Porphyry and Other Molybdenum Deposits of Idaho and Montana

Joseph E. Worthington

Idaho Geological Survey
University of Idaho
Moscow, Idaho

Technical Report 07-3
ISBN 1-55765-515-4

CONTENTS

Porphyry and Other Molybdenum Deposits of Idaho and Montana

Joseph E. Worthington[1]

INTRODUCTION

The present review is the result of about forty years of intermittent association with, study of, and exploration for, porphyry molybdenum deposits. Although the subject has been of little interest for the past decade or so, price increases since mid-2004 have greatly renewed interest in molybdenum. No attempt has been made at an exhaustive library search, nor has there been any comprehensive attempt to collect data on all current or recent programs.

The area under review includes the batholithic terrane of central Idaho and Montana, and comprises, perhaps, 100,000 square miles. It would be delimited by the international boundary to the north, the Cenozoic volcanics of the Columbia River, the Snake River, and the Yellowstone Plateau on the west and south, and the Rocky Mountain thrust front and nearby plutons to the east. The area is made up of the Idaho batholith and younger plutons in Idaho and the Boulder, Pioneer, and other large plutons plus smaller and younger plutons in Montana. The hosts to these plutons are folded and thrust faulted late-Precambrian and Phanerozoic sediments with lesser exposures of older Precambrian basement. There are also areas of Tertiary and recent cover, including volcanics and sediments, in both states. Much of the region is underlain by the late Precambrian Belt sedimentary basin. The molybdenum deposits appear to be restricted in age from Late Cretaceous to Eocene (98 m.y. to 36 m.y. using data from the Elsevier Geologic Time Table, Haq and Eysinga, 1987). Older and younger molybdenum deposits are known elsewhere in North America.

The present discussion is largely restricted to molybdenum-dominant mineralized systems where molybdenum is the principal potentially economic product. Some systems may contain minor copper, but most do not have significant amounts. Copper-dominated systems, typified by Butte, Montana, and numerous other occurrences, such as the older (Jurassic) occurrences of Washington and Adams counties of Idaho, are excluded, even though they may contain molybdenum. The term porphyry deposit in this discussion refers to a general type of large, bulk minable deposit, following usage in the A.I.M.E. Porphyry Copper Volume (Parsons, 1933, p. 338-340). Parsons explains that the word "porphyry" as a deposit name came from the first four deposits that were developed, which all contained prominent porphyritic rocks. Several that were developed later contained the bulk of their mineralization in wall rock, but the term "porphyry" was retained. It is well recognized that all so-called porphyry deposits do not contain porphyritic rocks, and many in this discussion certainly do not. Many, in fact, are listed merely as occurrences that could be examined further. Discoveries have been made in this manner, as will be discussed subsequently.

Nearly fifty molybdenum deposits are described with locations, ages (if available), brief details on rock composition, and literature references. Deposits are listed in Table 1, each with a location number that, in turn, is repeated in its heading in the text and corresponds to the location number on Figures 1 and 2. The ages are taken from research sources, and most are K/Ar dates. Where no dates are available, a stratigraphic age may be assigned, if it is obvious, or an analogy to a nearby date may be cited. Many of the deposits considered are of porphyry affiliation, using criteria cited above, and others are only quartz veins in granitic rocks. These will be divided into meaningful temporal and geologic groups, and those with more nearly favorable economics will be noted. The only molybdenite deposit in the region that has achieved significant production is the Thompson Creek deposit in Custer County, Idaho.

Though molybdenite does occur in some veins, these deposits will be considered only briefly, as they are not the principal focus of this report. Molybdenum deposits occur widely in the region with the most important being a

[1]Consulting geologist, Evergreen, Colorado

Table 1. Molybdenum Deposits of Idaho and Montana. See Figures 1 and 2 for the locations of deposits.

Prospect Name	State	Location Number
Tertiary Deposits		
Little Falls	Idaho	1
CUMO	Idaho	2
Ima	Idaho	3
Liver Peak	Montana	4
Bald Butte	Montana	5
Big Ben	Montana	6
Emigrant Gulch	Montana	7
Walton	Idaho	8
West Eight Mile	Idaho	37
Sawtooth Batholith	Idaho	40
Rocky Bar	Idaho	43
Red Mountain	Idaho	45
Devil's Creek	Idaho	46
Laramide Deposits		
Bentz	Montana	9
Miner's Gulch	Montana	10
Henderson Gulch	Montana	11
Black Pine Mine	Montana	12
North Flint Creek		
Tunstill	Montana	13
Tolean Lake	Montana	14
East Goat	Montana	15
Black Lion Mountain	Montana	16
Elkhorn Mine	Montana	17
Thompson Park	Montana	18
Golden Sunlight	Montana	19
Turnley Ridge	Montana	20
Granite Peak	Montana	21
Gold Bug-Hawkeye	Montana	22
Judith Peak-Red	Montana	23
Cannivan Gulch	Montana	26
Stewart Gulch	Montana	27
Belt Terrane Deposits		
Stonehorse	Montana	28
Armor Creek	Montana	29
Tim Creek	Montana	30
Black Pine	Montana	31
Ramona Creek	Montana	32
Eight Mile Creek	Montana	33
Chilco Mountain	Idaho	34
Spring Creek	Idaho	36
Monaghan	Montana	39
Hecla District	Montana	41
Kaniksu Batholith	Idaho	42
International Moly.	Idaho	42a
American Girl	Idaho	42b
Hotchkiss	Idaho	42c
Pre-Laramide Deposits		
Little Boulder Creek	Idaho	24
Ramey Creek	Idaho	25
Thompson Creek	Idaho	35
Virginia-Beth	Idaho	38
Cabin Creek	Idaho	44

porphyry type in differentiated intrusive systems or in large skarns. In some places having a single age and geologic environment, a closely spaced group of deposits may be considered a deposit cluster. A few are noted below. All molybdenum values will be reported as %Mo. Values reported as MoS_2 are recalculated as Mo.

MOLYBDENUM VEIN DEPOSITS

Large molybdenum vein systems are not always part of molybdenum porphyry systems, but they are mentioned in the (particularly older) literature, so are briefly considered here. Most early known prospects were on molybdenum veins, and a few had small production. Three known prospects in northern Idaho are associated with the Kaniksu batholith (Kirkham and Ellis, 1926; King, 1964, p. 135). The International Molybdenum Company produced about 1,000 pounds of molybdenite in 1938 from a pegmatitic quartz vein. Molybdenum veins also occur in the lower levels of the Ima mine, and King (1964) regarded the Walton prospect as a vein prospect. Numerous veins of varying sizes are described in the literature, but few have achieved significant production.

The principal interest in molybdenum veins is that they may be pathfinders to a major deposit. The best example is probably the Endako mine in British Columbia, which was known as an area of molybdenite veins as early as 1927 (Kimura and others, 1969, p. 699). Veins in the same area were also described by Armstrong (1949, p. 134). These veins were examined many times until 1952. Over the next 10 years, the prospect was further explored by several interests and was drilled by R & P Metals in 1962. Substantial disseminated mineralization around the veins was recognized, and the property was acquired by Placer Development in 1962. The history is described in detail in Rotherham and Kimura (1991). The prospect was then developed into a large disseminated molybdenum orebody beginning in 1964. Production continues today. Other examples could be cited, but disseminated and stockwork mineralization must be recognized and evaluated, if it occurs around a vein.

TERTIARY MOLYBDENUM DEPOSITS

The Tertiary molybdenum deposits are post-Laramide, upper Paleocene to Eocene in age, or about 55 m.y. to 36 m.y. (Haq and Van Eysinga, 1987). A large area is also included with the Tertiary deposits, which consists of the Sawtooth batholith, even though it is withdrawn from mineral entry. It contains potential for several deposits. There are also two deposits, Little Falls and CUMO, in the Idaho porphyry belt (which has other similar names). It is a northeast-trending linear zone of siliceous rhyolite dikes, mostly within the Idaho batholith, although it has been projected farther to the northeast. This will be discussed further. Number following the deposit name corresponds to its location in Figures 1 and 2.

Little Falls—1

Location: Idaho, Boise County, sec. 33, T. 9 N., R. 6 E.

Age: 41-42 m.y.

Geology: Tertiary, northeast-trending rhyolite dikes of the Idaho porphyry belt cut the Idaho batholith with siliceous pyritic zones containing molybdenite. There is a weathered surface of supergene argillic alteration with a molybdenum in soil anomaly. It is low grade.

References: Rostad (1967, 1978); Anderson (1947, plate 14).

CUMO—2

Location: Idaho, Boise County, secs. 17 and 18, T. 8 N., R. 6 E.

Age: 44 m.y.

Geology: Tertiary, northeast-trending rhyolite dikes of the Idaho porphyry belt cut the Idaho batholith with siliceous pyritic zones containing molybdenite. The weathered surface consists of supergene argillic alteration with a strong copper and molybdenum soil anomaly. The CUMO property was a geochemical discovery, drilled by AMAX and partners from 1968 through 1982. A recent notice in the George Cross Newsletter reports 26 drill holes defining 1.387 billion tons, grading 0.056% Mo. The large tonnage includes a smaller tonnage of better grade (444 million tons grading 0.08% Mo). There are also reported credits in copper and silver. CUMO has recently been acquired by Kobex Resources (TSX Venture) from Mosquito Resources (BIG Mining Publications, 2006).

Kobex drilled two holes totaling 1,085 meters, confirming thickness and grade indicated previously. Mosquito Resources resumed control of the property in October 2006.

References: Shannon (1971); Anderson (1947, plate 14); Rostad (1978); BIG Mining Publications (2006, p. 262); Gillerman and others (2007).

Red Mountain Prospect—45

Location: Idaho, Custer County, sec. 3, T. 19 N., R. 8 E., about 3 miles north of Yellow Pine.

Age: Eocene.

Geology: Quartz vein stockworks contain molybdenite in probable Eocene granite. The prospect was also explored for gold in the early 1990s.

Reference: Kiilsgaard and Bennett (1995, p. 131).

Rocky Bar District—43

Location: Idaho, Elmore County, on Roaring River, a south tributary to the Middle Fork of the Boise River, T. 4 N., R. 8 E.

Age: in granite mapped as Eocene.

Geology: Veins contain molybdenite, pyrite, and gold and silver credits in aplitic veins in probable Eocene granite.

Reference: Schrader (1924).

West Eight Mile—37

Location: Idaho, Lemhi County, sec. 11, T. 15 N., R. 24 E. (approximate), headwaters of Big Eight Mile Creek. Livingston (1919) reports it south of the Big Eight Mile Creek road about 3 miles south of the Bohannon Ranch, which may be at the junction of the Blue Jay mine road.

Age: Eocene(?) probable age based on nearby Ima and Blue Jay stocks.

Geology: Molybdenite was reported in a pegmatite chimney in granite. Several hundred pounds of molybdenite was reported shipped. The prospect is west of the Blue Jay mine.

References: King (1964, p. 138); Livingston (1919).

Devil's Creek Prospect—46

Location: Idaho, Elmore County, large area centered on sec. 19, T. 4 N., R. 8 E.

Age: Tertiary late phase of the Twin Springs pluton, 38-39 m.y.

Geology: The quartz monzonite of the Twin Springs pluton is intruded by quartz porphyry. The prospect was staked and explored by Inspiration in 1981. Geochemical values in soils and rocks ranged from 8 ppm to as high as

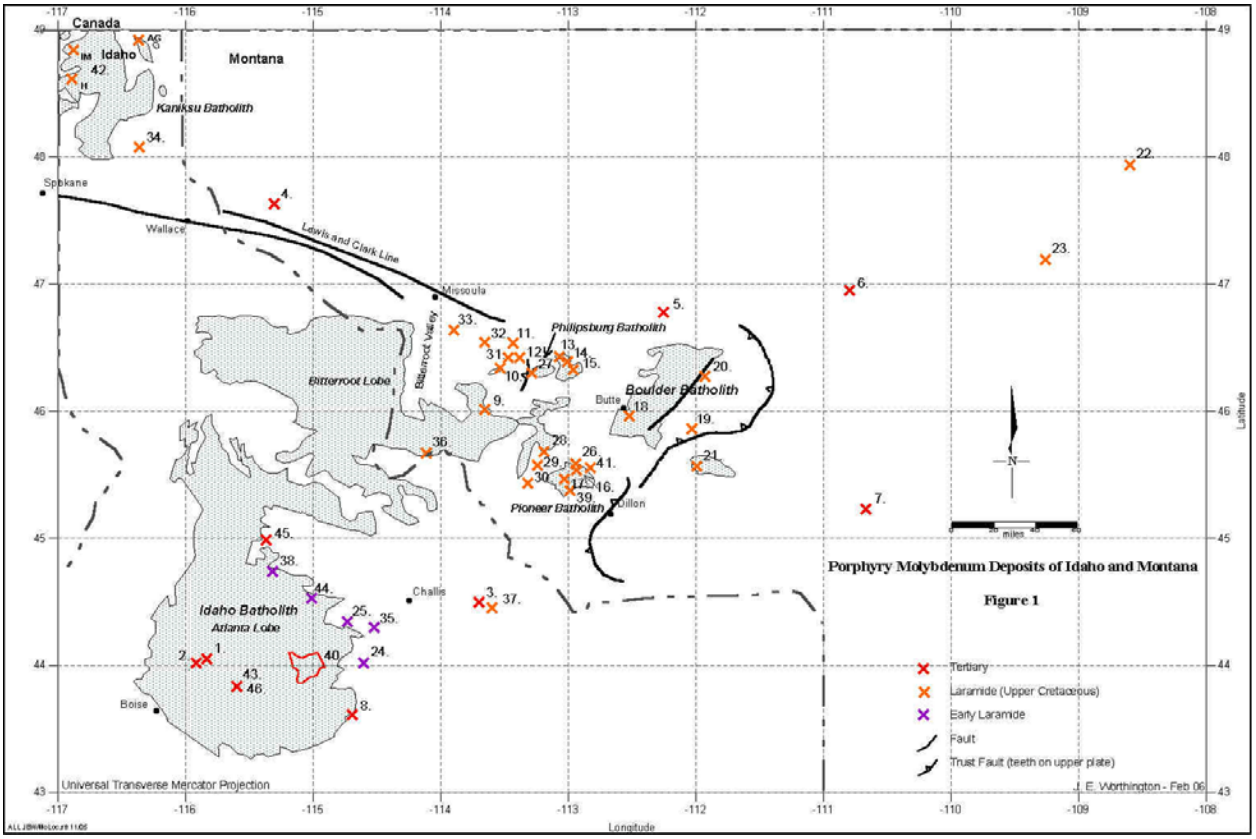

Figure 1. Porphyry molybdenum deposits of Idaho and Montana.

90 ppm. The property was not drilled as of 1984. No further information is available.

Reference: none except personal communication.

Walton—8

Location: Idaho, Custer County, sec. 7, T. 6 N., R. 19 E.

Age: Mapped as occurring in Eocene granite.

Geology: Quartz molybdenite veins are in quartz monzonite. Most are small, but some samples grade 0.12% to 0.36% Mo. Zones of veins may create the impression of dissemination. The White Mountain prospect is similar and occupies the same small stock as the Walton. It is about 2 miles south.

Reference: Kirkemo and others (1965, p. 55-58); Worl and others (1995, part A, plate 1).

Ima—3

Location: Idaho, Lemhi County, Blue Wing mining district, sec. 23, T. 14 N., R. 23 E.

Age: 41.3 m.y.; 48 m.y. Both ages are cited by Mutschler and others (1981, p. 878). The older age is consistent with other Tertiary deposits away from the Idaho porphyry belt and may be preferable.

Geology: A series of northwest-trending quartz huebnerite veins occurs in a system zoned outwardly to a polymetallic vein system. The veins cut Proterozoic metamorphosed Belt equivalent quartzites. Molybdenite increases with depth in the veins, and a molybdenite-bearing stock is exposed in deepest workings and appears in a few drill holes. The stock contains sericitic alteration. Grade is in the range of 0.054% Mo.

References: Armstrong and others (1979); Rostad (1971); Joralemon (1973); Callaghan and Lemmon (1941); Mitchell (1999).

Liver Peak (a.k.a. Goat Creek)—4

Location: Montana, Sanders County, 5 miles northeast of Thompson Falls.

Age: 49.7 m.y., rock biotite; 38.6 m.y., sericite from vein.

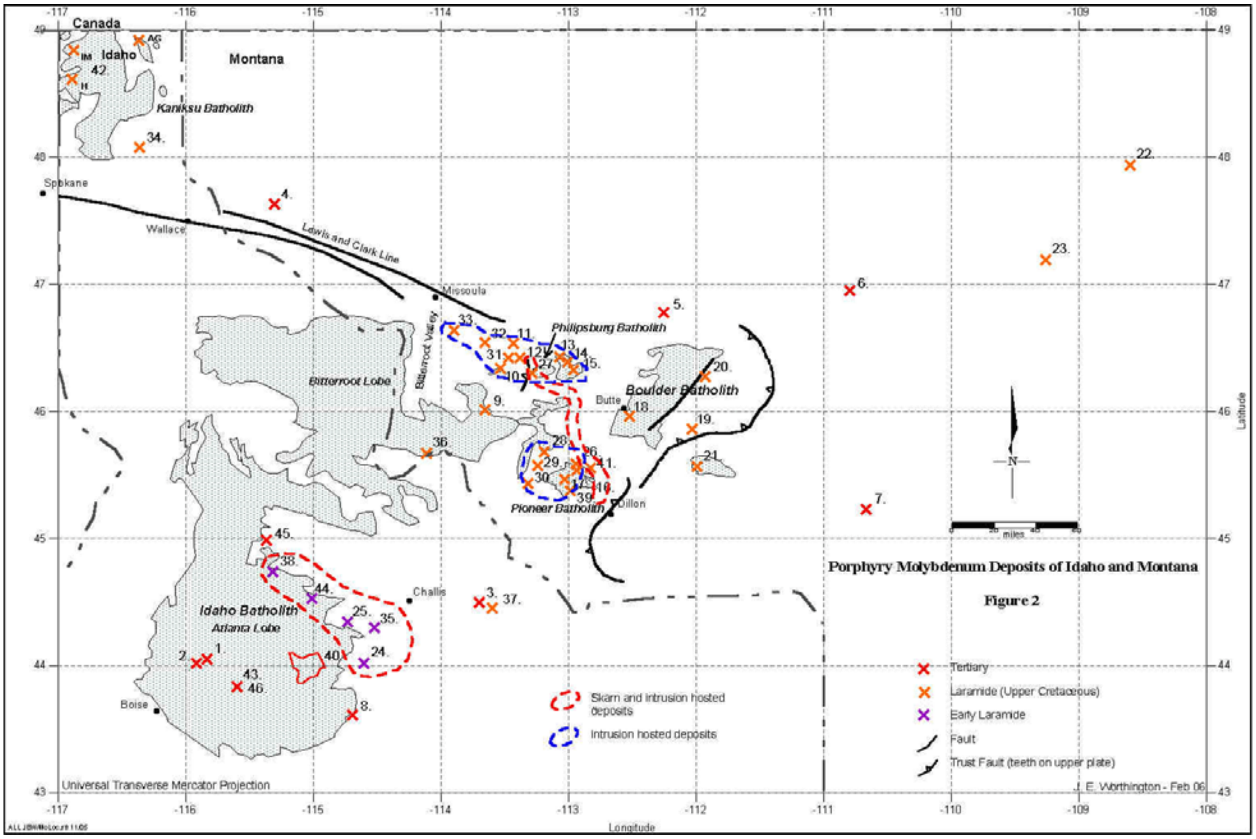

Figure 2. Porphyry molybdenum deposits of Idaho and Montana, showing deposit types.

Geology: Skarn mineralization, including tungsten, and a geochemical anomaly occur in Belt strata (Wallace Formation) at the surface. It was discovered by Bear Creek in 1967 as a stream sediment anomaly. The anomaly was staked by Bear Creek and, independently, by local prospectors in 1969. A small claim group was leased by ASARCO later in 1969 who drilled 6,000 feet in three core holes. This program demonstrated a large potential volume of deep low-grade disseminated molybdenite, but was not explored further. Noranda acquired the property in 1974 and, with Armco as a partner, drilled 10 holes to 3,000 feet or more resulting in the discovery of potentially over 100 million tons, grading 0.084% Mo. Mineralization was in Belt strata and a highly differentiated, non-outcropping Tertiary pluton. The ages quoted above for the pluton were determined by the U.S. Geological Survey. This deposit was reported to have been acquired by Idaho General Mines in late 2004, but is no longer shown as owned by them in the Northern Miner Handbook for 2006.

Reference: Lamarre and Moore (1981).

Bald Butte—5

Location: Montana, Lewis and Clark County, Marysvale mining district, sec. 10, T. 11 N., R. 6 W.

Age: 48 m.y.

Geology: Contact metamorphosed Belt series (Helena dolomite) was intruded by the Marysvale stock. An apophysis of the stock, called the Big Dike, was known to contain disseminated molybdenite. A weak molybdenum anomaly in Helena dolomite led to the discovery of mineralization under Bald Butte in an underlying pluton, which was presumed to be part of the Big Dike. It was then drilled by Amax around 1950. A resource of 20 million tons grading 0.2% Mo was reported. Additional drilling was done by Amax over the next few years. Subsequent development was undertaken by Gulf Oil and Mine Finders before the deposit was acquired by Cyprus Minerals in the 1990s. It has since been acquired in 2005 by United Bolero Development Corp., which has conducted mill tests at the Antonioli mill in Philipsburg and is now shipping ore irregularly to the same mill. United Bolero also reports (citing Gulf Oil) a resource of

131 million tons grading 0.077% Mo (Northern Miner, January 5, 2006).

References: Pardee and Schrader (1933, p. 63-76); Rostad (1969).

Big Ben—6

Location: Montana, Cascade County, sec. 21, T. 14 N., R. 8 E.

Age: Eocene, 49.5 m.y.

Geology: The terrane is early Proterozoic metamorphics intruded by Tertiary porphyries and breccia pipes. The Big Ben itself is a silicified pipe about 500 feet by 300 feet grading about 0.12% Mo (Kirkemo and others, 1965). Other pipes in the district are also mineralized. The Big Ben was drilled by the U.S. Bureau of Mines in the early 1940s; by ASARCO, eight holes in 1958-1959; and then extensively by AMAX in the 1970s. Amax was reported to have developed 120 million tons grading 0.096% Mo (private reports). The present status is unknown.

References: Kirkemo and others (1965); Marvin and others (1973).

Emigrant Gulch—7

Location: Montana, Park County, sec. 6, T. 7 S., R. 9 E.

Age: Eocene; the Absaroka Volcanics are dated by Smedes and Prostka (1972) at 44-49 m.y. Shaver (1978) assigns the dacite intrusives of the Emigrant Peak area to lower middle Eocene, or less than 50 m.y.

Geology: A porphyritic flow-banded rhyolite (Absaroka Volcanics) occurs with dacite intrusives, breccia pipes, and sericitic alteration. Copper is sometimes present. Molybdenite is reported in fractures with grade reported as 0.3% Mo (Kirkemo and others, 1965). Anaconda and others conducted considerable drilling from 1960 to 1970. Two centers of mineralization are noted in Stotelmeyer and others (1983): one primarily copper, and the other primarily molybdenum. The molybdenum center is described by Kirkemo and others (1965). The copper center has a reported resource of 164,838,000 tons, grading 0.26% copper (Stotelmeyer and others, 1983).

References: Smedes and Prostka (1972); Kirkemo and others (1965, p.69); Stotelmeyer and others (1983); Shaver (1978).

Sawtooth Batholith—40

Location: Idaho, Boise, Custer and Elmore counties, centered on T. 7 and 8. N, R. 12 and 13 E.

Age: Eocene, 44-49 m.y.

Geology: The Sawtooth batholith is within the Sawtooth Primitive Area (now the Sawtooth Wilderness Area), a large area about 314 square miles immediately southwest of Stanley, Idaho. It has been withdrawn from mineral entry since before 1970. It is included here because it has numerous molybdenum prospects and geochemical anomalies that make it very promising for intensive exploration, were that possible. It has been studied by the U.S. Geological Survey (Kiilsgaard and others, 1970), and this discussion is based on their data. This author has also flown over the area on several occasions between 1968 and 1978 and can attest to the prominent color anomalies that may be observed.

The Sawtooth Primitive Area is underlain by two principal rock types, the Atlanta lobe of the Idaho batholith and the Sawtooth batholith. The Atlanta lobe ranges from 70 to 80 m.y. and to 95 m.y. near Stanley. The so-called pink granite of the Sawtooth batholith, which is Tertiary, ranges from 42 to 49 m.y. and is possibly related to the Challis Volcanics. Geochemical studies by Kiilsgaard and others (1970), conducted as part of the Wilderness Study appraisal, indicate two populations of anomalies from the study area: a “tin suite,” anomalous in tin, beryllium, molybdenum, uranium, and niobium, which are generally associated with the Tertiary intrusives; and a “gold suite,” anomalous in gold, silver, lead, and zinc, occurring in Idaho batholith lithologies. The molybdenum occurrences of the Sawtooth Primitive Area are associated with the Sawtooth batholith and thus are Tertiary in age.

The extreme ruggedness of the Sawtooth Primitive Area has always inhibited exploration and development. The Sawtooth batholith within the Primitive Area covers approximately 100 square miles. The prospects noted by Kiilsgaard and others (1970) include a few older ones that predate the establishment of the Primitive Area, of which a few contain visible molybdenite. It should be noted that in steep, rugged, and weathered terrain, such as the Sawtooth Mountains, molybdenite can easily be removed from outcrop by physical or chemical weathering. There are also prominent altered areas, easily visible from the air. These appear generally brown to yellow, indicating disseminated sulfides, with (yellow) jarosite in higher sulfide concentrations. Over a dozen color anomalies are shown on Plate 2 of Kiilsgaard and others (1970), several of which are a mile or more in area. Several of the altered areas are anomalous in molybdenum, and about one-third of the stream sediment samples collected in the batholith in the USGS program were in excess of 10 ppm molybdenum. There has been very little modern exploration in the batholith because of the rugged terrain and subsequent mineral withdrawals. Only one drilling campaign is known, conducted by J. R. Simplot Co. Three core holes were drilled near Rock Creek in 1967 (Kiilsgaard and others, 1970, Figure 7, p. D20). An extraordinary concentration of molybdenum is suggested for such a restricted area, and if were access available, this would be a high priority area for molybdenum exploration.

Reference: Kiilsgaard and others (1970).

LARAMIDE MOLYBDENUM DEPOSITS

The Laramide molybdenum deposits, formed during the time of the Laramide orogeny, are almost certainly related to so-called Laramide intrusives. The term “Laramide” as used in this discussion is taken from Eardley (1951, p. 284). It refers to the great compressional orogeny in the western United States of the very late Cretaceous and slightly younger strata as well as associated intrusives and related ore deposits. It spans the interval from approximately 75 to 60 m.y. and thus includes the latter part of upper Cretaceous time and laps over into early Paleocene. It is also the time of emplacement of the Boulder batholith, which is 78-68 m.y. according to Tilling (1973). A few dates may be a slightly outside the above cited limits. Since there are more Laramide deposits than other types, they will be subdivided by host rock types.

INTRUSION-HOSTED DEPOSITS

Numerous intrusion and breccia pipe hosted molybdenum occurrences, as well as quartz molybdenite veins, are known in Idaho and western Montana. Some deposits are in nonporphyritic phases that are considered younger phases of a nearby batholith, and somewhat fewer are in porphyritic phases. They are generally considered to be Laramide in age, though only a few have been dated. An exhaustive search of the literature for dates has not been made. The deposits are characterized by either biotitic or sericitic alteration, or sometimes both. They rarely appear to be strongly mineralized systems and are generally low in grade (less than 0.05% Mo). Thompson Creek is, of course, the exception. There was one small outcrop at Thompson Creek beneath the Challis Volcanics that contained strong quartz sericite alteration and occasional relict visible molybdenite. Intrusion-hosted deposits may contain approximately equivalent values in copper, although molybdenum is dominant economically. Number following the deposit name corresponds to its location in Figures 1 and 2.

Kaniksu Batholith Cluster—42

Location: Idaho, Boundary and Bonner counties; three prospects.

International Molybdenum Co.—42a: Boundary County, sec. 27, R. 64 N., R. 4 W.

American Girl—42b: Boundary County, sec. 9, T. 64 N., R. 1 E.

Hotchkiss (Hines)—42c: Bonner County, sec. 3, T. 61 N., R. 5 W.

Age: 51 m.y., Harrison and others (1972).

Geology: A small group of vein occurrences is associated with the Kaniksu batholith in the Idaho panhandle, all in Boundary County. The Kaniksu batholith is north of the Lewis and Clark Line and may be unrelated to the Idaho batholith. None of the prospects appear significant, although the International Molybdenum had minor production. The northwest-trending veins at the International Molybdenum occur within the batholith and consist of molybdenite in brown glassy quartz (Kirkham and Ellis, 1926, p. 59). The terrain is heavily wooded, and the several vein occurrences might attract interest. They could be effectively explored by geochemical methods.

References: Kirkham and Ellis (1926); Harrison and others (1972); King (1964, p. 135).

Spring Creek—36

Location: Idaho, Lemhi County, secs. 34 and 35, T 25 N., R. 18 E. (Idaho Meridian). Spring Creek is a tributary to the Salmon River, heading north at Shoup. Access is also from Darby, Montana, via Route 473, or by poorer road from Shoup.

Age: Laramide(?), no known date.

Geology: In 1976, there were several valid claim groups in this area. A private report (Schmidt, 1976) provides some geological data. A series of northeast-trending quartz veins cut Proterozoic granite gneiss. The visible mineralization includes quartz, pyrite, and molybdenite in the veins. Wall rock is unaltered and barren of sulfides. There were a few high-grade assays, as much as 2.3% Mo. The area was explored by Utah International in 1971, Boldex Exploration in 1975, and probably others. No more recent activities are known.

References: King (1964, p. 135); E.A. Schmidt (private report, 1976).

Bentz—9

Location: Montana, Granite County, S½ sec. 5, T. 4 N., R. 16 W.

Age: Laramide(?), no known date.

Geology: The prospect consists of scattered quartz veins, striking northwest, as much as 10 inches in width, and containing molybdenite and chalcopyrite with potassic alteration. The veins are in fresh quartz monzonite near Belt sediments.

Reference: R.W. Thomssen (written commun.).

Miners Gulch—10

Location: Montana, Granite County, sec. 30, T. 8 N., R. 15 W.

Age: An undated younger small pluton in Miners Gulch granodiorite, which is 70.6 m.y.

Geology: A molybdenum anomaly is associated with a small sericite altered pluton in the larger stock. No other known work.

Reference: Loen and others (1989).

Henderson Gulch—11

Location: Montana, Granite County, secs. 2 and 3, T. 8 N., R. 14 W.

Age: Henderson pluton, 70.1 m.y.

Geology: A small exposed pluton (less than 1 square mile) consists of medium-grained granodiorite porphyry to quartz monzonite porphyry. Scheelite occurs disseminated and in small quartz-scheelite veins. Average grade is reported as 0.03% WO_3. Only traces of molybdenite occur in small quartz veins, but the prospect is included because of the common tungsten-molybdenite association. Drilling has been reported, but results are unknown.

References: Hughes (1975); Walker (1960, p. 17); Hundhausen (1949).

Black Pine Mine—12

Location: Montana, Granite County, secs. 8 and 17, T. 8 N., R. 14 W.

Age: Laramide, age of host intrusive probably similar to that at Henderson Gulch.

Geology: The Black Pine mine in sec. 17 was mined in conformable veins containing silver and tungsten in Belt strata. One mile to the north in sec. 8, a single drill hole by Inspiration intersects molybdenum porphyry mineralization in a dike probably related to the pluton at Henderson Gulch. This deposit can also be grouped into a deposit cluster with Miners Gulch, Henderson Gulch, and the Black Pine Belt molybdenum deposits.

References: Hundhausen (1949, Figure 2); Walker (1960, p. 7-12).

North Flint Creek Molybdenum Cluster—13, 14, and 15

Location: Montana, Granite County, three prospects:
Tunstill—13: sec. 28, T. 8 N., R. 12 W.
Tolean Lake—14: sec. 25, T. 8 N., R. 12 W.
East Goat Mountain—15: sec. 6, T. 7 N., R. 11 W.

Age: The Philipsburg and Mount Royal batholiths are 70 to 75 m.y. in age. The Mount Powell batholith is somewhat younger.

Geology: Three closely spaced molybdenum deposits occur in the northern Flint Creek Range, Granite County, Montana. All are in a northwest-trending area about 4 by 2 miles. Two are altered areas in batholithic rocks, and one is a poorly exposed vein. The Tolean Lake area is approximately in the center of the Mount Royal batholith. It is described as molybdenum associated with quartz vein stockworks in granitic rocks. The area is depicted as about 1 square mile. It was reported drilled by AMAX Exploration, and at least 4 million tons, grading 0.02% Mo, was estimated by the U.S. Bureau of Mines. A similar but smaller prospect was reported about 2 miles to the southeast on the northwest flank of East Goat Mountain. This prospect is in the Mount Powell batholith near its northwest end (where it appears to penetrate the Mount Royal batholith). The prospect was mapped, sampled, and drilled by Noranda (Ericksen and others, 1981), but results are unknown. The third prospect, known as Tunstill, is a quartz molybdenum vein near the west margin of the Mount Royal batholith in an area of very heavy cover. Geochemistry and geophysics (I.P.) produced only minor anomalies, and it was not drilled. All the prospects are considered Laramide in age

References: Ericksen and others (1981); Baty (1976); Hyndman and others (1982).

Black Lion Mountain—16

Location: Montana, Beaverhead County, secs. 30 and 31, T. 27 N., R. 12 W.

Age: Laramide by analogy with nearby Cannivan Gulch deposit. This and several following deposits are all in or near the Pioneer batholith. Zen (1988) lists several ages in the batholith, most ranging from 64 to 74 m.y.).

Geology: The Black Lion prospect was discovered about 2 miles south of the Cannivan Gulch deposit. It consists of quartz, biotite, molybdenite, pyrite veins and weak stockworks in a quartz monzonite related to the Pioneer batholith. There are also weak molybdenite occurrences in Belt quartzites on the east slopes of Black Lion peak. Three holes were drilled in the quartz monzonite west of Black Lion Lake with values all less than 0.05% Mo.

References: E.A. Schmidt (1973, private reports to Cyprus Mines Corporation); Zen (1988).

Hecla District—41

Location: Montana, Beaverhead County, sec. 2, T. 3 S., R. 11 W.

Age: Laramide (nearest dated rocks are Cannivan Gulch and the Pioneer batholith).

Geology: The ores are in irregular veins and replacements in the Cambrian Hasmark equivalent surrounding a domal structure exposing the basal Cambrian (Black Lion Conglomerate after Zen, 1988). The dome may overlie an intrusive, as postulated by Karlstrom (1948). Exposures (or float) of molybdenum porphyry mineralization have been reported (T. Chadwick, written commun.).

References: Karlstrom (1948); Zen (1988).

Elkhorn Mine—17

Location: Montana, Beaverhead County, sec. 14, T. 4 S., R. 12 W.

Age: Laramide (within the Pioneer batholith).

Geology: The prospect is an old silver vein in the quartz monzonite of the Pioneer batholith. A long adit exploring under the old vein workings was accessible in 1981. For a few hundred feet from the portal, the quartz monzonite contained sporadic quartz, biotite, and molybdenite veins. Further in the adit is more intense quartz sericite alteration and somewhat more abundant molybdenite. Neither zone has been adequately sampled, but both are probably 0.05% Mo or less. The quartz sericite zone appears to be higher in grade and should probably be explored further.

References: private reports to Cyprus Mines Corporation and Denison Mines Corporation by Worthington (1981) and also by Forsberg (1981).

Monaghan—39

Location: Montana, Beaverhead County, sec. 5, T. 5 S., R. 11 W.

Age: Laramide (within the Pioneer batholith).

Geology: A greisen zone about 600 feet in diameter lies within the Pioneer batholith and contains quartz molybdenite veins. This is in an area of high molybdenum stream sediment anomalies as recorded by Cyprus Mines in 1971.

Reference: Kirkemo and others (1965, p. 62-64).

Thompson Park—18

Location: Montana, Silver Bow County, exposures on paved highway, west of Pipestone Pass.

Age: Laramide, within the Boulder batholith.

Geology: Prominent jarosite staining occurs in sericitic Butte quartz monzonite on old U.S. Highway 10 west of Pipestone Pass, possibly in an aplitic facies. Molybdenite is present in an outcrop at a nearby railroad trestle.

Reference: none.

Golden Sunlight—19

Location: Montana, Jefferson County, secs. 19 and 30, T. 2 N., R. 3 E.

Age: Mineralization is contemporaneous with sill related to Elkhorn volcanics and is older than 79 m.y.

Geology: A large breccia pipe cuts Belt sediments and the sill, and plunges westward. It has been mined continuously for 20 years and is a large producer of gold by Placer Dome, Inc. The breccia pipe is reported to become a molybdenum porphyry at depth, although no information is available on the mineralization. Because of the large area of silicified and pyritic Belt sediments exposed at the surface, this occurrence could also be classed as a Belt terrane molybdenum deposit (see following discussion). The Golden Sunlight is certainly first and foremost a major gold deposit, but the reported occurrence of molybdenum porphyry mineralization at depth prompts including it here.

Reference: Foster and Childs (1993).

Turnley Ridge—20

Location: Montana, Jefferson County, Elkhorn mining district, sec. 15(?), T. 6 N., R. 3 W.

Age: Laramide; stocks in Elkhorn Volcanics are most likely to be Boulder batholith in age.

Geology: A stock in Elkhorn Volcanics is reported to contain molybdenum.

Reference: Senter (1976).

Granite Peak—21

Location: Montana, Madison County, secs. 18 and 19, T. 3 S., R. 3 W.; secs. 13 and 24, T. 3 S., R. 4 W.

Age: Laramide, Tobacco Root batholith is 75 m.y.

Geology: Granite Peak is within the Middle Mountain Roadless Area. It is also within the Tobacco Root batholith, which is a coarse porphyritic biotite-hornblende quartz monzonite with finer grained and aplitic phases. There are several iron-stained areas but little hydrothermal alteration. disseminated pyrite occurs in the quartz mon-zonite, and molybdenite and chalcopyrite are visible on fractures. Property was held by Burlington Northern Railroad in 1974. Two holes were drilled by Molycorp in 1971. Best results were 50 feet of 0.041% Mo in a core hole southeast of Granite Lake and 80 feet of 0.072% Mo in a core hole on the north slope of Granite Peak. As of 2006, the status is unknown.

References: O'Neill and Cather (1984, p. 721-723); Giletti (1966); E.A. Schmidt (written commun.).

Gold Bug-Hawkeye—22

Location: Montana, Phillips County, Gold Bug, sec. 22, T. 25 N., R. 24 E.; Hawkeye breccia is 1.5 miles east of Gold Bug mine.

Age: Gold Bug Mine, altered syenite porphyry, 62.4 m.y.; Hawkeye breccia 58-66 m.y.

Geology: Intrusive breccias occur in altered syenite porphyry at both localities. The Gold Bug breccia is reported to run 0.07% Mo, and also contains values in copper, lead, and silver. The Hawkeye breccia was investigated by AMAX around 1967.

References: Lindsey and Fisher (1985); Marvin and others (1980); Rostad (1978).

Judith Peak-Red Mountain—23

Location: Montana, Fergus County, Judith Peak, sec. 19, T. 17 N., R. 20 E.; Red Mountain is 1.25 miles east of Judith Peak.

Age: Judith alkali granite, 62 m.y.

Geology: Intrusive breccias in alkali granite at Judith Peak are reported to contain 0.03% Mo and also values in gold, copper, and lead. The brecciation and mineralization at Red Mountain are mapped similarly.

Reference: Lindsey and Fisher (1985).

SEDIMENT-HOSTED DEPOSITS

Several deposits are predominantly hosted in sedimentary rock, but there is almost always an associated intrusive, even if volumetrically small. In most deposits, part or all of the mineralization may be in the sedimentary host, usually contact metamorphosed. Number after deposit name corresponds to its location in Figures 1 and 2.

Cannivan Gulch—26

Location: Montana, Beaverhead County, Vipond mining district, secs. 16 and 21, T. 27 N., R. 11 W.

Age: intrusive, 66 m.y.; vein, 62 m.y.

Geology: The Cannivan Gulch deposit was discovered by Richard W. Thomssen by geologic prospecting in 1968. Thomssen was assigned the northern part of the Pioneer batholith as a target area by C.C. Goddard and J.E. Worthington, who were employees of Cyprus Mines Corporation. Thomssen found and recognized a small differentiated quartz monzonite body that intruded middle Paleozoic strata creating magnesian skarns in the Jefferson dolomite. The prospect was staked, mapped, and sampled in 1968. It was drilled starting in 1969 and intensively thereafter. Two ore zones were developed: one in the sericitic and potash feldspar altered intrusive (about 90 million tons, grading 0.09% Mo) and one in skarn (about 110 million tons, grading 0.11% Mo, with some recoverable copper). Cyprus ceased all activities in the early 1980s. The property was more recently acquired by United Bolero Development Corp. (TSX Venture), who now claims a resource of 300 million tons, grading 0.06% Mo). Since this deposit is really two separate deposits, it can also be grouped with the nearby Black Lion Mountain deposit as a deposit cluster.

References: Schmidt and Worthington (1977); Schmidt and others (1979); BIG Mining Publications (2006).

Stewart Gulch—27

Location: Montana, Granite County, Flint Creek mining district, sec. 18, T. 7 N., R. 13 E.

Age: Bimetallic phase of the Philipsburg batholith is 76.7 or 74 m.y., porphyries are probably younger.

Geology: The Flint Creek (Philipsburg) mining district has a long productive history from veins and replacements, mainly in Paleozoic sediments. Interest in the possibility of porphyry style mineralization at Philipsburg began about 1960 by Bear Creek Mining Company at the instigation of C.C. Goddard. Mineralized outcrops including skarns and small porphyry plugs in Stewart Gulch attracted his attention. Nothing resulted from this program, but seven years later, in 1967, Goddard inter-ested Cyprus Mines in the same concept. Cyprus drilled in 1968 and again in 1969 (in joint venture with Superior Oil). This program was successful in identifying porphyry-type molybdenum mineralization in skarn and delineating a small ore zone. The project was then abandoned as being too small. Next, the area was further explored by Denison Mines in 1980-1982. The work was proposed by J.E. Worthington (who earlier had been associated with Goddard) and D.B. Robertson. Detailed geophysical sur-veys (magnetics and induced polarization) were per-formed. Two more holes were drilled, but the program was not advanced. It was then terminated. Little interest since, though a rumor persists that a large company is interested.

The Stewart Gulch area at the north end of the Philipsburg district is underlain by folded Belt and Paleozoic strata intruded by the Philipsburg batholith and a younger sequence of differentiated porphyries of unknown age. These porphyries have been studied petrographically and are strongly porphyritic, with four or more recognizable phases, and are intensely altered. There is also crenulated quartz porphyry (Guilbert, private reports, 1981). The main district mineralization consists of precious metal veins in the batholith, base metal veins and replacements in the carbonates, and extensive skarns in the carbonates around the porphyries. The skarns are in the Madison Formation (Lodge Pole Limestone) and in the upper Jefferson Dolomite. Drilling in skarns suggests a resource of about 85 million tons, grading about 0.07% Mo. This resource is not the result of a detailed calculation, but was estimated from the few available drill holes with continuity established from an induced polarization survey. Copper is also present. The skarns are not completely drilled out, and the porphyry system is not adequately drilled.

References: Emmons and Calkins (1913); Worthington and Robertson (1982, private reports to Denison Mines); Worthington (2005, written commun.).

BELT TERRANE MOLYBDENUM DEPOSITS—28, 29, 30, 31, 32, 33, 34

Location: western Montana and northern Idaho, seven prospects.

Stonehorse—28: Montana, Beaverhead County, secs. 3, 4, 9, and 10, T. 2 S., R. 13 W.

Armor Creek (a.k.a. Odell Mountain)—29: Montana, Beaverhead County, secs. 27 and 34, T. 3 S., R. 13 W.

Tim Creek—30: Montana, Beaverhead County, secs. 9, 16, and 21, T. 5 S., R. 13 W.

Black Pine Prospect—31: Montana, Granite County, sec. 7, T. 8 N., R. 14 W.; sec. 12, T. 8 N., R. 15 W.

Ramona Creek—32: Montana, Granite County, secs. 26 and 35, T. 9 N., R. 16 W.

Eight Mile Creek—33: Montana, Ravalli County, sec. 5, T. 10 N., R. 18 W.

Chilco Mountain (a.k.a. Pyrite Creek)—34: Idaho, Kootenai and Bonner counties, sec. 32, T. 53 N., R. 1 W.

Geology: These prospects are all found in the Belt terrane. They were identified as having similar characteristics in the Cyprus program in the late 1970s. There are now ten known examples, but two are included in this report with Tertiary deposits (Liver Peak and Ima) because they have Tertiary dates, and one is the Golden Sunlight breccia pipe at depth that is included with intrusion-hosted deposits.

The deposits are all large areas of weak to moderate silicification and in places sericitization, in usually well-fractured to brecciated and iron-stained quartzite strata, with some stockwork quartz veining. All are weakly anomalous in molybdenum, and less commonly in copper. They usually contain consistent, but low, amounts of disseminated pyrite. Most of these prospects were discovered in the late 1960s, before gold was an important exploration target, and before widespread use of the atomic absorption analytical technique as applied to gold. No gold data exist on any of these prospects that I have ever seen, except at Golden Sunlight, which was always a known gold prospect. Gold analyses were certainly done in later work at some of the rest. Some breccias are associated with porphyritic intrusives, or, in some places, intrusives have been found at depth by drilling. The prospects are all large in area, typically 2 square miles or more. They are thus exploration targets of some significance based on size and geochemistry. One (Liver Peak) has shown a real increase in grade with deep drilling. All have been drilled with at least two or more holes. None of the deposits other than Golden Sunlight, however, has yet been developed as an economic deposit.

PRE-LARAMIDE MOLYBDENUM DEPOSITS

The time of these deposits is in the early upper Cretaceous or about 98 to 75 m.y. and may slightly overlap with the Laramide category. The pre-Laramide deposits are geographically distinct, however, and are grouped around the east margin of the Atlanta lobe of the Idaho batholith. Five deposits are in this grouping, but they include two of the largest, Thompson Creek and Little Boulder Creek. The two largest are also the only deposits that are dated in the group. The ages range from 84 to 88 m.y. It seems logical to include the three less well known occurrences with the others. The Thompson Creek deposit is the only one in the entire area to have achieved significant production, and will, therefore, be discussed in more detail. Number following the deposit name cor-responds to its location in Figures 1 and 2.

Thompson Creek—35

Location: Idaho, Custer County, T. 11 N., R. 16 E., centered on sec. 2.

Age: 88 m.y., pluton: 86 m.y., veins (Marvin and others, 1973a).

Geology: The Thompson Creek deposit is unusual in several ways, including age, size, alteration characteristics, and other geological attributes. It was discovered as a stream sediment anomaly at the mouth of Pat Hughes Creek in 1962 by Henry T. Eyrich. The discovery outcrop was in the headwaters of the creek in heavily wooded, steep, and not easily accessible terrain. The outcrop was heavily sericitized quartz monzonite with rare visible molybdenite. Though obscured on the ground be-cause of forest cover, it was spectacularly visible from the air. Grade was low in the outcrop with an average of 80 ppm Mo and hotspots of 0.06% Mo. Nothing further was done during 1962. A few years later in 1967, C.C. God-dard, along with J.E. Worthington, and the same H.T. Eyrich, began a program at the prospect. Claims were staked in 1967, and drilling soon demonstrated a significant improvement in grade over Eyrich's surface sampling. The prospect was explored and developed by Cyprus Mines Corporation from 1967 through 1983 when it was placed in production. The final development and production costs were funded by Amoco Oil Company (which had acquired Cyprus in 1979). It has been worked discontinuously from then to the present. Average grade has been in the range of 0.10 to 0.13% Mo for probably well over 100 million tons of production, with a lesser resource remaining.

Ages at Thompson Creek were determined to be around 88 m.y. for the pluton, and 86 m.y. for the vein mineralization (Marvin and others, 1973a). These ages are consistent with an age of 95 m.y. reported by Armstrong and others (1977) in the Idaho batholith (Atlanta lobe) near Stanley at the east margin of the batholith. The ages are also consistent with about a dozen more recent Idaho batholith ages from Stanley south to the White Cloud Peaks (Fisher and others, 1992). As exposed at the original surface, the quartz monzonite was equigranular with no obvious porphyritic phase or other direct evidence of a highly differentiated system. The Pat Hughes Creek outcrop was well oxidized with sparse remaining sulfides. Drill holes that penetrated the Challis Volcanic-quartz monzonite contact in the mineralized zone generally showed a few tens of feet of oxidation at the pre-Challis erosion surface.

By 1982, after over 300,000 feet of drilling, 8,500 feet of underground work, and the initiation of excavation, Schmidt and others (1982) reported a minable reserve of 173,680,000 tons averaging 0.115% Mo at a cut off of 0.05% Mo, with a waste to ore stripping ratio of 3.05:1. He also described a multiphased intrusive system with an outer zone of biotite granodiorite enclosing an inner zone of biotite quartz monzonite. The inner, deeper, and presumably younger quartz monzonite phase is lower in biotite but higher in potash feldspar and contains monazite. The molybdenum mineralization appears most likely to be related to this phase. Schmidt also mentions granite porphyry dikes lower in the system. Thus, there is evidence of differentiation in these rock sequences, but no evidence of a strongly differentiated system with multiple porphyries, dikes, and breccias as in some porphyry systems. The molybdenum occurs entirely in quartz veins, with very little dissemination. There is no zone of massive silicification. Alteration is characterized by pyrite, quartz, and sericite (mainly in veins) at shallow depths, now mostly mined out. The dominant alteration at depth (again in veins) is coarse biotite, in some places interleaved with molybdenite in quartz veins. Potash feldspar is also in the biotitic veins and disseminated potash feldspar in the younger intrusive at depth. High-grade sections are deeper in the pit where this is prominently displayed, as will be discussed subsequently. It is essentially a pure molybdenum system, producing premium grade concentrates with no significant credits in other elements or penalties from deleterious constituents. The Thompson Creek deposit appears to be geologically unique in the region, although it has similarities to the Endako deposit in British Columbia. Endako, in fact, served as a model in the early evaluations of Thompson Creek in 1969.

Cyprus operated Thompson Creek sporadically until

1993, when it was sold. The buyer was a private group that became the Thompson Creek Metal Company with Thompson Creek Mining Company as its operating subsidiary. Thompson Creek Metal Company also acquired a 75 percent interest in the Endako Mine and a metallurgical facility in Pennsylvania. They operated successfully into 2006 when negotiations were underway with Blue Pearl Mining Ltd. (TSE) about a possible sale. The sale was finalized in October of 2006, and all the principal assets of Thompson Creek Metal Company have been acquired by Blue Pearl. According to the Blue Pearl annual report for 2006, they are planning to expand production. They cite proven and probable mineral reserves of 64.5 million tons grading 0.119% Mo and a measured and indicated mineral resource of 178.6 million tons grading 0.094% Mo (Blue Pearl Mining Ltd., 2006 Annual Report, p. 3).

In 1999 and 2000, Thompson Creek Mining Company began a small exploration program to develop additional reserves, utilizing the mine geologist part time, a few temporaries, and consultants (including the writer). The company had two objectives: expanding pit reserves and reviewing other known prospects in the mine land position. The program began with a review of office data and an examination of prospects in the land position accompanied by geochemical sampling and magnetometer surveying. An abrupt decline in the price of molybdenum in the summer of 2000 caused the program to be terminated prematurely. Exploration was not resumed by Thompson Creek Mining Company; Blue Pearl's exploration plans are unknown.

One positive result of this short-lived exploration effort in 1999 and 2000 may have significant implications for elucidating the deposit's geology as well as suggesting exploration possibilities. During discussions of pit geology in the summer of 1999, a series of assay plans of active mine levels, including all blast holes, were examined. Because the large plan maps with hundreds of closely spaced assays were difficult to interpret, it was decided that it might be useful, if tedious, to contour them. The company's engineering department solved this problem and very quickly provided the 6950 level, then the deepest in the pit, contoured by computer at 0.1 and 0.2% Mo. Soon thereafter, five 50-foot bench plans from 6900 to 7100 in elevation were all contoured. As far as could be determined at that time, this had not been done before. There were no deeper levels because the 6950 elevation was the pit bottom, and higher levels were no longer readily accessible in old records. The patterns shown in the assays were most surprising. It had been known that the wide portion of the south end of the pit had consistently higher grades. The assay plans demonstrated that there was a roughly oval area that consistently assayed over 0.2% Mo. The shape from bench to bench was not always exactly similar because the pit walls and the material already mined caused minor alterations, but the high-grade feature was quite consistent from the 7100 level down to the 6900 level. It appeared to be close to vertical and to possibly enlarge slightly with depth. The feature is approximately 800 feet in a northwest dimension and 600 feet or more in a northeast dimension, with minor variations. All of the assays within the 0.2% Mo contour on the 7100 level were tabulated and averaged arith-metically by J.E. Worthington. There were 236 assays averaging 0.245% Mo for the feature on that level. The remainder of the pit was in the range of 0.1% Mo or less, with three or four smaller features, but with similar grade, in the northwest end of the pit. The smaller features were 200 to 400 feet in diameter, with grades also above 0.2% Mo. These smaller features also can be followed from level to level. The smaller features also appear to be close to vertical. These features could not have been recognized without the blast hole level plans, which were developed during mining and not available to Schmidt and others (1982) before the mineralization was exposed in the pit. Schmidt and his coworkers only had widely spaced drill holes and could not have seen the assay distributions that are now evident.

The description and identification of these features is a high priority in understanding the system and in attempting to predict mineralization at depth. Molybdenum porphyry systems commonly have large vertical ranges. The high-grade features in the level plans have not been defined geologically. The program for the year 2000 had planned to do this, but was not carried out. Observations in the south end of the pit during 1999 were limited to a few hours. It appeared that the higher grade areas contained above average concentrations of coarse-grained quartz-biotite-molybdenite mineralization. Geologic relationships were largely obscured by rubble on the pit floor. The high-grade bodies seem to be geologically distinct, but their character is not known with any certainty. They might be alteration pipelike features, possibly a separate, perhaps brecciated, intrusive phase. The mine geologist in 2003 described the areas of higher grade as structural intersections. Breccia pipes in the older literature are commonly described as occurring at structural intersections. They might be a combination of any of the above origins. Such a mineralized body with associated alteration and breccias could possibly be the missing differentiated intrusive, similar to those in other large molybdenum systems, which has appeared to be lacking at Thompson Creek.

Making the assumption that Thompson Creek is a large magmatic-hydrothermal system with high-grade, pipelike features is a different concept than that described in the earlier work of Schmidt and others (1982). Unfortunately, data are only available for 200 feet of vertical extent. Since they are strongly mineralized features, it can probably be assumed that they have considerable vertical range. Upward extensions are unknown, but the downward extension can still be explored. Downward, they could diminish in size and finally disappear like the root of a tooth. There is also the possibility of the high-grade bodies coalescing into a larger high-grade body. Apophyses of this deeper body would be now visible in the present pit. There is, therefore, a geologic possibility of a large target in the next 1,000 feet below the pit bottom, or approximately at the elevation of the Salmon River. The high-grade areas in the pit floor may grade in the range of 0.25% Mo. Therefore, a potential target area as much as 4,000 feet long may lie beneath the pit bottom with room for a high-grade molybdenum accumulation sufficiently large for underground mining. With some geologic work to sharpen the target, and possibly some geophysics, this deposit could be effectively drilled from the present pit, which is a different interpretation than that of Schmidt and others (1982). Their cross sections show an ore zone with both a top and a bottom, although their potassic alteration zone has no bottom. This writer would suggest that the ore might have originated at depth with the alteration. There is no suggestion of post-ore rotation. The vertical features in the blast hole data appear to be real and might represent such a feeder system.

Little Boulder Creek (a.k.a. White Cloud Peak)—24

Location: Idaho, Custer County, sec. 3, T. 8 N., R. 16 E.

Age: 61.5 m.y. (Armstrong and others, 1978); newer and more preferable ages are sericite from Mo-bearing quartz veins 84.65 m.y. and from quartz veins in sediments 84.8 m.y. (Winick and others, 2002).

Geology: A porphyritic biotite granite (Laramide) intrudes Wood River quartzite creating diopside skarn containing molybdenite. Biotite alteration is in the granite, but the molybdenite is in the sediments. The deposit lies near the crest of the White Cloud Peaks in a very environmentally sensitive area, which became a part of the Sawtooth National Recreation Area, a designation that restricted exploration and made future development unlikely. The prospect was acquired by ASARCO in 1967 and drilled with small helicopter-supported equipment. An early estimate by Keith Whiting in 1969 suggested 63.5 million tons grading 0.1% Mo. Another estimate by Theodore and Menzie (1984, p. 467) is 122 million tons grading 0.09% Mo, citing the U.S. Geological Survey. John C. Balla (written commun.) reports 123 million tons grading 0.11% Mo to a depth of 250 feet. Two deeper holes found 503 feet of 0.072% Mo and 713 Feet of 0.126% Mo, suggesting deeper potential.

All of the above data refer to the principal deposit, which has had most (maybe all) of the past drilling by ASARCO. Similar mineralization also lies about 3,100 feet to the south near Castle Lake. Two other nearby showings are to the north at the easternmost of the Boulder Chain Lakes and in Big Boulder Basin (Hall, 1995).

References: Balla and Smith (1980); Rostad (1978); Kirkemo and others (1965, p.54-55); Whiting (1991); Winick and others (2002); Hall (1995).

Ramey Creek—25

Location: Idaho, Custer County, 4 miles north of Sunbeam.

Age: maybe pre-Laramide.

Geology: Window in Challis Volcanics exposes Wood River quartzite with molybdenum anomaly intrusive not exposed but assumed.

Reference: J.H. Bright (written commun.).

Cabin Creek Prospect—44

Location: Idaho, Custer County, on the north side of Cabin Creek, about 6 miles west of the Sunbeam mine, T. 13 N., R. 14 E.

Age: pre-Laramide.

Geology: molybdenite stockworks in biotite granodiorite.

Reference: Hall (1995, p. 128).

Virginia-Beth—38

Location: Idaho, Valley County, Colt Creek, tributary to Little Pistol Creek.

Age: probably pre-Laramide.

Geology: A granite is injected by aplite and fractured, containing quartz, molybdenite, and other sulfides. There are a few high-grade samples.

Reference: Kirkemo and others (1965, p. 58-59).

GENERAL DISCUSSION

The preceding pages have included brief summaries of about fifty molybdenum occurrences of varying types and sizes, ranging from quartz molybdenum veins to large disseminated deposits. The larger deposits, often better known and with more available information, are discussed in more detail; the only one to have achieved significant production, Thompson Creek, is described extensively. The deposits have been subdivided by age and fall into three groups. The age groups have some distinctive geologic differences, which will be discussed further. Large potentially productive deposits occur in all age groups, and political considerations, particularly land withdrawals, are an important factor in considering future potential.

EVALUATION OF OUTCROPS

An important factor in evaluating molybdenum deposits in all age groups will be discussed briefly. Molybdenum deposits usually contain relatively small amounts of molybdenite, ranging from below 0.1% Mo to rarely over 1% Mo, and more rarely higher grades in veins. A few other sulfides are present, except pyrite and in places lesser amounts of chalcopyrite or other base metal sulfides. Surface oxidation of such deposits will be affected by the amount of pyrite present. Oxidized outcrops may be weakly limonitic, if pyrite content is low, or more strongly limonitic and jarositic if pyrite content is higher. Oxide molybdenum minerals, such as ferri-molybdite may be present, but not conspicuously. Many surface outcrops are depleted in molybdenum through either oxidation or leaching or because of surface mechanical depletion of soft molybdenite. It is not uncommon, therefore, to drill oxidized outcrops and find better-grade molybdenum beneath, although supergene enhancement is not usually expected. Some examples cited in this discussion include Liver Peak, CUMO, Thompson Creek, Cannivan Gulch, and Stewart Gulch. The presence of molybdenum in surface outcrop is, therefore, more important than its grade at the weathered surface in evaluating a molybdenum prospect, regardless of alteration. Outcrops with consistent values as low as 50 ppm Mo over a significant area should be drilled, particularly in the presence of porphyry dikes, breccias, or significant potassium alteration.

CLASSIFICATION OF MOLYBDENUM DEPOSITS

Several classifications of molybdenum deposits are already in the literature: notably, Westra and Keith (1981), Mutschler and others (1981), Keith and others (1993), and Wallace (1995). These researchers all appear to divide molybdenum deposits into two main groups. The first, more important group is considered to be the granite or Climax type, because of the economic importance of the Climax mine in the development of the molybdenum industry. The granite or Climax types are commonly centered on a small granite or granite porphyry stock, many with associated dikes and breccia bodies. Many have a massive silica cap and are high in fluorine. Most are circular in shape and have concentric alteration patterns. The second group of molybdenum deposits is known as the granodiorite or quartz monzonite type. This type is probably more numerous but is lower in grade. The granodiorite type may occur in equigranular intermediate igneous rocks and have fewer dikes and breccias. It is low in fluorine and does not necessarily have large silicified zones. This type is not as prominently circular and may be more irregular in shape. The distribution of these two types in Idaho and Montana will be discussed further. In a few cases, where the prospects are not yet thoroughly explored, classification may be uncertain.

AGES OF MOLYBDENUM DEPOSITS

The molybdenum deposits of Idaho and Montana can be grouped in three distinctive ages. There are thirteen Tertiary deposits, thirty of apparent Laramide age, and probably five from pre-Laramide time. Each time interval will be discussed individually.

Tertiary

The Tertiary molybdenum deposits are all within two very restricted age groups. The deposits in the Idaho porphyry belt are upper Eocene, 41 to 44 m.y. The remainder of the deposits, that have been dated, are lower middle Eocene, 48 to 50 m.y. and occur in both states. They share some common geologic characteristics. Some deposits are broadly in the area of similar aged volcanic fields, for example, the Challis Volcanic field of central Idaho. Such deposits appear to occur in an extensional tectonic regime.

All the referenced deposits appear to be granite. Four have been drilled sufficiently for a resource estimate, including the CUMO deposit which may be the largest in the entire group. Also interesting is that all the deposits in Montana, including three with tonnage estimates, are north of the Lewis and Clark Line. This may suggest that the molybdenum endowment of Tertiary molybdenum deposits is significantly greater than that of older deposits. There are, however, about three times as many older known occurrences. The Tertiary deposits may be scarcer and would be more difficult to find, but they may be better targets.

Laramide

The Laramide deposits are the largest group in this discussion. They are all granodiorite as far as is presently known. Few deposits have dates on the mineralization, and some have dates on the host intrusions, but all are in or associated with intrusives generally considered to be Laramide. Most of the deposits are in the Idaho batholithic terrane and its eastern extension in Montana. They are mostly associated with smaller batholiths or stocks east of the main batho-lith. The deposits are all south of the Lewis and Clark Line (Billingsley and Locke, 1941, p. 44; Calkins and Jones, 1914) except two in the Montana alkalic province (Lindsey and Fisher, 1985) and four in the Kaniksu batholith terrane (Kirkham and Ellis, 1926). These six deposits are probably not related to the Idaho batholith.

The Idaho batholith is described by Hyndman and others (various references) to be east of a Jurassic-Cretaceous subduction zone now in the approximate position of the western Idaho border. The batholith is bounded to the east by a system of folds and thrusts extending as far east in Montana as the Lombard thrust east of the Boulder batholith and the Tobacco Root batholith. The Idaho batholith has been divided into two segments: the Atlanta lobe, entirely in Idaho, and the Bitterroot lobe, mostly in Montana (Armstrong, 1975). Both lobes appear to be compositionally similar, but the Atlanta lobe is older. The ages are 100-75 m.y. for the Atlanta lobe and 80-70 m.y. for the Bitterroot lobe (Armstrong and others, 1977). Few deposits are known in either lobe, except for the Idaho porphyry belt deposits, which are in cross-cutting Tertiary intrusives. A few scattered copper prospects are reported in the Bitterroot lobe (Greenwood and Morrison, 1973), and they may be associated with metamorphic inclusions.

The Laramide molybdenum deposits that are primarily in the allochthonous terrane east of the Bitterroot lobe are the largest concentration of deposits in this two state area. The deposits are east of the Bitterroot Valley, south of the Lewis and Clark Line, north of the southern edge of the Bitterroot lobe (north of Dillon, Montana), and limited to the east by the thrust front of the Montana disturbed belt (Eardley, 1951, p. 294-297, Figure 166; Clapp, 1932). This area includes the Sapphire block of Hyndman, to be discussed further, and several important smaller batholiths: the Boulder, Philipsburg, Pioneer, and Tobacco Root. The deposits thus exist in a compressional tectonic regime.

The group of molybdenum deposits in Montana, east of the Bitterroot lobe, is a surprising concentration of twenty-four deposits, including two large ones, Cannivan Gulch and Stewart Gulch. The area, about 65 miles by 125 miles and trending approximately eastward, is bounded by north- and northwest-trending geologic structures. It is not related to northeastward-trending structural features as has been suggested by others (Foster and Childs, 1993; Armstrong and others, 1978). The area just described is of considerable size, not thoroughly explored, and highly favorable for new molybdenum discoveries.

Two subgroups of deposits are within the area in Montana. The first one, near Philipsburg, Montana, contains several deposits, including Stewart Gulch. It lies within and east of the Sapphire Mountains and the Sapphire block of Hyndman. Recent studies conducted as a part of Wilderness appraisals (Wallace and others, 1999) allow for a possible better definition of some geologic relationships. Wallace and others (1999) describe the Sapphire thrust plate between the Idaho and Boulder batholiths as being composed of large flat thrust slices, mainly of the massive quartzites of the Missoula Group. These thrust slices were then folded and broken by a younger event of complex imbricate thrusts, all still in Laramide time. Wallace and others (1989, p. 28) offer a map of these relationships that shows the flattish folded thrusts west of Anaconda, and the imbricate zone to the north and east. It would appear that all the known molybdenum occurrences are in the flattish, folded zone. The relative ages of the folding, thrusting, and intrusive activity are not known with certainty. The second subgroup of deposits includes those at the north end and to the west of the Pioneer batholith (including Cannivan Gulch). Mapping is not sufficiently detailed to speculate on similar relationships to those at Philipsburg, although it would not be a poor assumption.

The Laramide deposits are the most numerous in this discussion and are also the most diverse geologically. One group, called "Belt Terrane," has not been considered previously as a group. These deposits are broadly similar, and their most common characteristic is widespread, but weak, anomalous molybdenum (5-10 ppm Mo) in Belt quartzites. Several have been drilled to shallow depths but have not proven to contain higher concentrations. Deep drilling at Liver Peak, however, was successful, and they must remain intriguing, if not high priority, targets. The same can be said for many of the smaller intrusion-hosted deposits. The most interesting category must be the skarn-hosted deposits, where important tonnages are indicated at Cannivan Gulch and Stewart Gulch.

In both cases, the original target was intrusive hosted mineralization, but the mineralization in skarn could not be ignored. The porphyries at Stewart Gulch are also a highly differentiated sequence suggestive of a granite deposit. The porphyries have not been dated.

Pre-Laramide

The pre-Laramide group contains two large deposits, which have been dated, and three smaller occurrences in similar geologic environments. The ages for Thompson Creek and Little Boulder Creek range from 88 to 84 m.y. These ages are typical of about a dozen ages in the 90 to 80 m.y. range cited by Fisher and others (1992) for the Stanley-White Cloud Peaks region at the east margin of the Atlanta lobe. The remaining three of the pre-Laramide deposits are also at the batholithic margin to the northwest of Thompson Creek. The relationship of these deposits to the thrust terrane farther to the east (Ruppel, 1978) is not mapped in as much detail as in Montana, so the relationships are less certain. Significantly, two of the deposits are large, indicating that all three age subdivisions are capable of producing large deposits.

CONCLUSIONS AND EXPLORATION PRIORITIES

All of the molybdenum deposits in Montana that are Laramide in age and south of the Lewis and Clark Line are directly associated with the Bitterroot lobe of the Idaho batholith and are near its east margin or farther east associated with other smaller, related plutons. The molybdenum deposits in Idaho that are pre-Laramide in age are all on or near the east margin of the Atlanta lobe. Both groups are granodiorite. The time of emplacement of these deposits is near the end of batholithic emplacement and compressional tectonics. The Tertiary molybdenum deposits are Eocene and probably related to similarly aged volcanic fields in extensional terranes. All are either north of the Lewis and Clark Line or in the area of the Atlanta lobe, and all are granite types. There is no obvious explanation for the geographic division of Tertiary granite types and Cretaceous granodiorite types. The change in tectonic regime might suggest shallower emplacement for the granite (Tertiary) deposits. There are many more deposits of Laramide or older age than those of Tertiary age. A larger percentage of the Tertiary deposits have been drilled sufficiently to have a resource estimate, including CUMO, the largest though a low-grade deposit. There-fore, there may be greater total molybdenum endowment in the Tertiary.

Without regard to political considerations, three significant areas of numerous deposits should deserve exploration attention. The first is defined by Thompson Creek and Little Boulder Creek in a belt of middle Paleozoic sediments and small plutons near the margin of the Atlanta lobe. Unfortunately, this area is withdrawn from mineral entry south of the Salmon River. Some of the northern part around Thompson Creek and perhaps to the northwest still can be explored and should have good priority. The Pioneer batholith and surrounding sediments in Montana are another priority area. The third would be the Philipsburg, Mount Royal, Mount Powell, and Miners Gulch plutons with surrounding middle and lower Paleozoic sediments in Montana.

As another part of a final generalization, it must be admitted that the clarion call of promoters of worthless and sometimes not so worthless prospects is that the ore gets better with depth. While this is all too often a pipe dream, we must recognize that molybdenum porphyry systems have large vertical extent, and drilling deeper into molybdenum porphyry systems has paid handsome returns in some well-known cases. Perhaps, it would not be economically sound to recommend drilling every molybdenum porphyry prospect to extreme depths. It is also true that we do not have sufficiently definitive criteria, beyond the concepts discussed herein, to select the ultimate winners from a large group of prospects. It is incontrovertible, however, that such deep drilling has sometimes been very rewarding; it cannot be ignored that of all of the deposits that have had more than a few thousand feet of drilling, most have shown significant increases in grade with depth. The courage to recommend deep drilling must, therefore, be a part of the potentially successful exploration manager's equipment.

ACKNOWLEDGMENTS

A compilation such as this is obviously not the work of a single person operating independently. It is the result of over forty years of intermittent effort with numerous companies as an employee and as a consultant. During this time, associates and friends have helped formulate many of the concepts discussed herein. These people include, but are not limited to, Charles C. Goddard, Richard W. Thomssen, Eberhard A. Schmidt, Richard W. Woodcock, John M. Guilbert, David Jonson, Daniel B. Robertson, Robert G. Blair, and Henry T. Eyrich. In addition, Virginia S. Gillerman and Reed S. Lewis of the Idaho Geological Survey have been encouraging and patient as I have made revisions to meet the Survey's scientific and publishing standards. To all, I am immensely grateful, but reserve to myself any and all responsibility for imperfections or inaccuracies that may remain in the manuscript.

REFERENCES

Anderson, A.L., 1947, Geology and ore deposits of the Boise Basin, Idaho: U.S. Geological Survey Bulletin 944-C, Plate 14.

Armstrong, J.E., 1949, Fort St. James map area, Cassiar and Coast districts, B.C.: Geological Survey of Canada Memoir 252, 210 p.

Armstrong, R.L., 1975, Precambrian (1500 m.y. old) rocks of central Idaho—the Salmon River Arch and its role in Cordilleran sedimentation and tectonics: American Journal of Science, v. 275-A, p. 437-467.

Armstrong, R.L., and V.F. Hollister, 1978, K-Ar dates for mineralization in the White Cloud-Cannivan porphyry molybdenum belt of Idaho and Montana—A reply: Economic Geology, v. 73, no. 7, p. 1368-1369.

Armstrong, R.L., V.F. Hollister, and J.E. Harakal, 1978, K-Ar dates for mineralization in the White Cloud-Cannivan porphyry molybdenum belt of Idaho and Montana: Economic Geology, v. 73, no. 1, p. 94-96.

————, 1979, K-Ar dates for mineralization in the White Cloud-Cannivan porphyry molybdenum belt of Idaho and Montana—A reply: Economic Geology, v. 74, no. 3, p. 699-700.

Armstrong, R.L., W.H. Taubeneck, and P.O. Hales, 1977, Rb-Sr geochronometry of Mesozoic granitic rocks and their Sr isotopic composition, Oregon, Washington, and Idaho: Geological Society of America Bulletin, v. 88, no. 3, p. 397-411.

Balla, J.C., and R.G. Smith, 1980, Geology of the Little Boulder Creek deposit, Custer County, Idaho (abs.): U.S. Geological Survey Open-File Report 81-355, p. 246-247.

Baty, B., 1976, Fission track age dates from three granitic plutons in the Flint Creek Range, Granite County, Montana: Northwest Geology, v. 5, p. 34-41.

Bennett, E.H., 1980, Granitic rocks of Tertiary age in the Idaho batholith and their relation to mineralization: Economic Geology, v. 75, no. 2, p. 278-288.

Bennett, E.H., and C.R. Knowles, 1983, Tertiary plutons and related rocks in central Idaho, *in* D.H. McIntyre, ed., Symposium on the Geology and Mineral Deposits of the Challis 1° x 2° quadrangle, Idaho: U.S. Geological Survey Bulletin 1658, Chapter F, p. 81-96.

Billingsley, P., and A. Locke, 1941, Structures of ore districts in the continental framework: American Institute of Mining and Metallurgical Engineers Transactions, v. 144, p. 9-64.

Calkins, F.C., and E.L. Jones, Jr., 1914, Economic geology of the region around Mullan, Idaho, and Saltese, Montana: U.S. Geological Survey Bulletin 540-E, p. 167-211.

Callaghan, E., and D.L. Lemmon, 1941, Tungsten resources of the Blue Wing district, Lemhi County, Idaho: U.S. Geological Survey Bulletin 931-A, 21 p.

Cavanaugh, P.C., 1979, The geology of the Little Boulder Creek molybdenum deposit, Custer County, Idaho: University of Montana M.S. thesis, 100 p.

Clapp, C.H., 1932, Geology of a portion of the Rocky Mountains of northwestern Montana: Montana Bureau of Mines and Geology Memoir 4, 30 p.

Clark, K.F., 1972, Stockwork molybdenum deposits in the western Cordillera of North America: Economic Geology, v. 67, no. 6, p. 731-758.

Davies, J.F., 1989, Some temporal-spatial aspects of North American porphyry deposits: Economic Geology, v. 84, no. 8, p. 2300-2306.

Eardley, A.J., 1951, Structural Geology of North America: Harper & Brothers, New York, p. 294-297, fig. 166.

Emmons, W.H., and F.C. Calkins, 1913, Geology and ore deposits of the Philipsburg quadrangle: U.S. Geological Survey Professional Paper 78, 271 p.

Ericksen, G.E., R.W. Leinz, and L.Y. Marks, 1981, Mineral resources of the Flint Creek Range Wilderness Study Area, Granite and Powell counties, Montana: U.S. Geological Survey Open-File Report 81-1095, 8 p.

Fisher, F.S., and K.M. Johnson, 1995, Geology and mineral resource assessment of the Challis 1° x 2° degree quadrangle, Idaho: U.S. Geological Survey

Professional Paper 1525, 39 p.

Fisher, F.S., D.H. McIntyre, and K.M. Johnson, 1992, Geologic map of the Challis 1° x 2° quadrangle, Idaho: U.S. Geological Survey Miscellaneous Geological Investigations, Map I-1819.

Foster, F., and J.F. Childs, 1993, An overview of significant lode gold systems in Montana: Exploration and Mining Geology, v. 2, p. 217-244.

George Cross Newsletter, 1995, Report on CUMO drilling, February 16.

Giancola, Diane, ed., 2006, Canadian and American Mines Handbook: Business Information Group Mining Publications, Toronto, Canada, 672 p.

Giletti, B.J., 1966, Isotopic ages from southwestern Montana: Journal of Geophysical Research, v. 71, p. 4029-4036.

Gillerman, V.S., E.H. Bennett, and M.J. Weaver, 2007, Idaho: Mining Engineering, v. 59, no. 5, p. 82-86.

Greenwood, W.R., and D.A. Morrison, 1973, Reconnaissance geology of the Selway-Bitterroot Wilderness Area: Idaho Bureau Mines and Geology Pamphlet 154, 32 p.

Hall, W.E., 1995, Cretaceous molybdenum stockworks, *in* F.S. Fisher and K.M. Johnson, eds., Geology and Mineral Resource Assessment of the Challis 1° x 2° Quadrangle, Idaho: U.S. Geological Survey Professional Paper 1525, p. 127-130.

Hall, W.E., E.A. Schmidt, S.S. Howe, and M.J. Brock, 1984, The Thompson Creek, Idaho porphyry molybdenum deposit—An example of a fluorine deficient molybdenum granodiorite system, *in* T.V. Janelidge and A.G. Tvalehredidge, eds., Proceedings of the Sixth Quadrennial IAGOD Symposium, Stuttgart, Germany, p. 349-357.

Hammarstrom, J.M., M.L. Zientek, and J.E. Elliott, 1993, Mineral resource assessment of the Absaroka-Beartooth Study Area, Custer and Gallatin National Forest, Montana: U.S. Geological Survey Open-File Report 93-0207, 19 p.

Haq, B.U., and F.W.B. Van Eysinga, 1987, Geological Time Table: Elsevier Science Publishers, 1 sheet.

Harrison, J.E., M.D. Kleinkopf, and J.D. Obradovich, 1972, Tectonic events at the intersection between the Hope fault and the Purcell Trench, northern Idaho: U.S. Geological Survey Professional Paper 719, 24 p.

Hobbs. S.W., W.H. Hays, and D.H. McIntyre, 1991, Geologic map of the Bayhorse area, central Custer County, Idaho: U.S. Geological Survey Miscellaneous Geologic Investigations, Map I-1882.

Hughes, G.J., Jr., 1975, Relationship of igneous rocks to structure in the Henderson-Willow Creek igneous belt, Montana: Northwest Geology, v. 4, p. 5-25.

Hundhausen, R.J., 1949, Investigation of Henderson Gulch tungsten deposit, Granite County, Montana: U.S. Bureau Mines Report of Investigation 4513, 8 p.

Hyndman, D.W., 1983, The Idaho batholith and associated plutons: Geological Society of America Memoir 159, p. 213-240.

Hyndman, D.W., A.J. Silverman, R. Ehinger, W.R. Benoit, and R. Wold, 1982, The Philipsburg batholith of western Montana: Montana Bureau of Mines and Geology Memoir 49, p. 30.

Hyndman, D.W., J.L. Talbot, and R.B. Chase, 1975, Boulder batholith: A result of a block detached from the Idaho batholith infrastructure: Geology, v. 3, no. 7, p. 401-404.

Hyndman, D.W., and L.D. Williams, 1977, The Bitterroot lobe of the Idaho batholith: Northwest Geology, v. 6, no. 1, p. 1-16.

Johnson, K.M., R.S. Lewis, E.H. Bennett, and T.H. Kiilsgaard, 1988, Cretaceous and Tertiary intrusive rocks of south-central Idaho, *in* P.K. Link and W.R. Hackett, eds., 1988, Guidebook to the Geology of Central and Southern Idaho: Idaho Geological Survey Bulletin 27, p. 55-86.

Joralemon, P., 1973, Exploration at the Ima mine: Private report to the Bradley Mining Company.

Karlstrom, T.N.V., 1948, Geology and ore deposits of the Hecla mining district, Beaverhead County, Montana: Montana Bureau of Mines and Geology Memoir 25, 87 p.

Keith, J.D., E.H. Christiansen, and R.B. Carten, 1993, The genesis of giant porphyry molybdenum deposits, *in* B.H. Whiting, C.J. Hodgson, and R. Mason, eds., Giant Ore Deposits: Society of Economic Geologists, Special Publication 2, p. 285-317.

Kiilsgaard, T.H., and E.H. Bennett, 1995, Tertiary molybdenum stockworks, *in* D.H. Fisher and K.M. Johnson, eds., Geology and Mineral Resource Assessment of the Challis 1°x 2° Quadrangle, Idaho: U.S. Geological Survey Professional Paper 1525, p. 131-134.

Kiilsgaard, T.H., J.L. Freeman, and J.S. Coffman, 1970, Mineral resources of the Sawtooth Primitive Area, Idaho: U.S. Geological Survey Bulletin 1319-D, 174 p.

Kimura, E.T., and A.P. Drummond, 1969, Geology of the Endako molybdenum deposit: Canadian Institute of Mining, Metallurgy and Petroleum Bulletin, v. 62, no. 7, p. 699-708.

King, P.B., and H.M. Beikman, 1974, Geologic map of the United States: U.S. Geological Survey.

King, R.U., 1964, Molybdenum, *in* Mineral and Water Resources of Idaho: U.S. Geological Survey, U.S. Senate, Committee on Interior and Insular Affairs, p. 133-138.

Kirkemo, H., C.A. Anderson, and S.C. Creasy, 1965, Investigations of molybdenum deposits in the conterminous United States, 1942-1960: U.S. Geological Survey Bulletin 1182-E, 90 p.

Kirkham, V.R.D., and E.W. Ellis, 1926, Geology and ore deposits of Boundary County, Idaho: Idaho Bureau of Mines and Geology Bulletin 10, 78 p.

Klepper, M.R., R.A. Weeks, and E.T. Ruppel, 1957, Geology of the Southern Elkhorn Mountains, Jefferson and Broadwater counties, Montana: U.S. Geological Survey Professional Paper 292, 82 p.

Lamarre, A.L., and R.L. Moore, 1981, Geology and exploration of the Liver Peak molybdenum prospect, Montana: Northwest Mining Association 87th Annual Meeting, Spokane, Washington.

Lidke, D.J., and C.A. Wallace, 1992, Rocks and structure of the north-central part of the Anaconda Range, Deer Lodge and Granite counties, Montana: U.S. Geo-logical Survey Bulletin 1993, 31 p.

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

Link, P.K., B. Skipp, M.H. Hart, Jr., S. Janecke, and B.R. Burton, 1988, Structural and stratigraphic transect of south-central Idaho, *in* P.K. Link and W.R. Hackett, Guidebook to the Geology of Central and Southern Idaho: Idaho Geological Survey Bulletin 27, p. 5-42.

Livingston, D.C., 1919, Tungsten, cinnabar, manganese, molybdenum, and tin deposits of Idaho: University of Idaho, School of Mines, Bulletin, v. 14, no. 2, 72 p.

Loen, J.S., M.J. Blaskowski, and J.E. Elliott, 1989, Geology and mineral deposits of the Miners Gulch area, Granite County, Montana: U.S. Geological Survey Bulletin 1791, 51 p.

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

Marvin, R.F., C.M. Tschang, H.H. Mehnert, and J. Magnam, 1973a, Late Cretaceous age for molybdenum mineralization in Custer County, Idaho: Isochron West, no. 7, p. 1.

Marvin, R.F., I.J. Witkind, W.R. Keefer, and H.H. Mehnert, 1973b, Radiometric ages of intrusive rocks in the Little Belt Mountains, Montana: Geological Society of America Bulletin, v. 84, no. 6, p. 1977-1986.

Mitchell, V.E., 1999, History of the Ima mine, Lemhi County, Idaho: Idaho Geological Survey Staff Report 99-2, 39 p.

Moye, F.J., W.R. Hackett, J.D. Blakely, and L.G. Snider, 1988, Regional geologic setting and volcanic stratigraphy of the Challis volcanic field, central Idaho, *in* P.K. Link and W.R. Hackett, Guidebook to the Geology of Central and Southern Idaho: Idaho Geological Survey Bulletin 27, p. 87-98.

Mutschler, F., E.G. Wright, S. Ludington, and J.T. Abbott, 1981, Granite molybdenum systems: Economic Geology, v. 76, no. 4, p. 874-897.

O'Neill, J.M., and E.E. Cather, 1984, Middle Mountain-Tobacco Root Roadless Area, Montana, *in* S.P. Marsh, S.J. Kropschot, and R.G. Dickenson, Wilder-ness Mineral Potential: U.S. Geological Survey Professional Paper 1300, v. 2, p. 721-723.

Pardee, J.T., and F.C. Schrader, 1933, Metalliferous deposits of the greater Helena mining region, Montana: U.S. Geological Survey, Bulletin 842, 318 p.

Parsons, A.B., 1933, The Porphyry Coppers: American Institute of Mining and Metallurgical Engineers, New York City, p. 338-340.

Ross, C.P. 1931, A classification of the lode deposits of south-central Idaho: Economic Geology, v. 26, p. 169-185.

————, 1963, Evolution of ideas relative to the Idaho batholith: Northwest Science, v. 37, no. 2, p. 45-60.

Rostad, O.H., 1967, Geochemical case history at the Little Falls molybdenum prospect, Boise County, Idaho: Canadian Geological Survey Paper 66-54, p. 249-252.

————, 1969, The use of geochemistry at the Bald Mountain molybdenite prospect, Lewis and Clark County, Montana: Colorado School of Mines Quarterly, v. 64, no. 1, p. 437-450.

————, 1971, Offset geochemical anomalies at the Ima mine, Lemhi County, Idaho: Canadian Institute of Mining, Metallurgy and Petroleum Special Volume 11, p. 241-246.

————, 1978, K-Ar dates for mineralization in the White Cloud-Cannivan porphyry molybdenum belt of Idaho and Montana—A discussion: Economic Geology, v. 73, p. 1366-1368.

Rotherham, D.C., and E. Kimura, 1991, History of discovery and development of the Endako molybdenum deposit, *in* V.F. Hollister, ed., Case Histories of Mineral Discoveries: Society for Mining, Metal-lurgy, and Exploration, Inc., Colorado, v. 3, p. 155.

Ruppel, E.T., 1978, Medicine Lodge thrust system, east-central Idaho and southwest Montana: U.S. Geological Survey Professional Paper 1031, 23 p.

Ruppel, E.T., C.A. Wallace, R.G. Schmidt, and D.A. Lopez, 1981, Preliminary interpretation of the thrust belt in south-west and west-central Montana and east central Idaho, *in* T.E. Tucker, ed., Montana Geological Society Field Conference and Symposium Guidebook to Southwest Montana, p. 139-159.

Schmidt, E.A., M.J. Broch, and F.K. Fenne, 1991, Geology of the Thompson Creek molybdenum deposit, Custer County, Idaho, *in* V.F. Hollister, ed., Case Histories of Mineral Discoveries: Society for Mining, Metallurgy, and Exploration, v. 3, p. 175-182.

Schmidt, E.A., M.J. Broch, and R.O. White, 1982, Summary geologic report, Thompson Creek project, Custer County, Idaho: Private report to Amoco Minerals Company.

Schmidt, E.A., and J.E. Worthington, 1977, Geology and mineralization of the Cannivan Gulch molybdenum deposit, Beaverhead County, Montana: Geological Association of Canada, Program with Abstracts, v. 2, p. 46.

Schmidt, E.A., J.E. Worthington, and R.W. Thomssen, 1979, K-Ar dates for mineralization in the White Cloud-Cannivan porphyry molybdenum belt of Idaho and Montana—A discussion: Economic Geology, v. 74, p. 698-699.

Schrader, F.C., 1924, Molybdenite in the Rocky Bar district, Idaho: U.S. Geological Survey Bulletin 750-F, p. 87-100.

Senter, L.E., 1976, Geology and porphyry molybdenum mineralization of the Turnley Ridge stock in the Elkhorn mining district, Jefferson County, Montana: Eastern Washington University M.S. thesis, 73 p.

Shannon, S.S., Jr., 1971, Evaluation of copper and molybdenum geochemical anomalies at the CUMO prospect, Boise County, Idaho: Canadian Institute of Mining, Metallurgy and Petroleum Special Volume 11, p. 247-250.

Shaver, K.C., 1978, Chronology of dacite intrusion in the northwest end of the Absaroka-Gallatin volcanic province, Montana: Northwest Geology, v. 7, p. 20-26.

Smedes, H.W., and H.J. Prostka, 1972, Stratigraphic framework of the Absaroka volcanic supergroup in the Yellowstone National Park region: U.S. Geological Survey Professional Paper 729-C, 33 p.

Stotelmeyer, R.B., F.I. Johnson, D.S. Lindsey, J. Ridenour, S.W. Schmauch, 1983, Economic appraisal of the North Absaroka Wilderness Study Area, *in* U.S. Geological Survey and U.S. Bureau of Mines, Mineral Resources of the North Absaroka Wilderness Study Area, Park and Sweet Grass Counties Montana: U.S. Geological Survey Bulletin 1505-C, p. 115-236.

Talbot, J.L., 1977, The role of the Idaho batholith in the structure of the Northern Rocky Mountains, Idaho and Montana: Northwest Geology, v. 6, no. 1, p. 17-24.

Tansley, W., P.A. Schafer, and L.H. Hart, 1933, A geological reconnaissance of the Tobacco Root Mountains, Madison County, Montana: Montana Bureau of Mines and Geology Memoir 9, 57 p.

Theodore, T.G., and W.D. Menzie, 1984, Fluorine-deficient porphyry molybdenum deposits in the western North American Cordillera, *in* T.V. Janelidge and A.G. Tvalehredidge, Proceedings of the Sixth Quadrennial IAGOD Symposium: Stuttgart, Germany, p. 463-470.

Tilling, R.I., 1973, Boulder batholith, Montana: A product of two contemporaneous but chemically distinct magma series: Geological Society of America Bulletin, v. 84, no. 12, p. 3874-3900.

Walker, D.D., 1960, Tungsten resources of Montana: Deposits of the Philipsburg batholith, Granite and Deer Lodge counties, Montana: U.S. Bureau of Mines Report of Investigations 5612, 55 p.

Wallace, C.A., D.J. Lidke, J.E. Elliott, J.D. Desmarias, J.D. Obradovich, D.A. Lopez, S.E. Zarske, B.A. Heise, M.J. Blaskowski, and J.S. Loen, 1992, Geologic map of the Anaconda-Pintlar Wilderness and Contiguous Roadless Area, Granite, Deer Lodge, Beaverhead, and Ravalli counties, western Montana: U.S. Geological Survey Miscellaneous Field Studies, Map MF-1633-C.

Wallace, C.A., D.J. Lidke, M.R. Waters, and J.D. Obradovich, 1989, Rocks and structure of the Southern Sapphire Mountains, Granite and Ravalli counties, western Montana: U.S. Geological Survey Bulletin 1824, 29 p.

Wallace, S.R., 1995, The Climax-type molybdenum deposits: What they are, where they are, and why they are: Economic Geology, v. 90, p. 1359-1380.

Weis. P.L., 1963, Molybdenum, *in* Mineral and Water Resources of Montana: U.S. Geological Survey for the Committee on Interior and Insular Affairs: Montana Bureau of Mines and Geology Special Publication 28, p. 86, fig. 26.

Westra, G., and S.B. Keith, 1981 Classification and genesis of stockwork molybdenum deposits: Economic Geology, v. 76, no. 4, p. 844-873.

Whiting, K., 1991, Discovery of the Little Boulder Creek molybdenum deposit Custer County, Idaho, *in* Case Histories of Mineral Discoveries: Society for Mining, Metallurgy and Exploration, Colorado, v. 3, p. 163.

Winick, J.A., C.D. Taylor, M.J. Kunk, and D. Unruh, 2002, Revised $^{40}Ar/^{39}Ar$ ages of the White Cloud molybdenum deposit, Custer County, Idaho: Geological Society of America, Abstracts with Programs, v. 34, no. 6, p. 337.

Wiswall, G., 1977, Structural styles and the sequence of deformation related to the Sapphire tectonic block: Northwest Geology, v. 6, no. 2, p. 51-59.

Worl, R.G., P.K. Link, G.R. Winkler, and K.M. Johnson, 1995, Geology and mineral deposits of the Hailey 1° x 2° quadrangle and the western part of the Idaho Falls 1° x 2° quadrangle, south-central Idaho—An overview: U.S. Geological Survey Bulletin 2064, Part A, p. A-10, Plate I.

Zen, E-An, 1988, Bedrock geology of the Vipond Park 15-minute, Stine Mountain 7.5-minute, and Maurice Mountain 7.5-minute quadrangles, Pioneer Mountains, Beaverhead County, Montana: U.S. Geological Survey Bulletin 1625, 49 p.