# Epithermal mineralization and intermediate volcanism in the Virginia City area, Nevada

Stephen. B. Castor,* Larry. J. Garside, and Christopher D. Henry
*Nevada Bureau of Mines and Geology/178, University of Nevada, Reno NV 89557*
Donald. M. Hudson
*1540 Van Petten St., Reno NV 89503*
William. C. McIntosh
*New Mexico Bureau of Mines and Mineral Resources, Socorro NM 87801*

## ABSTRACT

**Epithermal deposits in the Virginia City area of Storey, Washoe and Lyon Counties, Nevada, were major sources of silver and gold. The area produced 8.25 Moz Au and 192 Moz Ag, mostly from the Comstock Lode. Despite intense prior investigation, including 49 K-Ar and fission-track age dates, age relationships between magmatism and mineralization were imprecisely known. Our new geologic mapping and $^{40}Ar/^{39}Ar$ dating define several distinct Miocene magmatic and hydrothermal events in the area. In addition, we propose revisions of the volcanic stratigraphy.**

**Middle Miocene calc-alkaline intermediate magmatism in the Virginia City area occurred in at least four pulses. Andesite flows and flow breccias that mostly crop out in the south part of the area represent the oldest pulse at 17.7–18.3 Ma. In the past, these rocks were included in the lower part of the Alta Formation; we refer to them as the Silver City andesites. Andesites erupted at 15.2–15.8 Ma in and west of the Comstock district comprise the second pulse. We refer to these rocks, previously mapped as the upper Alta Formation and the Kate Peak Formation, as the Virginia City volcanics. The Davidson diorite was emplaced near the end of this pulse. The Virginia City andesites are probably the remnants of a stratovolcano centered approximately on the Comstock district, and the Davidson diorite may have been an extensive intrusion into the core of this stratovolcano. Younger andesites that include extrusive and intrusive rocks previously assigned to the Kate Peak Formation were emplaced at 14.2–14.9 Ma in and north of the Comstock district. We have assigned these rocks to the Flowery Peak magmatic suite. The latest pulse is represented by a 12.9-Ma dacite dome.**

**Hydrothermal alteration and mineralization in the area also occurred during several mid-Miocene pulses. The oldest, sericitic alteration about 6 km west of the Comstock Lode, has been dated at 18.1 Ma, overlapping with the eruption of the Silver City andesites. Widespread high-sulfidation alteration at 15.3–15.5 Ma (alunite) is approximately coeval with the Virginia City volcanics, which host it, and the Davidson diorite, which cuts it. Approximately contemporary low-sulfidation mineralization (15.5 Ma on adularia) occurred at Jumbo, about 5 km west of the Comstock Lode. Dates on the contiguous Comstock and Silver City Lodes cluster tightly at 14.1 Ma (adularia); whereas dates from the Occidental and Flowery Lodes to the east are 13.4 Ma (adularia). High-sulfidation alteration in the Geiger Grade area north of Virginia City gave a relatively imprecise age of 13.5 Ma (alunite).**

*E-mail, scastor@unr.edu

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**During its waning stages, the 14.2- to 14.9-Ma Virginia City magmatic suite may have provided heat and other components for the highly productive Comstock mineralization. The extensive Davidson diorite intrusive activity, once considered a possible source of Comstock hydrothermal components, took place more than 1 Ma before Comstock mineralization. However, high-sulfidation hydrothermal activity may have accompanied the Davidson intrusive episode.**

**Key Words:** Epithermal, precious metal, volcanism, age dates, Comstock

## INTRODUCTION

Epithermal deposits in the Virginia City area of Storey, Washoe, and Lyon Counties, Nevada, were major sources of silver and gold during the late 19th and early 20th centuries. Five low-sulfidation vein systems have been defined in the area: 1) the Comstock Lode, a dominantly NNE-striking vein system that underlies Virginia City, 2) the Silver City vein system, a NNW-striking vein system that intersects and extends south of the Comstock Lode; 3) the Occidental Lode, a NNE-striking vein system 2–3 km east of the Comstock Lode, 4) the Flowery deposits, NE-striking veins east of the Occidental Lode; and 5) NE-striking veins in the Jumbo district about 4 km west of the Comstock Lode (Fig. 1). Mining in the Virginia City area produced 8.25 Moz Au and 192 Moz Ag, mostly from bonanza deposits along the Comstock Lode and mostly during the period 1860–1890 (Bonham and Papke, 1969).

Despite intense prior investigation, including 49 K-Ar and fission-track ages (Vikre et al., 1988; Ashley et al., 1979; Whitebread, 1976), age relationships between magmatism and mineralization were imprecisely known. New geologic mapping (Hudson et al., in preparation) and $^{40}Ar/^{39}Ar$ dating (Castor et al., 2002; Vikre et al., 2003; Table 1) define several distinct Miocene magmatic and hydrothermal events in the area. On the basis of this new information, revisions of the volcanic stratigraphy are necessary. In addition, the new $^{40}Ar/^{39}Ar$ dates allow us to put some constraints on the chronologic relationship between magmatism and mineralization in the area.

## LITHOLOGIC SETTING

The oldest rocks in the Virginia City area are sedimentary and igneous rocks of probable Jurassic age intruded by Cretaceous granitoid rocks (Thompson, 1956). These are overlain by Oligocene to early Miocene felsic ash-flow tuffs (Bingler; 1978). However, most of the rocks exposed in the district and the most important ore hosts are early to middle Miocene intermediate volcanic and intrusive rocks.

Gianella (1936) assigned early to middle Miocene andesitic rocks of the Silver City area to four units: the Alta andesite series, the Kate Peak andesite series, the Knickerbocker andesite, and the American Ravine andesite. Later, Thompson (1956) applied the terms Alta Formation and Kate Peak Formation to Gianella's series. Our mapping and $^{40}Ar/^{39}Ar$ age determinations have revealed difficulty in the use of these units. We propose stratigraphic revisions based on the new data (Fig. 2), retaining the Sutro Tuff, Davidson Diorite, and the American Ravine Andesite (a minor intrusive unit) as defined previously, abandoning the Knickerbocker Andesite, and retaining the Alta and Kate Peak as subunits within a new unit called the Virginia City volcanics.

On the basis of new $^{40}Ar/^{39}Ar$ ages, we define four magmatic episodes in the Virginia City area. From oldest to youngest, these are: 17.7- to 18.3-Ma rocks of the Silver City magmatic suite; 15.2- to 15.8-Ma rocks of the Virginia City magmatic suite; 14.2- to 14.9-Ma rocks of the Flowery Peak magmatic suite; and the 12.9-Ma dacite dome. In many cases, it is difficult to assign intermediate rocks of the Virginia City Quadrangle to one of these suites on the basis of mineralogy, texture, or chemistry. This lithologic uncertainty is aggravated by the effects of hydrothermal alteration in many places. However, some general lithologic characteristics are noted below.

### Silver City suite (17.7 to 18.3 Ma)

Rocks of the Silver City suite include an effusive sequence mapped by Thompson (1956) as part of the Alta Formation but which we call the Silver City andesites. Flow rocks in this suite are generally difficult to distinguish from those in the Virginia City suite on the basis of mineral assemblages and textures; however, sections of Silver City suite rocks generally include distinctive flow breccias. To the south and southwest of the Jumbo district, the basal part of this unit consists of a distinctive hornblende-rich, plagioclase-poor andesite.

### Virginia City suite (15.2 to 15.9 Ma)

The rocks of the Virginia City suite generally contain small plagioclase phenocrysts, rarely contain biotite, may or may not contain hornblende, and commonly contain both clinopyroxene and orthopyroxene. We refer to the effusive rocks of this suite, previously mapped as the upper Alta Formation and the Kate Peak Formation (Thompson, 1956), as the Virginia City volcanics. The Davidson diorite, also emplaced during this episode, yielded an $^{40}Ar/^{39}Ar$ age of 15.3 Ma (Table 1). The Virginia City andesites probably represent the extrusive remnants of a stratovolcano centered approximately on the Comstock district (Vikre, 1989), and the Davidson diorite an intrusion into the core of this stratovolcano (Criss and Champion, 1991). However, the dominance of flow rock and a general lack of pyro-

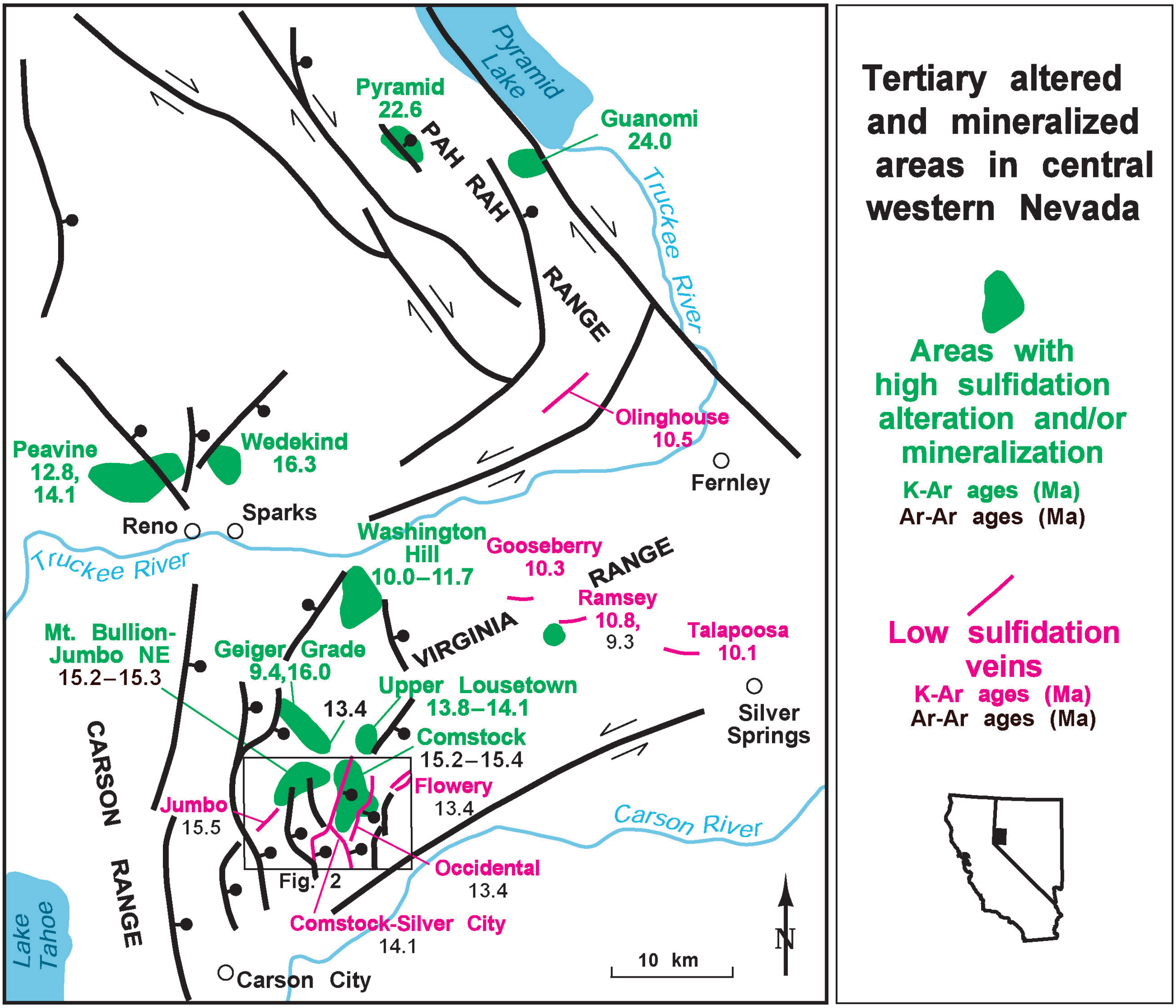


Figure 1. Map of Miocene alteration and mineralization in the Virginia City region, Nevada.

clastic deposits in this rock suite indicate that the suite does not represent a typical stratovolcanic edifice (Cas and Wright, 1988). The Virginia City volcanics lie locally on the Sutro Tuff, a distinctive light-colored, bedded sequence of fine- to coarse-grained volcaniclastic rock that overlies the Silver City andesites (Fig. 2). Finely laminated parts of the Sutro record a period of lacustrine deposition (Gianella, 1936).

We have subdivided the Virginia City volcanics into several lithologic units (Hudson et al., in preparation). The most extensive unit, the Alta andesite, is typified by pyroxene andesite flows containing fine plagioclase phenocrysts. This unit makes up most of the exposures between the Comstock and Occidental Lodes (Fig. 3) and underlies much of the highlands west of the Comstock Lode. We put coeval flow rock with relatively coarse plagioclase found east of the Occidental Lode in the Kate Peak andesite subunit.

**Flowery Peak suite (14.2–14.9 Ma)**

Andesitic rocks of the Flowery Peak suite were emplaced in and to the north of the Comstock district. The rocks of the Flowery Peak suite are generally rich in hornblende and commonly contain biotite. Most also contain large, stubby plagioclase phenocrysts. They include extrusive and intrusive rocks previously assigned to the Kate Peak Formation by Thompson (1956). Some notable intrusive masses include the Sugarloaf and Mount Abbie plugs and a swarm of dikes extending SSE from near Geiger Summit into the Virginia City area. Dikes that

**TABLE 1. ISOTOPE $^{40}$AR/$^{39}$AR AGE DATES, VIRGINIA CITY AREA, NEVADA.**

| Sample | Age(Ma) | 2σ | Material | Rock Type | Location | Map Reference |
|---|---|---|---|---|---|---|
| Late dacite | | | | | | |
| S | 12.64 | 0.21 | hornblende | rhyodacite | Chalk Hills Quadrangle | Schwartz and Faulds, 2004 |
| U | 12.73 | 0.14 | hornblende | tuff | Chalk Hills Quadrangle | Schwartz and Faulds, 2004 |
| C02-21 | 12.91 | 0.18 | hornblende | dacite | Occidental Quarry | Fig. 3 |
| Flowery Peak suite | | | | | | |
| H02-139 | 14.20 | 0.43 | plagioclase | biot-hbd dacite | NE VC Quadrangle | Hudson and others, in prep. |
| COM-962 | 14.39 | 0.20 | hornblende | andesite lava | | Fig. 3 |
| H02-138 | 14.51 | 0.12 | hornblende | hbd andesite bx | NE VC Quadrangle | Hudson and others, in prep. |
| C02-14 | 14.53 | 0.11 | hornblende | andesite intrusion | Sugarloaf Quarry | Fig. 3 |
| COM-960C | 14.53 | 0.42 | hornblende | andesite dike | | Fig. 3 |
| H02-136 | 14.58 | 0.12 | hornblende | biot-hbd intrusion | NE VC Quadrangle | Hudson and others, in prep. |
| H01-1 | 14.72 | 0.14 | biotite | andesite lava | | Fig. 3 |
| H01-2 | 14.75 | 0.22 | hornblende | andesite lava | | Fig. 3 |
| H02-140 | 14.82 | 0.17 | hornblende | andesite intrusion | Mount Abbie | Hudson and others, in prep. |
| C00-126A | 14.89 | 0.20 | hornblende | hbd andesite lahar | | Hudson and others, in prep. |
| Virginia City suite | | | | | | |
| COM 910 | 15.23 | 0.20 | hornblende | andesite lava | Overman pit | Fig. 3 |
| COM-966 | 15.32 | 0.12 | biotite | diorite | Savage Mine | Fig. 3 |
| C01-19 | 15.35 | 0.22 | plagioclase | px andesite flow | NW VC Quadrangle | Hudson and others, in prep. |
| COM-963 | 15.43 | 0.26 | hornblende | andesite lava | west flank Kate Peak | Fig. 3 |
| H01-5 | 15.78 | 0.32 | hornblende | andesite lava | Twin Peaks | Fig. 3 |
| VCH-1037 | 15.79 | 0.20 | hornblende | hbd andesite | W VC Quadrangle | Hudson and others, in prep. |
| VCL-15 | 15.80 | 0.40 | plagioclase | andesite | Knickerbocker shaft | Fig. 3 |
| C01-20 | 15.82 | 0.13 | hornblende | andesite lava | N of Jumbo | Fig. 3 |
| Silver City suite | | | | | | |
| H01-6 | 17.69 | 0.22 | hornblende | andesite lava | Woodville | Fig. 3 |
| H01-8 | 17.94 | 0.32 | hornblende | andesite lava | Oest Mine | Fig. 3 |
| C00-84 | 18.02 | 0.24 | hornblende | hbd andesite | | Fig. 3 |
| C00-112 | 18.25 | 0.36 | hornblende | andesite breccia | | Fig. 3 |
| C00-47 | 18.32 | 0.32 | hornblende | hbd andesite | | Fig. 3 |
| Flowery-Occidental low-sulfidation veins | | | | | | |
| C02-15 | 13.33 | 0.04 | adularia | qtz-cc-adularia vein | Lady Bryan pit | Fig. 3 |
| CN85-25 | 13.36 | 0.05 | adularia | qtz-adularia vein | N Flowery district | Fig. 3 |
| H00-51 | 13.39 | 0.04 | adularia | qtz-cc-adularia vein | Occidental Mine | Fig. 3 |
| C02-20 | 13.40 | 0.04 | adularia | qtz-adularia vein | Brunswick decline | Fig. 3 |
| C02-19 | 13.53 | 0.03 | adularia | qtz-adularia vein | Sevenmile Canyon | Fig. 3 |
| Comstock-Silver City low-sulfidation veins | | | | | | |
| H00-61 | 14.06 | 0.04 | adularia | qtz-adularia vein | Lucerne pit | Fig. 3 |
| H00-62 | 14.08 | 0.05 | adularia | qtz-adularia vein | Kendall cut | Fig. 3 |
| H01-4 | 14.10 | 0.06 | adularia | qtz-adularia vein | Imperial pit | Fig. 3 |
| NS-402 | 14.17 | 0.06 | adularia | qtz-adularia vein | New Savage Mine | Fig. 3 |
| Jumbo low-sulfidation veins | | | | | | |
| C02-72C | 15.49 | 0.04 | adularia | qtz-adularia vein | Jumbo district | Fig. 3 |
| Geiger Grade high-sulfidation alteration | | | | | | |
| VH02-1 | 13.49 | 0.70 | alunite | alunitized breccia | Virginia Highlands | Hudson and others, in prep. |
| Virginia City-Jumbo high-sulfidation alteration | | | | | | |
| H02-144 | 15.26 | 0.14 | alunite | alunite-qtz ledge | Yellowjacket Mine area | Fig. 3 |
| C02-69C | 15.32 | 0.37 | alunite | alunite-pyrite rock | Jumbo NE | Fig. 3 |
| H02-142 | 15.40 | 0.29 | alunite | alunite-qtz ledge | Mount Bullion | Fig. 3 |
| VC-14C | 15.50 | 0.40 | alunite | alunite-pyrite rock | Union shaft area | Fig. 3 |
| VC-14C | 14.72 | 0.64 | alunite | alunite-pyrite rock | Union shaft area | Fig. 3 |
| West of Jumbo sericite | | | | | | |
| VCH-1055 | 18.11 | 0.54 | sericite | alt. Santiago Cyn Tuff | West of Jumbo | Fig. 3 |

All ages are reported for the first time in this publication, except for samples S and U. More detailed data will be available in Hudson et al. (in preparation).

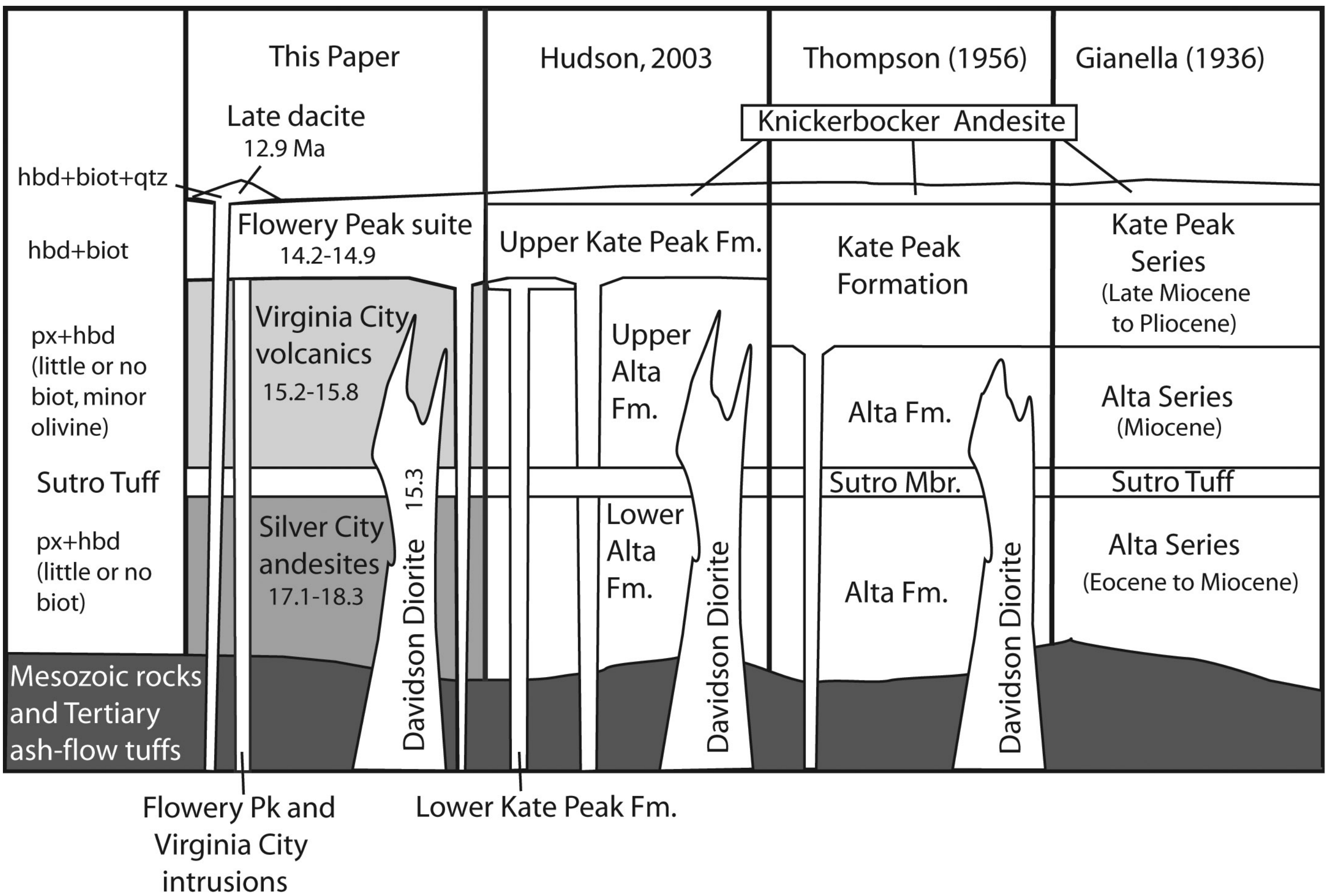


Figure 2. Comparison of Virginia City area stratigraphic units. Abbreviations: hbd, hornblende; biot, biotite; qtz, quartz; px, pyroxene.

parallel both the Comstock and Silver City Lodes (but are too narrow to show on Figure 3) are also part of the Flowery Peak suite, along with NW-striking dikes in the Bain Spring area outside Figure 3 (Berger et al., 2003) and in the Flowery district. In addition to intrusive rocks, the Flowery Peak suite also includes the andesite of Flowery Peak, which consists of andesitic flows and lesser interbedded lahar deposits that unconformably overlie widely altered rocks of the Virginia City suite.

**Late dacite (12.9-Ma)**

Quartz-bearing dacite flow domes are present in the east and northeast parts of the Virginia City area. The dacite is characterized by significant amounts of quartz phenocrysts, and large, stubby plagioclase phenocrysts. Volumetrically significant occurrences include the Occidental quarry dome, probably the Mount Grosch dome, and flow domes north and east of the Flowery district (Fig. 3). Tuff and other volcanic rocks, along with distinctly bedded volcaniclastic rocks and diatomite, in the Chalk Hills area northeast of Virginia City have yielded dates of 12.6 to 12.8 Ma (Schwartz and Faulds, 2004), which are indistinguishable in age from the 12.9-Ma dacite (Fig. 4).

**STRUCTURAL SETTING**

The Miocene rocks in the Virginia City area are dominantly tilted westward, possibly due to rotation along a series of eastward-dipping normal faults. In much of the area, rocks that predate the Flowery Peak magmatic episode dip west to northwest at 10 to 35 degrees. However, in some areas, such as in the hangingwall of the Silver City and Occidental Lodes, they are flat lying or nearly so. Thompson (1956) observed little difference between dips of the oldest Tertiary rocks (Oligocene ash-flow tuffs) and Miocene rocks. On the basis of our mapping, the effusive rocks of the Flowery Peak series, as well as the late dacite domes, have more shallow dips. This suggests tilting prior to 14.2 Ma. However, 12.6- to 12.8-Ma tuffs and volcanic rocks in the nearby Chalk Hills generally dip westward or northwestward at 20 degrees (Schwartz and Faulds, 2002), suggesting that much of the Virginia City area tilting postdated 12.6 Ma. The steeper dips of the extrusive rocks of the Virginia City suite may, in part, include primary dips along the west flank of the proposed stratovolcano.

Normal faults that may have accommodated rotation of the Miocene volcanic strata westward include that which controlled

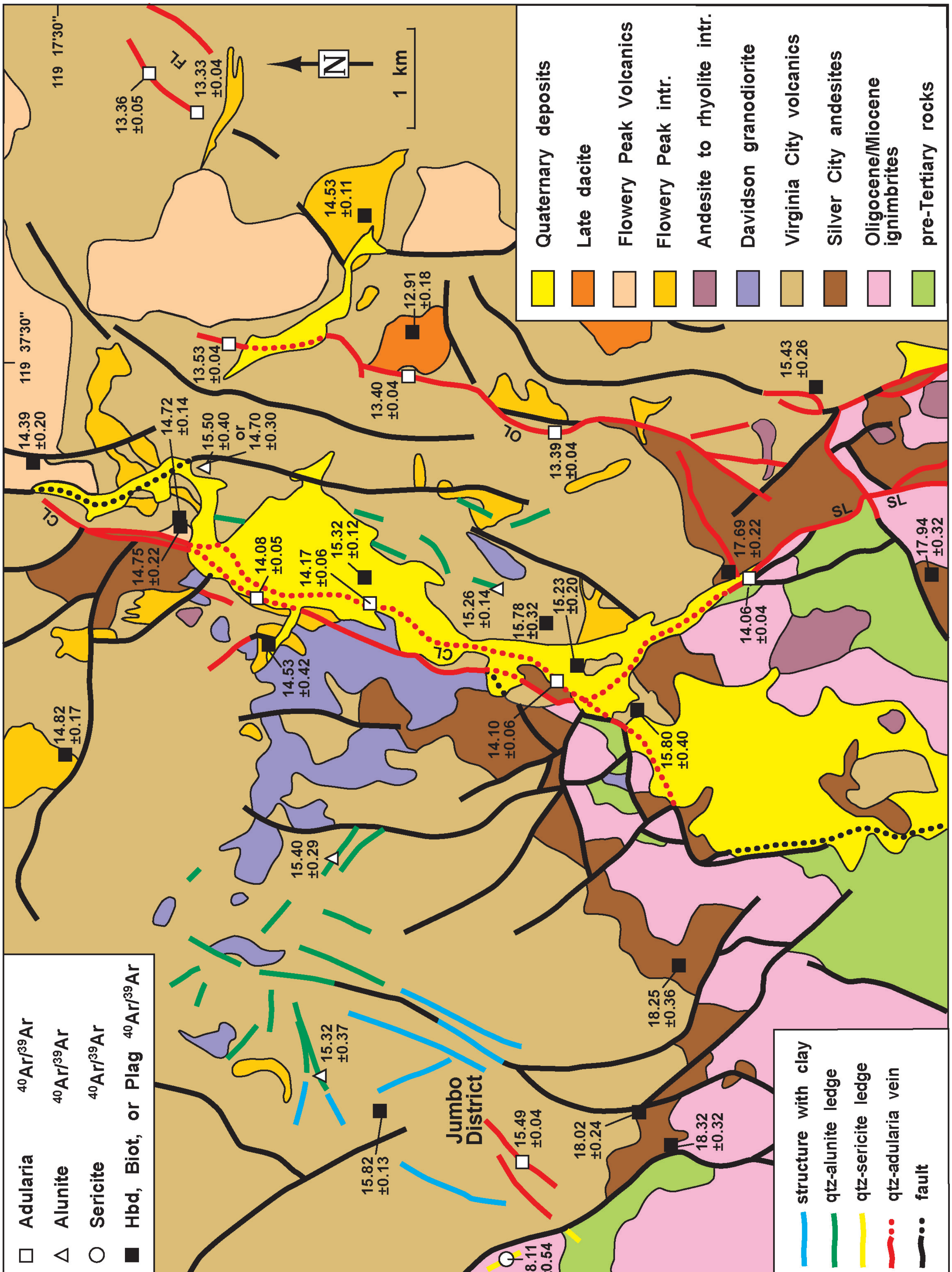


Figure 3. Geologic map of the Virginia City area, Nevada, showing age determinations for Miocene rocks and alteration minerals associated with precious metal mineralization. Ages shown in millions of years. Open symbols are alteration mineral ages. Closed symbols are rock age determinations. SL = Silver City Lode; CL =Comstock Lode; FL = Flowery Lode; OL = Occidental Lode, intr. = intrusive.

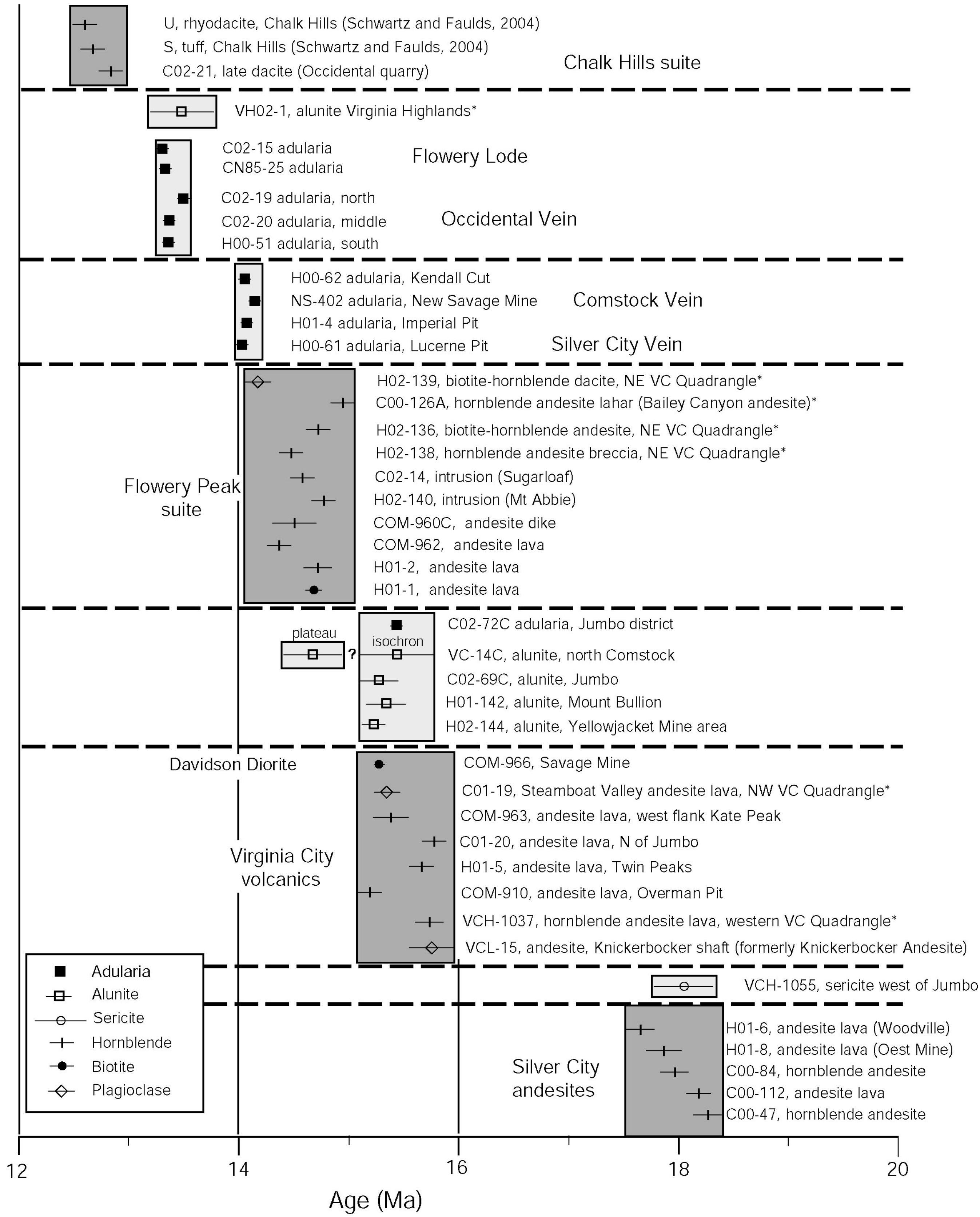


Figure 4. Magmatic and mineralization/alteration episodes in the Virginia City area, Nevada. Episode age limits are shown by shaded boxes: gray for magmatism; light gray for alteration and mineralization. Two ages are shown for sample VC-14C (also see Table 1).

the Comstock Lode, along with a series of similar faults to the west that placed hanging-wall Miocene andesites against each other and against pre-Tertiary basement. On the basis of earlier studies, maximum vertical displacements along the Comstock and Silver City Lodes are 900 m and 500 m, respectively (Gianella, 1936; Hudson, 2003). Berger et al. (2003) postulated that the Comstock Lode formed along an extensional stepover between NW-striking dextral slip faults. However, on the basis of our mapping, we interpret structure in the Virginia City area to be a complex of mostly normal faults, many of which are concave-eastward or otherwise non-planar, that stepped eastward during Miocene extension. Displacement along such faults locally would have a lateral component due to their scalloped shape. Gianella (1936) distinguished an episode of pre-Comstock mineralization displacement from a post-mineralization displacement episode. Post-mineralization movement clearly took place along both the Comstock-Silver City and Occidental-Flowery veins; however, the age of this later movement has not been established. In the Silver City area, displacement along horst- and graben-forming, east- to east-northeast-striking faults probably was concurrent with Comstock-Silver City fault movement.

To the west of the Comstock Lode, the Virginia City volcanics are cut by mineralized faults or fractures that exhibit crudely radial orientation (Fig. 3). These structures may have formed during deformation associated with the postulated 15.2- to 15.9-Ma stratovolcano, and in particular with doming by intrusion of the Davidson diorite. In places, andesite dikes that we correlate with the Davidson occur along such structures. It is possible that the form of some of the later concave-eastward normal faults was affected by magmatic activity as well, for instance as caldera-related fracturing or as sector collapse during volcanism.

## ALTERATION AND MINERALIZATION

The Virginia City area was the site of episodic Miocene mineralization and associated complex alteration patterns. Hudson (2003) defined and mapped several alteration types in the area related to both high- and low-sulfidation hydrothermal activity. The high-sulfidation alteration in the area was first described by Whitebread (1976) and dated by Vikre et al. (1988). Mineralization associated with this alteration episode was not economically important, although prospects northwest of Jumbo (Fig. 1) have yielded samples with elevated gold, silver, arsenic, tellurium, and bismuth contents (Tingley et al., 1999). High-sulfidation alteration minerals include quartz, pyrite, the alunite-group minerals (alunite, natroalunite and minamiite), the clay minerals (kaolinite and dickite), and local pyrophyllite and diaspore. Tourmaline-quartz ledges in one area are an unusual feature that seems to be related to high-sulfidation activity (Fig. 3). Hudson (2003) described zoning of high-sulfidation assemblages around relatively narrow quartz-alunite ledges and clay-altered faults (some of which are shown on Fig. 3) that occur in more widespread zones of clay alteration.

Our new $^{40}Ar/^{39}Ar$ ages on alunite in the area indicate that high-sulfidation alteration between the Occidental and Comstock Lode, and in the footwall of the Comstock Lode between exposures of Davidson Diorite and the Jumbo district, occurred between 15.3 and 15.5 Ma (Fig. 4; Table 1). Alunite in the north part of the Comstock district may fall into this age range (15.3–15.5 Ma) or it may be younger because it gave ages of 14.72±0.64 Ma or 15.50±0.40 Ma, depending on the method of age calculation (Table 1). For comparison, a single $^{40}Ar/^{39}Ar$ age of 13.5 Ma was obtained on alunite from a large area of high-sulfidation alteration in the Geiger Grade area to the north of Virginia City. More dating is needed to resolve the age range of what are apparently several periods of high-sulfidation alteration in the area.

Four areas of low-sulfidation mineralization occur in the Virginia City area: 1) the highly productive Comstock and Silver City Lodes; 2) the Occidental Lode; 3) Flowery district deposits; and 4) Jumbo district veins. The first three are typified by quartz + adularia + calcite veins containing electrum, silver sulfides, and local base metal sulfides (Vikre, 1989; Hudson, 2003). Ore minerals have not been identified in the Jumbo veins. Becker (1882) and Coats (1940) defined and described propylitic alteration in the area. Hudson (2003) defined three types of propylitic alteration in the Virginia City area with distributions that indicate an association with low-sulfidation mineralization, as well as associated illitic and sericitic alteration. The Jumbo district veins contain very little adularia, but altered adjacent country rock contains abundant adularia.

Our $^{40}Ar/^{39}Ar$ ages define three distinct episodes of low-sulfidation mineralization in the Virginia City area. Adularia from a single sample in the Jumbo district yielded an age of about 15.5 Ma, which is indistinguishable from the age of nearby high-sulfidation mineralization (Table 1; Fig. 4). Adularia from the Comstock and Silver City Lodes gave tightly clustered ages of 14.1 to 14.2 Ma (Table 1). Adularia from the Occidental Lode and the Flowery district gave ages of 13.3 to 13.5 Ma (Table 1), showing that mineralization in those areas was later than the Comstock-Silver City mineralization.

Sericitized biotite from an altered area west of the Jumbo district has given an age that is distinctly older than the alteration and mineralization ages discussed above. Originally, this was considered as a possible age for Jumbo vein mineralization (Castor et al., 2002); however, it is clearly too old based on the age of Jumbo adularia. The sericite age suggests a hydrothermal episode coeval with Silver City magmatism; however, the distribution of this alteration, which seems to occur only in the Oligocene to early Miocene ash-flow tuffs, is not well known.

## DISCUSSION

Miocene structural history is intertwined with magmatic and hydrothermal history in the Virginia City area. Early high-sulfidation alteration in the area (Mount Bullion-Jumbo and

Comstock, Fig. 1) formed during the Virginia City magmatic episode, probably during or shortly after stratovolcano development. The pattern of such alteration suggests association with intrusion of the Davidson diorite. Cross-cutting relationships indicate that some diorite emplacement postdated the high-sulfidation alteration (Hudson, 2003), but this does not contradict the Davidson high-sulfidation association. Some high-sulfidation alteration types in the Virginia City area are known to be relatively shallow on the basis of subsurface sampling (Hudson, 2003), which suggests genesis in the steam-heated environment which produces relatively thin alteration blankets on some active Cascade volcanoes (Rytuba et al., 2003). However, pyrophyllite, diaspore, and tourmaline occurrences indicate a magmatic hydrothermal component for Virginia City high-sulfidation alteration, as do alunite sulfur isotope data (Rye et al., 1992; Vikre, 1998). Shallow magmatic-hydrothermal alteration is associated with the Pliocene andesite-dacite Maidu stratocone in the Lassen Peak area (John et al., 2005, this volume) and high-sulfidation alteration is associated with porphyry mineralization in the Cascade Range (Ashley et al., 2003). The age of low-sulfidation mineralization in the Jumbo area is not distinguishable from that of the Mount Bullion-Jumbo high-sulfidation alteration.

Our new adularia ages indicate that formation of the Comstock and Silver City Lodes followed eruption of the Virginia City volcanics and intrusion of the Davidson diorite by more than a million years. Thus, formation of the important Comstock ore was not related to that magmatic episode, in contrast to a connection proposed by Criss and Champion (1991). The new adularia ages also indicate that displacement along structures that were to become the Comstock and Silver City Lodes took place at or before 14.1 Ma; however, some displacement clearly postdated mineralization (Hudson, 2003; Gianella; 1936). Displacement along the Occidental Lode and along structures in the Flowery district took place at or before 13.3 Ma; although there is also evidence for post-mineralization displacement along these structures.

Based on our data, neither the Comstock-Silver City nor the Occidental-Flowery mineralization episodes are clearly related to a particular episode of magmatic activity. However, the Comstock-Silver City mineralization episode was contemporaneous with the youngest part of the Flowery Peak magmatism, and thus the mineralization may have been associated with late-stage magmatism during that episode. Vikre (1989) suggested that Comstock, Silver City and Occidental Lode mineralization was coeval and related to 13–14 Ma "Kate Peak" intrusive activity in the area. This is essentially correct within the constraints of his K-Ar ages, but the Occidental mineralization is younger than the Comstock-Silver City episode on the basis of more accurate $^{40}Ar/^{39}Ar$ ages. No potential magmatic association for the Occidental-Flowery mineralization has been determined; however, it is interesting that our Geiger Grade alunite age (which could date synchronous magmatism) is indistinguishable from the Occidental-Flowery adularia ages. Dike rocks in the Flowery district, which are locally altered, have not been dated.

We have no answer as yet to the question, "Why were the Comstock Lode silver-gold deposits, which contained some of the most productive bonanza ore in the United States, emplaced where they were, and why were they so rich?"

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