

Paleozoic and Mesozoic contact-metamorphosed sedimentary strata Using criteria based on variation patterns of mean contents of wrap the north and south ends of the batholith and steepen toward K_2 0, Na_2 0, CaO, and SiO₂, Tilling (1973) proposed that most rocks of the batholith can be assigned to two magma series: 1) the the contact. At the north, the country rocks chiefly are in contact main series -- consisting principally of plutons in the central of the batholith. There, the contact is highly irregular in detail, but the strike overall is largely parallel with south-dipping host rocks. However, at depth the batholith must steepen and dip consisting mainly of plutons in the southern part of the batholith (see map and legend). For any given SiO2 content or other northward, as suggested by the the presence of satellitic stocks and differentiation index, the rocks of the main magma series contain erosion-exhumed cupolas. Moreover, the inferred gentle northwar plunge of the batholith is compatible with the formation of a broad more K_20 and less Na_20 than do those of the sodic magma series (Tilling, 1973, Figs. 7 - 10). contact aurole, locally as much as 2.5 km wide, composed of hornfels and other contact-metamorphic rocks (Knopf, 1957; Rice, 1977). The distinction between the two series is well expressed by Pb Metamorphic grade ranges from pyroxene-hornfels to albite-epidote isotopic ratios but is not evident in the initial Sr ratios facies with increasing distance from the batholith. (Tilling, 1973). It is also seen in a variety of other data: variation patterns for U, Th, Rb, and Sr (Tilling, 1973, Figs. 11 At the south end of the batholith, the dips of the Paleozoic and and 12); modal proportions of quartz, plagioclase, and alkali Mesozoic country rock and primary foliation of the batholith, where feldspar (Tilling, 1973, Fig. 16); oxygen and hydrogen isotope developed, are nearly vertical or dip steeply north or south. The variations (Tilling, 1977); and, possibly, crystal morphology an steep nature of the batholith-country rock contact is also suggested chemical composition of zircon (Effimoff, 1972). In a recent by a much narrower zone of contact metamorphism, compared with that trace-element study of the plutons in the southern part of the observed at the north end. Locally, the forcible emplacement of the indicated by the shearing, vertical stretching and series is also supported by variation patterns for Nb, Zr, Pb, Cu, shouldering aside of the country rock. The western wall of the batholith is buried beneath younger The differences between the two magma series cannot be ascribed deposits, but extensive, though generally poorly outcropping, simply to change in chemical and isotopic composition of magma with exposures of the roof are preserved in the western part of the

batholith region. These exposures constitute overall gently determined by contact relations and K-Ar age data, overlap. Fo west-dipping strata of the pre-batholith Elkhorn Mountains Volcanics example, the Rader Creek pluton is the earliest known member of the (Kev) and a few large, irregular roof pendants of pre-Kev sodic series but is older than the Butte Quartz Monzonite of the rocks. One large roof remnant of Kev lies near the north-central main series. Chemical data provide permissive evidence that part of the batholith (near Wickes) and is partly overlain by the suggests that many of the satellitic plutons could represent members of the sodic series older than the Rader Creek rocks. All the members of the main-series rocks can be related by differentiation Some late plutons of the batholith, and innumerable small bodies of a single parental magma, whereas the various plutons of the sodic of aplite-alaskite-pegmatite were emplaced along a north-northeast trending zone along the central axis of the batholith. This zone series do not seem to be related by magmatic differentiation also marks the loci of abundant late-stage veins, which are no (Tilling, 1973). Magmas that formed the sodic-series rocks are shown in this compilation but are shown in detail by Becraft and inferred to have been derived from two or more discrete sources o others (1963) and Smedes (1966), as well as dikes and plugs o distinct Rb/Sr and strontium and lead isotopic ratios, or from a single heterogeneous source characterized by intrinsic differences post-batholith quartz latite and rhyolite. Discontinuous screens of in Rb/Sr and Sr and Pb isotopic ratios from one part to another. pre-batholith volcanic and older rocks and fault zones lie near the western limit of the exposures of the batholith. Both chemically and isotopically, rocks of the pre-batholith Collectively, these observations related to the shape and Elkhorn Mountains Volcanics (Kev) resemble the earliest members of contact relations of the plutons indicate that faults of the main-series plutonic rocks, confirming abundant field relations that suggest that they are genetically associated. However, the north-northeast trend played a prominent role before, during, and after batholith emplacement and post-batholith volcanism. Kev rocks only show chemical affinity to rocks of the main magma series; there appears to be no Kev extrusive equivalents of the sodic magma series (Tilling, 1974). These observations, based on Internal structures

Boulder batholith are largely massive and do not exhibit strongly Volcanics (Rutland and others, 1984; Rutland, 1985, 1986). Ir expressed rock fabric. However, the marginal parts of some plutons contrast, the post-batholith Lowland Creek Volcanics are chemically and, less commonly, their interiors show internal structures, akin to the felsic members of the sodic magma series. However, defined by steeply dipping planar foliation marked by alinement of isotopically they are more similar to the main series (especially Pb minerals and/or platy inclusions or by gently dipping schlieren in isotopes) but are somewhat more radiogenic in terms of both of Pb the roof zone. Locally, particularly along contacts against country and Sr isotopic ratios than batholith rocks of either series rock or other batholith rocks, the plutonic rocks contain abundant mafic inclusions, composed of sharply outlined to diffuse aggregates of ferromagnesian minerals and plagioclase of the same compositio Except for three small bodies (1g) in the north-central part blocks of inclusion-rich rock from near the roof or contact zones of the batholith, all bodies large enough to show at the compilation that have foundered into the less crystallized (hss viscous) scale that can be unambiguously assigned (with currently available data) to the sodic magma series are restricted to the southwester In places, two or more steep foliations are preserved in the part of the region, i.e., south of Butte (lat. 46°N) and west of same rock; these structures are well developed in some plutons (e.g., bp, bqm, and cg) in the southwestern part of the batholith. The older structure, consisting of alined mafic

As earlier noted by Grout and Balk (1934), most rocks of the

minerals, mafic inclusions, and plagioclase, is interpreted to be

caused by primary flow during pluton emplacement; the younger

structure, marked by alined large alkali- feldspar megacrysts, is

that formed late in cooling history, when the pluton had largely

solidified. Joints that formed still later in the cooling history

of some main-series plutons, especially the bqm, became the loci

osition. In the Rader Creek pluton, the emplacement of mafic

The Boulder batholith is fringed by a number of satellitic

plutons within 50 km of its margins. These plutons vary widely in

size, composition, texture, grain size, and relationship to country

rock. The larger satellites [e.g., the Hell Canyon (hc), Moose

Creek (mc), and Moosetown (mt) plutons) nearest to the main

intrusive mass are considered to be part of the batholith proper in

Most of the satellite bodies intrude Proterozoic (Belt) and

younger sedimentary rocks or the Elkhorn Mountains Volcanics; very

few, most notably the Hell Canyon pluton (hc), intrude Archean

metamorphic rocks. The northwesterly elongation of the Hell Canyon,

and possibly also the Donald pluton, appears to be controlled by

faults in the Archean basement rocks (see Schmidt and others,

975). Some satellites are uniform in composition, and others are

neterogeneous because they are contaminated, are highly

differentiated, are composite or zoned plutons. Available chemical

anything, they show closer affinity to the sodic-series rather than

Calc-alkalic volcanism in the region occurred episodically

during the Cenozoic after the cessation of plutonism. After the

batholith and its related metalliferous quartz veins were eroded to

a surface of mature relief, the Lowland Creek Volcanics and related

intrusive rocks (Tlv, Tli) of quartz-latite composition were

Extensional block-faulting of basin-and-range style occurred before

and during this volcanism and continued intermittently throughout

volcanism recurred, producing rhyolitic lavas, tuffs, and associated intrusive rocks (Trv, Tri) of the Avon Volcanics. Volcanic ash

ntermontane basins, which were faulted episodically during

Oligocene, Miocene, and Pliocene time. Ore deposits occur locally

in the Tlv (e.g., in the Lowland Creek area) and in the Trv

(e.g., near Rimini and along Warm Springs Creek). Basaltic lava

flows (Tb) along Crow Creek (east-central margin of the map)

represent the youngest known igneous activity in the compilation

distinct from those of the batholith rocks proper and that,

main-series rocks (Tilling, 1973, Fig. 5).

Post-batholith igneous history

this and most previous studies of the Boulder batholith region.

for injection of felsic rocks (principally aplite, alaskite, and

bodies (mb) was in part joint controlled. Some later generations

of fractures were occupied by metalliferous quartz veins and/or by

interpreted to reflect late crystal growth along incipient joints

about longitude 112°10'. However, there are a few other bodies of the north and east of these boundaries. Such areal distribution is grossly compatible with the long-known larger-scale regional zonation of increasing K20 eastward for the Western United States (e.g., Lindgren, 1915; Moore, 1959, 1962). Tilling (1973, Fig. 18) suggested that plutonic rocks to the west and south of the Bould batholiths) are similar to, or more sodic than, the sodic-series rocks. However, recent data indicate that the regional zonation is northeastern part of the Pioneer batholith are chemically akin to not overlap, that for the entire Boulder batholith (.7055-.7092) (Zen and others, 1975; Snee, 1978, 1982; Hammarstrom, 1982; Marvin and others, 1983; Arth and others, 1986). The Big Hole Canyon pluton (west of map), a composite mass located between the Boulder and Pioneer batholiths near Dewey, Montana, is characterized by chemical affinity to the sodic-series rocks and has Sr, Rb/Sr, SIR (Zinter, 1982; Zinter and others, 1983; L.W. Snee, oral communication, 1987). The composite McCartney Mountain stock of Boulder-batholith age (south of map), also located between the

the limited chemical data, have been substantiated by a recent

systematic study of the geochemistry of the Elkhorn Mountains

Regional zonation

Quartz diorite

Quartz diorite

PLAGIOCLASE

SODIC MAGMA

Monzonite

Monzonite Monzodiorite.

scheme used in this compilation (modified from Johannsen,

1939); B, scheme of Streckeisen (1976). Fields of modes

of rocks of the Boulder batholith from Tilling (1973,

EXTENT, COMPOSITION, AND STRUCTURE OF THE BATHOLITH

the instrusive mass that extends from near Helena to south of Butte,

Montana (Weed, 1899). Since then, hundreds of papers, maps, and

geochemical and geophysical surveys have been published on the

patholith and vicinity, and its nature and mode of emplacement have

been vigorously debated (Hamilton and Myers, 1967, 1974; Klepper and

others, 1971b, 1974; Hyndman and others, 1975). The brief

discussion below only highlights selected aspects of the batholith

appropriate to the scale and information content of this compilation

The batholith is an elongate north-northeast-trending composite

epizonal body of calc-alkalic plutonic rocks--approximately 100 km

long and 50 km wide, covering an area of about 5,700 km2. It is

plutons that range from potassic ultramafic rocks and melagabbro,

through granodiorite and quartz monzonite, to granite and syenite.

However, a single pluton, the Butte Quartz Monzonite (bqm),

constitutes nearly 73% of the exposed batholith (Tilling, 1974)

The other plutons of granodiorite and mafic rocks border the bqm

on its north, south, and southeast edges. Collectively, the

approximately 80 to 70 Ma. [K-Ar ages cited in this compilation

have been recalculated using the new conventional decay constants of

Steiger and Jager (1977) now used in geochronology and thus are

leucocratic granodiorites and quartz monzonites being the youngest (Knopf, 1956, 1957, 1963; Tilling and others, 1968).

Implicit throughout the systematic mapping and dating studies of

the 1960's was the working premise that all the intrusions making up

the composite batholith are part of a single magma series. As the

results of isotopic studies became available, however, this

long-held notion became suspect. Despite the narrow restriction of

the batholith rocks in time and space, lead and strontium isotope

data clearly preclude the derivation of all the rocks from a single,

isotopically well-mixed magma source (Doe and others, 1968). This

finding prompted a reexamination of all field and analytical data

and the acquisition of additional chemical analyses to ascertain

whether the isotopic variations might also be expressed by

Two-magma series model

variations in rock chemistry.

slightly older than the published ages. In general, the younge

batholith rocks were emplaced over a 10 million-year time span

In 1899, Walter Harvey Weed gave the name Boulder batholith to

Potassic granite

FELDSPAR

ALKALI

FELDSPAR

MAIN MAGMA

Figure 1. Classification and nomenclature of plutonic rocks: A,

Quartz gabbro

45°

Because the Boulder batholith region hosts many rich ore

deposits, the rocks of the batholith, its satellite plutons, and

surrounding terrane have been the targets of many mapping and

topical studies [see, for example, the references cited in Klepper and others (1957), Robinson and others (1968), and Tilling (1973,

1974)]. In the mid-1950's, the U.S. Geological Survey (USGS) began

These geologic mapping and related topical studies (informally

called "the Boulder batholith project") were essentially complete

Elkhorn Wilderness Study Area (Greenwood and others, 1978, pla

1970's in connection with the mineral resource assessment of the

I). Since then, systematic geologic mapping (scale 1:250,000) and

geophysical surveys of the Butte, Dillon, and White Sulphur Springs

2-degree sheets--which include the Boulder batholith region--have

been in progress as part of the USGS' regional mapping and/or

mineral-resource assessment programs (see, for example, Ruppel and

This compilation draws from published and unpublished maps of

the component plutons of the Boulder batholith and its satellites,

and of the distribution and principal structures of pre- and

post-batholith rocks and deposits. The purpose of the map and

1) to summarize the available mapping and other data on the

plutonic rocks, at a scale that allows the entire batholith to

2) to serve as a general guide for future studies to better

more-detailed mapping or by topical investigations.

understand this classic igneous terrane, whether through

Geologic information from which the map was compiled is

indicated in the index to source data. Other than the segment along

the northern part of the batholith mapped by Adolph and Eleanora B.

Knopf (Knopf, 1963), the bulk of the mapping was done by members of

the U.S. Geological Survey (USGS). The stratigraphic and structural

details of the pre- and post-batholith rocks shown in the source

geologic maps have been highly generalized in our compilation, not

only to accentuate the plutonic units, but also to avoid unnecessary

and in the final 1:250,000 maps of the Butte, Dillon, and White

Sulphur Springs 2-degree sheets scheduled to be published in the

Boulder batholith and its satellites. More-detailed compilation of

the pre- and post-batholith rocks, we believe, would be better, and

more appropriately, done by those actively involved in the current

This compilation would not have been possible without the maps,

cooperation, and encouragement of our USGS colleagues who have

worked, or currently are working, in and around the Boulder

helpful and supportive. Special thanks go to E-an Zen (USGS,

Reston) and Edward T. Ruppel (Director, MBMG) for their constructive

criticism and helpful suggestions on earlier versions of this may

and accompanying text, and to Jerry Russell, Karen Gray, and Lo

Moore (USGS, Reston and Menlo Park) for cartographic advice and

assistance in the preparation of the map. Last but not least, we

(HWS and RIT) dedicate this map to the memory of Montis (Monty) R.

Klepper--our associate, friend, mentor, and the driving force behind

his death in November 1978, Monty, when physically able,

the Boulder batholith project. Even during the final months before

NOMENCLATURE OF IGNEOUS ROCKS

done before 1972, the year when the International Union of Geological Sciences (IUGS) endorsed the classification and

nomenclature agreed upon by the IUGS Submission on the Systematics

nomenclature used in nearly all the original sources cited (see

ndex) was a slight modification of the scheme proposed by Johannsen

(1939), as shown in Figure la. Because of the widespread use of the

compilation is based, for continuity and consistency we also use

modified Johannsen scheme in the previous studies upon which this

that scheme in this compilation, rather than the (now) commonly

in Figure 1b. In his mapping of the north-central and northwestern

margin of the map area, Knopf (1963) used Nockolds' (1954) classification, which is similar to that used in this compilation

except for the use of adamellite instead of quartz monzonite. Also, in the Nockolds' classification, adamellite is a rock in which alkali feldspar makes up 40 to 60 percent of total feldspar,

whereas, in the modified Johannsen scheme we use, quartz monzonite refers to a rock in which alkali feldspar makes up 35 to 65 percent

The description of pyroclastic units in the pre- and post-

batholith volcanic rocks in this compilation largely follows the

terminology of Wentworth and Williams (1932), conforming with usage

accepted classification and nomenclature of Streckeiser

Virtually all the geologic mapping used for this compilation was

participated actively in this compilation.

of total feldspar.

in the original data sources.

batholith region. Throughout the years of the Boulder batholith project, the Montana Bureau of Mines and Geology (MBMG) was most

near future. Therefore, this map focuses on plutonic rocks of the

be portrayed in a single map sheet of manageable size (for field

others, 1983; Wallace and others, 1987).

a major effort, directed by (the late) Montis R. Klepper, to map t

In summary, chemical, isotopic, and mineralogic data for the Boulder batholith seem best interpreted in terms of two magma series, emplaced in the same brief time span but chemically and the sodic magma series may be further split into two groups on the basis of rare-earth-element patterns. The main and sodic magma series of the Boulder batholith are believed to have been derived from two or more sources within the lower crust or upper mantle (Doe and others, 1968). However, for the rocks of the Pioneer batholith, with its high SIR values, a significant crustal component is batholith's limited areal extent, Tilling (1973) favors vertically zoned source regions, whereas Lambe (1981) prefers two laterally

For reasons not fully understood, the main-series rocks host the rich ore deposits that made the Boulder batholith region famous, whereas the sodic-series rocks contain far fewer major deposits none on the scale of those in the Butte District. According to Lambe (1981), the main-series rocks tend to host Au, Ag, Cu, Pb, Zn, Mn (and Mo at Butte) mineralization, but the sodic-series rocks are generally characterized by Au, Ag, Mo, W, Sn mineralization. Shape and contact relations

The principal plutons of the batholith and the satellitic stocks are steep-walled bodies. Exceptions include many of the aplite alaskite-pegmatite bodies (a, commonly gently dipping sheets), the Moose Creek pluton (mc, a moderately inclined irregular laccolith Smedes and others, 1980), and the granitic facies of the Climax Gulch pluton (gr, overall sheet-like). The east margin of the Fikhorn Mountains Volcanics (Kev) and the Rader Creek pluto: (rc), is remarkably linear. This feature is interpreted as evidence for the emplacement of the eastern part of the bqm along as pre-existing fault zone of north-northeast trend, parts of which were obliterated by stopping during emplacement. North of the batholith, the presence of the fault zone is reflected by intensely rocks. Near the northern end of the eastern margin, a downwardtapering screen of sheared and thermally metamorphosed volcanic rocks separates the main batholith mass from a large dike-like lobe to the east. Near the southern end of the eastern margin, a narrow septum of sheared rocks. Late Precambrian to Late Cretaceous in age, separates the Butte Quartz Monzonite and the older Rader Creek

Arth, J.G., Zen, E-an, Sellers, George, and Hammarstrom, Jane, 1986, High initial Sr isotopic ratios and evidence for magma mixing in the Pioneer batholith of southwestern Montana: Journal of Geology, v. 94, p. 419-430. Becraft, G.E., and Pinckney, D.M., 1961, Preliminary geologic map of the northwest quarter of the Boulder quadrangle, Montana: U.S. Geological Survey Mineral Inv. Field Studies Map Becraft, B.E, Pinckney, D.M., and Rosenblum, Sam, 1963, Geology and mineral deposits of the Jefferson City quadrangle, Jefferson and Lewis and Clark Counties, Montana: U.S. Geological Survey Prof. Paper 428, 101 p., map 1:48,000. Brimhall, G.H., Jr., 1977, Early fracture-controlled disseminated mineralization at Butte, Montana: Economic Geology, v. 72, Derkey, R.E., 1986, The Emery mining district, Powell County Montana, in Lawson, D.C., compiler, Directory of Montana Mining Enterprises: Montana Bureau of Mines and Geology, Bulletin 124, p. 30-42 and Map Sheet 2. Doe, B.R., Tilling, R.I., Hedge, C.E., and Klepper, M.R., 1968, Lead southwestern Montana: Economic Geology, v. 63, p. 884-906. Effimov, Igor, 1972, The chemical and morphological variations of zircons from the Boulder batholith, Montana [Ph.D. Thesis]: Cincinnati, Ohio, Univ. Cincinnati, 136 p. Freeman, V.L., Ruppel, E.T., and Klepper, M.R., 1958, Geology of part of the Townsend Valley, Broadwater and Jefferson 481-556, maps at 1:48,000. Friberg, L.M., and Vitaliano, C.J., 1981, The petrology of the McCartney Mountain stock, southwestern Montana: Northwest Geology, v. 10, p. 32-45. Greenwood, W.R., Ludington, Steve, Miller, W.R., Hanna, W.F., 1978, Mineral resource assessment, with a section on geophysical exploration (by W.R. Miller, Steve Ludington, and W.R. Greenwood), a section on geological and geochemical evaluation (by Steve Ludington and W.R. Greenwood), and a section on uranium and thorium potential (by K. J Wenrich-Verbeek, W.R. Miller, V.J. Suits, and J.G. McHugh), in Chapter A, Mineral resources of the Elkhorn Wilderness Study Area: U.S. Geological Survey Open-File Report 78-325, p. 7-82, map 1:48,000. Grout, F.F., and Balk, Robert, 1934, Internal structures in the

Boulder batholith: Geol. Soc. America Bull., v. 45, p. Hamilton, W.B., and Myers, W.B., 1967, The nature of batholiths: U.S. Geol. Survey Prof. Paper 554-C, 30 p. Hamilton, W.B., and Myers, W.B., 1974, Nature of the Boulder batholith of Montana: Geol. Soc. America Bull., v. 85, p. Hammarstrom, J.M., 1982, Chemical and mineralogical variation in the Open-File Report OF-82-148, 178 p. Hyndman, D.W., Talbot, J.L., and Chase, R.R., 1975, Boulder batholith: A result of emplacement of a block detached from the Idaho batholith infrastructure: Geology, 3, p. 401-404 Indiana University Geologic Field Station Staff, 1964, Geologic map of the Jefferson Island quadrangle, Montana: 1:48,000, Johannsen, Albert, 1939, A descriptive petrography of the igneous rocks: Chicago, Ill., University of Chicago Press, 318 p. Klepper, M.R., and Tilling, R.I., 1970, Geologic maps of the Delmoe the Twin Bridges quadrangles, Montana: U.S. Geol. Survey, 48,000, unpublished. Klepper, M.R., and Tilling, R.I., 1972, Unpublished reconnaissance for this compilation, 1:180,000. Klepper, M.R., Weeks, R.A., and Ruppel, E.T., 1957, Geology of the southern Elkhorn Mountains, Montana: U.S. Geol. Survey Prof. Paper 292, 82 p., maps at 1:31,250. Klepper, M.R., Ruppel, E.T., Freeman, V.L., and Weeks, R.A., 1971a. Geology and mineral deposits, east flank of the Elkhorn Mountains, Broadwater County, Montana: U.S. Geol. Survey Klepper, M.R., Robinson, G.D., and Smedes, H.W., 1971b, On the nature of the Boulder batholith of Montana: Geol. Soc. America Bull., v. 82, p. 1563-1580. Klepper, M.R., Robinson, G.D., and Smedes, H.W., 1974, Nature of the Boulder batholith of Montana: Discussion: Geol. Soc. America Bull., v. 85, p. 1953-1958.

Knopf, Adolph, 1956, Argon-potassium determination of the age of the Boulder bathylith, Montana: American Journal Science, v. Knopf, Adolph, 1957, The Boulder bathylith of Montana: American Journal of Science, v. 255, p. 81-103. Knopf, Adolph, 1963, Geology of the northern part of the Boulder bathylith and adjacent area, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I-381, 1:48,000. Northern part revised on basis of unpublished maps of R. G. Schmidt, 1978, 1:48,000. Lambe, R.N., 1981, Crystallization and petrogenesis of the southern portion of the Boulder batholith, Montana [Ph.D. Thesis]: Berkeley, California, Univ. California, Berkeley, 171 p. Lindgren, Waldemar, 1915, The igneous geology of the Cordilleras and onn., Yale University, Silliman Foundation, p. 234-286. Marvin, R.F., Zen, E-an, Hammarstrom, J.M., and Mehnert, H.M., 1983, Cretaceous and Paleocene potassium-argon mineral ages the northern Pioneer batholith and nearby igneous rocks in southwest Montana: Isochron/West, no. 38, p. 11-16. Mathews, G.W., McClain, L.K., and Johanns, W.M., 1977, Petrogenetic aspects of the Hell Canyon pluton and its relation to the Boulder batholith, southwestern Montana: Northwest Geology, Mertie, J.B., Jr., Fischer, R.P., and Hobbs, S.W., 1951, Geology of the Canyon Ferry quadrangle, Montana: U.S. Geol. Survey Bull. 972, 97 p., map at 1:48,000. Meyer, C., Shea, E.P., and Goddard, C.C., and Staff, 1968, Ore deposits at Butte, Montana, in Ridge, J.D., ed., Ore deposits of the United States, 1933-1967: New York, Amer. Inst. Mining, Metall. Petroleum Engineers, v. 2, p. Moore, J.G., 1959, The quartz diorite boundary line in the Western United States: Journal Geology, v. 67, p. 198-210.

Moore, J.G., 1962, K/Na ratio of Cenozoic igneous rocks of the Western United States: Geochim. et Cosmochim. Acta, v. 26, Nockolds, S.R., 1954, Average chemical composition of some igneous rocks: Geol. Soc. America Bull., v. 65, p. 1007-1032. Pinckney, D.M., and Becraft, G.E., 1961, Preliminary geologic map of the southwest quarter of the Boulder quadrangle, Montana: U.S. Geol. Survey Mineral Inv. Field Studies Map MF-187, 1:48,000. Additions from unpublished mapping of H.J. Prostka, H.J., 1964, Reconnaissance geologic map of the Avon area, Montana: U.S. Geol. Survey, 1:2: Prostka, H.J., 1966, Igneous geology of the Dry Mountain quadrangle Jefferson County, Montana: U.S. Geol. Survey Bull. 1221-F, 21 p., map at 1:24,000. Rice, J.M., 1977, Contact metamorphism of impure dolomitic limestone in the Boulder Aureole, Montana: Contrib. Mineral. Petrol., v. 59, p. 237-259. Robinson, G.D., 1963, Geology of the Three Forks quadrangle, Montana: U.S. Geol. Survey Prof. Paper 370, 143 p., map at Robinson, G.D., Klepper, M.R., and Obradovich, J.D., 1968, Overlapping plutonism, volcanism, and tectonism in the Boulder batholith region, western Montana, in Coats, R.R., Hay, R.L., and Anderson, C.A., eds., Studies in Volcanology

- a memoir in honor of Howel Williams: Geol. Soc. America

Ruppel, E.T., 1961, Reconnaissance geologic map of the Deer Lodge quadrangle, Powell, Deer Lodge, and Jefferson Counties, Montana: U.S. Geol. Survey Mineral Inv. Field Studies Map MF-174, 1:48,000. Ruppel, E.T., 1963, Geology of the Basin quadrangle, Montana: U.S. Geol. Survey Bull. 1151, 121 p., map at 1:48,000. Ruppel, E.T., O'Neil, and Lopez, D.A, 1983, Preliminary geologic map of the Dillon 1 x 2 quadrangle, Montana and Idaho: U.S Geol. Survey Open-File Report OF-83-168, 1:250,000. Rutland, C., Vogel, T.A., and Greenwood, W.R., 1984, Major element chemical evolution of the Cretaceous Elkhorn Mountains Volcanics, southwestern Montana: Abstracts with Programs, Geol. Soc. America, v. 16, no. 6, p. 641. (Abstract). Rutland, C., 1985, The geochemistry of the Elkhorn Mountains Volcanics and its relationship to the magma chamber of the Boulder batholith [Ph.D. Thesis]: East Lansing, Michigan, Michigan State Univ., 96 p. southwestern Montana: Implications for the early evolution Mountain Section Abstracts with Programs, v. 18, no. 3, P 408. (Abstract). 1979, Near-surface batholiths, related volcanism,

Rutland, C., 1986, Geochemistry of the Elkhorn Mountains Volcanics, Schmidt, C.J., Smedes, H.W., Suttner, L.J., and Vitaliano, C.J. tectonism, sedimentation, and mineral deposition: Guidebook for Penrose Conference--Granite II: Geol. Soc. America, Gregson, Montana, June 24-29, 111 p. Schmidt, R.G., 1978, Geologic map of parts of the East Helena, Elliston, and Rattlesnake Mountain quadrangles, Montana: U.S. Geol. Survey, 1:48,000, unpublished. Smedes, H.W., 1958, Geologic map of the eastern part of the Melrose quadrangle, Montana: U.S. Geol. Survey, 1:48,000, Smedes, H.W., 1959, Geologic map of the Wickiup Creek quadrangle, Smedes, H.W., 1966, Geology and igneous petrology of the northern Elkhorn Mountains, Jefferson and Broadwater Counties, Ontana: U.S. Geol. Survey Prof. Paper 510, 116 p., map at Smedes, H.W., 1967, Preliminary geologic map of the Butte South quadrangle, Montana: U.S. Geol. Survey Open-File Leport 67-203, 1:24,000. Supplemented by unpublished maps (1972) of H.W. Smedes. Smedes, H.W., 1968, Preliminary geologic map of part of the Butle North quadrangle, Silver Bow, Deer Lodge, and Jefferson Counties, Montana: U.S. Geol. Survey Open-File Report 68-254, 1:24,000. Supplemented by unpublished maps (1972) of H.W. Smedes. Smedes, H.W., Klepper, M.R., Pinckney, D.M., Becraft, G.E., and

Ruppel, E.T., 1962, Preliminary geologic map of the Elk Park quadrangle, Jefferson and Silver Bow Counties, Montana: U.S. Geol. Survey Mineral Inv. Field Studies Map MF-246, 1:48,000. S medes, H.W., Klepper, M.R., and Tilling, R.I., 1968, The Boulder batholith, Montana: Description of geology and road log: Field Trip No. 3, Rocky Mountain Section Meeting, Geol. Soc. America, Bozeman, Montana, May 8, 1968, 21 p. Smedes H.W., Hammond, P., and Hanna, W., 1980, Geology and mineralresources evaluation of the Humbug Spires Primitive Area, Iontana: U.S. Geological Survey Open-File Report 80-836. Snee, L.W., 1978, Petrography, K-Ar ages, and field relations of the igneous rocks of part of the Pioneer Batholith, southwestern Montana [Master's Thesis]: Columbus, Ohio, Ohio State Univ., 110 p. Snee, L.W., 1982, Emplacement and cooling of the Pioneer Batholith, southwestern Montana [Ph.D. Thesis]: Columbus, Ohio, Ohio State Univ., 320 p. Steiger, R.H., and Jager, E., 1977, Subcommission on geochronologyconvention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Sciences Letters, v. Streckeisen, Albert, 1973, Plutonic rocks: Classification and nomenclature recommended by the IUGS Submission on the Systematics of Igneous Rocks: Geotimes, v. 18, p. 26-30. Streckeisen, Albert, 1976, To each plutonic rock its proper name: Tilling, R.I., 1964, Variation in modes and norms of a "homogeneous" pluton of the Boulder batholith, Montana, in Geological Survey research 1964: U.S. Geol. Survey Prof. Paper 501-D, Tilling, R.I., 1968, Zonal distribution of variations in structural state of alkali feldspar within the Rader Creek pluton, Boulder batholith, Montana: Journal Petrology, v. 9, p. Tilling, R.I., 1973, The Boulder batholith, Montana: A product of two contemporaneous but chemically distinct magma series:

Weed, W.H., 1899, Granitic rocks of Butte, Montana, and vicinity:

Weeks, R.A, 1974, Geologic map of the Bull Mountain area, Jefferson

Wentworth, C.K., and Williams, Howel, 1932, The classification and

Zinter, G.G., 1982, The geology and petrology of the Big Hole Canyon

Zinter G.G., Snee, L.W., and Sutter, J.F., 1983, Geology, petrology,

Zen, E-an, Marvin, R.F., and Mehnert, H.H., 1975, Preliminary

County, Montana: U.S. Geol. Survey Open-File Report 74-354,

1:48,000. Southern part from unpublished map of R.A. Weeks.

terminology of the pyroclastic rocks: Natl. Research

petrographic, chemical, and age data on some intrusive and

associated contact metamorphic rocks, Pioneer Mountains, southwestern Montan: Geol. Soc. America Bull., v. 86, p.

pluton, Silver Bow and Beaverhead Counties, Monta

[Master's Thesis]: Buffalo, New York, State Univ. of New York, Buffalo, 88 p.

and age of emplacement of the Big Hole Canyon intrusion

near Dewey, southwest Montana: Abstracts with Programs,

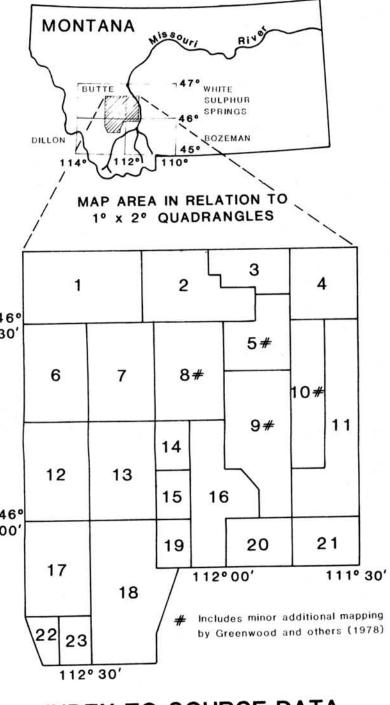
Geol. Soc. America, v. 15, no. 5, p. 412. (Abstract).

Geol. Soc. America Bull., v. 84, p. 3879-3900. Tilling, R.I., 1974, Composition and time relations of plutonic and associated volcanic rocks, Boulder batholith region, Montana: Geol. Soc. America Bull., v. 85, p. 1925-193). Tilling, R.I., 1977, Interaction of meteoric waters with magmas of the Boulder batholith, Montana: Economic Geology, v. /2, no. 5, p. 859-864. Tilling, R.I., Klepper, M.R., and Obradovich, J.D., 1968, K-Ar ages and time span of emplacement of the Boulder batholith Montana: Amer. Journal Science, v. 266, no. 8., p. 671-689. Wallace, C.A., Schmidt, R.G., Lidke, D.J., Water, M.R., Elliot:, MAFIC AND ULTRAMAFIC ROCKS J.E., French, A.B., Whipple, J.W., Zarske, S.E. Blaskowski, M.J., Heise, B.A., Yeoman, R.A., O'Neil J.M., Mafic and ultramafic rocks, undivided; includes melanorite Lopez, D.A., Robinson, G.D., and Klepper, M.R., 1987, Preliminary geologic map of the Butte lo x 2o quadrangle, western Montana: U.S. Geol. Survey Open-File Report OF-86-292, 14 p., map at 1:250,000. Watson, S.M., 1986, The Boulder batholith as a source for the Elkhorn MountainsVolcanics, southeast quarter of the Deer Lodge 15' quadrangle, southwestern Montana: Missoula, Montana, University of Montana, M.S. Thesis, 100 p.

petrographically and chemically by Smedes (1966). ROCKS OF THE SODIC MAGMA SERIES Leucocratic quartz monzonite and granodiorite of the Climax

Gulch pluton. Cuts the Butte Quartz Monzonite and the Burton Park granodiorite. This pluton varies widely in texture mineralogy, and chemical composition, but the predominan locally may contain as many as 300 phenocrysts (as large as 2 x 4 cm) of alkali feldspar per square meter. Compared to th contain relatively more quartz and plagioclase, and fewer erromagnesian minerals. Ranges in modal composition feldspar 20 to 35%; quartz 24 to 30%; hornblende 0 to 4%; biotite 4 to 8%; and accessory minerals < 1 to 2 locally, the rocks grade into, and are cut by, a more-felsi and finer-grained facies, which, where large enough, is shown as gr on the map. The youngest K-Ar age determinations for the Boulder batholith, 69.5 to 70.5 Ma, were obtained on biotite and hornblende, respectively, in the one sample of Climax Gulch pluton dated (see Tilling and others, 1968,

More-granitic, finer-grained, and slightly younger facies of the Climax Gulch pluton. Grades into and locally cuts the



INDEX TO SOURCE DATA (See References Cited)

13. Smedes and others (1962) 14. Becraft and Pinckney (1961) 2. Knopf (1963) 3. Schmidt (1978) 15. Pinckney and Becraft (1961) 4. Mertie and others (1951) 17. Smedes (1967) 18. Klepper and Tilling (1970, 1972) 6. Ruppel (1961) 19. Prostka (1966) 7. Ruppel (1963) 8. Becraft and others (1963) 20. Indiana University 9. Klepper and others (1957) 10. Klepper and others (1971a) 22. Smedes (1958) Freeman and others (1958)
Smedes (1959)

DESCRIPTION OF MAP UNITS

CLAY, SILT, SAND, AND GRAVEL, UNDIVIDED (QUATERNARY AND TERTIARY) ncludes alluvium, colluvium, glacial deposits, terrace OLCANIC ROCKS AND RELATED HYPABYSSAL INTRUSIVE ROCKS

Basalt lava flows, most probably Upper Miocene or Lower liocene, but could be as old as Oligocene (Klepper and Rhyolite lava flows and tuffs of the Upper Eocene and Lower

Oligocene (?) Avon Volcanics of the Helena Volcanic field. Rhyolite dikes and plugs, intrusive equivalents of the Avon Volcanics (Trv). Quartz-latite tuff, welded tuff, and lava flows of the Middle Eocene Lowland Creek Volcanics.

Lowland Creek Volcanics (Tlv). Shown separately only where not coincident with extrusive rocks and in the roof pendant near Wickes in the Jefferson City quadrangle ROCKS OF THE BOULDER BATHOLITH AND ITS SATELLITE STOCKS (UPPER CRETACEOUS AND PALEOCENE) Note: The boxes in the map legend for the main and sodic

Quartz-latite intrusive rocks contemporaneous with the

magma series are arranged according to relative position in the intrusive sequence, if known from field relations and/or radiometric age data (recalculated using the new conventional decay constants of Steiger and Jager, 1977

ROCKS OF THE MAIN MAGMA SERIES LEUCOCRATIC ROCKS

Aplite, alaskite, granite pegmatite, quartz-monzonit pegmatite, potassic leucogranite, quartz pegmatite, and quartz-tourmaline pegmatite, undivided; aplite and alaskite predominate. Generally small bodies of variable texture and structure, occurring as pods, dikes, sheets, and complexes, only few of which are entirely of a single rock type. Quartz, sodic plagioclase and alkali feldspar typically make up at least 98% of the rock, with biotite and lesser amounts magnetite, sphene, apatite, zircon, and, occasionally, allanite constituting the remaining 2%. Bodies commonly are layered, either regularly or irregularly, and some are Textures commonly change along as well as across the layers. Miarolitic cavities are common in these rocks, containing well-formed crystals of quartz (clear, smoky, or amethyst), alkali-feldspar (microcline, orthoclase, perthite and microperthite), albite-oligoclase, tourmaline, and silvery green muscovite (?); locally, molybdenite, epidote, pyrite, magnetite, sphene, and allanite are conspicuous.

Granite porphyry, light to pinkish gray with phenocrysts of show at the scale of this compilation only in the central part of the batholith. Compositionally similar to aplite-alaskite, but is distinctly more porphyritic and generally sheared and strongly altered. It shows both gradational and cross-cutting contact against Butte Quartz Monzonite (**bqm**); its relationship to the other silicic facies of the bqm is unknown. Because of their gradation into the **bqm**, these relatively rare rocks are believed to be nearly contemporaneous with the bom. The granite porphyry almost certainly is not related to the quartz porphyry dikes that cut the bqm, but pre-date mineralization, in the Butte district. As described by Brimhall (1977), the quartz porphyry dikes always show sharp contacts with the bqm and are distinctly younger (< 64 Ma; Meyer and others, 1968). Quartz monzonite of the Homestake pluton, well exposed in the Northern Pacific Railroad cut at Continental Divide this pluton represent a continuous gradational series between the Butte Quartz Monzonite (bqm) and the alaskite-aplite

> cast, depending on the amount of alkali feldspar. Contacts between the variants in the series can be gradational or sharp, in which case the more felsic of the two rocks in contact invariably is the younger. Many bodies of rock similar to those of the Homestake pluton occur throughout the Butte Quartz Monzonite but are too small to be

(a); accordingly, the texture and mineralogy of these rock

may vary widely, ranging between those characteristic of the

two end members. Most are light gray and some have pinkish

shown at compilation scale. Coarse-grained quartz monzonite of the Pulpit Rock pluton, located in the central part of the batholith (west of Boulder); overall light gray, but pinkish alkali feldspar i conspicuous. Mineralogically and texturally similar to the coarser grained varieties of the Butte Quartz Monzonite (bqm) but containing more quartz, plagioclase, and alkali porphyritic locally with large phenocrysts (or "megacrysts" of alkali feldspar, which commonly contain inclusions of earlier crystallized minerals alined along crystal faces. Generally grades into but locally cuts bqm. In contrast to the Homestake-type rocks, the Pulpit Rock quartz monzonite rarely shows gradational contacts against aplite-alaskite

Felsic quartz monzonites of unnamed plutons similar in color texture. Commonly grades into the Butte Quartz Monzoni (bqm) but cross-cutting contacts, where observed, always show the bqm to be older. Some typical bodies of these rocks occur along the southern border of the Butte Quartz Monzonite (e.g., Spire Rock, west of Whitetail Basin).

Butte Quartz Monzonite (= Clancy Granodiorite of Knopf, 1957 1963). Ouartz Monzonite and subordinate granodiorite, mostl light gray to pinkish gray in color; locally, the margina parts of the body appear darker gray because of greate abundance of ferromagnesian minerals. The rocks grade into and are cut by the silicic facies described above; locally and very rarely, thin dark dikes of undetermined composition (lamprophyre?), commonly highly altered, also cut the ban The general ranges in the principal constituent minerals (by volume) are: plagioclase 20 to 48%. alkali-feldspar 15 45%, quartz 15 to 40%, biotite < 1 to 12%, hornblende < to 8%, pyroxene sparse but locally as much as 5%. These wide ranges reflect the gradation of bqm between its related silicic facies. Average grain size commonly varies from < 1 to 3 mm, and textures also vary widely, including xenomorphic, hypidiomorphic, equigranular, and seriate. Much of the bqm is distinctly porphyritic, with conspicuous subhedral to euhedral phenocrysts of poikilitic alkali feldspar, whose length can be as great as 5 cm or more.

Despite mappable textural, color, and compositional variants -- of which more than a dozen have been mapped (fo example, see Becraft and others, 1963; Ruppel, 1963; and Smedes, 1966)--all the rocks that constitute the Butte Quartz Monzonite (bqm) are considered to be parts of a single large pluton because of the predominance of gradational contacts between the bqm variants and of close chemical and The textural and mineralogical differences are attributed to intermittent magma movement and mixing of magma fractions that reached different degrees of crystallization. These differences are best developed in parts of the pluton in proximity to country rock or older batholith rocks and are less common in the interior of the pluton.

Unionville Granodiorite and granogabbro of Knopf (1963), undivided; mostly light- to medium-gray, seriate augitenornblende-biotite granodiorite locally including dark-gray hypersthene granogabbro near contacts. Biotite commonly occurs as large bronze-colored, irregular poikilitic plates that continued to grow late in the crystallization history of

equigranular, xenomorphic to hypidiomorphic, in texture. Granodiorite of the Burton Park pluton; medium-grained, bluish-gray equigranular rock, containing poikilitic biotite, that forms a moderate-size pluton near southern end of the batholith. Several smaller satellitic bodies of granodiorite (sgd) cutting Proterozoic rocks in the area are similar in appearance to the Burton Park granodiorite and possibly correlative. Even though compositionally similar to the Unionville Granodiorite, the Burton Park rocks can only be assigned provisionally to the main magma series (Tilling 1974). In contrast to the Butte Quartz Monzonite, both the Unionville Granodiorite and Burton Park plutons contain very

hyperite, gabbro, syenogabbro, mafic monzonite, syenodiorite augite quartz monzonite, and rare layers of peridotite in gabbro. These rocks, highly variable in composition an exture, may occur as a single rock type or, more commonly form a complex of diverse rock types. Field relations and geochronometric data indicate the mafic and ultramafic rock almost exclusively along its margins. A representative suite of these complex rocks has been well characterized

Quartz monzonite of the Hell Canyon pluton, which forms the southern tip of the batholith. Although compositionally homogeneous, the pluton varies from medium-grained, light gray, slightly porphyritic rocks at its narrow southern end to coarse-grained, highly porphyritic varieties in the central and northern parts. Alkali-feldspar phenocrysts as large as 3 x 6 cm (Mathews and others, 1977), commonly contain inclusions of nearly all other minerals in discontinuous strings parallel to crystal faces. distinctive feature of many of the Hell Canyon rocks is the presence of conspicuous, equant quartz "eyes," some of which may attain 1 cm in size. The Hell Canyon rocks are cut by rare, generally small, bodies of aplite (ap). Rare aplite bodies that cut the Hell Canyon pluton; though

virtually indistinguishable from the abundant aplites associated with the Butte Quartz Monzonite, these aplites are

assumed to be related genetically to the Hell Canyon rocks

eucocratic rocks of the sodic magma series, is virtually

because of spatial association. Leucocratic granodiorite of the Donald pluton; mineralogically similar to but slightly more felsic than rocks of the Hell Canyon pluton. Equigranular, medium grained, light gray varieties predominate, but highly porphyritic rocks, with large pinkish alkali-feldspar phenocrysts also are common, locally forming spectacular castellated craggy exposures. This unit, like most other

devoid of aplitic or pegmatitic bodies. Granodiorite and quartz monzonite of the Moose Creek pluton; consists of a probably early facies in the northern part of medium- to fine-grained, light gray granodiorite that contains abundant inclusions of diorite, and a main mass of medium- to coarse-grained, mostly porphyritic muscovitebiotite quartz monzonite with phenocrysts of alkali feldspar and quartz. Locally cut by small dikes and irregular bodies of quartz porphyry. Except for the presence of minor muscovite, the rocks are mineralogically and chemically similarly to those of the Donald pluton. Moreover, like the Donald rocks, the Moose Creek pluton locally is well exposed

ENE of Divide; see Smedes and others, 1980). Leucocratic rocks of the poorly exposed Moosetown pluton. In color, mineralogy, texture, and grain size resemble those of the nearby Moose Creek pluton (mc).

Fine- to medium-grained, light gray, granodiorite and quartz monzonite, mostly equigranular; in places moderately to strongly altered. Lithologically similar to the finergrained varieties of the Donald and Hell Canyon plutons. Several unnamed plutons in the central and northern part of the batholith represent the only bodies of 1g rocks large enough to show at the scale of this compilation. The 1g rocks satisfy the chemical criteria (see Tilling, 1973) u o define the sodic-series rocks in the southern end of the batholith. These rocks, none of which have been dated radiometrically, cut the Butte Quartz Monzonite; their specific relation to the other sodic-magma-series rocks is

Porphyritic granodiorite of Knopf (1957, 1963), typically light gray and coarse grained; a homogenous pluton characterized by phenocrysts of alkali feldspar (as large as 2 x 3 cm) uniformly distributed throughout. A representative mode (by volume) is: plagioclase 40%, alkali feldspar 24%, quartz 25%, biotite 7%, hornblende 3%, with magnetite, sphene, apatite, and zircon making up the remaining 1%. This rock cuts the adjacent "granodiorite undivided" of Knopf (1963). Two K-Ar age determinations on biotite in the only sample of this pluton dated averaged 73.6 Ma, within the ange of ages found for other leucocratic rocks of the batholith (Tilling and others, 1968, Fig. 2). The rocks are chemically similar to some of the rocks of the Climax Gulch pluton (cg), but available analytical data only permit provisional assignment to the sodic magma series (Tilling,

Granodiorite and quartz monzonite of the zoned Rader Creek pluton, the largest of the plutons of the sodic magma series. The weathered surfaces of these rocks generally are darker (browner) than those of the adjacent Butte Quartz Monzonite and Donald pluton. In fresh exposures, however, most Rader Creek rocks are distinctly bluish gray. The southwestern part of the pluton is composed of mediumgrained, equigranular granodiorite, which grades continuously and nearly imperceptibly into quartz monzonite in the northeastern part. Also, rocks in the northernmost end of the exposed pluton are conspicuously porphyritic rather than equigranular; these rocks are the only ones in the entire batholith to have the porphyritic texture expressed by plagioclase phenocrysts (dark gray and as long as 1 cm), rather than alkali-feldspar phenocrysts. Detailed descriptions of the mineralogical and chemical zonation of The Rader Creek pluton is cut by the Butte Quartz main magma series (the Unionville and Burton Park) are unknown because nowhere are these rocks in contact. However, K-Ar ages for the Rader Creek rocks (74.4-78.4 Ma) and the Unionville Granodiorite (74.0-79.5 Ma) largely overlap, but (Tilling and others, 1968, Table 3). Locally, the pluton is cut by rare aplite bodies (too small to show at compilation

Fine- to coarse-grained mafic bodies that intrude the Rader Creek pluton; occur as irregular plugs and ring dikes, and, much less commonly, as thin dikes (only the larger bodies lithology, but others are composed of several distinct lithologies. Compositionally, these rocks are heterogeneous and predominantly dioritic to gabbro, but granodioritic rocks may make up much of the ring-dike complexes, generally the interior portions. These mafic bodies probably were intruded before the emplacement of the Butte Quartz Monzonite. Detailed descriptions of several of the Rader Creek mafic bodies is given in Smedes and others (1968). The relative proportion of late matic intrusions in the Rader Creek pluton is much higher than that in the Butte

Creek as well as aplitic rocks (see below).

scale) and also by a number of mafic ("lamprophyric")

intrusions (mb), which contain inclusions of the Rader

BATHOLITH ROCKS AND SATELLITIC BODIES NOT ASSIGNED TO MAGMA SERIES Many small plutons within the batholith and most satellitic bodies cannot be assigned to one or the other of the magma series because either the chemical criteria cannot be met unambiguously or the pertinent compositional data are lacking. Moreover, because the satellitic bodies occur as isolated masses in country rock and very few of them have been dated radiometrically, their positions in the intrusive sequence cannot be established. Accordingly, for this

Quartz Monzonite. The relationship among late mafic bodies

associated with different plutons of the batholith is not

compilation, we only show them by gross compositional type regardless of age as follows: Leucocratic rocks, light gray granodiorite and quartz monzonite, undivided: variable in texture, fine- to medium-grained. These rocks are relatively sparse. Intermediate rocks, light- to medium-gray granodiorite to quartz monzonite, undivided; variable in texture and grain size, but coarse-grained varieties are rare.

Granodioritic rocks, undivided; mostly equigranular, mediumgrained, and dark gray. Mafic and, less commonly, ultramafic brownish-weathering rocks, undivided; highly variable in texture and grain size. Includes some plutons that are composite bodies, composed of

PREBATHOLITH VOLCANIC AND VOLCANICLASTIC ROCKS AND CONTEMPORANEOUS Basalt and olivine-basalt lava flows and flow breccias commonly poorly exposed and/or altered. In the reconnaissance map of Prostka (1964), this unit was considered to be Tertiary, possibly post-Avon Volcanics (Trv). More recent studies (Derkey, 1986; Watson, 1986) consider these rocks, certainly where mapped in detail in the

Volcanics (Kev).

Emery mining district, to be "separate, but time equivalent

to the middle and upper members of the Elkhorn Mountains

series. In the central part of the batholith, the upper

sedimentary member of the Kev is cut by the Butte Quartz

Elkhorn Mountains Volcanics and Slim Sam Formation, undivided. Tuffaceous sedimentary rocks of the Slim Sam Formation and basalt lavas; basalt and andesite tuff, reccia, and agglomerate; and rhyolite welded tuff of the Field relations and radiometric age data demonstrate that the Kev and the earliest batholith rocks are nearly contemporaneous, but, where diagnostic cross-cutting relationships can be observed, the batholith rocks are invariably the younger (Becraft and others, 1963; Robinson the middle member of the Kev near the northeastern end o the batholith is cut by mafic rocks (m) of the main magma

Basaltic and andesitic hypabyssal intrusive rocks contemporaneous with the Elkhorn Mountains Volcanics MESOZOIC AND LATE PALEOZOIC SEDIMENTARY ROCKS, UNDIVIDED Includes the Permian Phosphoria Fm., Jurassic Swift and

Morrison Fm. and the Cretaceous Kootenai and Colorado Fms. PALEOZOIC SEDIMENTARY ROCKS, UNDIVIDED Includes the Cambrian Flathead Quartzite, Wolsey Shale, Meagher Limestone, Park Shale, Pilgrim Fm., Hasmark Dolomite, Devonian and Mississippian Three Forks Shale; Mississippian Fm.; and Pennsylvanian Quadrant Fm.

Lodgepole Limestone, Mission Canyon Limestone, and Amsden SEDIMENTARY ROCKS OF THE BELT SUPERGROUP, UNDIVIDED (See original sources given in index for details concerning stratigraphic nomenclature of the rocks mapped) Includes formations and units mapped in the northern part as Empire Fm., Spokane Fm., Helena Dolomite; Marsh Fm., and Greenhorn Mountain Quartzite; in the eastern part as Empire Shale, Spokane Shale, and Greyson Shale; and in the southern part as LaHood Fm., Quartzite of Table Mountain, Greyson Shale, Argillite of Red Mountain, Empire Fm., Helena Dolomite, and Highland quartzite. GABBRO, DIABASE, AND BASALT INTRUSIVE ROCKS CONSIDERED TO BE

BELT AGE (PROTEROZOIC) METAMORPHIC ROCKS, UNDIVIDED (ARCHEAN) Mostly gneiss and schist; lesser amounts of amphibolite and

endorsement by the USGS.

This map is preliminary and has not been reviewed for conformity with U.S. Geological

Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes and does not imply