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Potential for Alkaline Igneous Rock-Related Gold Deposits in the Colorado Plateau Laccolithic Centers

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ABSTRACT

Several types of productive gold deposits in the Rocky Mountains, ranging in age from 79 Ma to 26 Ma, show a close spatial, temporal, and genetic association with alkaline igneous rocks. Deposit types range from porphyry copper–precious metal systems characterized by Cu>Ag>Au or platinum-group elements, through transitional types, to epithermal precious-metal-only deposits commonly characterized by Au>Ag. The alkaline rocks associated with these deposits represent mantle melts which fractionated in crustal-level magma chambers. Coeval calc-alkaline igneous rocks formed by crustal melting and magma mixing occur with the alkaline rocks at many localities.

The igneous rocks of the Colorado Plateau laccolithic centers fall into two age groups: early Laramide (≈72–70 Ma) and middle Tertiary (33–23 Ma). Calc-alkaline diorite porphyries are the most voluminous igneous rocks in these centers. Essentially coeval alkaline syenite porphyries occur at Mount Pennell in the Henry Mountains, the North and Middle Mountain centers in the La Sal Mountains, and the Navajo Mountain center. Small volumes of late-stage peralkaline granite and rhyolite are also present at the Mount Pennell and North Mountain centers. The rock chemistry and alteration-mineralization assemblages of the Colorado Plateau laccolithic centers were compared to those of productive Rocky Mountain alkaline rock-related gold deposits. This comparison suggests a modest potential for discovery of gold deposits at several Colorado Plateau localities.

INTRODUCTION

A significant part of the gold production and reserves from Laramide and younger ore deposits in the Rocky Mountains comes from hypogene deposits associated with alkaline igneous rocks (table 1, fig. 1; Mutschler and others, 1990). In this report we compare the major-element chemistry of these productive alkaline rock suites with chemical data from the igneous rocks exposed in the laccolithic centers of the Colorado Plateau. The comparison suggests a possibility for discovery of alkaline rock-related gold deposits at several Colorado Plateau laccolithic centers, including the Henry and La Sal Mountains and Navajo Mountain, all in Utah.

Alkaline igneous rocks have been defined in many ways, and confusing nomenclature schemes based largely on variations in modal mineralogy abound. In this paper we use whole-rock major-element oxide analyses to define alkaline rocks as those igneous rocks that either (1) have weight percent Na_2O+K_2O>0.3718 (weight percent SiO_2) –14.5; or (2) have mol Na_2O + mol K_2O > mol Al_2O_3. Criterion 1 is from Macdonald and Katsura's (1964) alkalis versus silica plot for separating alkaline from subalkaline basalts (fig. 2). Criterion 2 defines peralkaline rocks in the sense of Shand (1951). Criteria 1 and 2 are independent; that is, peralkaline rocks as defined by criterion 2 need not satisfy criterion 1. Note that silica saturation (the presence or absence of either modal or normative feldspathoids) is *not* a criterion for alkaline rocks as used here. Alkaline rocks range in composition from relatively primitive kimberlites, lamproites, lamprophyres, and alkali basalts to highly evolved felsic syenites, phonolites, and peralkaline granites, rhyolites, and trachytes.

The worldwide association of a variety of types of gold deposits with alkaline igneous rocks (Mutschler and Mooney, 1993) suggests a genetic relationship. Various possibilities have been suggested to explain the relationship:

1. Parental alkaline magmas may be generated by partial mantle melting at sites where deeply penetrating fault systems extend through the crust (Cameron, 1990).

2. Gold may be transported from the deep mantle by mafic alkaline magmas (Rock and others, 1989).

3. The generally high volatile content of alkaline magmas (Bailey and Hampton, 1990; Webster and others, 1992) could provide ligands for gold acquisition, transport, and deposition (Cameron and Hattori, 1987; Mutschler and Mooney, 1993).

ACKNOWLEDGMENTS

Many colleagues in academia, industry, and government have helped us to compile data on the alkaline igneous rocks of the Cordillera and their associated mineral deposits. For providing us with unpublished material we especially thank James E. Elliott, Fess Foster, Bruce A. Geller, Stephen R. Mattox, Thomas C. Mooney, and Peter D. Rowley. Constructive reviews by Thomas Frost and Steve Ludington helped to clarify both our ideas and our expression.

ALKALINE ROCK-RELATED GOLD DEPOSITS OF THE ROCKY MOUNTAINS

Laramide and younger alkaline rock-related gold deposits in the Rocky Mountains are listed in table 1, and some typical ore-related rock assemblages are plotted on total alkali-silica (TAS) variation diagrams in figure 3. Many of these assemblages include relatively primitive mafic alkaline rocks together with highly evolved or fractionated rocks. This combination suggests that crustal level parking (perhaps at neutral buoyancy levels) and fractionation have been important processes in the evolution of these suites. Coeval calc-alkaline rocks are common at many Rocky Mountain alkaline rock localities (fig. 3*E–H*) and are predominant at some of them. In many cases the calc-alkaline magmas probably resulted from partial crustal melting by heat and volatiles from mantle-derived alkaline magmas that either ponded in or underplated the crust. In these situations mixing of calc-alkaline and alkaline magmas can produce a variety of hybrid magmas as at the Rosita–Silver Cliff volcanic centers, Colorado (fig. 3*H*).

Precious metal-bearing deposits associated with Rocky Mountain alkaline igneous centers can be divided into three

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Table 1. Laramide and younger alkaline igneous rock-related gold deposits of the Rocky Mountains.

Locality	Igneous rocks	Age in Ma (method)[1]	Ore deposits	References[2]
Boulder County telluride camps (Eldora, Gold Hill, Jamestown, Magnolia, Sugarloaf, Sunset, Ward), Colorado	Alkaline to transitional sodic-syenite, quartz syenite, and bostonite stocks; bostonite and lamprophyre dikes. Coeval calc-alkaline plutons also present. An older (~74–60 Ma) alkaline and calc-alkaline suite of plutons is also present.	55 and 45 ($^{40}Ar/^{39}Ar$, FT)	Pyritic Au vein deposits. Au-Ag telluride vein and breccia deposits. Fluorspar-Ag-Pb vein and breccia deposits. Polymetallic Ag (Pb, Zn, Cu, Au) vein deposits. Epithermal W (wolframite) vein deposits. Stockwork Mo mineralization in quartz syenite stock. Production 1859–1990: Au, ~34,200 kg; +Ag, Cu, Pb, W, Zn.	Davis and Streufert (1990); Gable (1984) C; Jenkins (1979) C; Kane and others (1988) A; Kelly and Goddard (1969); F. E. Mutschler (unpub. data, 1990) C; Nash and Cunningham (1973); Phair and Jenkins (1975) C; Saunders (1991); Walter and Geller (1992) A.
Central City–Idaho Springs, Colorado	Alkaline to transitional sodic-syenite, quartz syenite, and bostonite stocks; bostonite dikes and breccia-pipes. Coeval calc-alkaline plutons also present.	65–58 (K-Ar, Rb-Sr)	Zoned district with central pyritic Au vein and breccia-pipe deposits and peripheral polymetallic vein deposits, both of which are probably related to calc-alkaline plutons. Late Au-Ag telluride-quartz-fluorite vein and breccia-pipe deposits, U vein deposits, and Mo breccia-pipe deposits related to alkaline plutons. District production 1859–1987: Au, ~171,070 kg; Ag, >2,278,000 kg; +Cu, Pb, Zn, U, W. Production from deposits directly related to alkaline rocks 1859–1984: Au, ~3,110 kg; +Ag, Pb, W.	Bastin and Hill (1917) C; Budge and Romberger (1983); Davis and Streufert (1990); Dickin and others (1986); F. E. Mutschler (unpub. data, 1990) C; Phair (1952) C; Phair and Jenkins (1975) C; Rice and others (1985) C; Rice and others (1982) A; Spurr and Garrey (1908) C; Wallace (1989).
Cripple Creek, Colorado	Large volcanic vent-diatreme subsidence basin complex includes alkaline phonolite, latite-phonolite, trachyphonolite, trachydolerite, trachyte, and syenite plutons, dikes, breccia pipes, and volcanic ejecta. Lamprophyre and foidal basalt dikes and breccia pipes common.	35–29 (K-Ar)	High-grade Au (Ag) telluride epithermal vein, stockwork, breccia-pipe, and disseminated deposits. Low-grade native Au (on pyrite) disseminated deposits. Production 1891–1990: Au, 653,175 kg; Ag, >7,300 kg. Reserves 1990: Au, >9,500 kg.	Cross (1895) C; Davis and Streufert (1990); Eriksson (1987); Fears and others (1986); Koschmann (1949); Lindgren and Ransome (1906) C; Loughlin (1927) C; Loughlin and Koschmann (1935); Marvin and others (1974) A; F. E. Mutschler (unpub. data, 1990) C; Mutschler and others (1985); Nelson (1989, 1990); Pontius (1991); Saunders (1988); Thompson and others (1985).
La Plata Mountains, Colorado	Early calc-alkaline to transitional diorite-monzonite porphyry sills, laccoliths, dikes, and stocks. Younger alkaline stocks include syenite (2), monzonite (1), and diorite (2). Lamprophyre and trachyte dikes, some of which are pre-mineralization, are the youngest igneous rocks.	70–67 (K-Ar, FT)	Porphyry Cu (Ag, PGE, Au) deposit in syenite stock. Au-Cu skarn and contact breccia deposits. Pyritic Au vein and replacement deposits. Ag-Au bearing polymetallic vein and replacement deposits. Au-Ag telluride vein and replacement deposits. Ruby silver vein deposits. Production 1878–1990: Au, ~6,850 kg; Ag, ~63,360 kg; +Cu, Pb, Zn. Reserves 1990: Au, ~6,875 kg; Ag, >170,000 kg.	Armstrong (1969) A; Cross and others (1899) C; Cunningham and others (1977) A; Eckel and others (1949); Lux (1977) C; McDowell (1971) A; Mutschler and others (1985); Saunders and May (1986); Werle and others (1984) C.
Rosita, Colorado	Volcanic-plutonic caldera system, includes alkaline syenogabbro diorite, monzonite, and trachyte plutons; lamprophyre dikes. Coeval high-silica rhyolites and other calc-alkaline volcanics and intrusions. Adjacent coeval Silver Cliff caldera system exposes high-silica rhyolites and intermediate calc-alkaline volcanics and intrusions.	33–27 (K-Ar, FT)	Au-Ag telluride-base metal sulfide and sulfosalt breccia-pipe deposit. Ag-Au bearing polymetallic vein deposits. Extensive acid-sulfate (alunite) alteration. REE-bearing apatite-magnetite veins and breccia-pipe deposits. Production 1872–1959: Au, ~3,110 kg; +Ag, Cu, Pb, Zn.	Cross (1896) C; Emmons (1896); Hildebrand and Conklin (1974); Kleinkopf and others (1979); McEwan (1986); F. E. Mutschler (unpub. data, 1990) C; Phair and Jenkins (1975) C; Sharp (1978) A; Sharp and Naeser (1986) A.
Caribou Mountain (Mount Pisgah), Idaho	Alkaline shonkinite-diorite subvolcanic plutonic complex.	52–50 (K-Ar)	Porphyry, skarn, and vein Cu (Au, Ag) deposits. Production 1870s–1959: Au, ≤1,860 kg; +Ag, Cu.	Anderson and Kirkham (1931); Hamilton (1961); Huntsman (1984, 1988) A.

Table 1. Laramide and younger alkaline igneous rock-related gold deposits of the Rocky Mountains—Continued.

Locality	Igneous rocks	Age in Ma (method)[1]	Ore deposits	References[2]
Goose Lake stock, Cooke City, Montana	Alkaline syenite-monzonite composite stock.	~76 (K-Ar)	Porphyry and pegmatitic Cu (Ag, PGE, Au) sulfide deposits. Major productive precious metal deposits of Cooke City district are related to younger (~40 Ma) felsic plutons and intrusive breccias.	Cordalis (1984); Elliott (1974, 1979) A; J. E. Elliott (unpub. data, 1983) C; Holt (1961); Lovering (1930); F. E. Mutschler (unpub. data, 1983) C; Mutschler and others (1985); Simons and others (1979); Size (1967).
Judith Mountains (Warm Spring, Maiden, Gilt Edge), Montana	Older calc-alkaline plutonic suite (69–67 Ma) includes quartz monzonite, monzonite, diorite, and rhyolite. Younger alkaline plutonic suite (65–62 Ma) includes syenite (with cumulate alkali gabbro and Cu-bearing sulfide inclusions), tinguaite (with cumulate ijolite inclusions), and peralkaline granite.	69–62 (K-Ar)	Au-Ag telluride and native gold vein, limestone replacement, and breccia deposits. Ag-Au bearing polymetallic vein deposits. Disseminated sulfide and skarn Au mineralization at Linster dome. Intense K-metasomatism, disseminated pyrite, and calcite-fluorite-quartz-sulfide-barite-aegirine-scapolite veining in Red Mountain area suggests possible buried carbonatite or alkaline rock-related porphyry metals system. Production 1880–1987: Au, 10,420 kg; Ag, 9,860 kg; +Cu, Pb. Reserves 1988: Au, >750 kg; Ag, 5,445 kg.	Giles (1983); Goddard (1988); Hall (1976) C; Kirchner (1982) A, C; Kohrt (1991); Lindsey and Fisher (1985); Marvin and others (1980) A; F. E. Mutschler (unpub. data, 1990) C; Priesmeyer (1986); Wallace (1953) C; Weed and Pirsson (1898) C; Zhang and Spry (1991).
Little Belt Mountains (Neihart), Montana	Alkaline shonkinite, syenite, monzonite plutons; lamprophyre dikes. Coeval calc-alkaline plutons include high-silica granites and rhyolites.	59; 55–46 (K-Ar)	Ag-Au bearing polymetallic vein and replacement deposits. Au skarn deposit. Fe skarn deposits. Au-Ag telluride vein and breccia mineralization. Gem sapphire deposits in hybrid mafic alkaline lamprophyre dike. Ag (Au) stockwork and disseminated deposit in rhyolite breccia-pipe. Stockwork Mo deposit in high-silica granite-rhyolite intrusive complex. Production 1881–1984: Au, ~2,085 kg; Ag, >9,420 kg; +Cu, Pb, Zn, gemstones.	Armstrong and others (1982) A; Baker and others (1991); Brownlow and Komorowski (1988); Clabaugh (1952) C; Dahy (1991); Embry (1987) C; Marvin and others (1973) A; Meyer and Mitchell (1988); Olmore (1991); Pirsson (1900) C; Rupp (1980) C; Schutz and others (1988); Walker (1991); Witkind (1970, 1973) C; Woodward (1991).
Little Rocky Mountains (Zortman-Landusky), Montana	Alkaline and transitional syenite plutons and trachyte dikes. Coeval calc-alkaline monzonite, quartz monzonite, and granite(?) plutons.	67–60 (K-Ar)	Au-Ag electrum and telluride stockwork, breccia, and vein deposits. Production 1884–1989: Au, 35,520 kg; Ag, >76,000 kg. Reserves 1990: Au, 23,850 kg; Ag, 267,500 kg.	Hastings (1988); Lindsey and Fisher (1985); Marvin and others (1980) A; F. E. Mutschler (unpub. data, 1990) C; Roemmel (1982) C; Russell (1991) C; Russell and Gabelman (1991); Ryzak (1990); Weed and Pirsson (1896) C; White and Lawless (1989); Wilson and Kyser (1988, 1989) C.
Moccasin Mountains (Kendall), Montana	Alkaline to transitional syenite, trachyte plutons and intrusion breccias. Coeval calc-alkaline rocks include rhyolite plutons and intrusion breccias.	66–64; 53 (K-Ar, FT)	Au-Ag telluride and electrum stratabound (limestone karst breccia) and intrusion breccia deposits. Production 1893–1987: Au, 14,000 kg; Ag, ~6,221 kg. Reserves 1989: Au, 6,800 kg.	Blixt (1933) C; Garverich (1991); Kurisoo (1991); Lindsey (1982, 1985) A, C; Lindsey and Fisher (1985); Lindsey and Naeser (1985) A; Marvin and others (1980) A; F. E. Mutschler (unpub. data, 1990) C.
Whitehall (Golden Sunlight), Montana	Calc-alkaline(?) latite sills; alkaline trachybasalt hypabyssal plutons. Post-mineralization lamprophyre dikes.	≥79 (K-Ar)	Epithermal stockwork and disseminated Au-Ag electrum and telluride deposit with Fe, Cu, Pb, Zn, Mo, As sulfides, etc., in hydrothermal breccia-pipe. Zones downward to porphyry-style Cu-Mo (Ag, Au) mineralization. Production 1890–1987: Au, 17,511 kg; Ag, 8,616 kg; +Cu, Pb, Zn. Reserves 1988: Au, 77,760 kg; Ag, ~77,760 kg.	Fess Foster, Golden Sunlight Mines, Inc. (written commun., 1991) A, C; Foster and Chadwick (1990); Porter and Ripley (1985).

Table 1. Laramide and younger alkaline igneous rock-related gold deposits of the Rocky Mountains—Continued.

Locality	Igneous rocks	Age in Ma (method)[1]	Ore deposits	References[2]
Cerrillos, New Mexico	Alkaline monzonite, syenite, diorite plutons; lamprophyre dikes. Coeval(?) latite-trachybasalt volcanics.	Oligocene >27 (K-Ar)	Cu (Ag, Au) porphyry system. Ag-Au bearing polymetallic vein deposits. Turquoise deposits. Production 1902–1956: Au, 43 kg; Ag, 3,890 kg; +Cu, Pb, Zn, gemstones.	Akright (1979); Aldrich and others (1986) A; Clarke (1915) C; Disbrow and Stoll (1957); Giles (1991); North and McLemore (1988); Sun and Baldwin (1958) C; Wargo (1964).
Jicarilla Mountains, New Mexico	Alkaline syenogabbro, monzonite, and syenite plutons.	38 (K-Ar)	Au-Ag disseminated and vein mineralization in altered syenite and syenogabbro plutons. Fe skarn mineralization. Production 1905–1968: Au, ~260 kg; +Ag. Reserves 1985: large but low-grade Au-Ag resource.	Allen and Foord (1991) A, C; North and McLemore (1988); Segerstrom and Ryberg (1974) A, C; Segerstrom and others (1979).
Nogal (Sierra Blanca), New Mexico	Two pulses of alkaline magmatism. Older (~37 Ma) event includes trachybasalt to trachyphonolite flows; essexite and nepheline syenite plutons. Younger (30–27 Ma) event includes trachyte, quartz trachyte, and rhyodacite volcanics; syeno-diorite, peralkaline syenite, and peralkaline granite plutons.	~37; 30–27 (K-Ar)	Au-Ag-Cu breccia-hosted deposits. Polymetallic vein mineralization. Stockwork Mo-Cu mineralization. Production 1902–1953: Au, ~470 kg; Ag, ~620 kg; +Cu. Reserves 1991: Au, ~3,300 kg; +Ag.	Allen and Foord (1991) A, C; Allen and McLemore (1991) C; Black (1977) C; Cepeda (1990); Fulp and Woodward (1991); Giles and Thompson (1972) A, C; North and McLemore (1988); Thompson (1968; 1972 A, C; 1991).
Ortiz (Old Placers), New Mexico	Older (~34 Ma) calc-alkaline suite includes latite-andesite and gra-nodiorite plutons. Younger (30–26 Ma) alkaline suite includes nepheline monzonite plutons, latite plutons and dike swarms, and a diatreme vent breccia.	~34; 30–26 (K-Ar)	Cu-Ag skarn deposit. Au-Ag (Cu, W) breccia-pipe deposit. Porphyry Cu (Au, Ag) deposit. Au-Ag polymetallic vein deposits. Production 1833–1987: Au, ~10,890 kg; +Ag, Cu, Pb, W, Zn. Reserves 1990: Au, 18,560 kg; +Ag, Cu.	Kay (1986) C; Maynard and others (1990) A; Maynard and others (1991) A; Ogilvie (1908) C; Wright (1983).
San Pedro (New Placers), New Mexico	Alkaline–calc-alkaline syenite, monzonite plutons.	Oligocene	Au-Cu-W skarn deposit. Ag-Pb-Zn limestone replacement deposit. Production 1909–1938: Au, 3,640 kg; Ag, 9,490 kg; +Cu, W, Zn.	Atkinson (1961); Elston (1967); Lindgren and others (1910); North and McLemore (1988).
White Oaks, New Mexico	Large breccia-pipe complex intruded by alkaline syenogabbro to syenite plutons and lamprophyre plugs and dikes.	34 (K-Ar)	Au-Ag (W) vein, stockwork, and breccia-hosted epithermal deposits. Production 1879–1984: Au, 5,070 kg; +Ag, Cu, W.	Allen and Foord (1991); Griswold (1959); Lindgren and others (1910); North and McLemore (1988); Ronkos (1991) A.
Northern Black Hills, South Dakota	Alkaline, peralkaline, and calc-alkaline plutons include nephe-line syenite, syenite, peralkaline syenite, phonolite, tinguaite, trachyte, monzonite, quartz monzonite, peralkaline rhyolite, rhyolite, and lamprophyres.	~60–53 (K-Ar)	Au-Ag (Pb-W) vein, stockwork, replace-ment, breccia-pipe, and disseminated deposits in intrusions and sedimentary rocks. Production 1875–1989: Au, ~87,090 kg; +Ag, Cu, Pb, W, Zn. Reserves: 1989: Au, 121,200 kg.	DeWitt and others (1986); Grun-wald (1970) C; Irving (1899) C; Kirchener (1971) C; Larsen (1977) C; Loomis and Alexander (1990); Noble (1948) C; Norton (1989); Paterson (1990); Paterson and others (1989); Pirsson (1894) C; Sharwood (1911) C; Shearer (1990).

[1] FT in age method indicates fission track age.
[2] A or C following date indicates that reference contains age date (A), or major-element chemical analyses (C).

types, or deposit models. Attributes of the two end-member models are summarized in table 2. The third, transitional, model can show features of both end-member models.

Porphyry copper–precious metal deposits.—These occur in or adjacent to shoshonitic syenite stocks and are characterized by precious metals contained in copper sulfides occurring in stockworks, disseminations, veins, pegmatite dikes and segregations, endoskarns, exoskarns, and local immiscible sulfide concentrations; by relatively high sulfur abundance; and by Cu>Ag>Au or PGE (platinum-group elements). Examples include the Allard stock, La Plata Mountains, Colo. (Werle and others, 1984); the Goose Lake stock, Cooke City, Mont. (Elliott, 1972, 1974; Lovering, 1930); and the Cerrillos district, New Mexico

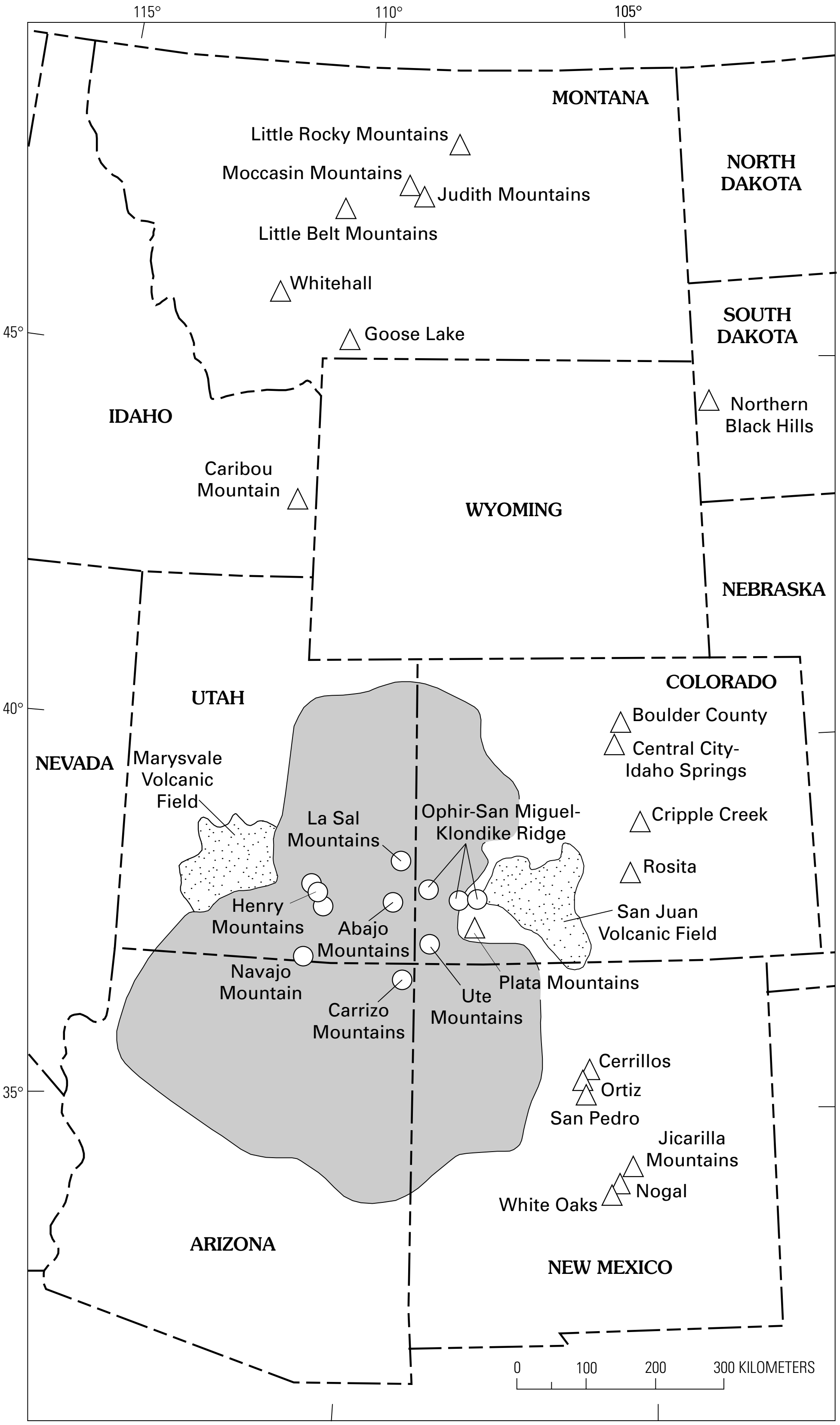

Figure 1. Rocky Mountain and Colorado Plateau localities discussed in text. Circles are Colorado Plateau laccolithic centers; triangles are Laramide and younger alkaline igneous rock-related gold deposits.

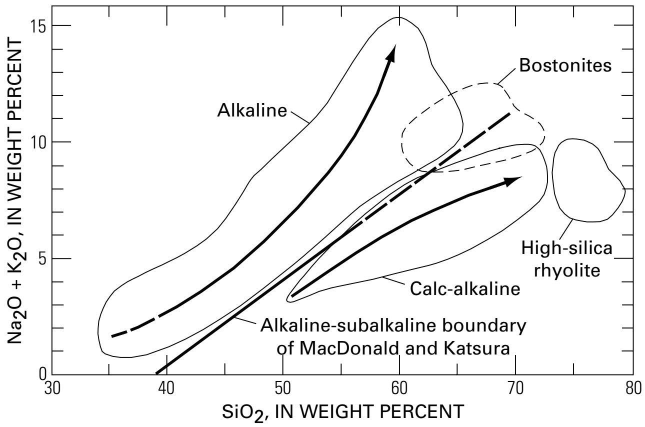

Figure 2. Total alkali-silica plot showing Macdonald and Katsura's (1964) boundary for separating alkaline and subalkaline rocks, and compositional fields for alkaline rocks related to precious metal deposits and selected other rock types. Arrows show generalized fractionation trends.

(Giles, 1991). In alkaline rock porphyry copper deposits, the precious metals constitute byproducts or coproducts of copper production. Deposits of this type in Mesozoic accreted terranes are being actively mined in British Columbia (McMillan, 1991; Schroeter and others, 1989).

Epithermal gold deposits.—These are generally associated with syenites, trachytes, phonolites, and lamprophyres, and they occur in a variety of settings including volcanic vent complexes, breccia pipes, hot-spring and geyser systems, bonanza veins, and replacements and disseminations in sedimentary and igneous rocks. They are characterized by Au (Ag)-telluride and native gold mineralization, relatively low sulfur abundance, and commonly by Au>Ag. Examples of bonanza epithermal vein deposits include the Cripple Creek district (Loughlin and Koschmann, 1935), the Boulder County telluride camps (Saunders, 1991), and the Bessie G mine in the La Plata Mountains (Saunders and May, 1986), all in Colorado.

Table 2. Attributes of alkaline rock-related precious-metal systems.

[PGE=platinum-group elements]

Attribute	Epithermal Au systems (example, Cripple Creek, Colorado)	Porphyry copper–precious metal systems (example, Allard stock, Colorado)
Recoverable metals	Au>Ag (precious metals usually sole products or major products).	Cu>Ag>PGE or Au (precious metals usually byproducts or coproducts).
Mineralization	Largely open-space vein filling	Disseminated, pegmatitic, vein, local immiscible sulfides, skarn.
Au-bearing species	Tellurides, native Au	Native Au (largely in sulfides)
Hydrothermal alteration	Vein envelope and/or pervasive	Pervasive.
Facies	Propylitic, K-metasomatism, carbonatic, redox (phyllic).	Propylitic, K-metasomatism, carbonatic, redox (phyllic, solfataric).
S (as S^{-2}) abundance ..	Relatively low	High.
Volatile-element concentrations:		
Te	Very high	Moderate.
Tl	High	Low.
Hg	Generally high	Low.
As, Sb	Generally high	Variable.
Ore stage fluids:		
Temperature	≤210 °C	~300–800 °C.
Salinity	Low (≥5 wt. % NaCl)	High.
CO_2 content	High	High (often saturated).
H_2O	Meteoric dominated	Magmatic dominated.
Pressure	1– >350 bars	~350–1000 bars.
Source of precious metals	Au from bisulfide and/or ditelluride complexes; carbonyl complexes(?).	Ag and PGE from chloride complexes; at least some Au late in sequence from bisulfide complexes(?).

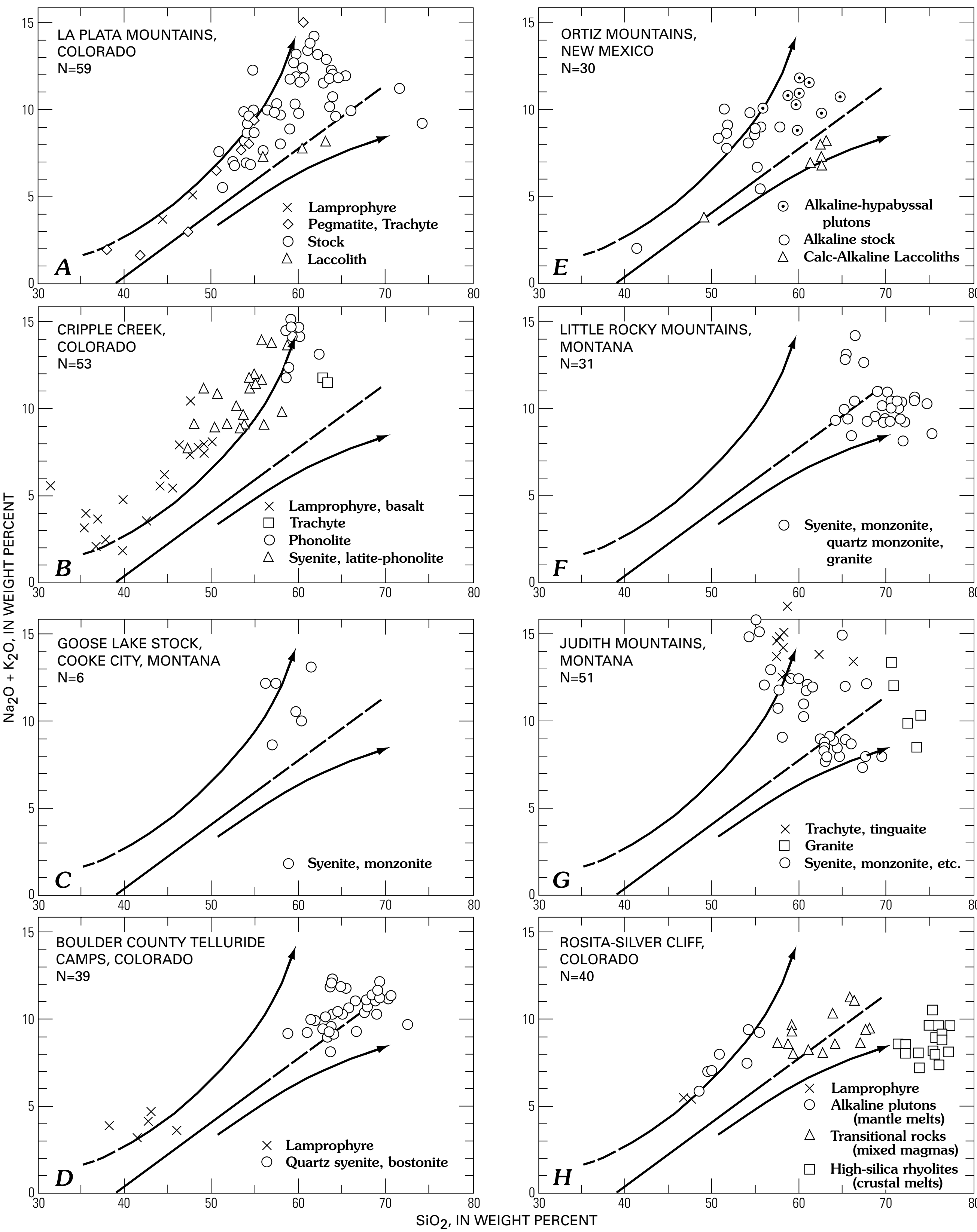

Figure 3. Total alkali-silica plots for selected alkaline rock suites related to gold deposits in the Rocky Mountains. Data from references listed in table 1. Boundary between alkaline and calc-alkaline rocks shown by inclined line. Curved arrows show generalized fractionation trends: upper arrow for ore-related alkaline rocks; lower arrow for calc-alkaline rocks. *N* indicates number of samples.

Noteworthy low-grade bulk-tonnage epithermal deposits include those of the Little Rocky (Russell, 1991), Moccasin (Kurisoo, 1991), and Judith (Giles, 1983) Mountains, Mont.

Transitional epithermal-mesothermal gold-silver deposits.—These include disseminated, breccia-pipe, skarn and vein Au-Ag (Cu, Pb, Zn, W) deposits related to syenite-monzonite-diorite plutons. The disseminated deposits range from Au-only porphyry to sedimentary-rock-hosted micron-size Au. Gold mineralization in the porphyry and skarn deposits typically appears to be late in the paragenetic sequence (post-base metal) and to be accompanied by retrograde alteration events. Examples include the Ortiz Mountains (Maynard and others, 1991), Jicarilla Mountains (Allen and Foord, 1991), and perhaps the White Oaks district (Ronkos, 1991), New Mexico; the Red Mountain area, Judith Mountains, Mont. (Hall, 1976); and some of the Tertiary districts in the northern Black Hills, S.Dak. (Paterson and others, 1988).

These three deposit models may represent a vertical (and perhaps short-term temporal) progression. All three types are associated with chemically similar alkaline rocks (see fig. 3) and show similar hydrothermal alteration assemblages (table 2). The ore fluids for both epithermal and porphyry copper–precious metal systems were CO_2-rich and relatively oxidized. Fluid inclusions in vein and rock minerals are CO_2-rich. Alteration assemblages, both pervasive ones and those found as envelopes around veins, feature carbonate minerals and hematite. Ore-stage gangue minerals commonly include carbonates and sulfates, and negative $\delta^{34}S$ values in sulfides are common. The two end-member deposit types differ, however, in Au, Ag, PGE, Cu, and S abundances, in volatile-element concentrations, and in ore-fluid pressure, temperature, and composition (table 2), suggesting that they were deposited from separate fluids. Cameron and Hattori (1987) proposed a scheme for the essentially simultaneous development of two chemically distinct fluids in an oxidized (high f_{O_2}), CO_2-rich magma chamber, which Mutschler and Mooney (1993) modified to explain the formation of epithermal "gold-only" deposits above and (or) peripheral to alkaline rock-related porphyry copper–precious metal systems. This model is shown diagrammatically in figure 4. A fractionated, oxidized, CO_2-saturated alkaline magma chamber exsolves a CO_2-rich, highly saline, metal-bearing aqueous fluid, which then unmixes into two immiscible phases: (1) a high-salinity fluid into which Cu, Fe, Ag, and PGE are partitioned as Cl complexes, which can form porphyry copper mineralization with high Ag and (or) PGE values; and (2) a low-salinity H_2O–CO_2 fluid into which Au (±As, Hg, Sb) is partitioned as S and (or) Te complexes which can form epithermal Au-dominated mineralization.

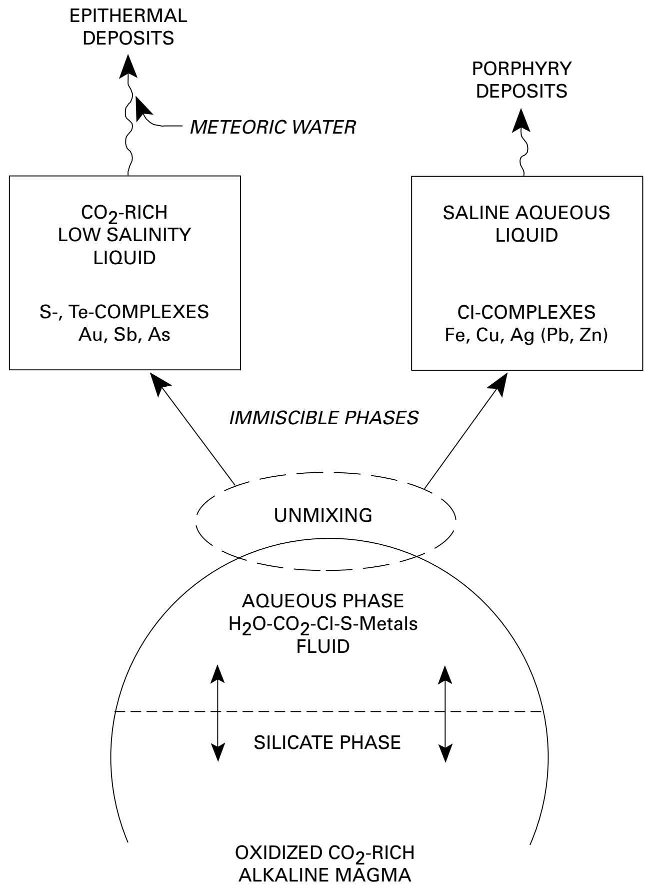

Figure 4. Schematic model for the evolution of two ore fluids from an oxidized CO_2-rich alkaline magma chamber. From Mutschler and Mooney (1993).

PROSPECTING GUIDES

A variety of gold-bearing deposits are associated with alkaline rocks; consequently various techniques may be useful in prospecting for different types of deposits (Mutschler and Mooney, 1993). Some useful indicators are as follows:

1. The source-host alkaline rocks for both porphyry and epithermal mineralization show evidence of significant crustal-level fractionation; thus chemically diverse suites of alkaline (eralization.

2. Both porphyry and epithermal deposits are accompanied by one or more of the following pervasive hydrothermal alteration assemblages (diagnostic characteristics in parentheses): K-metasomatism (whole-rock $K_2O>Na_2O$; hydrothermal K-feldspar and (or) biotite), carbonatic (whole-rock $CO_2>0.5$ weight percent; hydrothermal carbonate minerals; CO_2-rich fluid inclusions), redox (whole-rock $Fe_2O_3>1.5$ FeO; hydrothermal hematite), $\delta^{34}S$ evidence that sulfide S equilibrated with sulfate S, or sulfidization (hydrothermal pyritization and (or) sulfate minerals).

3. Concealed porphyry and skarn deposits, which have relatively high sulfide concentrations, may be recognized by induced polarization surveys.

Table 3. Colorado Plateau laccolithic centers.

Locality	Igneous rocks	Age in Ma (method)[1]	Mineralization and alteration	References[2]
Carrizo Mountains, Arizona	Calc-alkaline diorite porphyry laccoliths, sills, and dikes. Younger (Oligocene) minette plugs and dikes of Navajo volcanic field are also present.	~70 (K-Ar)	Near Pastora Peak, brecciated sandstone cemented by veinlets of quartz overlies fractured diorite porphyry containing sparse pyrite and rare chalcopyrite.	Armstrong (1969) A; Cross (1894) C; Lux (1977) C; O'Sullivan and Beikman (1963); Strobell (1956).
Ophir–San Miguel–Klondike Ridge, Colorado	West-trending belt of four stocks and many laccoliths, sills and dikes extends from Ophir on the west flank of the San Juan dome to Glade Mountain and Klondike Ridge. Calc-alkaline plutons range from microdiorite to porphyritic adamellite. Oil test wells have intersected buried sills of similar composition in the Paradox Member of the Hermosa Formation. A small andesite vent(?) crops out at Glade Mountain. Post-mineralization lamprophyre dikes occur in the Mount Wilson district.	33–26 (K-Ar)	Two types of productive fissure veins occur in the Iron Springs (Ophir or Ames) and Mount Wilson districts at the east end of the porphyry belt: (1) Gold veins—narrow high-grade pyrite-arsenopyrite-quartz (±chalcopyrite, carbonate, barite) veins. (2) Silver-base metal veins—galena-sphalerite-pyrite-chalcopyrite-tetrahedrite-quartz-carbonate-barite veins. Vein-envelope and pervasive alteration includes propylitic, quartz-sericite, and pyritic assemblages. Estimated total production since 1882: Au, 3,888 kg; Ag, 28,250 kg; Cu, Pb, Zn, W.	Bromfield (1967) C; Lipman and others (1976) A; McDowell (1971) A; Shawe and others (1968) C; Steenland (1962); Vogel (1960).
Sleeping Ute Mountain (or "Ute Mountains"), Colorado	Calc-alkaline diorite porphyry forms three stocks, three bysmaliths, and many laccoliths, sills, and dikes. Small dikes and sills of lamprophyre (spessartite) are younger than the diorite porphyry.	~72 (K-Ar, FT)	Minor shear-zone-controlled pyrite-chalcopyrite-quartz-carbonate barite veins occur in sandstone. A large part of the Marble Mountain bysmalith has been pyritized, sericitized, and propylitized; small showings of oxide copper minerals are present. Several small travertine-cemented breccia pipes are younger than the lamprophyres and may represent post-Laramide hot-spring activity.	Cross (1894) C; Cunningham and others (1977) A; Ekren and Houser (1965) C.
Abajo Mountains, Utah	Calc-alkaline diorite porphyry forms two stocks surrounded by shatter zones (which include intrusion breccias), many laccoliths, sills, and dikes. Two additional stocks may be present in the subsurface.	32–23 (FT, K-Ar)	Disseminated, stockwork, and vein Au-bearing pyrite-quartz-carbonate (±chalcopyrite, sphalerite, galena, ruby, silver?) deposits occur in shear zones in both stocks and at the margins of several laccoliths. Pervasive to shear-zone-controlled propylitic alteration occurs in both stocks and several laccoliths. Alkali metasomatism altered some East Mountain stock diorite porphyry to alkaline compositions. Minor, undocumented gold production from a few small lode mines and placers.	Armstrong (1969) A; Nelson and others (1992) A; Sullivan and others (1991) A; Witkind (1964) C.
Henry Mountains, Utah	Calc-alkaline to mildly alkaline diorite porphyry occurs in five distinct laccolithic centers at Mounts Ellen, Pennell, Hillers, Holmes, and Ellsworth. Each center consists of a central stock, in part surrounded by a zone of shattered indurated sedimentary rocks and diorite porphyry cut by irregular diorite porphyry intrusions; numerous bysmaliths, laccoliths, sills, and dikes. At the youngest center (Mount Pennell, ~25 Ma), the diorite porphyry stock is cut by a complex alkaline syenite porphyry stock, which in turn is intruded by small peralkaline granite porphyry plugs and dikes. The most primitive igneous rock recognized in the Henry Mountains is a basalt porphyry occurring in the shatter zone and as small sills at the Mount Ellen center.	31–23 ($^{40}Ar/^{39}Ar$, FT)	Vein and shear-zone-controlled stockwork and disseminated Cu-Au-Ag deposits have been prospected at all the central stocks and shatter zones. They are most extensively developed at the Mount Pennell and Mount Ellen centers. The hypogene vein assemblage includes pyrite, chalcopyrite, bornite, molybdenite, magnetite, hematite, quartz, and carbonates. Pervasive propylitic alteration occurs in many plutons; pervasive alkali metasomatism and pyritization have affected central stocks and shatter zones, some of which also show epidote-amphibole-garnet skarn development. Silicification is present in mineralized shear zones at the Mount Pennell center. Reported production since 1889 from Mount Ellen (Bromide Basin): Au, 21 kg; Ag, 93 kg; Cu, 8.2 Mg. Mount Pennell lode production since 1925: Au<1 kg. Small amounts of placer gold are reported to have been recovered from streams draining Mounts Ellen and Pennell.	Butler and others (1920); Cross (1894) C; Doelling (1980); Dubiel and others (1988a, b; 1990) A; Engel (1959) C; Hunt and others (1953) C; Hunt (1988) C; Kilinc (1979) C; Nelson (1991) C; Nelson and Davidson (1993) C; Nelson and others (1992) A; Sullivan and others (1991) A.

Table 3. Colorado Plateau laccolithic centers—Continued.

Locality	Igneous rocks	Age in Ma (method)[1]	Mineralization and alteration	References[2]
La Sal Mountains, Utah	Calc-alkaline to mildly alkaline diorite porphyry occurs in three laccolithic centers at North, Middle, and South Mountains. Each center has a central stock, several peripheral laccoliths and/or bysmaliths, and dikes and sills of diorite porphyry. At the North Mountain center the diorite porphyry is cut by a small stock and dikes of alkaline syenite porphyries. Emplacement of the syenites was accompanied by hydrothermal alteration and mineralization. A single syenite porphyry laccolith/sill is present at the Middle Mountain center. A group of explosion breccia pipes associated with small peralkaline granite and rhyolite porphyry plutons formed during or shortly after the emplacement of the alkaline syenite porphyries. Coeval peralkaline rhyolite and nosean trachyte porphyry dikes mark the final magmatic event at North Mountain.	28–25 ($^{40}Ar/^{39}Ar$, FT)	Fissure vein and fracture-zone-controlled stockwork and disseminated Cu-Au-Ag deposits have been prospected at all three centers. Alteration and mineralization are most extensively developed at North Mountain, where they accompanied emplacement of the syenite porphyries. Here pervasive and vein envelope alkali metasomatism, pyritization, carbonatic, and redox assemblages are widespread. Hypogene vein minerals include pyrite, chalcopyrite, bornite, hematite, quartz, carbonates, and fluorite. A second stage of carbonate, hematite, and silica alteration and minor sulfide mineralization accompanied formation of the explosion breccia pipes at North Mountain. Small ore shipments were made from several North Mountain mines, but production figures are not available. Traces of placer gold occur in pre-Wisconsin gravels derived from North and Middle Mountains.	Armstrong (1969) A; Butler and others (1920); Cross (1894) C; Hunt (1958) C; Irwin (1973) C; Nelson (1991) C; Nelson and others (1992) A; Stern and others (1965) A; Sullivan and others (1991) A
Navajo Mountain, Utah	Small alkaline quartz-bearing syenite porphyry intrusion exposed on southwest side of ~10-km-diameter dome probably uplifted by emplacement of buried pluton.	No data	Primary hematite in syenite indicates crystallization at high-Po_2 conditions. Most of the sedimentary rocks exposed on the top of the dome are highly silicified.	Condie (1964)

[1] FT = fission-track.
[2] A or C following date indicates that reference contains age date (A), or major-element chemical analyses (C).

4. Low-sulfide "invisible," or micron- (micrometer) size Au deposits may be recognized by geochemical anomalies in Au (>10 ppb) and some of the following: Ag, As, Bi, Ce, F, Hg, Sb, Se, Te, Tl, U, V, W, and high Ba and Sr in Ba:Sr:Rb ratios. Gold, commonly at levels in the parts-per-billion range, is the only universal geochemical guide to ore; concentrations and dispersion halos of other "pathfinder" elements can vary widely from deposit to deposit, even within a single district (Mutschler and others, 1985).

ALKALINE ROCKS AND MINERALIZATION IN THE COLORADO PLATEAU LACCOLITHIC CENTERS

Depending on how the borders of the Colorado Plateau are defined, laccolithic centers on the plateau can be enumerated differently. We have somewhat arbitrarily considered that the Laramide-age La Plata, Ouray, and Rico laccolithic centers in Colorado are Rocky Mountain features, whereas we have included the Laramide age Sleeping Ute Mountain (or "Ute Mountains"), Colo., and Carrizo Mountains, Ariz. as Colorado Plateau features. In a similar fashion, we have excluded the middle Tertiary West Elk Mountains, Colo., laccoliths from the Colorado Plateau.

Data on the lithology, form, age, and associated mineralization of the igneous rocks in the Colorado Plateau laccolithic centers (fig. 1) are summarized in table 3. Total alkali-silica (TAS) plots for those laccolithic centers for which whole-rock chemical analyses are available are shown in figure 5. Most of the igneous rocks fall into two groups:

1. Dominantly calc-alkaline intermediate (55–65 weight percent SiO_2) rocks, here collectively termed *diorite porphyry*. Different investigators have applied various names to these rocks, including diorite-monzonite porphyry, diorite porphyry, granodiorite, granodiorite porphyry, microgabbro, microgranogabbro, monzonite porphyry, plagioclase-hornblende porphyry, porphyritic adamellite, quartz diorite porphyry, and quartz monzonite porphyry. Diorite porphyry forms concordant plutons, including laccoliths and sills, and discordant stocks, dikes, and bysmaliths. It constitutes more than 90 percent of the igneous rocks exposed in the major laccolithic centers of the Colorado Plateau (Hunt, 1956; Hunt and others, 1953) and adjacent areas. On TAS plots most of the diorite porphyries fall within the compositional fields of the mid-Tertiary

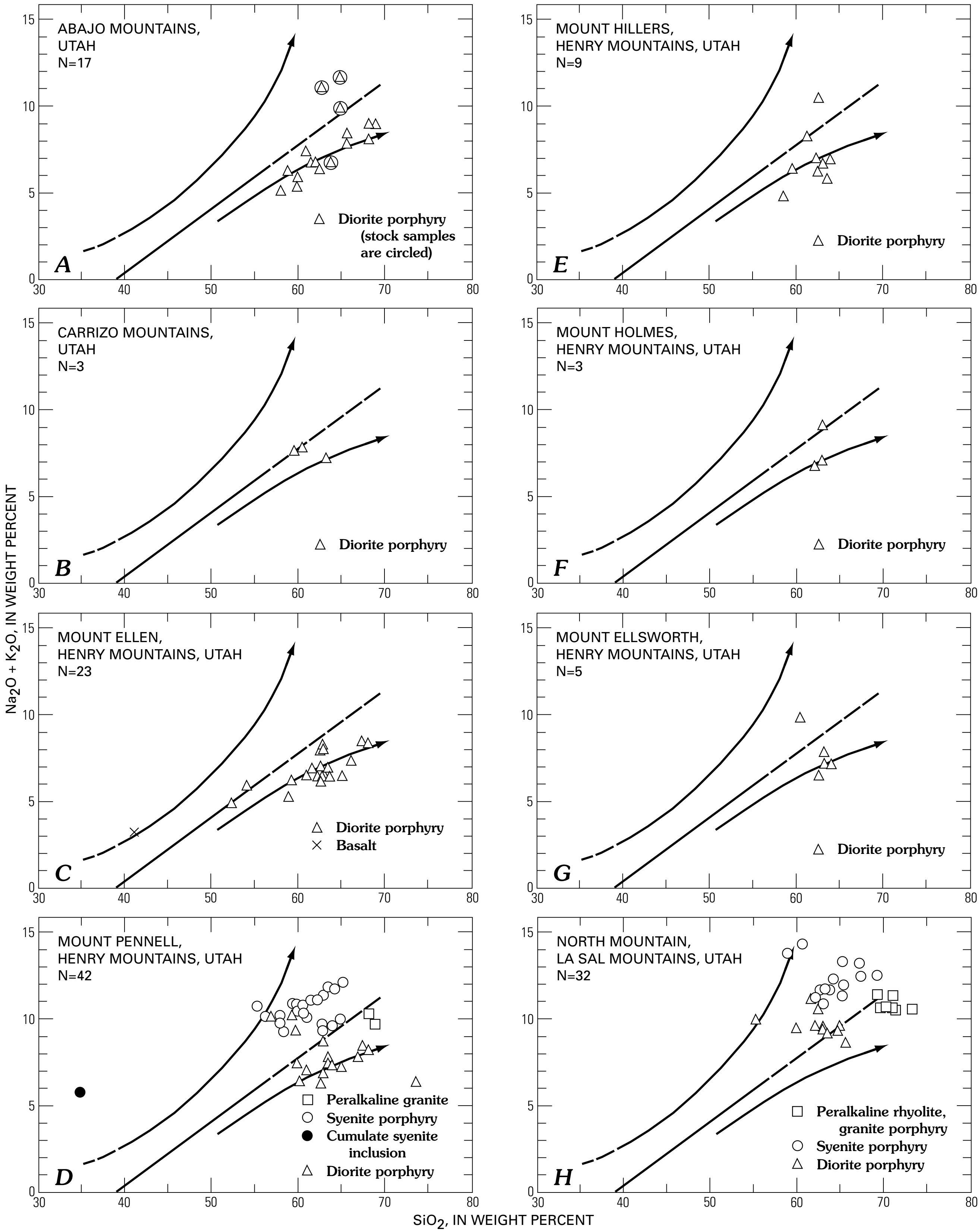

Figure 5 (above and facing page). Total alkali-silica plots for Colorado Plateau laccolithic centers. Data from references listed in table 3. Boundary between alkaline and calc-alkaline rocks shown by inclined line. Curved arrows show generalized fractionation trends: upper arrow for ore-related alkaline rocks; lower arrow for calc-alkaline rocks. *N*, number of samples.

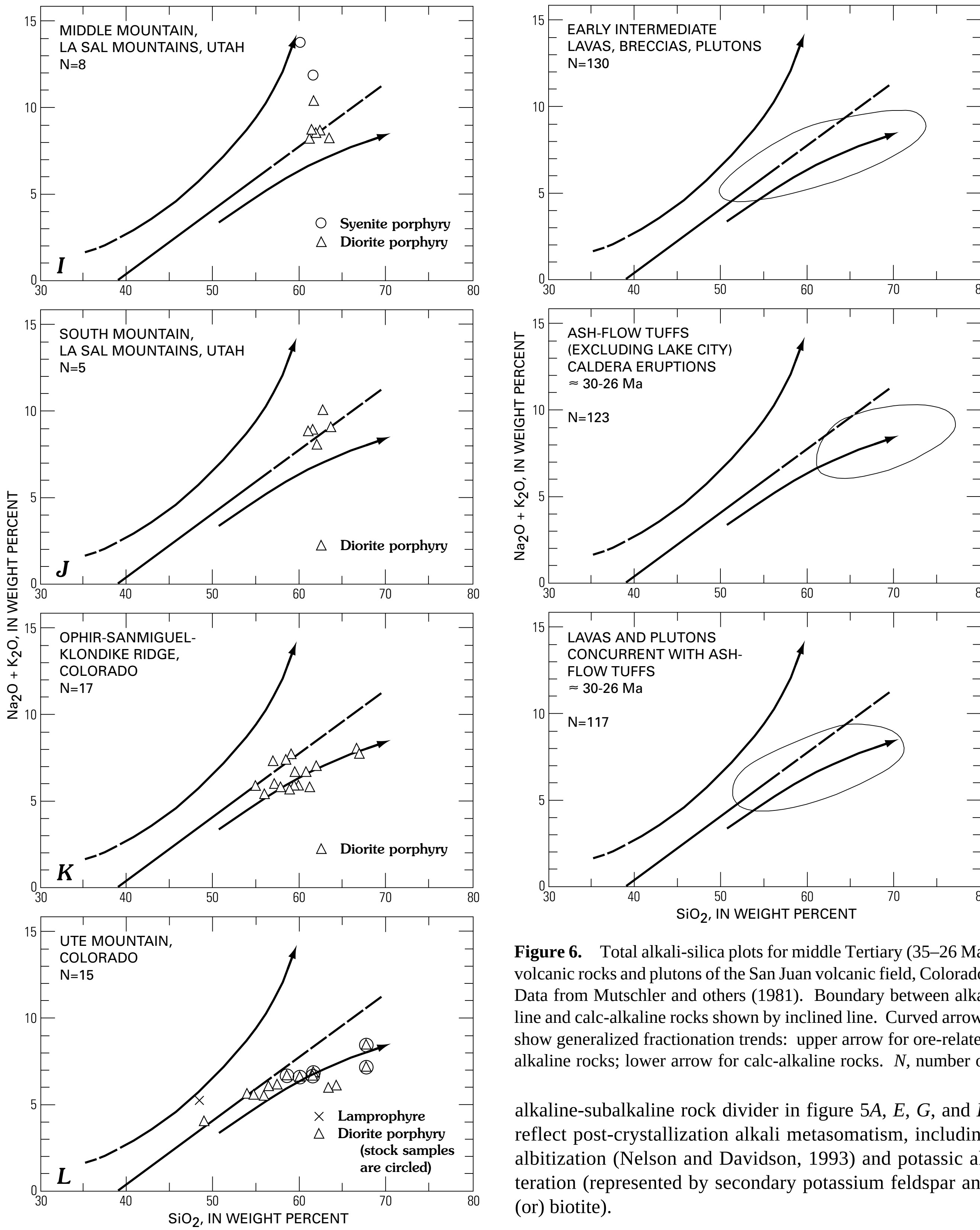

Figure 6. Total alkali-silica plots for middle Tertiary (35–26 Ma) volcanic rocks and plutons of the San Juan volcanic field, Colorado. Data from Mutschler and others (1981). Boundary between alkaline and calc-alkaline rocks shown by inclined line. Curved arrows show generalized fractionation trends: upper arrow for ore-related alkaline rocks; lower arrow for calc-alkaline rocks. *N*, number of

calc-alkaline volcanics and plutons of the San Juan volcanic field, Colorado, as shown in figure 6. Many of the diorite porphyry analyses that plot significantly above the alkaline-subalkaline rock divider in figure 5*A*, *E*, *G*, and *H* reflect post-crystallization alkali metasomatism, including albitization (Nelson and Davidson, 1993) and potassic alteration (represented by secondary potassium feldspar and (or) biotite).

2. Alkaline intermediate (55–65 weight percent SiO_2) rocks, here collectively termed *syenite porphyry*. These rocks occur at the Mount Pennell center in the Henry Mountains and at the North and Middle Mountain centers

in the La Sal Mountains, Utah, forming stocks, sills, irregular plutons, and dikes, all of which are younger than the diorite porphyry plutons. In addition to these well known localities, Condie (1964) has described a small quartz-bearing, highly oxidized, syenite porphyry pluton on the southwest flank of the Navajo Mountain dome, Utah. Both nepheline- and quartz-normative syenite porphyries are present in the La Sal and Henry Mountains. Although most of the La Sal syenite porphyries are peralkaline, none of the analyzed Henry Mountain syenite porphyries are. The syenite porphyries of the Henry and La Sal Mountains are chemically distinct from, and have no counterpart in, the voluminous coeval mid-Tertiary rocks of the San Juan volcanic field of southwestern Colorado, as shown by comparing the TAS plots of figure 5*D*, *H*, and *I* with figure 6. In fact, in both the San Juan, Colo. (Mutschler and others, 1987), and Marysvale, Utah (Mattox, 1992; Rowley and others, this volume), volcanic fields, alkaline magmatism is essentially restricted to bimodal (alkali basalt/trachybasalt-rhyolite) suites, which began to erupt during the onset of extensional faulting at ≈23 Ma.

Nelson and Davidson (1993) have presented isotopic evidence that both the diorite porphyry and syenite porphyry magmas of the Henry Mountains were derived from the same mantle source, but that they probably represent different degrees, or depths, of partial melting. According to Nelson and Davidson the parental magmas for the two suites reacted with, and assimilated, crustal rocks at different parking levels.

Pervasive hydrothermal alteration and local base- and precious-metal mineralization followed emplacement of the syenite porphyry stocks at both the North Mountain center in the La Sals and the Mount Pennell center in the Henry Mountains (Hunt, 1958; Hunt, 1988; Irwin, 1973; Nelson and others, 1992). Propylitic (chlorite-calcite-epidote-magnetite-hematite) alteration generally extends farthest from the stocks. Other, generally more proximal, pervasive alteration assemblages include hornfels skarn (aegirine-augite, riebeckite, glaucophane, hedenbergite, actinolite, biotite, magnetite, hematite, garnet), alkali metasomatism (albitization and subordinate potassium feldspathization), carbonatic alteration (calcite, siderite?), redox alteration (hematitization), and sulfidization (pyrite±base-metal sulfides). Narrow breccia zones and small fissure veins occur locally, commonly following sheeted zones. Hypogene vein minerals include quartz, carbonates, fluorite, Au-bearing pyrite, chalcopyrite, bornite, galena, sphalerite, molybdenite, magnetite, and hematite. Similar but less intense alteration and mineralization occurred in and adjacent to some diorite porphyry plutons at most of the other Colorado Plateau laccolithic centers. (See table 3.)

At the North Mountain center in the La Sals the alteration and mineralization caused by the syenite porphyry were accompanied and also followed by formation of the breccia pipes (volcanic vents?) and coeval small peralkaline rhyolite porphyry plutons and dikes (Ross, 1992). Several of these pipes exceed 500 m in maximum horizontal dimension. A second alteration and mineralization event is represented by disseminated hematite, minor vein chalcopyrite and pyrite, and vug and cone sheet-fracture filling by calcite and quartz in the pipes. At North Mountain, the final intrusive phases are late-stage to postmineralization peralkaline rhyolite porphyry and nosean trachyte porphyry dikes that crosscut most intrusive phases, breccia pipes, and pervasively altered areas (Ross, this volume). Peralkaline granite also occurs as the youngest intrusive phase in the Mount Pennell center of the Henry Mountains, where Hunt (1988) suggests it preceded or accompanied mineralization.

EXPLORATION POTENTIAL FOR GOLD IN THE COLORADO PLATEAU LACCOLITHIC CENTERS

Three features that are characteristic of productive alkaline rock-related gold deposits in the Rocky Mountains (tables 1, 2) are also present in the Colorado Plateau laccolithic centers:

1. The centers include highly fractionated alkaline plutons such as the syenites of Mount Pennell in the Henry Mountains, North Mountain in the La Sals, and Navajo Mountain. Evolved peralkaline granites and rhyolites are also present at Mount Pennell and North Mountain.

2. Pervasive hydrothermal alteration, including alkali metasomatism and propylitic, carbonatic, redox, pyritic, and silicic alteration, has been reported at most of the laccolithic centers.

3. Subeconomic occurrences of hypogene gold have been recognized in the Abajo, Henry, and La Sal Mountains, and significant historic gold-silver production took place in the Ophir–San Miguel centers.

In the last decade, several major mining companies have evaluated the precious metal potential of the Colorado Plateau laccolithic centers with geochemical surveys, and, in the La Sal Mountains, with drilling programs. Although some geochemical anomalies and limited mineralized drill intercepts have been found, no economic ore deposits were discovered. However, relatively large areas of geologically suitable terrain remain untested, especially for low-sulfide, low-grade gold deposits. Inasmuch as such “invisible” deposits are still being discovered in and adjacent to well-studied mining camps (see Tooker, 1990, for example), we conclude that a modest potential exists for finding economic alkaline rock-related gold deposits in the laccolithic centers of the Colorado Plateau.

REFERENCES CITED

Akright, R.L., 1979, Geology and mineralogy of the Cerrillos copper deposit, Santa Fe County, New Mexico, *in* Ingersoll, R.V., Woodward, L.A., and James, H.L., eds., Guidebook of Santa Fe Country: New Mexico Geological Society Annual Field Conference, 30th, Santa Fe, N. Mex., October 4–6, 1979, p. 257–260.

Aldrich, M.J., Jr., Chapin, C.E., and Laughlin, A.W., 1986, Stress history and tectonic development of the Rio Grande rift, New Mexico: Journal of Geophysical Research, v. 91, p. 6199–6211.

Allen, M.S., and Foord, E.E., 1991, Geological, geochemical and isotopic characteristics of the Lincoln County porphyry belt, New Mexico—Implications for regional tectonics and mineral deposits, *in* Barker, J.M., Kues, B.S., Austin, G.S., and Lucas, S.G., eds., Guidebook of the Sierra Blanca, Sacramento and Capitan Ranges, New Mexico: New Mexico Geological Society Annual Field Conference, 42d, p. 97–113.

Allen, M.S., and McLemore, V.T., 1991, The geology and petrogenesis of the Capitan pluton, New Mexico, *in* Barker, J.M., Kues, B.S., Austin, G.S., and Lucas, S.G., eds., Guidebook of the Sierra Blanca, Sacramento and Capitan Ranges, New Mexico: New Mexico Geological Society Annual Field Conference, 42d, p. 115–127.

Anderson, A.L., and Kirkham, V.R.D., 1931, Alkaline rocks of the Highwood type in southeastern Idaho: American Journal of Science, 5th series, v. 22, p. 51–68.

Armstrong, R.L., 1969, K-Ar dating of laccolithic centers of the Colorado Plateau and vicinity: Geological Society of America Bulletin, v. 80, p. 2081–2086.

Armstrong, R.L., Harakal, J.E., and Hollister, V.F., 1982, Eocene mineralization at Mount Tolman (Keller), Washington, and Silver Dyke, Montana: Isochron/West, no. 33, p. 9–10.

Atkinson, W.W., 1961, Geology of the San Pedro Mountains, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 77, 49 p.

Bailey, D.K., and Hampton, C.M., 1990, Volatiles in alkaline magmatism: Lithos, v. 26, p. 157–165.

Baker, D.W., McBride, Gwen, and Dahy, James, 1991, Field guide, Little Belt Mountains, *in* Baker, D.W., and Berg, R.B., eds., Guidebook of the Central Montana alkalic province: Montana Bureau of Mines and Geology Special Publication 100, p. 144–162.

Bastin, E.S., and Hill, J.M., 1917, Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colorado: U.S. Geological Survey Professional Paper 94, 379 p.

Black, K.D., 1977, Petrology, alteration, and mineralization of two Tertiary intrusives, Sierra Blanca igneous complex, New Mexico: Fort Collins, Colo., Colorado State University M.S. thesis, 124 p.

Blixt, J.E., 1933, Geology and gold deposits of the North Moccasin Mountains, Fergus County, Montana: Montana Bureau of Mines and Geology Memoir 8, 25 p.

Bromfield, C.S., 1967, Geology of the Mount Wilson quadrangle, western San Juan Mountains, Colorado: U.S. Geological Survey Bulletin 1227, 100 p.

Brownlow, A.H., and Komorowski, J.-C., 1988, Geology and origin of the Yogo sapphire deposit, Montana: Economic Geology, v. 83, p. 875–880.

Budge, Suzanne, and Romberger, S.B., 1983, Trace element distribution around precious/base metal veins, Idaho Springs dist., CO: Geological Society of America Abstracts with Programs, v. 15, p. 398.

Butler, B.S., Loughlin, G.F., Heikes, V.C., and others, 1920, The ore deposits of Utah: U.S. Geological Survey Professional Paper 111, 672 p.

Cameron, E.M., 1990, Alkaline magmatism at Kirkland Lake, Ontario—Product of strike slip orogenesis: Canada Geological Survey Paper 90–1C, p. 261–269.

Cameron, E.M., and Hattori, Keiko, 1987, Archean gold mineralization and oxidized hydrothermal fluids: Economic Geology, v. 82, p. 1177–1191.

Cepeda, J.C., 1990, The Capitan dike swarm, Lincoln County, New Mexico—A Tertiary alkalic magma system: Geological Society of America Abstracts with Programs, v. 22, p. 5.

Clabaugh, S.E., 1952, Corundum deposits of Montana: U.S. Geological Survey Bulletin 983, 100 p.

Clarke, F.W., 1915, Analyses of rocks and minerals from the laboratory of the United States Geological Survey, 1880–1914: U.S. Geological Survey Bulletin 591, 376 p.

Condie, K.C., 1964, Crystallization Po_2 of syenite porphyry from Navajo Mountain, southern Utah: Geological Society of America Bulletin, v. 75, p. 359–362.

Cordalis, Charles, 1984, Mineralogy and petrology of the Copper King platinum prospect, Park County, Montana: Butte, Mont., Montana College of Mineral Science and Technology M.S. thesis, 62 p.

Cross, Whitman, 1894, The laccolithic mountain groups of Colorado, Utah, and Arizona: U.S. Geological Survey 14th Annual Report, pt. 2, p. 165–241.

———1895, General geology of the district, part 1 *of* Geology and mining industries of the Cripple Creek district, Colorado: U.S. Geological Survey 16th Annual Report, pt. 2, p. 13–109.

———1896, Geology of Silver Cliff and the Rosita Hills, Colorado: U.S. Geological Survey 17th Annual Report, pt. 2, p. 263–403.

Cross, Whitman, Spencer, A.C., and Purington, C.W., 1899, La Plata folio, Colorado: U.S. Geological Survey Geological Atlas Folio 60, 14 p.

Cunningham, C.G., Naeser, C.W., and Marvin, R.F., 1977, New ages for intrusive rocks in the Colorado mineral belt: U.S. Geological Survey Open-File Report 77–573, 7 p.

Dahy, J.P., 1991, Geology and igneous rocks of the Yogo sapphire deposit, Little Belt Mountains, Montana, *in* Baker, D.W., and Berg, R.B., eds., Guidebook of the Central Montana alkalic province: Montana Bureau of Mines and Geology Special Publication 100, p. 45–54.

Davis, M.W., and Streufert, R.K., 1990, Gold occurrences of Colorado: Colorado Geological Survey Resource Series, no. 28, 101 p.

DeWitt, Ed, Redden, J.A., Wilson, A.B., Buscher, David, and Dersch, J.S., 1986, Mineral resource potential and geology of the Black Hills National Forest, South Dakota and Wyoming: U.S. Geological Survey Bulletin 1580, 135 p.

Dickin, A.P., Rice, C.M., and Harmon, R.S., 1986, A strontium and oxygen isotope study of Laramide magmatic and hydrothermal activity near Central City, Colorado: Economic Geology, v. 81, p. 904–914.

Disbrow, A.E., and Stoll, W.C., 1957, Geology of the Cerrillos area, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 48, 73 p.

Doelling, H.H., 1980, Mineral deposits of the Henry Mountains, *in* Picard, M.D., ed., Henry Mountains Symposium: Utah Geological Association Publication 8, p. 287–296.

Dubiel, R.F., Bromfield, C.S., Church, S.E., Kemp, W.M., Larson, M.J., Peterson, Fred, and Neubert, J.T., 1988a, Mineral resources of the Bull Mountain Wilderness Study Area, Garfield and Wayne Counties, Utah: U.S. Geological Survey Bulletin 1751–B, p. B1–B12.

———1988b, Mineral Resources of the Mt. Hillers Wilderness Study Area, Garfield County, Utah: U.S. Geological Survey Bulletin 1751–C, p. C1–C14.

Dubiel, R.F., Bromfield, C.S., Church, S.E., Kemp, W.M., Larson, M.J., Peterson, Fred, and Pierson, C.T., 1990, Mineral resources of the Mount Pennell Wilderness Study Area, Garfield County, Utah: U.S. Geological Survey Bulletin 1751–D, p. D1–D17.

Eckel, E.B., Williams, J.S., Galbraith, F.W., and others, 1949, Geology and ore deposits of the La Plata district, Colorado: U.S. Geological Survey Professional Paper 219, 179 p.

Ekren, E.B., and Houser, F.N., 1965, Geology and petrology of the Ute Mountains area, Colorado: U.S. Geological Survey Professional Paper 481, 74 p.

Elliott, J.E., 1972, Platinum at Cooke City, Mont.: U.S. Geological Survey Professional Paper 750–A, p. A36.

———1974, The geology of the Cooke City area, Montana and Wyoming, *in* Voight, Barry, ed., Rock mechanics, the American Northwest: University Park, Pa., The Pennsylvania State University, p. 102–107.

———1979, Geologic map of the southwest part of the Cooke City quadrangle, Montana and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I–1084, scale 1:24,000.

Elston, W.E., 1967, Summary of the mineral resources of Bernalillo, Sandoval, and Santa Fe Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 81, 81 p.

Embry, P.A., 1987, Petrogenesis of the Yogo Peak stock, Little Belt Mountains, Montana: Missoula, Mont., University of Montana M.S. thesis, 94 p.

Emmons, S.F., 1896, The mines of Custer County, Colorado: U.S. Geological Survey 17th Annual Report, pt. 2, p. 405–472.

Engel, C.G., 1959, Igneous rocks and constituent hornblendes of the Henry Mountains, Utah: Geological Society of America Bulletin, v. 70, p. 951–980.

Eriksson, C.L., 1987, Petrology of the alkalic hypabyssal and volcanic rocks at Cripple Creek, Colorado: Golden, Colo., Colorado School of Mines M.S. thesis, 114 p.

Fears, D.W., Mutschler, F.E., and Larson, E.E., 1986, Cripple Creek, Colorado—A petrogenetic model: Geological Society of America Abstracts with Programs, v. 18, p. 599.

Foster, Fess, and Chadwick, Tom, 1990, Relationship of the Golden Sunlight mine to the Great Falls tectonic zone: Tobacco Root Geological Society 15th Annual Field Conference Guidebook, p. 77–81.

Fulp, M.S., and Woodward, L.A., 1991, Mineral deposits of the New Mexico alkalic province: Geological Society of America Abstracts with Programs, v. 23, no. 4, p. 23.

Gable, D.J., 1984, Geologic setting and petrochemistry of the Late Cretaceous–Early Tertiary intrusives in the northern Front Range mineral belt, Colorado: U.S. Geological Survey Professional Paper 1280, 33 p.

Garverich, M.R., 1991, Field guide, North Moccasin and Judith Mountains, *in* Baker, D.W., and Berg, R.B., eds., Guidebook of the Central Montana alkalic province: Montana Bureau of Mines and Geology Special Publication 100, p. 175–184.

Giles, D.L., 1983, Gold mineralization in the laccolithic complexes of central Montana, *in* Babcock, J.W., chairperson, The genesis of Rocky Mountain ore deposits—Changes with time and tectonics: Wheat Ridge, Colo., Denver Region Exploration Geologists Society, p. 157–162.

———1991, Gold mineralization in the Cerrillos district, New Mexico: Geological Society of America Abstracts with Programs, v. 23, no. 4, p. 24.

Giles, D.L., and Thompson, T.B., 1972, Petrology and mineralization of a molybdenum-bearing alkalic stock, Sierra Blanca, New Mexico: Geological Society of America Bulletin, v. 83, p. 2129–2148.

Goddard, E.N., 1988, Geologic map of the Judith Mountains, Fergus County, Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I–1729, scale 1:31,680.

Griswold, G.B., 1959, Mineral deposits of Lincoln County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 67, 117 p.

Grunwald, R.R., 1970, Geology and mineral deposits of the Galena mining district, Black Hills, South Dakota: Rapid City, S.Dak., South Dakota School of Mines and Technology Ph. D. thesis, 323 p.

Hall, R.J., 1976, Petrology of diamond drill core from Judith Peak–Red Mountain area, Fergus County, Montana: Cheney, Wash., Eastern Washington University M.S. thesis, 38 p.

Hamilton, J.A., 1961, Geology of the Caribou Mountain area, Bonneville and Caribou Counties, Idaho: Moscow, Idaho, University of Idaho M.S. thesis, 59 p.

Hastings, J.S., 1988, Gold deposits of Zortman-Landusky, Little Rocky Mountains, Montana, *in* Schafer, R.W., Cooper, J.J., and Vikre, P.G., eds., Bulk mineable precious metal deposits of the western United States: Reno, Nev., Geological Society of Nevada, p. 187–205.

Hildebrand, F.A., and Conklin, N.M., 1974, A breccia dike containing rare-earth-bearing apatite, molybdenite and magnetite at Iron Hill, Custer County, Colorado: Economic Geology, v. 69, p. 508–515.

Holt, R.E., 1961, Copper King project, Goose Lake district, Park County, Montana: Denver, Colo., Bear Creek Mining Company unpublished report, 21 p.

Hunt, C.B., 1956, Cenozoic geology of the Colorado Plateau: U.S. Geological Survey Professional Paper 279, 99 p.

———1958, Structural and igneous geology of the La Sal Mountains, Utah: U.S. Geological Survey Professional Paper 294–I, p. 305–364.

Hunt, C.B., Averitt, Paul, and Miller, R.L., 1953, Geology and geography of the Henry Mountains region, Utah: U.S. Geological Survey Professional Paper 228, 234 p.

Hunt, G.L., 1988, Petrology of the Mt. Pennell central stock, Henry Mountains, Utah: Brigham Young University Geology Studies, v. 35, p. 81–100.

Huntsman, J.R., 1984, Caribou Mountain—A porphyry copper deposit in southeastern Idaho: Economic Geology, v. 79, p. 748–754.

———1988, Structural controls and age of the Caribou Mountain intrusion, southeastern Idaho: Geological Society of America Abstracts with Programs, v. 20, p. 421.

Irving, J.D., 1899, A contribution to the geology of the northern Black Hills: New York Academy of Science Annals, v. 12, p. 187–340.

Irwin, T.D., 1973, The petrologic evolution of the North Mountain stock, La Sal Mountains, Utah: Tucson, Ariz., University of Arizona M.S. thesis, 71 p.

Jenkins, R.E., II, 1979, Geology, geochemistry and origin of mineral deposits in the Hill Gulch area, Jamestown, Colorado: Golden, Colo., Colorado School of Mines Ph. D. thesis, 220 p.

Kane, W.T., Atkinson, W.W., Jr., and Snee, L.W., 1988, Trace element geochemistry and Ar/Ar geochronology of epithermal mineralization, Four Mile Canyon, Boulder County, Colorado: Geological Society of America Abstracts with Programs, v. 20, p. A353.

Kay, B.D., 1986, Vein and breccia gold mineralization and associated igneous rocks at the Ortiz mine, New Mexico, U.S.A.: Golden, Colo., Colorado School of Mines M.S. thesis, 179 p.

Kelly, W.C., and Goddard, E.M., 1969, Telluride ores of Boulder County, Colorado: Geological Society of America Memoir 109, 237 p.

Kilinc, I.A., 1979, Melting relations in the quartz diorite-H_2O and quartz diorite-H_2O-CO_2 systems: Neues Jahrbuch für Mineralogie, 1979, no. 2, p. 67–72.

Kirchener, J.G., 1971, Petrology and petrography of the phonolite porphyry intrusions of the northern Black Hills, South Dakota: Iowa City, Iowa, University of Iowa Ph. D. thesis, 199 p.

Kirchner, G.L., 1982, Field relations, petrology, and mineralization of the Linster Peak dome, Fergus County, Montana: Missoula, Mont., University of Montana M.S. thesis, 115 p.

Kleinkopf, M.D., Peterson, D.L., and Mattick, R.E., 1979, Gravity, magnetic, and seismic studies of the Silver Cliff and Rosita Hills volcanic area, Colorado: U.S. Geological Survey Professional Paper 726–F, p. F1–F17.

Kohrt, P.B., 1991, Alkalic rocks of the Judith Mountains, central Montana, *in* Baker, D.W., and Berg, R.B., eds., Guidebook of the Central Montana alkalic province: Montana Bureau of Mines and Geology Special Publication 100, p. 77–85.

Koschmann, A.H., 1949, Structural control of the gold deposits of the Cripple Creek district, Teller County, Colorado: U.S. Geological Survey Bulletin 955–B, p. 19–60.

Kurisoo, Peter, 1991, Gold deposits of the Kendall mining district, Fergus County, Montana, *in* Baker, D.W., and Berg, R.B., eds., Guidebook of the Central Montana alkalic province: Montana Bureau of Mines and Geology Special Publication 100, p. 39–44.

Larsen, R.K., 1977, Geology, alteration and mineralization of the northern Cutting stock, Lawrence County, South Dakota: Rapid City, S.Dak., South Dakota School of Mines and Technology M.S. thesis, 147 p.

Lindgren, Waldemar, Graton, L.C., and Gordon, C.H., 1910, The ore deposits of New Mexico: U.S. Geological Survey Professional Paper 68, 361 p.

Lindgren, Waldemar, and Ransome, F.L., 1906, Geology and gold deposits of the Cripple Creek district, Colorado: U.S. Geological Survey Professional Paper 54, 516 p.

Lindsey, D.A., 1982, Geologic map and discussion of selected mineral resources of the North and South Moccasin Mountains, Fergus County, Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I–1362, scale 1:24,000.

———1985, A gold-mineralized breccia zone at Kendall, North Moccasin Mountains, Fergus County, Montana: U.S. Geological Survey Professional Paper 1301–C, p. 43–56.

Lindsey, D.A., and Fisher, F.S., 1985, Mineralized breccias in intrusive complexes of Late Cretaceous and Paleocene age, north-central Montana: U.S. Geological Survey Professional Paper 1301–A, p. 1–34.

Lindsey, D.A., and Naeser, C.W., 1985, Relation between igneous intrusion and gold mineralization in the North Moccasin Mountains, Fergus County, Montana: U.S. Geological Survey Professional Paper 1301–B, p. 35–41.

Lipman, P.W., Fisher, F.S., Mehnert, H.H., Naeser, C.W., Luedke, R.G., and Steven, T.A., 1976, Multiple ages of mid-Tertiary mineralization and alteration in the western San Juan Mountains, Colorado: Economic Geology, v. 71, p. 571–588.

Loomis, T.A., and Alexander, D.L., 1990, The geology of the Foley Ridge gold mine, *in* Fourth Western Regional Conference on Precious Metals and the Environment, Lead, S. Dak., September 19–22, 1990, Proceedings: AIME, Society for Mining, Metallurgy, and Exploration, Black Hills Section, p. 77–87.

Loughlin, G.F., 1927, Ore at deep levels in the Cripple Creek district, Colorado: American Institute of Mining and Metallurgical Engineers Technical Publication 13, 32 p.

Loughlin, G.F., and Koschmann, A.H., 1935, Geology and ore deposits of the Cripple Creek district, Colorado: Colorado Scientific Society Proceedings, v. 13, no. 6, p. 217–435.

Lovering, T.S., 1930, The New World or Cooke City mining district, Park County, Montana: U.S. Geological Survey Bulletin 811–A, p. 1–87.

Lux, D.R., 1977, A major element geochemical study of Laramide igneous rocks of the Colorado mineral belt: Houston, Texas, Rice University M.S. thesis, 77 p.

Macdonald, G.A., and Katsura, T., 1964, Chemical composition of Hawaiian lavas: Journal of Petrology, v. 5, p. 82–133.

Marvin, R.F., Hearn, B.C., Jr., Mehnert, H.H., Naeser, C.W., Zartman, R.E., and Lindsey, D.A., 1980, Late Cretaceous-Paleocene-Eocene igneous activity in north central Montana: Isochron/West, no. 29, p. 5–25.

Marvin, R.F., Witkind, I.J., Keefer, W.R., and Mehnert, H.H., 1973, Radiometric ages of intrusive rocks in the Little Belt Mountains, Montana: Geological Society of America Bulletin, v. 84, p. 1977–1986.

Marvin, R.F., Young, E.J., Mehnert, H.H., and Naeser, C.W., 1974, Summary of radiometric age determinations on Mesozoic and Cenozoic igneous rocks and uranium and base metal deposits in Colorado: Isochron/West, no. 11, 41 p.

Mattox, S.R., 1992, Geochemistry, origin, and tectonics of mid-Tertiary and late Tertiary and Quaternary volcanic rocks, southern Marysvale volcanic field, Utah: De Kalb, Ill., Northern Illinois University Ph. D. thesis, 239 p.

Maynard, S.R., Nelsen, C.J., Martin, K.W., and Schultz, J.L., 1990, Geology and gold mineralization of the Ortiz Mountains, Santa Fe County, New Mexico: Mining Engineering, v. 42, no. 8 (August), p. 1007–1011.

Maynard, S.R., Woodward, L.A., and Giles, D.L., 1991, Tectonics, intrusive rocks, and mineralization of the San Pedro–Ortiz porphyry belt, north-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 137, p. 57–69.

McDowell, F.W., 1971, K-Ar ages of igneous rocks from the western United States: Isochron/West, no. 2, p. 1–16.

McEwan, C.J.A., 1986, Geological, stable isotope and fluid inclusion evidence for concealed epithermal precious metal mineralisation, Rosita Hills, Colorado: Geological Society of America Abstracts with Programs, v. 16, p. 688.

McMillan, W.J., 1991, Porphyry deposits in the Canadian Cordillera: British Columbia Ministry of Energy, Mines and Petroleum Resources Paper 1991–4, p. 253–276.

Meyer, H.O.A., and Mitchell, R.H., 1988, Sapphire bearing ultramafic lamprophyre from Yogo, Montana—An ouachitite: Canadian Mineralogist, v. 26, p. 81–88.

Mutschler, F.E., Griffin, M.E., Stevens, D.S., and Shannon, S.S., Jr., 1985, Precious metal deposits related to alkaline rocks in the North American Cordillera—An interpretive review: Geological Society of South Africa Transactions, v. 88, p. 355–377.

Mutschler, F.E., Larson, E.E., and Bruce, R.M., 1987, Laramide and younger magmatism in Colorado—New petrologic and tectonic variations on old themes: Colorado School of Mines Quarterly, v. 82, no. 4, p. 1–47.

Mutschler, F.E., and Mooney, T.C., 1993, Precious metal deposits related to alkaline igneous rocks—Provisional classification, grade-tonnage data, and exploration frontiers, *in* Kirkham, R.V., Sinclair, W.D., Thorpe, R.I., and Duke, J.M., eds., Mineral deposit modeling: Geological Association of Canada Special Paper 40.

Mutschler, F.E., Mooney, T.C., and Johnson, D.C., 1990, Precious metal deposits related to alkaline igneous rocks—A space-time trip through the Cordillera, *in* Fourth Western Regional Conference on Precious Metals and the Environment, Lead, S. Dak., September 19–22, 1990, Proceedings: AIME, Society for Mining, Metallurgy, and Exploration, Black Hills Section, p. 43–59.

Mutschler, F.E., Rougon, D.J., Lavin, O.P., and Hughes, R.D., 1981, PETROS—A data bank of major-element chemical analyses of igneous rocks (version 6–1): Boulder, Colo., NOAA National Geophysical Data Center (magnetic tape).

Nash, J.T., and Cunningham, C.G., Jr., 1973, Fluid-inclusion studies of the fluorspar and gold deposits, Jamestown district, Colorado: Economic Geology, v. 68, p. 1247–1262.

Nelson, S.E., 1989, Geology, alteration, and mineral deposits of the Cresson diatreme, Cripple Creek district, Colorado: Fort Collins, Colo., Colorado State University M.S. thesis, 147 p.

———1990, Geology, alteration and Au-Ag mineralization of the Cresson diatreme, Cripple Creek district, Colorado: Geological Society of America Abstracts with Programs, v. 22, no. 6, p. 40–41.

Nelson, S.T., 1991, Mid-Tertiary magmatism of the Colorado Plateau—The Henry and La Sal Mountains, Utah: Los Angeles, Calif., University of California Ph. D. thesis, 318 p.

Nelson, S.T., and Davidson, J.P., 1993, Interactions between mantle-derived magmas and mafic crust, Henry Mountains, Utah: Journal of Geophysical Research, v. 98, p. 1837–1852.

Nelson, S.T., Sullivan, K.R., and Davidson, J.P., 1992, New age determinations of central Colorado Plateau laccoliths, Utah—Recognizing disturbed K-Ar systematics and re-evaluating tectonomagmatic relationships: Geological Society of America Bulletin, v. 104, p. 1547–1560.

Noble, J.A., 1948, High-potash dikes in the Homestake mine, Lead, South Dakota: Geological Society of America Bulletin, v. 59, p. 927–940.

North, R.M., and McLemore, V.T., 1988, A classification of the precious metal deposits of New Mexico, *in* Schafer, R.W., Cooper, J.J., and Vikre, P.G., eds., Bulk mineable precious metal deposits of the western United States: Reno, Nev., Nevada Geological Society, p. 625–659.

Norton, J.J., 1989, Bald Mountain gold mining region, northern Black Hills, South Dakota: U.S. Geological Survey Bulletin 1857–C, p. C1–C13.

Ogilvie, I.H., 1908, Some igneous rocks from the Ortiz Mountains, New Mexico: Journal of Geology, v. 16, p. 230–238.

Olmore, S.D., 1991, Geologic summary of the Big Ben molybdenum deposit near Neihart, Montana, *in* Baker, D.W., and Berg, R.B., eds., Guidebook of the Central Montana alkalic province: Montana Bureau of Mines and Geology Special Publication 100, p. 124–127.

O'Sullivan, R.B., and Beikman, H.M., 1963, Geology, structure, and uranium deposits of the Shiprock quadrangle, New Mexico and Arizona: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–345, scale 1:250,000.

Paterson, C.J., 1990, Magmatic-hydrothermal model for epithermal-mesothermal Au-Ag deposits in the northern Black Hills, *in* Fourth Western Regional Conference on Precious Metals and the Environment, Lead, S. Dak., September 19–22, 1990, Proceedings: AIME, Society for Mining, Metallurgy, and Exploration, Black Hills Section, p. 89–102.

Paterson, C.J., Lisenbee, A.L., and Redden, J.A., 1988, Gold deposits in the Black Hills, South Dakota, *in* Diedrich, R.P., Dyka, M.A.K., and Miller, W.R., eds., Thirty-Ninth Field Conference guidebook—Eastern Powder River Basin–Black Hills: Wyoming Geological Association Field Conference, 39th, Casper, Wyo., Sept. 9–11, 1988, p. 295–304.

Paterson, C.J., Uzunlar, Nuri, Groff, J., and Longstaffe, F.J., 1989, A view through an epithermal-mesothermal precious metal system in the northern Black Hills, South Dakota—A magmatic origin for the ore-forming fluids, *in* Keays, R.R., Ramsay, W.R.H., and Groves, D.I., eds., The geology of gold deposits—The perspective in 1988: Economic Geology Monograph 6, p. 564–570.

Phair, George, 1952, Radioactive Tertiary porphyries in the Central City district, Colorado, and their bearing upon pitchblende deposition: U.S. Geological Survey Trace-Element Investigations Report TEI–247, 53 p.

Phair, George, and Jenkins, L.B., 1975, Tabulation of uranium and thorium data on the Mesozoic-Cenozoic intrusive rocks of known chemical composition in Colorado: U.S. Geological Survey Open-File Report 75–501, 57 p.

Pirsson, L.V., 1894, On some phonolite rocks from the Black Hills: American Journal of Science, 3rd series, v. 47, p. 341–346.

———1900, Petrography of igneous rocks of the Little Belt Mountains, Montana: U.S. Geological Survey 20th Annual Report, pt. 3, p. 463–581.

Pontius, J.A., 1991, Geology and gold mineralization of the Cresson deposit, Cripple Creek, Colorado: Northwest Mining Association 97th Annual Convention, Dec. 1–6, 1991, Spokane, Wash., Abstract Booklet, p. 26.

Porter, E.W., and Ripley, Edward, 1985, Petrologic and stable isotope study of the gold-bearing breccia pipe at the Golden Sunlight deposit, Montana: Economic Geology, v. 80, p. 1689–1706.

Priesmeyer, S.T., 1986, Geology and gold mineralization on the New Year mine and North Giltedge properties, Fergus County, Montana: Moscow, Idaho, University of Idaho M.S. thesis, 84 p.

Rice, C.M., Harmon, R.S., and Shepherd, T.J., 1985, Central City, Colorado—The upper part of an alkaline porphyry molybdenum system: Economic Geology, v. 80, p. 1769–1796.

Rice, C.M., Lux, D.R., and Macintyre, R.M., 1982, Timing of mineralization and related intrusive activity near Central City, Colorado: Economic Geology, v. 77, p. 1655–1666.

Rock, N.M.S., Groves, D.I., Perring, C.S., and Golding, S.D., 1989, Gold, lamprophyres, and porphyries—What does their association mean?, *in* Keays, R.R., Ramsay, W.R.H., and Groves, D.I., eds., The geology of gold deposits—The perspective in 1988: Economic Geology Monograph 6, p. 609–625.

Roemmel, J.S., 1982, A petrographic and economic evaluation of the White Cow intrusion, Little Rocky Mountains, Montana: Missoula, Mont., University of Montana M.S. thesis, 51 p.

Ronkos, C.J., 1991, Geology, alteration and gold mineralization in the White Oaks mining district, Lincoln County, New Mexico: Geological Society of America Abstracts with Programs, v. 23, no. 4, p. 88.

Ross, M.L., 1992, Geology and petrology of the Oligocene North Mountain intrusive center, La Sal Mountains, Utah: Geological Society of America Abstracts with Programs, v. 24, no. 6, p. 59.

Rupp, J.A., 1980, Tertiary rhyolite dikes and plutons of the northern Little Belt Mountains, Montana: Cheney, Wash., Eastern Washington University M.S. thesis, 136 p.

Russell, C.W., 1991, Gold mineralization in the Little Rocky Mountains, Montana, *in* Baker, D.W., and Berg, R.B., eds., Guidebook of the Central Montana alkalic province: Montana Bureau of Mines and Geology Special Publication 100, p. 1–18.

Russell, C.W., and Gabelman, Joan, 1991, Field guide, Little Rocky Mountains, *in* Baker, D.W., and Berg, R.B., eds., Guidebook of the Central Montana alkalic province: Montana Bureau of Mines and Geology Special Publication 100, p. 185–194.

Ryzak, David, 1990, Gold deposits of active mining areas, Little Rocky Mountains, Montana, *in* Fourth Western Regional Conference on Precious Metals and the Environment, Lead, S. Dak., September 19–22, 1990, Proceedings: AIME, Society for Mining, Metallurgy, and Exploration, Black Hills Section, p. 61–75.

Saunders, J.A., 1988, Textural and geochemical characteristics of gold mineralization from the Cresson mine, Cripple Creek district, Colorado, U.S.A.: Institution of Mining and Metallurgy Transactions, section B, v. 97, p. B36–B39.

———1991, Gold deposits of the Boulder County gold district, Colorado: U.S. Geological Survey Bulletin 1857–I, p. I37–I48.

Saunders, J.A., and May, E.R., 1986, Bessie G—A high-grade epithermal gold telluride deposit, La Plata County, Colorado, U.S.A., *in* Macdonald, A.J., ed., Gold '86—An International Symposium on the Geology of Gold Deposits, Toronto, 1986, Proceedings: Willowdale, Ontario, Konsult International, p. 436–444.

Schroeter, T.G., Lund, C., and Carter, G., 1989, Gold production and reserves in British Columbia: British Columbia Ministry of Energy, Mines and Petroleum Resources Open File 1989–22, 86 p.

Schutz, J.L., Fulp, M.S., Suchomel, B.J., and Woodward, L.A., 1988, Geology and precious-metal mineralization at the Lenny mine, Little Belt Mountains, central Montana, *in* Schafer, R.W., Cooper, J.J., and Vikre, P.G., eds., Bulk mineable precious metal deposits of the western United States: Reno, Nev., Geological Society of Nevada, p. 747.

Segerstrom, Kenneth, and Ryberg, G.E., 1974, Geology and placer gold deposits of the Jicarilla Mountains, Lincoln County, New Mexico: U.S. Geological Survey Bulletin 1308, 25 p.

Segerstrom, Kenneth, Stotelmeyer, R.B., and Williams, F.E., 1979, Mineral resources of the White Mountain Wilderness and adjacent areas, Lincoln County, New Mexico: U.S. Geological Survey Bulletin 1453, 135 p.

Shand, H.S., 1951, Eruptive rocks, 4th edition: New York, John Wiley, 488 p.

Sharp, W.N., 1978, Geologic map of the Silver Cliff and Rosita volcanic centers, Custer County, Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I–1081, scale 1:24,000.

Sharp, W.N., and Naeser, C.W., 1986, Apatite fission-track age for the Bull Domingo boulder pipe, Custer County, Colorado, chap. H *of* Peterman, Z.E., and Schnabel, D.C., eds., Shorter contributions to isotope research: U.S. Geological Survey Bulletin 1622, p. 77–80.

Sharwood, W.J., 1911, Analyses of some rocks and minerals from the Homestake mine, Lead, South Dakota: Economic Geology, v. 6, p. 729–789.

Shawe, D.R., Simmons, G.C., and Archbold, N.L., 1968, Stratigraphy of Slick Rock district and vicinity, San Miguel and Dolores Counties, Colorado: U.S. Geological Survey Professional Paper 576–A, p. A1–A108.

Shearer, C.K., 1990, Geochemistry of Laramide igneous intrusions, northern Black Hills, with implications for petrogenetic relationships and magma sources, *in* Peterson, C.J., and Lisenbee, A.L., eds., Metallogeny of gold in the Black Hills, South Dakota: Society of Economic Geologists Guidebook Series, v. 7, p. 35–42.

Simons, F.S., Armbrustmacher, T.J., van Noy, R.M., Zilka, N.T., Federspiel, F.E., and Ridenour, James, 1979, Mineral resources of the Beartooth Primitive area and vicinity, Carbon, Park, Stillwater, and Sweet Grass Counties, Montana, and Park County, Wyoming: U.S. Geological Survey Bulletin 1391–F, p. F1–F125.

Size, W.B., 1967, The petrology of the Goose Lake Tertiary intrusive complex, Park County, Montana: De Kalb, Ill., Northern Illinois University M.S. thesis, 96 p.

Spurr, J.E., and Garrey, G.H., 1908, Economic geology of the Georgetown quadrangle (together with the Empire district), Colorado: U.S. Geological Survey Professional Paper 63, 422 p.

Steenland, N.C., 1962, Gravity and aeromagnetic exploration in the Paradox basin: Geophysics, v. 27, p. 73–89.

Stern, T.W., Newell, M.F., Kistler, R.W., and Shawe, D.R., 1965, Zircon uranium-lead and thorium-lead ages and mineral potassium-argon ages of La Sal Mountains rocks, Utah: Journal of Geophysical Research, v. 70, p. 1503–1507.

Strobell, J.D., Jr., 1956, Geology of the Carrizo Mountains area in northeastern Arizona and northwestern New Mexico: U.S. Geological Survey Oil and Gas Investigations Map OM–160, scale 1:48,000.

Sullivan, K.R., Kowallis, B.J., and Mehnert, H.H., 1991, Isotopic ages of igneous intrusions in southeastern Utah—Evidence for a Mid-Cenozoic Reno–San Juan magmatic zone: Brigham Young University Geology Studies, v. 37, p. 139–144.

Sun, M.-S., and Baldwin, Brewster, 1958, Volcanic rocks of the Cienega area, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 54, 80 p.

Thompson, T.B., 1968, Hydrothermal alteration and mineralization of the Rialto stock, Lincoln County, New Mexico: Economic Geology, v. 63, p. 943–949.

———1972, Sierra Blanca igneous complex, New Mexico: Geological Society of America Bulletin, v. 83, p. 2341–2356.

———1991, The Bonito-Nogal district, Lincoln County, New Mexico: Geological Society of America Abstracts with Programs, v. 23, no. 4, p. 99.

Thompson, T.B., Trippel, A.D., and Dwelley, P.C., 1985, Mineralized veins and breccias of the Cripple Creek district, Colorado: Economic Geology, v. 80, p. 1669–1688.

Tooker, E.W., 1990, Gold in the Bingham district, Utah: U.S. Geological Survey Bulletin 1857–E, p. E1–E16.

Vogel, J.D., 1960, Geology and ore deposits of the Klondike Ridge area, Colorado: U.S. Geological Survey Open-File Report, 206 p.

Walker, G.E., 1991, Geology of the Barker mining district, Judith Basin and Cascade Counties, Montana, *in* Baker, D.W., and Berg, R.B., eds., Guidebook of the Central Montana alkalic province: Montana Bureau of Mines and Geology Special Publication 100, p. 28–37.

Wallace, A.R., 1989, Gold in the Central City mining district, Clorado: U.S. Geological Survey Bulletin 1857–C, p. C38–C47.

Wallace, S.R., 1953, The petrology of the Judith Mountains, Fergus County, Montana: Ann Arbor, Mich., University of Michigan Ph. D. thesis, 245 p.

Walter, R.C., and Geller, B.A., 1992, Age of telluride-stage mineralization from single-crystal $^{40}Ar/^{39}Ar$ dating of vein-deposited adularia [abs.]: Eos, v. 73, no. 14, Spring Meeting Supplement, p. 362.

Wargo, J.G., 1964, Geology of a disseminated copper deposit near Cerrillos, New Mexico: Economic Geology, v. 59, p. 1525–1538.

Webster, I.D., Taylor, R.P., and Bean, C., 1992, Water-rich pantellerite magma—Analysis of glass inclusions from Fantale volcano, Ethiopia [abs]: Eos, v. 73, no. 14, Spring Meeting Supplement, p. 368.

Weed, W.H., and Pirsson, L.V., 1896, Geology of the Little Rocky Mountains: Journal of Geology, v. 4, p. 399–428.

———1898, Geology and mineral resources of the Judith Mountains of Montana: U.S. Geological Survey 18th Annual Report, pt. 3, p. 437–616.

Werle, J.L., Ikramuddin, Mohammed, and Mutschler, F.E., 1984, Allard stock, La Plata Mountains, Colorado—An alkaline rock-hosted porphyry copper–precious metal deposit: Canadian Journal of Earth Sciences, v. 21, p. 630–641.

White, P.J., and Lawless, J.V., 1989, Geochemistry of porphyry-hosted Au-Ag deposits in the Little Rocky Mountains, Montana—A discussion: Economic Geology, v. 84, p. 970–971.

Wilson, M.R., and Kyser, T.K., 1988, Geochemistry of porphyry-hosted Au-Ag deposits in the Little Rocky Mountains, Montana: Economic Geology, v. 83, p. 1329–1346.

———1989, Geochemistry of porphyry-hosted Au-Ag deposits in the Little Rocky Mountains, Montana—A reply: Economic Geology, v. 84, p. 971–973.

Witkind, I.J., 1964, Geology of the Abajo Mountains area, San Juan County, Utah: U.S. Geological Survey Professional Paper 453, 110 p.

———1970, Composite dikes in the Little Belt Mountains, central Montana: U.S. Geological Survey Professional Paper 700–C, p. C82–C88.

———1973, Igneous rocks and related mineral deposits of the Barker quadrangle, Little Belt Mountains, Montana: U.S. Geological Survey Professional Paper 752, 58 p.

Woodward, L.A., 1991, Metallic mineralization in the Yogo and Running Wolf mining districts, Little Belt Mountains, Montana, *in* Baker, D.W., and Berg, R.B., eds., Guidebook of the Central Montana alkalic province: Montana Bureau of Mines and Geology Special Publication 100, p. 19–27.

Wright, A., 1983, The Ortiz gold deposit (Cunningham Hill)—Geology and exploration: Nevada Bureau of Mines and Geology Report 36, p. 42–51.

Zhang, Xiaomao, and Spry, P.G., 1991, Mineralogical and fluid inclusion characteristics of the epithermal Gies gold-silver telluride deposit, Judith Mountains, Montana—A preliminary study, *in* Baker, D.W., and Berg, R.B., eds., Guidebook of the Central Montana alkalic province: Montana Bureau of Mines and Geology Special Publication 100, p. 63–76.

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