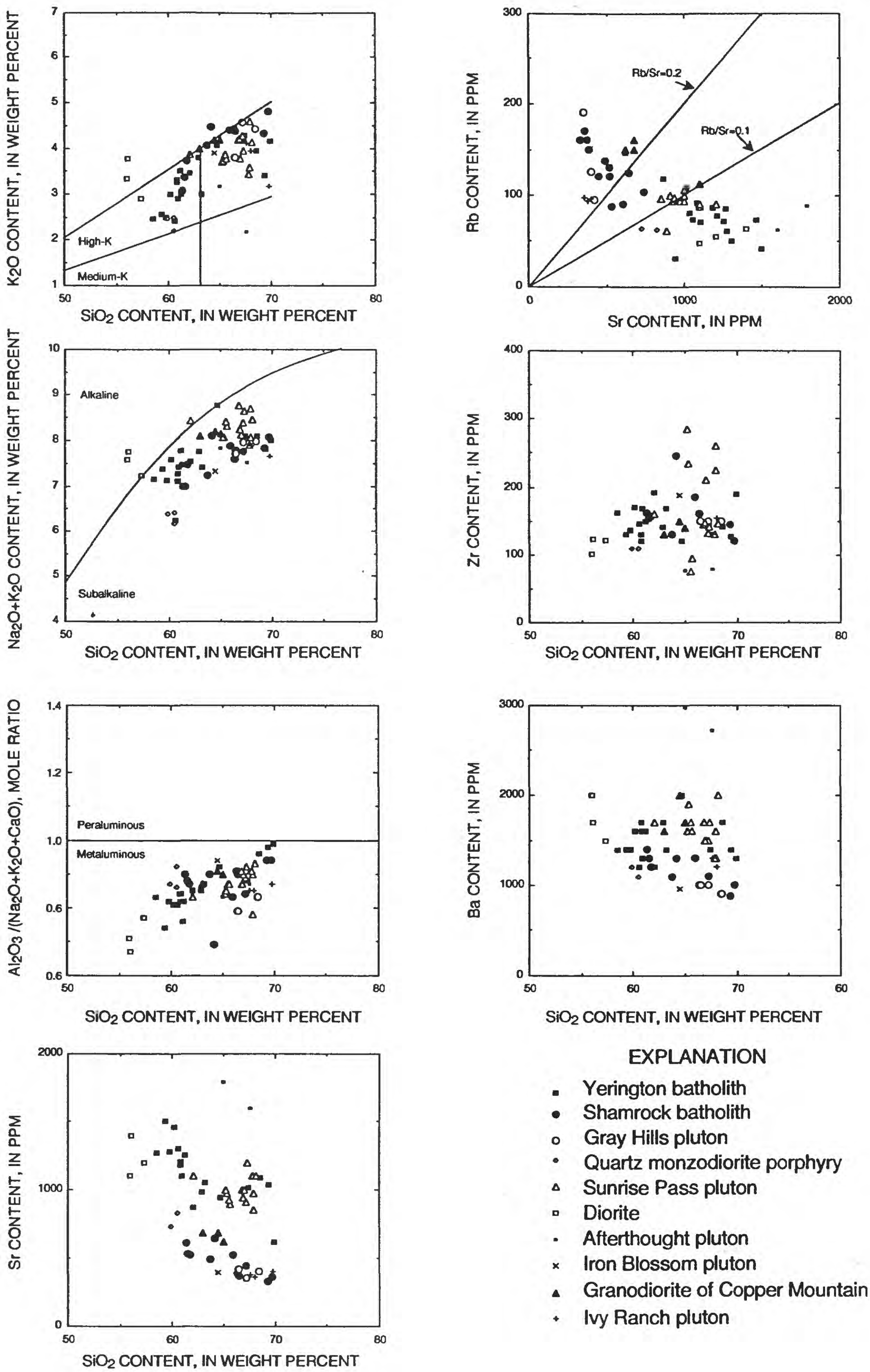


Figure 4. Plots of major and trace-element chemical data for Middle Jurassic plutons in the Yerington area. Alkaline-subalkaline boundary from Irvine and Barager (1971). High-K and medium-K fields are for orogenic andesites as defined by Gill (1981). Data from Bingler (1978), Dilles (1984), John (1992), and S.B. Keith (written commun., 1990).

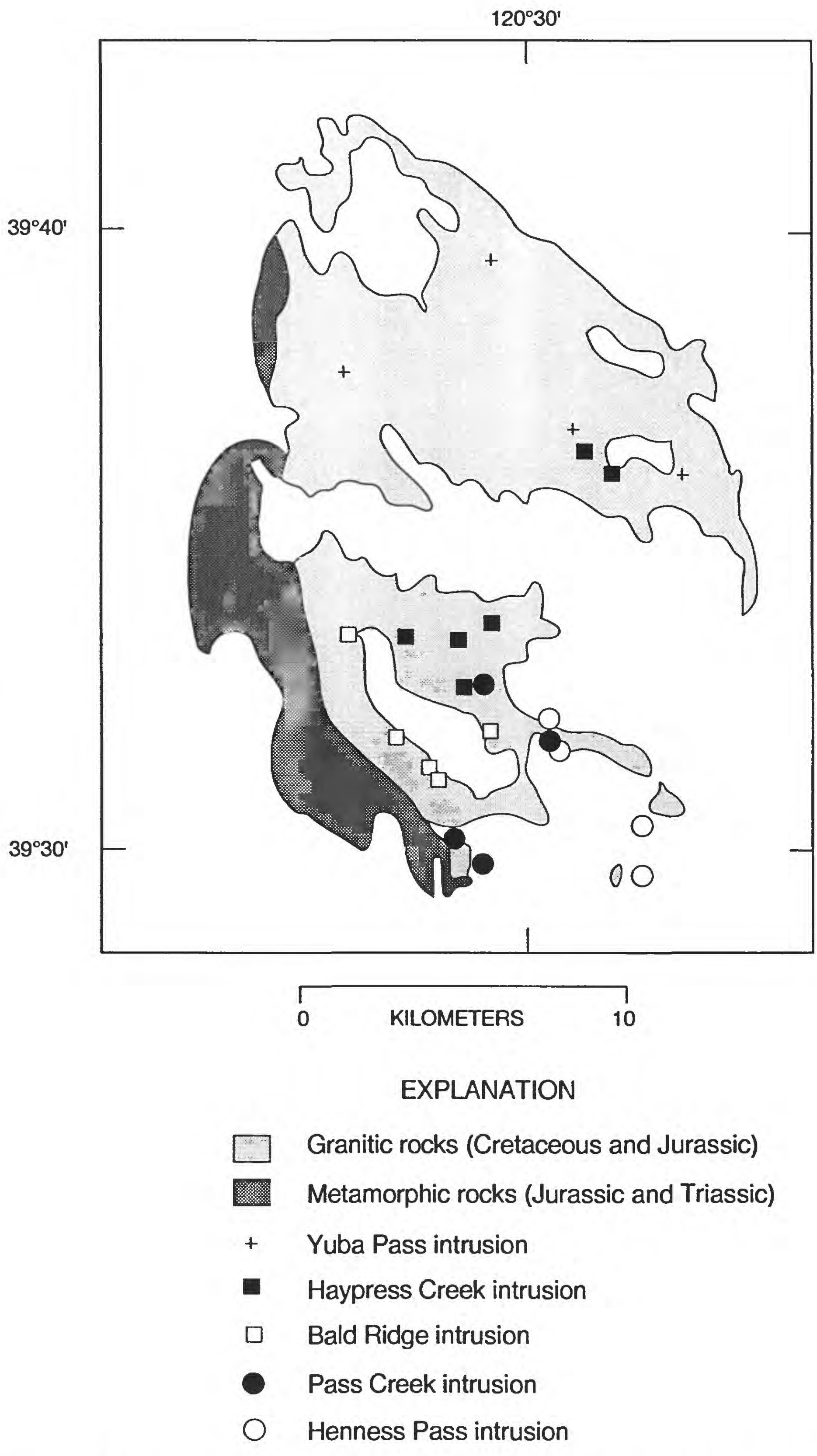


Figure 5. Map showing approximate distribution of intrusions in the Haypress Creek area and locations of samples used to define distribution of intrusions and in strontium isotope studies.

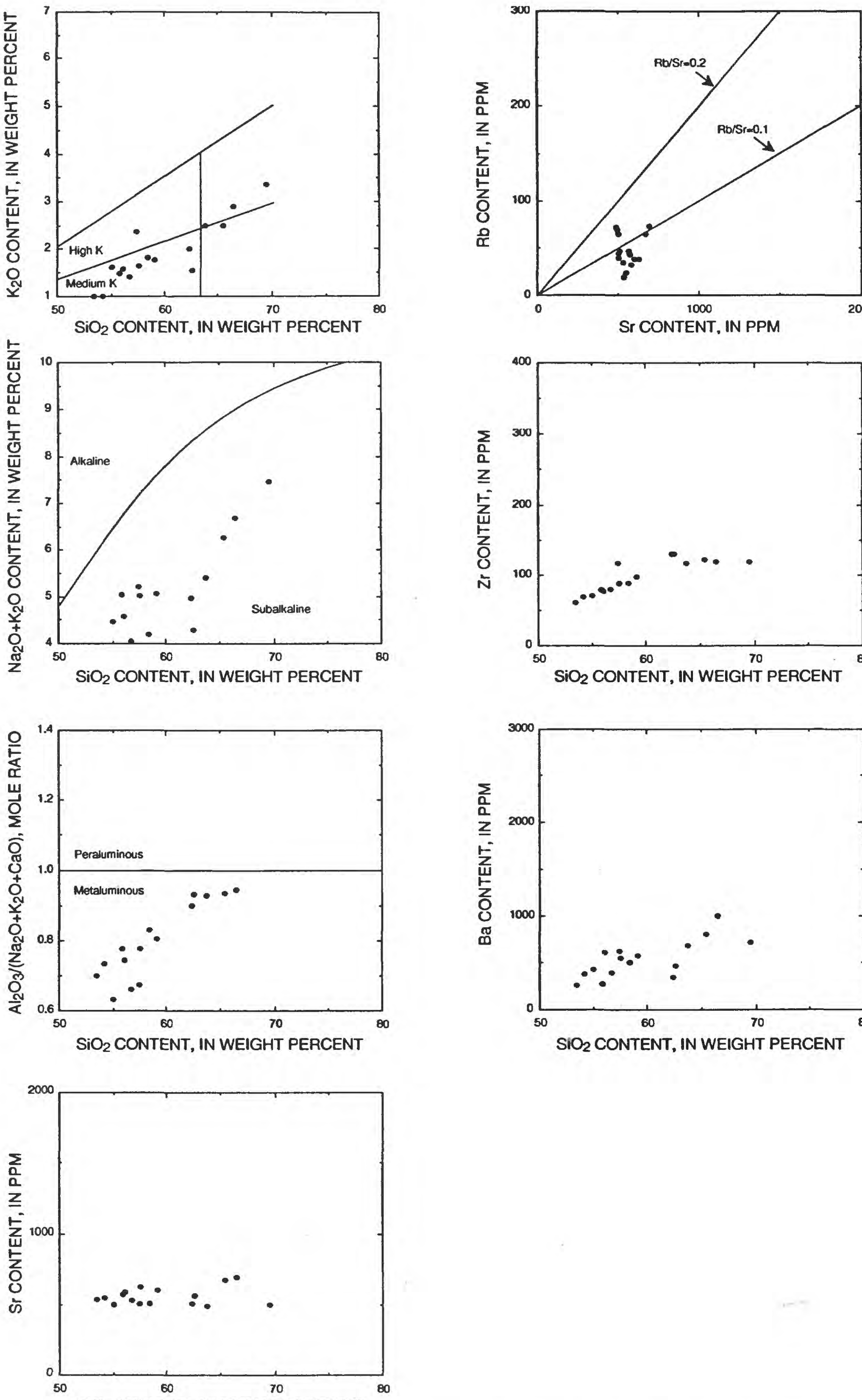


Figure 6. Plots of major and trace-element chemical data for the Middle to Late Jurassic Emigrant Gap pluton in northern Sierra Nevada. Alkaline-subalkaline boundary from Irvine and Barager (1971). High-K and medium-K fields are for orogenic andesites as defined by Gill (1981). Data from Wracher (1991).

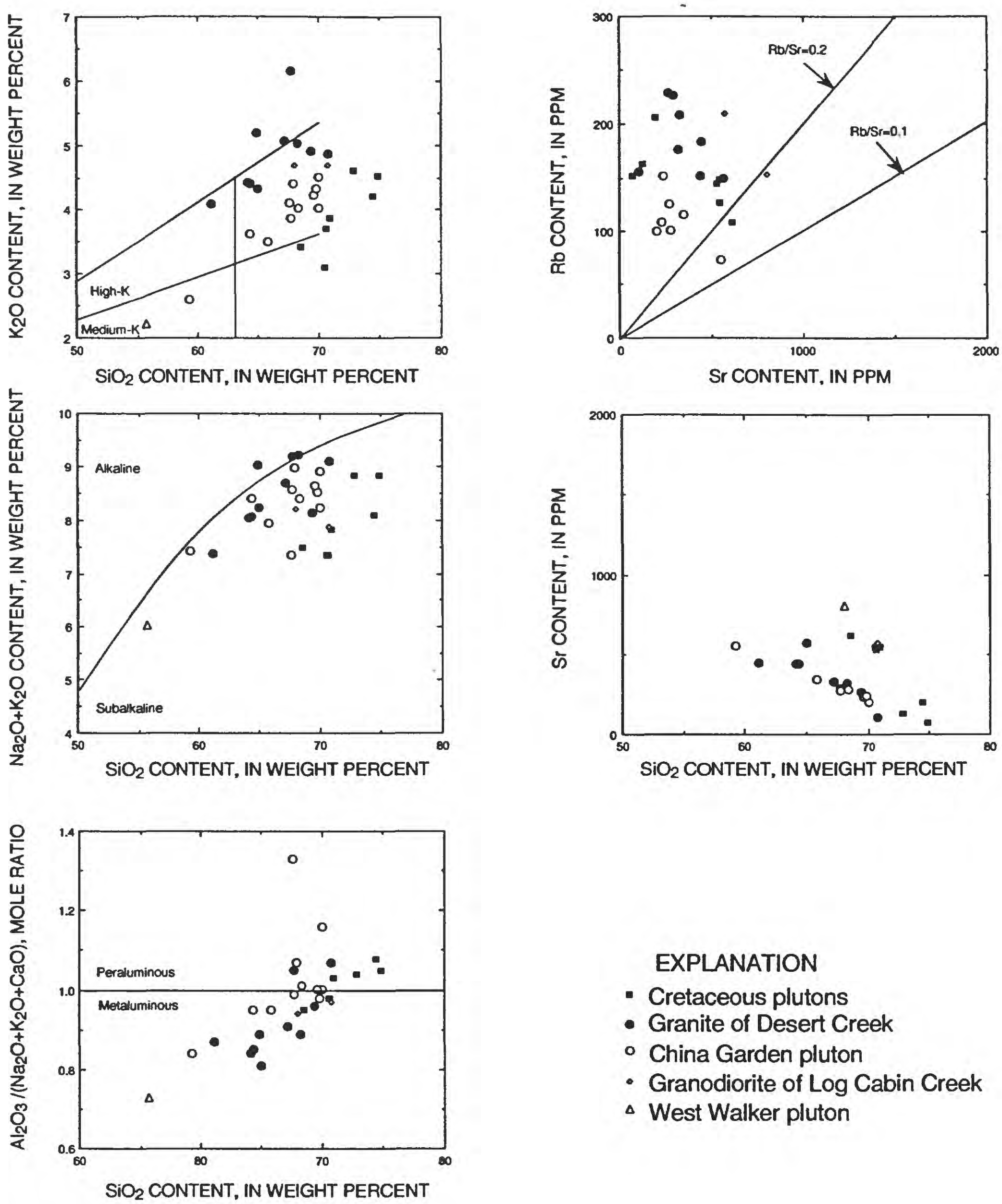


Figure 7. Plots of major and trace-element chemical data for Late Jurassic plutons, the China Garden pluton, and other Late Cretaceous plutons in the West Walker River area. Alkaline-subalkaline boundary from Irvine and Barager (1971). High-K and medium-K fields are for orogenic andesites as defined by Gill (1981). Data from Schweickert (1976) and A.C. Robinson (unpub. data).

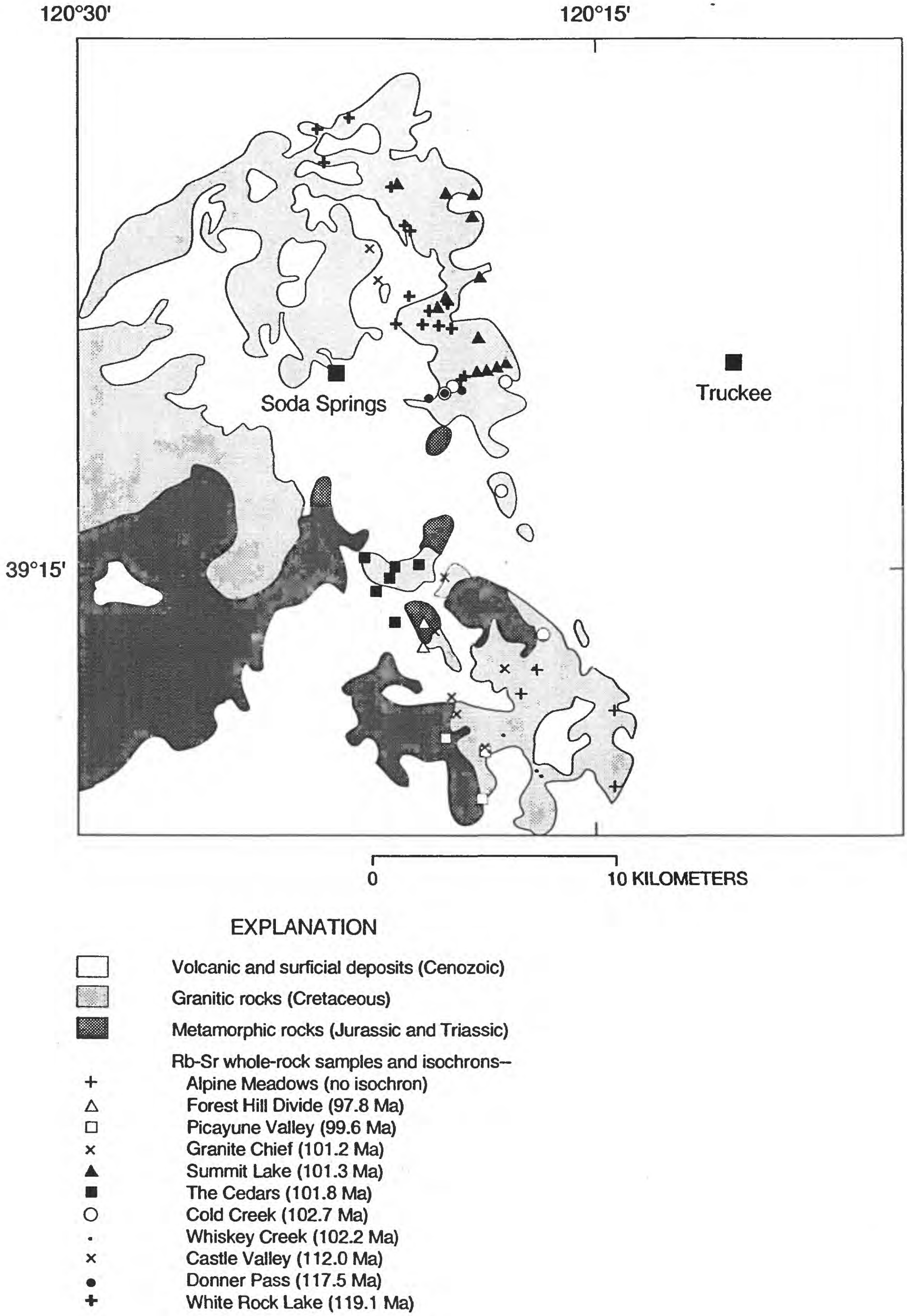


Figure 8. Map showing approximate distribution of plutons in the Donner Pass area and locations of samples used to define distribution of intrusions and in strontium isotope studies.

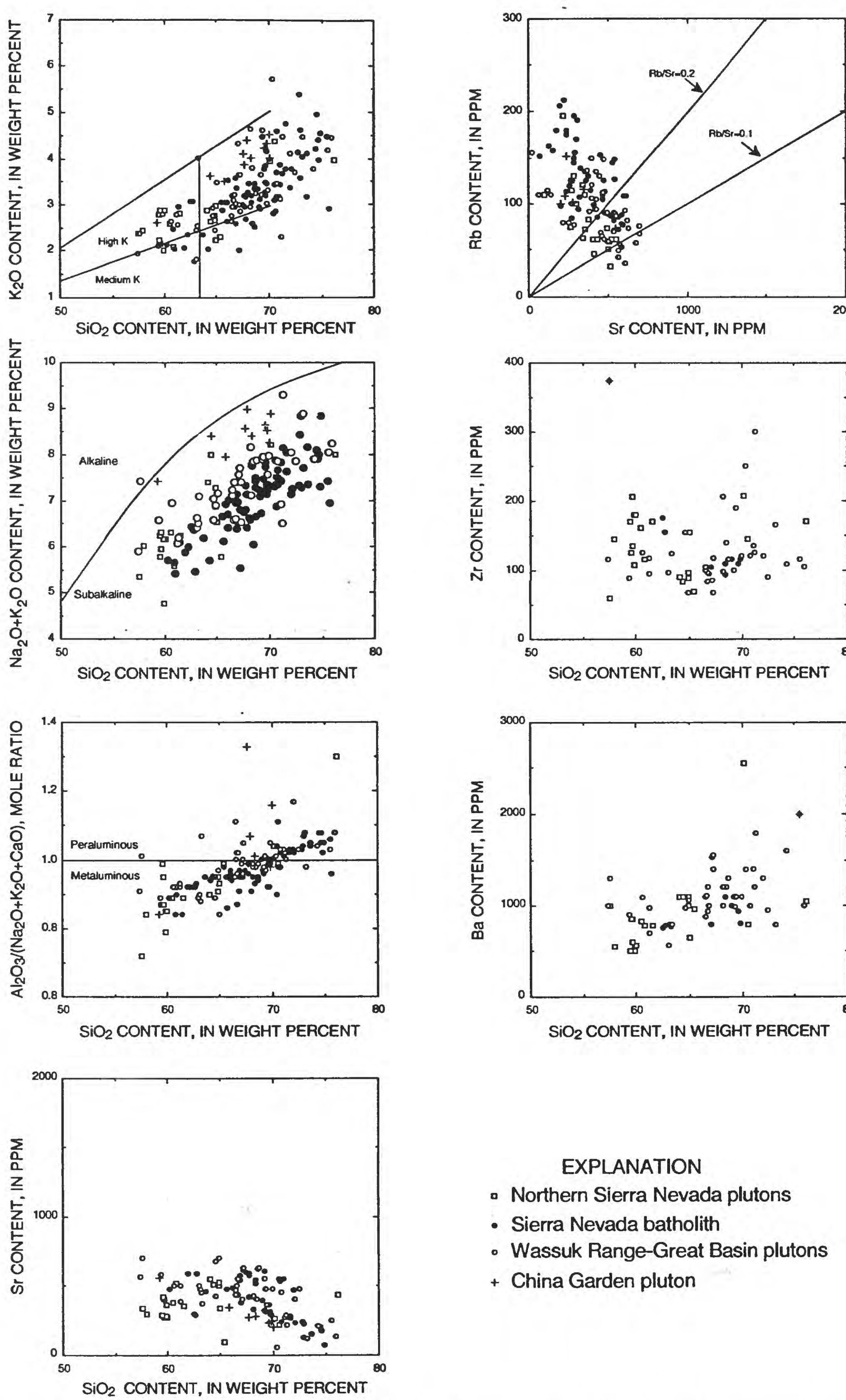


Figure 9. Plots of major and trace-element chemical data for Cretaceous plutons. Northern Sierra Nevada plutons are poorly dated plutons north and west of Reno that are isolated from the rest of the Sierra Nevada batholith. Alkaline-subalkaline boundary from Irvine and Barager (1971). High-K and medium-K fields are for orogenic andesites as defined by Gill (1981). Data from Thompson and White (1964), Bingler (1978), Armin and John (1983), Lee (1984), Ague and Brimhall (1988), S.B. Keith (written commun., 1990), John (1992), A.C. Robinson (unpub. data), D.S. Harwood (written commun., 1991), and R.A. Armin and D.A. John (unpub. data).

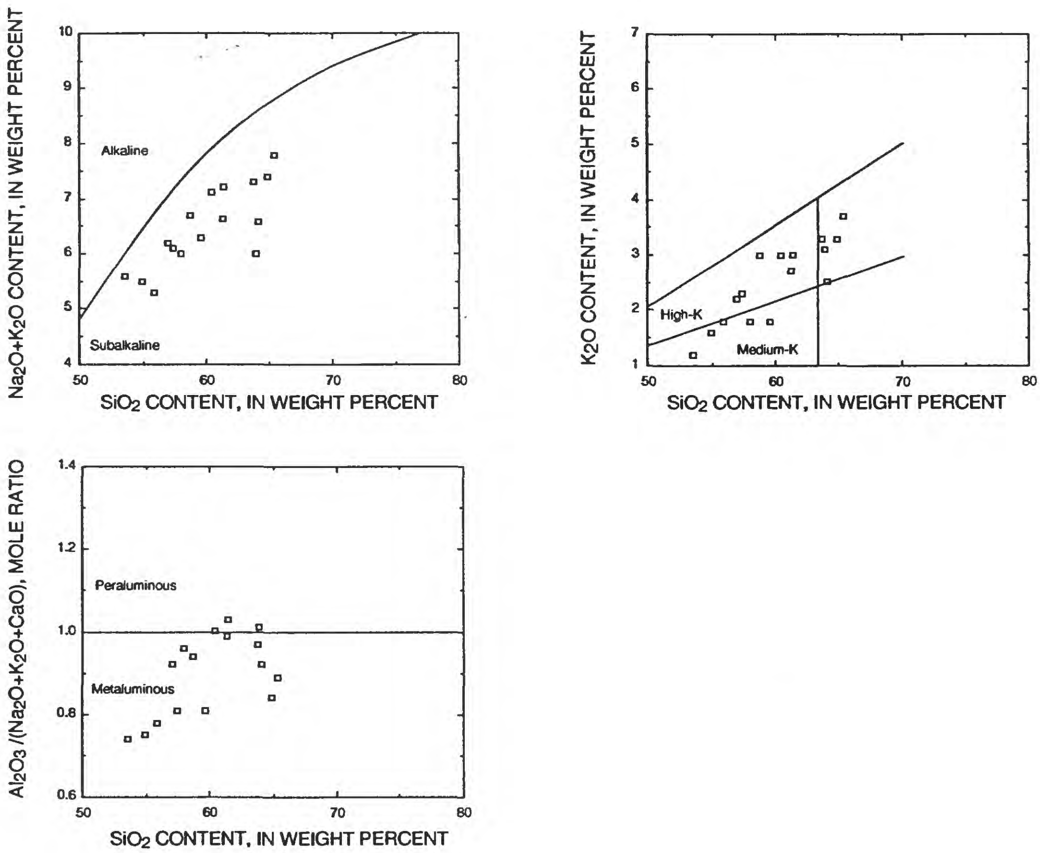


Figure 10. Plots of major-element chemical data for Tertiary plutons. Alkaline-subalkaline boundary from Irvine and Barager (1971). High-K and medium-K fields are for orogenic andesites as defined by Gill (1981). Data from Thompson and White (1964), Wallace (1975), and Hudson (1977).

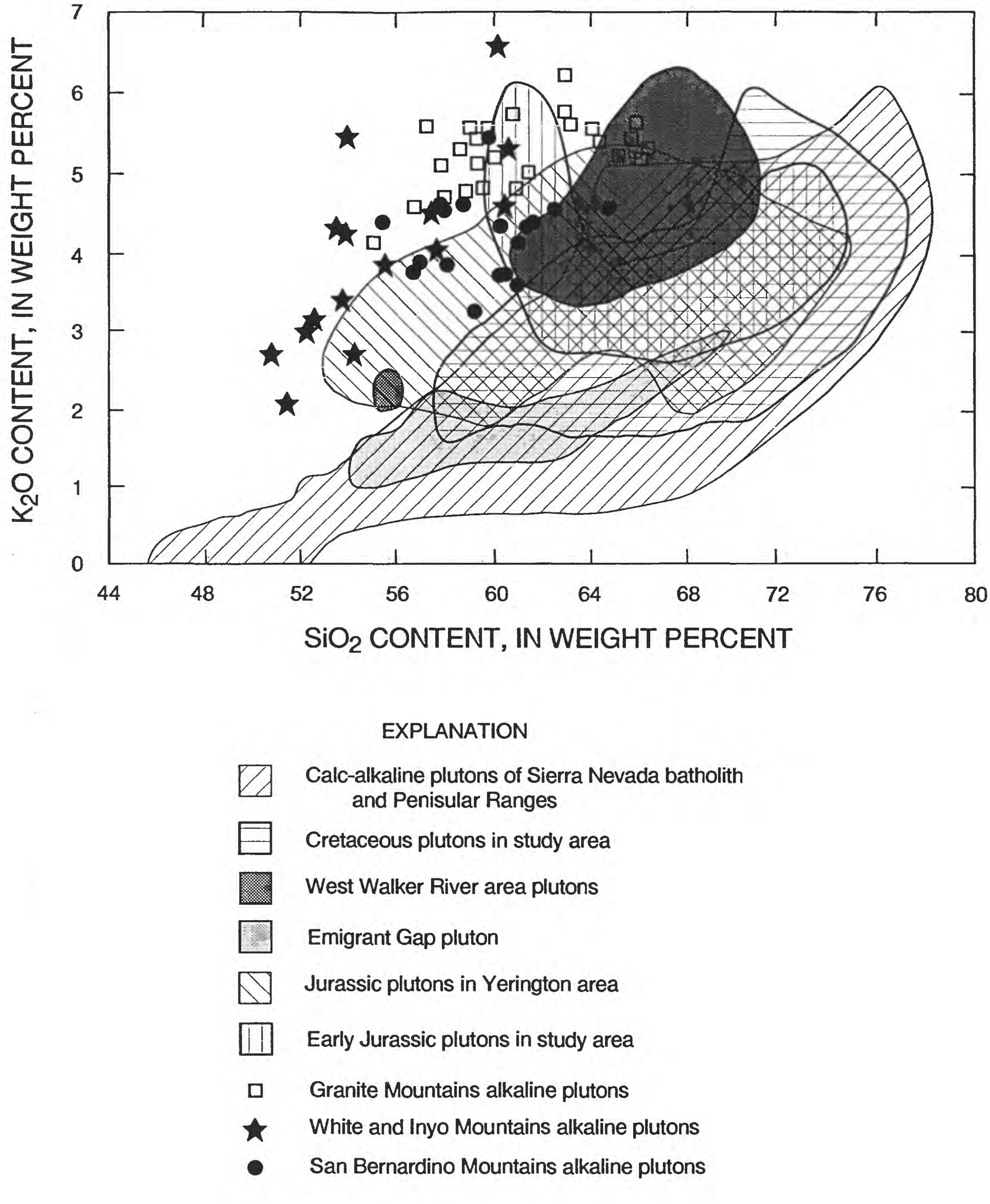


Figure 11*A*. Plot of K_2O versus SiO_2 comparing plutons in the study area with alkaline plutons in the White and Inyo Mountains, Granite Mountains, and San Bernardino Mountains, and with calc-alkaline plutons from the Sierra Nevada batholith and Penisular Ranges. Figure modified from Miller (1978, fig. 2).

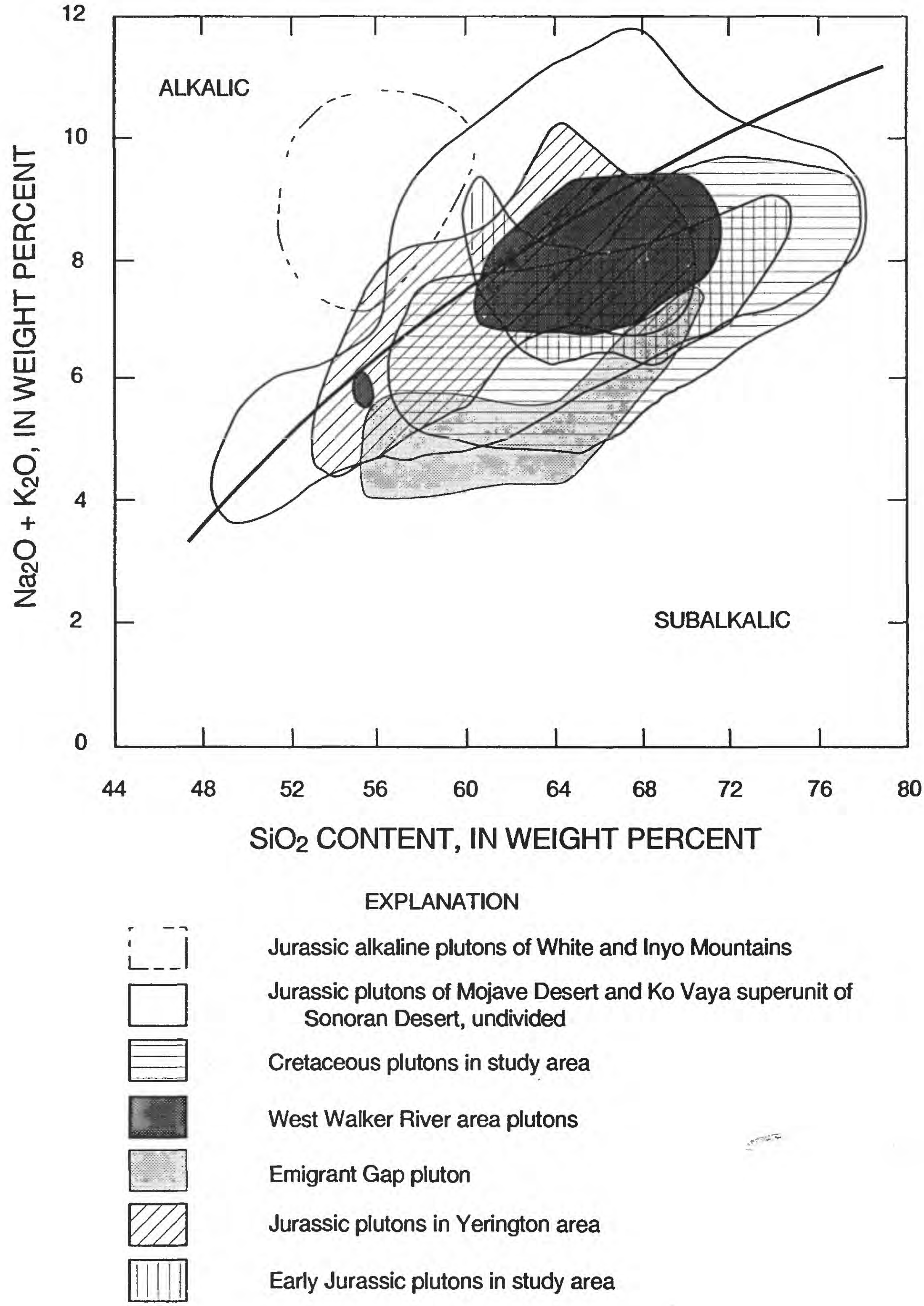


Figure 11*B*. Plot of Na_2O+K_2O versus SiO_2 comparing plutons in the study area with Jurassic plutons in the southern Cordilleria. Figure modified from Fox and Miller (1990, fig. 10).

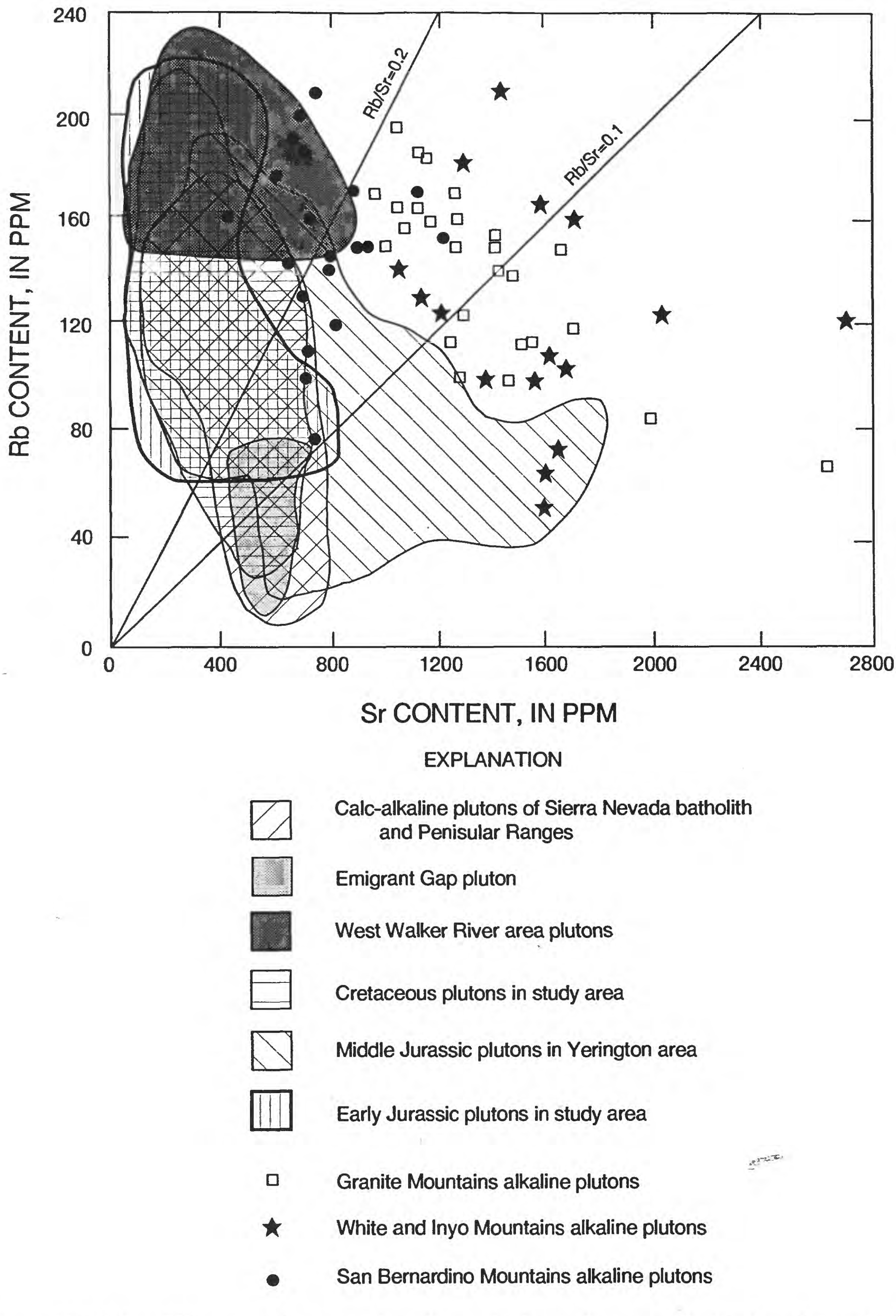


Figure 11*C*. Plot of Rb versus Sr comparing plutons in the study area with alkaline plutons in the White and Inyo Mountains, Granite Mountains, and San Bernardino Mountains, and with calc-alkaline plutons from the Sierra Nevada batholith and Penisular Ranges. Figure modified from Miller (1978, fig. 4).

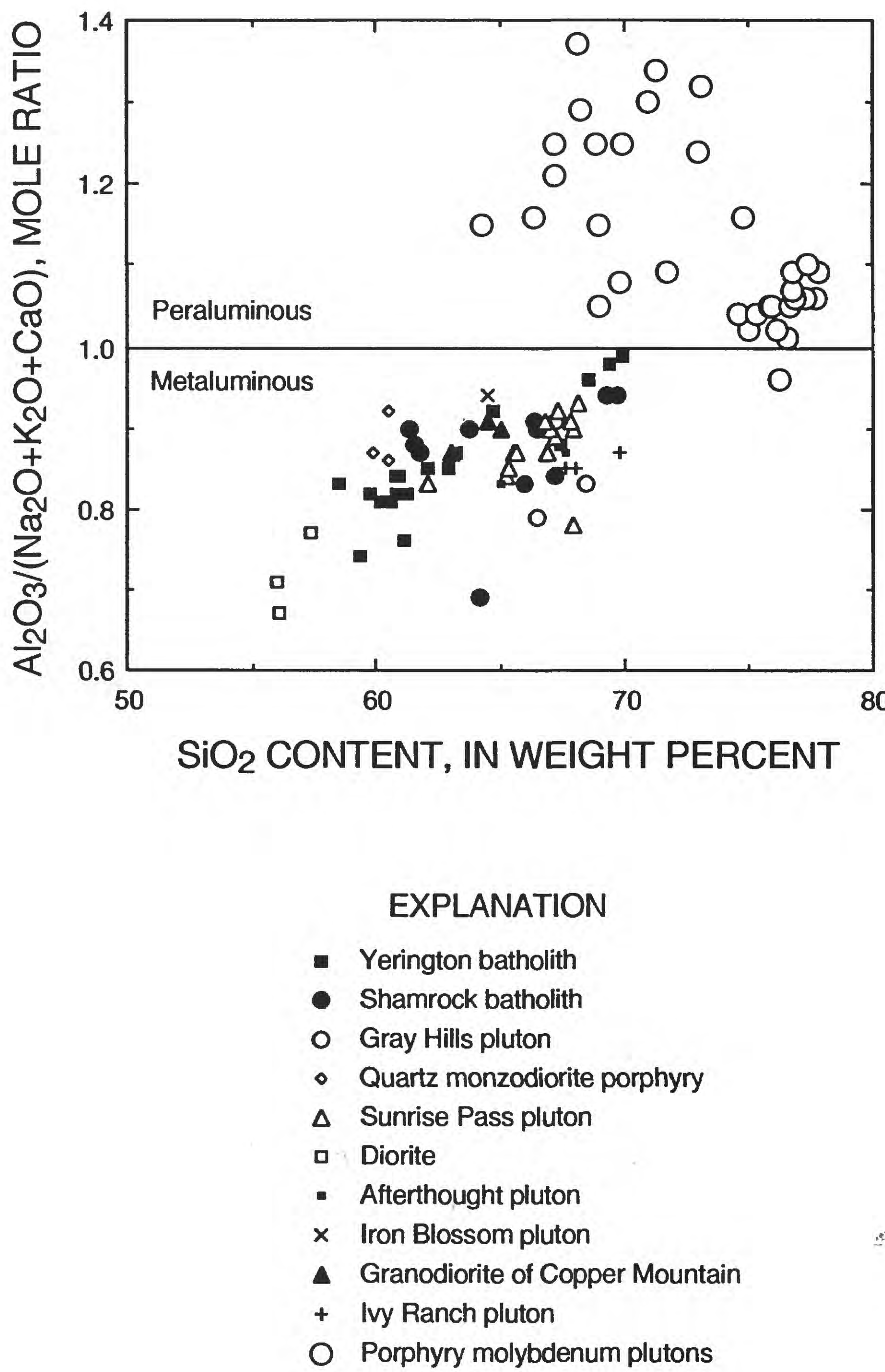
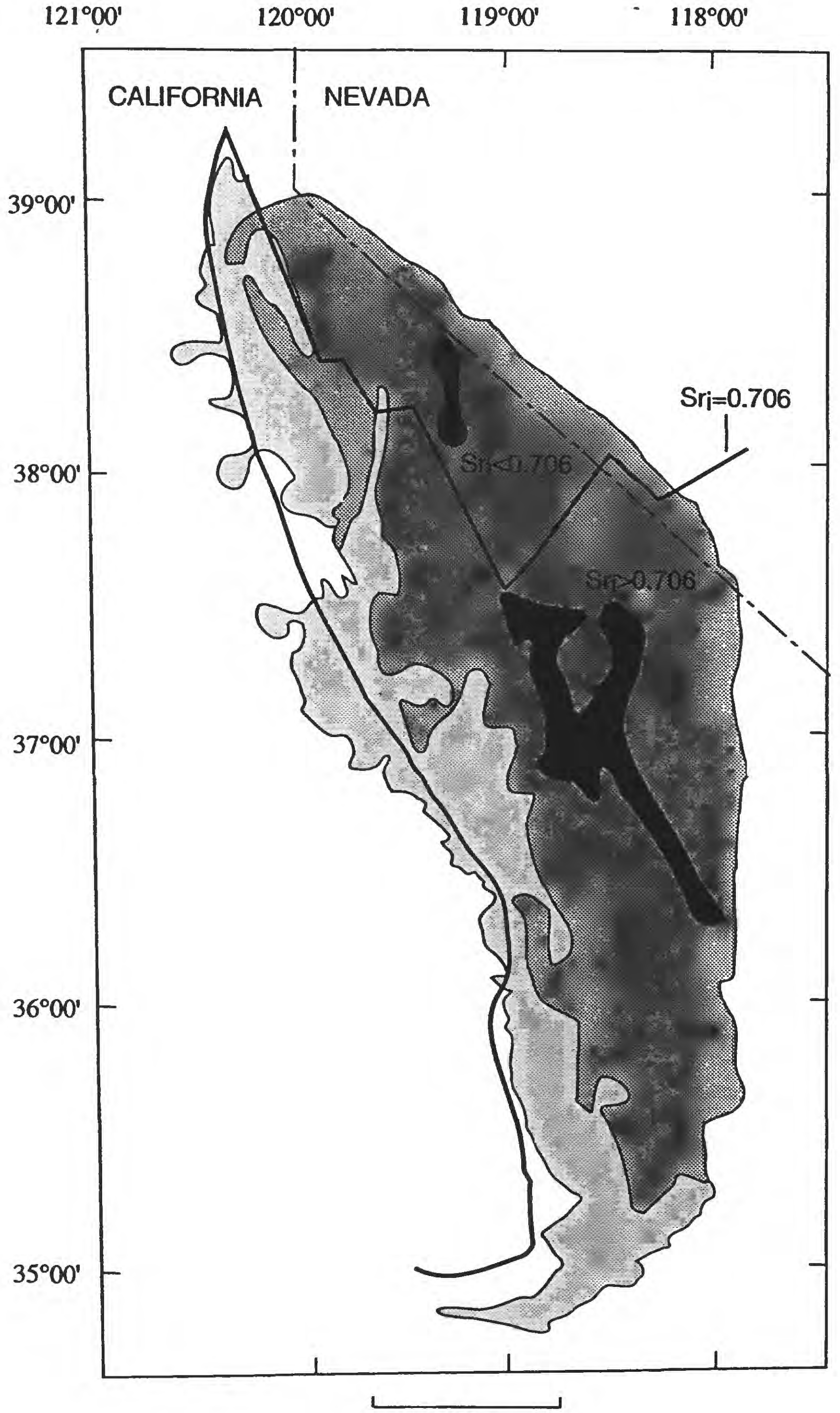


Figure 11*D*. Plot of SiO_2 versus molar $Al_2O_3/(K_2O+Na_2O+CaO)$ for Middle Jurassic plutons in the study area and porphyry molybdenum-related plutons. Porphyry molybdenum plutons are from Westra and Keith (1981).



EXPLANATION

- Areas underlain by Precambrian basement or derivitive sedimentary rocks as defined by Ague and Brimhall (1988b)
- Areas of thin or absent Precambrian basement or derivitive sedimentary rocks (Ague and Brimhall, 1988b)
- Other parts of Sierra Nevada batholith
- Initial $^{87}Sr/^{86}Sr$=0.706 isopleth (Kistler, 1990)

Figure 12. Map showing relationship of initial $^{87}Sr/^{86}Sr$ ratio (Sr_i) = 0.706 isopleth (from Kistler, 1990) and types of basement rocks as inferred from granitic rocks in the Sierra Nevada batholith as defined by Ague and Brimhall (1988a,b). Areas with Sr_i>0.706 are inferred to overlie Precambrian basement or derivative sedimentary rocks.