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# Montana's Industrial Minerals

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# Preface

This paper, which was presented May 1, 1989 at the 25th Forum on the Geology of Industrial Minerals, will be pubished by the Oregon Department of Geology and Mineral Industries in a volume of papers presented at this meeting. This information is put on open file with the Montana Bureau of Mines and Geology to make it readily available before final publication.

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## Abstract

Because of Montana's diverse geology more than thirty industrial mineral commodities occur in the state. Twelve of these are now being produced, mainly for out-of-state markets and eight others have been mined in the past. Market and transportation constraints limit the mining of others.

Very pure talc from Archean dolomitic marble is mined at four localities for use in paints, paper, ceramics, plastics and cosmetics. Chlorite veins in Precambrian quartzofeldspathic gneiss are mined at the only chlorite mine in the U.S. Several million tons of vermiculite has been mined from the Libby deposit where this mineral formed by weathering of the biotitite core of a Jurassic ultramafic body. A Tertiary-age lamprophyre dike at Yogo in central Montana yields blue sapphires; sapphires are also recovered from placers in western Montana. Since 1929 phosphate from the Permian Phosphoria Formation has been mined in the Garrison district.

Barite is mined from veins in metasedimentary rocks of the Belt Supergroup. Travertine from extensive deposits north of Yellowstone National Park is quarried for facing. Marine Cretaceous formations are a source of bentonite now primarily used for engineering applications. Gypsum from the Kibbey Formation of the Mississippian Big Snowy Group is sold to cement plants. Limestone is quarried by two cement manufacturers, one lime manufacturer and also for use in sugar beet refining. Sand and gravel from fluvial deposits is provided for local markets and crushed stone for railroad ballast is produced from two quarries.

Fluorspar, silica, kaolinitic clay, brick clay, graphite, mica, optical calcite and asbestos have been mined in Montana, but because of changing market conditions are no longer mined.

A number of other commodities known to occur in Montana are undeveloped either because of lack of markets, transportation constraints, or lack of information on the extent of the deposits. Corundum and sillimanite deposits occur in Archean metamorphic rocks of southwestern Montana. These metamorphic rocks also have contributed garnets to alluvial deposits. Carbonatite bodies in Precambrian rocks in southwestern Montana contain rare earths and monazite is reported in several placer deposits. Paleozoic formations contain large reserves of high-purity limestone and dolomite. In the subsurface of eastern Montana, Mississippian and Devonian formations contain extensive salt and potash beds. Eocene alkalic igneous rocks in central Montana, some syenitic, are a possible feldspar resource. Tertiary sedimentary rocks in southwestern Montana contain diatomaceous earth and tuffaceous beds suitable for pozzolan. The zeolites clinoptilolite, mordenite, laumontite and stilbite occur in both Cretaceous and Tertiary formations. Sodium sulfate deposits occur in shallow lakes in northeastern Montana and similar lakes in central Montana offer the potential for discovery of additional deposits.

Because of continually changing markets, commodities will be produced in the future that have not even been considered as having economic potential in the past.

## Introduction

The purpose of this discussion of 30 industrial mineral commodities is to provide brief information on known deposits and in some instances possibilities for exploration for new deposits. The varying degree of coverage of specific commodities is intentional. Those commodities for which recent summary or comprehensive publications are not available are described in more detail. Localities of some of these depsoits are shown in Figure 1. References cited in the commodity descriptions will enable the reader to obtain more detailed information about specific deposits. Two older publications that provide more detailed information on some of these commodities, as well as information on metallic mineral resources, are Montana Bureau of Mines and Geology Special Publication 28 (1963) and Sahinen and Crowley (1959). Also, Bentley and Mowat, (1967) give locality information but no references for 32 nonmetallic commodities in addition to similar information for metalliferous occurrences.

In the following discussion, the industrial mineral commodities are described in alphabetical order with references listed at the end of the paper.

Asbestos

Although currently considered more of a detriment to mineral development than an economic commodity, a brief discussion of asbestos is included because asbestiform anthophyllite has been mined from one deposit and attempts were made to produce chrysotile from another. At the Karst deposit, 32 mi southwest of Bozeman, irregular veins of fibrous anthophyllite occur in peridotite bodies within Archean gneiss and schist (Perry, 1948, p. 36-39). Anthophyllite fibers typically oriented nearly perpendicular to the vein contacts are as much as one foot long. Total production from this mine which has been inactive since the 1950's, is 1800 tons.

Attempts have been made to mine and mill chrysotile asbestos from the Cliff Lake deposit in the southern Madison Range 65 mi southwest of Bozeman (Perry, 1948, p. 39,40). Both chrysotile and massive serpentine occur in Archean dolomitic marble next to a Precambrian gabbro dike. In another area chrysotile veinlets less than 0.75 in thick occur in Archean dolomitic marble at the Anderson deposit 32 mi southwest of Dillon (Sahinen and Crowley, 1959, p. 5).

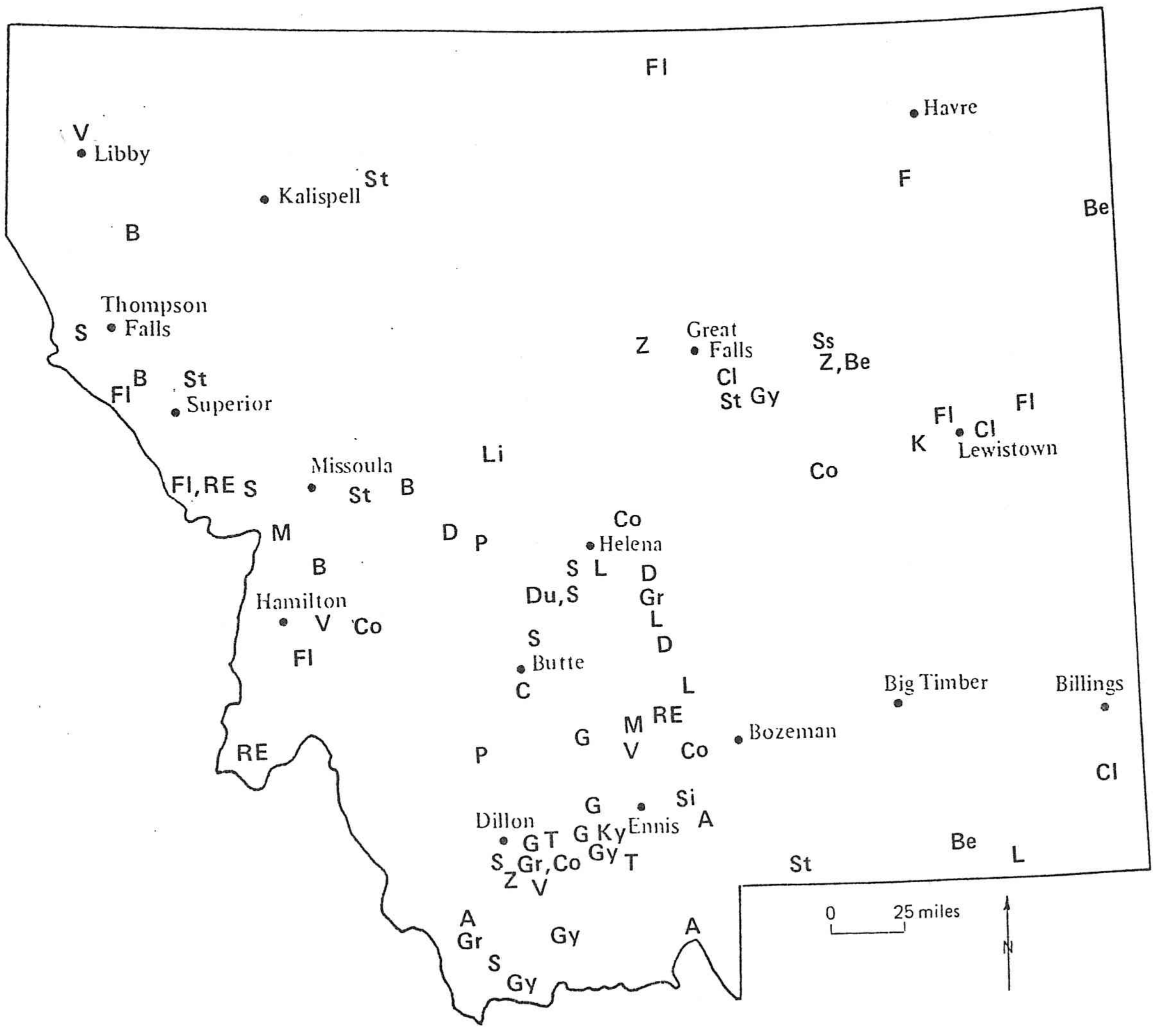


Figure 1—Localities of some industrial mineral commodities in western Montana. Extensive bedded deposits are not shown. Symbols used are A, asbestos; B, barite; Be, bentonite; C, chlorite; Cl, clay; Co, corundum; D, diatomite; Du, dumortierite; F, feldspar; Fl, fluorspar; G, garnet; Gr, graphite; Gy, gypsum; K, kaolinite; Ky, kyanite; L, limestone; Li, lithium; M, mica; P, phosphate; RE, rare earth elements; S, silica; Si, sillimanite; Ss, sodium sulfate; St, stone; T, talc; V, vermiculite; Z, zeolite.

Barite

Barite veins that have been mined are confined to metasedimentary rocks of the Proterozoic Belt Supergroup. Quartz and fragments of country rock are the most abundant impurities in these veins which are typically devoid of metallic minerals. The largest concentration of mineable veins is in the Elk Creek-Coloma district 30 mi east of Missoula where veins occur in the Garnet Range Formation of the Belt Supergroup within 1.2 mi of the exposed contact of the Cretaceous granitoid Garnet stock (Berg, 1988, p. 48-68). The thickest vein, the Elk Creek vein, which is mined from underground workings reaches a maximum thickness of 27 ft and averages 7 ft.

Barite has also been mined from five other deposits in this same district. Although production figures for the barite mines in the Elk Creek-Coloma district are not available, cumulative production up to 1988 probably was in the range between 150,000 and 200,000 tons (Berg, 1988, p. 56). Another deposit, the Kenelty mine 28 mi southeast of Libby, produced an estimated 40,000 tons of barite during the years of production from 1978 to 1983 (Berg, 1988, p. 23). Other small producers, now inactive, are the Mullan mine 25 mi northwest of Superior and the Sheep Creek (Brechbill) and the Burnt Fork mines 24 and 27 mi respectively south of Missoula.

Chlorite

Chlorite is mined at the Antler deposit 25 mi southeast of Butte in the Silver Star district. Chlorite veins formed by hydrothermal replacement of Precambrian quartzofeldspathic gneiss and are typically surrounded by envelopes of sericitic alteration (Berg, 1983). The veins consist of the magnesian chlorite clinochlore with muscovite, zircon, rutile and limonite in trace concentrations (Berg, 1986, p. 497). When examined in 1982, the thickest vein exposed was 26 ft thick. Chloritic alteration of quartzofeldspathic gneiss is present throughout the southern flank of the Highland Mountains south and west of the Antler mine, mainly associated with northwest-trending high-angle faults.

## Clays

### Bentonite

Bentonite in Montana has two mjor sources, Tertiary-age sediments deposited in intermontane basins in the southwestern part and marine Cretaceous formations exposed on the plains (Berg, 1969). The Tertiary sediments contain bentonite suitable for lining irrigation ditches and similar uses, but they are generally of the low swelling variety and contain too much sand-size detritus for many applications. Cretaceous formations contain large reserves of good quality bentonite. Knechtel and Patterson (1956, p. 48) tentatively estimated reserves of 108 million tons in the Montana part of the Hardin district southeast of Billings. Mineable bentonite beds in this district are in the Thermopolis Shale, Mowry Shale, Belle Fourche Shale and Bearpaw Shale. Farther north in the Vananda area, 85 mi northeast of Billings, two bentonite beds 3 to 4 ft thick in the Bearpaw Shale have been mined (Berg, 1970). Bentonite has been mined in northern Montana near Glasgow and Malta from what are presumed to be these same two beds for use in drilling mud and for pelletizing taconite iron ore concentrate. The very productive Clay Spur Bed of the Mowry Shale, which extends into southeastern Montana from the Black Hills district, has also been extensively mined (Knechtel and Patterson, 1962, p. 971). The Arrow Creek Bed (also known as the Geyser bed) in the Bootlegger Member of the Blackleaf Formation contains large deposits of bentonite in central Montana east of Great Falls. Samples tested from this and other beds in this area have been judged unsatisfactory for drilling mud or taconite pelletizing (Great Northern Railway Company Mineral Research and

Development Department, 1960). Extensive bentonite deposits approximately 35 miles southeast of Lewistown may be correlative with the Arrow Creek Bed.

### Expandable Shale

Marine Cretaceous formations also contain shale suitable for expansion to make lightweight aggregate (Berg and others, 1968, p. 68,69). The Blackleaf Formation was a source of expandable shale in the Great Falls area (Sahinen, 1957). Presently clay formed by weathering of the LaHood Formation of the Precambrian Belt Supergroup is mined for this purpose from a deposit about 35 mi southeast of Butte and expanded at a plant in Three Forks (Berg and others, 1968, p. 51,52).

### Brick Clay

Although Montana no longer has any operating brick plants, there are substantial clay deposits suitable for brick and other structural clay products in the Morrison Formation (Jurassic) and overlying Kootenai Formation (Cretaceous) (Berg and others, 1968, p. 68,69). Fire clay from kaolinitic beds in the Kootenai Formation has been mined in the area east of Great Falls and used in brick.

### Kaolin

The largest known kaolinite deposit in Montana is the Whiteware deposit (unmined) 8 mi northwest of Lewistown in the South Moccasin Mountains. This deposit was formed by hydrothermal alteration of shale and sandstone of Cretaceous or Pennsylvanian age near Tertiary intrusives (Dougan, 1947, p. 2). Clay from this deposit has been identified as the dickite polytype of kaolinite. The U.S. Bureau of Mines determined by extensive sampling and testing that this clay is suitable for manufacture of whiteware (Roby and Robertson, 1949).

Corundum

Montana is well known to gemologists for its sapphire deposits. The most famous of these is the Yogo deposit 45 m southwest of Lewistown where the source of the attractive sky-blue sapphires is a Tertiary lamprophyre dike (Claybaugh, 1952, p. 6-34; Dhay, 1988). Sapphires are mined from gravels along the Missouri River northeast of Helena and farther west from gravels in the vicinity of Rock Creek 15 mi southwest of Philipsburg. Sapphires from these deposits, unlike those from the Yogo deposit, show a variety of pale shades of green, blue, and for the Rock Creek sapphires, also yellow and yellowish brown (Zeihen, 1987, p. 87).

Deposits of corundum which is not of gem quality are less well known. These deposits are relatively thin lenses of corundum-bearing gneiss in Archean metamorphic rocks. Three of these deposits southwest of Bozeman have been investigated by the U.S. Bureau of Mines (Clabaugh and Armstrong, 1950). The largest, the Elk Creek deposit approximately 17 mi southwest of Bozeman, contains several thousand tons of rock with 10 percent corundum.

Farther to the southwest the Camp Creek corundum deposit is 10 mi southeast of Dillon in the Ruby Range. Corundum gneiss lenses in Archean marble range from 20 to 130 ft in length and from 4 to 20 ft in thickness (Heinrich, 1950, p. 11). Beneficiation tests on a 800-pound sample containing 28 percent corundum conducted by the U.S. Bureau of Mines showed that a concentrate containing 92.5 percent $Al_2O_3$ can be produced by flotation (Smith and Llewellyn, 1987). The protolith of this corundum gneiss is thought to be an aluminous clay layer which was subsequentially metamorphosed during high-grade regional metamorphism (Haartz, 1979).

## Diamonds

Diatremes in north-central Montana with kimberlitic affinities and, in at least one instance containing upper mantle xenoliths, have been prospected for diamonds, but with no success. This swarm of late middle Eocene diatremes extends from the vicinity of the Little Rocky Mountains southwestward across the Missouri River (Hearn, 1968 and Hearn and Boyd, 1975). The Williams diatreme on the southwestern flank of the Little Rocky Mountains contains dunite and peridotite upper mantle xenoliths as well as xenocrysts of kimberlite indicator minerals (Hearn and McGee, 1983, p. 9).

## Diatomite

Pardee (1925, p. 44) reported two occurrences of diatomite in the Townsend Valley. The northern occurrence, north of Beaver Creek approximately 21 mi southeast of Helena, consists of two beds. Each bed is reported to be of chalk-white diatomite about one foot thick in Oligocene-age clay and tuff. The second occurrence is about 36 mi southeast of Helena where Pardee (1925, p. 44) described a 10-foot thick bed of impure diatomite. A bed of impure diatomite 2 ft thick occurs in the Tertiary Cabbage Patch beds south of the Clark Fork River near Drummond, 45 mi southeast of Missoula (Gwinn, 1961).

## Dolomite

Four Paleozoic formations contain substantial dolomite deposits. The Middle Cambrian Meagher Limestone is dolomitic in part in southwestern Montana. Some beds of the Upper Cambrian Pilgrim Limestone exposed in southwestern and central Montana are nearly pure dolomite (Perry, 1949, p. 31). The Ordovician Big Horn Dolomite, limited to south central Montana and ranging in thickness from 250 to

500 ft, is a major potential dolomite source (Balster, 1971, p. 289). The Jefferson Dolomite of Devonian age and exposed in western and central Montana is another potentil source. This formation ranges from 200 to 700 ft in thickness in Montana (Balster, 1971, p. 264).

Feldspars

The Tertiary alkalic rocks of the central part of the state appear to offer the best potential sources of feldspars for use in ceramics or glass. The Little Rocky Mountains, Judith Mountains, North and South Moccasin Mountains, Highwood Mountains and Bearpaw Mountains all contain syenitic plutonic or hypabyssal igneous rocks. The Rocky Boy stock in the Bearpaw Mountains, 90 mi northeast of Great Falls, contains a variety of alkalic rock types including nepheline - bearing shonkinites and syenites (Pecora, 1942, fig. 2). This stock is exposed over an area of about 12 sq mi and may be a potential source of feldspar or nepheline syenite. Syenitic plutons in both the Bearpaw Mountains and the Highwood Mountains 75 mi to the southwest may also have potential for development of feldspar resources.

Fluorspar

Fluorspar has been mined from three deposits in western Montana, all close to the Idaho batholith (Cretaceous), which is exposed in the Bitterroot Range along the Idaho-Montana border. The Snowbird and Spar deposits, west and northwest of Missoula respectively, are in metasedimentary rocks of the Wallace Formation of the Proterozoic Belt Supergroup. At both deposits fluorite occurs in pods associated with masses of white quartz and calcite (Sahinen, 1962, p. 11-16). The much larger Crystal Mountain deposit, situated in the Sapphire Range 60 mi south of Missoula, is in granite probably related to the Boulder batholith and gneiss presumably formed by metamorphism of rocks of the Belt Supergroup. Other fluorite prospects are reported in the area northwest of Missoula (Corn, 1953) and further exploration in this area of western Montana might reveal more deposits.

Fluorite also occurs in hydrothermal veins within and adjacent to the Boulder batholith. These veins are in most instances associated with metalliferous deposits (Sahinen, 1962, p. 16-26). They are typically small and it is unlikely that fluorite could be economically recovered except as a coproduct of metal production.

Fluorite occurs in veins and disseminations in alkalic igneous rocks and the adjacent sedimentary rocks exposed in the isolated mountains of central Montana (Ross, 1950 and Sahinen, 1962). In the Sweet Grass Hills, South Moccasin Mountains and Judith Mountains of central and northern Montana, fluorite veins occur in limestone of the Mississippian Madison Group and the adjacent igneous rocks. In the Little Rocky Mountains of north central Montana, fluorite is disseminated in a porphyritic syenite (Sahinen, 1962, p. 33-34). It is interesting that in these same mountain ranges gold deposits are being mined or have been mined in several instances in close association with the fluorite occurrences.

## Garnet

Major bedrock garnet occurrences are confined to two geologic environments: grossularite-bearing skarns adjacent to Laramide granitoid plutons in south-western Montana and Archean metamorphic rocks in southwestern Montana. Of these two environments the Archean metamorphic rocks and placer deposits derived from them seem to to have the greater possibility of economic development. Garnet occurs in amphibolite, hornblende gneiss, quartzofeldspathic gneiss, anthophyllite gneiss, schist and garnetite in the Archean metamorphic rocks. Relatively widespread amphibolite is an important source of garnet in the placer deposits. The unusual rock garnetite is exposed in the northern end of the Tobacco Root Mountains 35 mi southwest of Butte. This rock consists of 20 to 80 percent pyralspite garnet and 20 to 70 percent quartz (McClain, 1977, p. 1).

The areas of greatest potential for alluvial concentrations of garnet are streams that drain mountain ranges in southwestern Montana where garnetiferous metamorphic rocks are exposed. The garnetiferous alluvium in Granite Creek in the southern Tobacco Root Mountains has been investigated as a possible source. Farther south in the Greenhorn Range, garnets have been recovered by rockhounds from the gravels along Barton Gulch which also drains an area of Archean metamorphic rocks. Eluvial concentrations of almandite garnets averaging about 0.25 inches in diameter are reported in the area north of the main road in the Sweetwater Basin 20 mi southeast of Dillon (Heinrich and Rabbit, 1960, p. 33).

## Graphite

Lump graphite has been mined from irregular vein-like bodies in Archean gneiss, schist, dolomitic marble and pegmatite at the Crystal Graphite mine in the Ruby Range 10 mi southeast of Dillon (Perry, 1948, p. 13-17). Total production of graphite from this mine and from the Bird's Nest claim less than one mile northeast is estimated to be 2350 tons, mainly mined during 1918 and 1919 (Cameron and Weiss, 1960, p. 252, 253). At a prospect on Kate Creek, 35 mi southwest of Dillon, graphite occurs in a fault zone between Paleozoic sedimentary rocks and Archean metamorphic rocks (Perry, 1948, p. 17-20).

A deposit variously reported to contain graphite, amorphous graphite or fixed carbon is situated north of Indian Creek on the east flank of the Elkhorn

Mountains 25 mi southeast of Helena near Townsend. Klepper and others (1971, p. 48) described lignitic shale near the top of the Morrison Formation north of Indian Creek. Possibly these beds of lignitic shale have been metamorphosed by Cretaceous dikes and sills to form graphitic material. In the late 1970's an effort was made by the Black Diamond Graphite Co. to market material from this deposit for refractory use.

Gypsum

The most extensive gypsum deposits in Montana are in the Great Falls-Lewistown area of the west-central part of the State. Gypsum for use in cement manufacture is mined from the Kibbey Formation of the Mississippian Big Snowy Group from a deposit near Raynesford, 32 mi southeast of Great Falls. Perry (1949, p. 12) reported a thickness of 27 ft for a gypsum bed at this locality. However, he explained that this measurement was on a weathered exposure and may not accurately represent the true thickness. A few miles west near Riceville (24 mi southeast of Great Falls) a gypsum bed averaging 4 to 6 ft has been mined (Perry, 1949, p. 13). This bed is in the Otter Formation which overlies the Kibbey Formation and also is part of the Big Snowy Group.

The Piper Formation of the Upper Jurassic Ellis Group contains gypsum beds which have been mined in the Lewistown area. West of Lewistown at Hanover a 7-ft and a 10-ft-thick bed of gypsum separated by 140 ft of calcareous shale have been mined (Miller, 1959, p. 35). At Heath east of Lewistown a 13 to 17-ft-thick bed, also in the Piper Formation, was mined for wall board (Perry, 1949, p. 8). The lower 8 to 12 ft of this bed is nearly pure gypsum.

In south central Montana 40 mi southwest of Billings near Bridger, gypsum beds averaging 15 to 20 ft thick near the top of the Triassic Chugwater Formation have been mined (Knappen and Moulton, 1930, p. 67). The Talent Gypsum property

40 mi southeast of Dillon at an elevation of 9,000 ft in the Snowcrest Range contains indicated ore reserves of 1,400,000 tons that range from 63.8 to 92.4 percent gypsum (Johns, 1980, p. 22,23). Two smaller deposits 40 mi southwest of Dillon, also in the Big Snowy Group, together contain at least 700,000 tons of rock that ranges from 47 to 93 percent gypsum (Johns, 1980, p. 1). Farther to the east in the Gravelly Range a 20-ft bed of gypsum occurs in the Jurassic Ellis Formation (Mann, 1954, p. 26). Spring deposits of gypsum are found in the vicinity of this bed.

Limestone

In common with most states, limestone is an abundant mineral commodity in Montana. The Madison Group of Mississippian age is the largest limestone resource in the state. Limestone beds of this group are exposed on the flanks of mountains in central and southwestern Montana and in the Disturbed Belt along the Rocky Mountain front in the northwestern part of the State. The Madison Group is divided into the Lodgepole Formation and the overlying Mission Canyon Formation which contains higher purity limestone. Much of the Mission Canyon Formation can be classified as high-calcium limestone containing more than 95 percent $CaCO_3$, less than 5 percent $MgCO_3$ and less than 3 percent other impurities (Chelini, 1965, p. 10). At some localities unusually pure beds in this formation contain more than 98 percent $CaCO_3$ (Landreth, 1968, p. 6). The Mission Canyon Formation is up to 900 ft thick in central Montana (Smith and Gilmour, 1980, p. X17). Limestone from the Mission Canyon Formation is quarried near Townsend for lime manufacture and near Warren in south central Montana for use in sugar beet refining. Limestone has also been quarried near Drummond for sugar beet refining.

Although the $CaCO_3$ content is lower than in the Mission Canyon Formation, the underlying Lodgepole Formation is an important source of limestone for cement manufacture. Analyses of limestone from the Lodgepole Formation at five localities show a range from 72.8 to 88.2 percent $CaCO_3$ (Chelini, 1965, p. 19,37,38,44, 47). This formation reaches a maximum thickness of 780 ft in central Montana (Smith and Gilmour, 1980, p. X15).

The Meagher Formation, a Cambrian limestone exposed in central and southwestern Montana, is also a source of high-purity limestone. Limestone from the Meagher Formation formerly quarried for smelter flux at the south end of the Helena Valley contained 93.2 percent $CaCO_3$ (Perry, 1949, p. 39). Other potential sources of $CaCO_3$ are the travertine deposits near Lewistown, north of Yellowstone National Park, and southwest of Dillon (Berg, 1974, p. 19,20).

Lithium

Lithium occurs in anomalous concentrations in Oligocene-age lacustrine sediments exposed in a band 4200 ft long by 1000 ft wide near Lincoln 55 mi northeast of Missoula (Brenner-Tourtelot and others, 1978). Some stratigraphic intervals are reported to contain nearly 0.1 percent lithium. Other Oligocene sedimentary rocks from the Helena and Townsend Valleys contain much lower lithium concentrations.

Magnesite

Although there are no known major deposits in Montana, magnesite has been identified in at least three localities in southwestern Montana closely associated with talc in Archean dolomitic marble (Berg, 1979, p. 10,11). Because of the difficulty of distinguishing magnesite from dolomite in the field, one wonders if magnesite may be more abundant in dolomitic marble than has been recognized.

## Mica

Pegmatites in the Archean metamorphic rocks of southwestern Montana have yielded small amounts of muscovite mica. The greatest production of about 10 tons was from the Sappington pegmatite west of Three Forks, 45 mi southeast of Butte (Heinrich, 1949, p. 23). Mica production from other pegmatites, mainly during World War II, was much less. The numerous pegmatites in southwestern Montana are small, usually less than 100 ft long and 20 ft thick and are concordant to foliation of the enclosing gneiss. Some have quartz cores; others are mixtures of quartz, microcline, plagioclase with lesser amounts of biotite, muscovite and sometimes schorl. Muscovite books are up to 5 in across (Heinrich, 1949, p. 11-25).

A large deposit of muscovite schist produced by the metamorphism of an argillaceous unit in the Belt Supergroup is exposed near the head of McClain Creek in the Bitterroot Range 13 mi southeast of Missoula. Exploratory drilling has shown this deposit to be extensive (Dominick Job, personal communication, 1989). The schist also contains quartz and feldspar.

## Phosphate

The Western Phosphate Field encompasses northern Utah, western Wyoming, eastern Idaho and southwestern Montana extending as far north as the Elliston district 20 mi northwest of Helena. The Permian Phosphoria Formation has been divided into six members of which the uppermost Retort Phosphatic Shale Member contains the largest phosphate resources (Popoff and Service, 1965, p. 19). This member contains beds of phosphorite and thin-bedded carbonaceous mudstone. The Meade Peak Phosphatic Shale Member, which is stratigraphically lower in the Phosphoria Formation, is also an important phosphate resource. Structural complexities caused by faulting and folding during Larmide time require that phosphorite beds would have to be mined by underground methods in most instances. Popoff and Service (1965, p. 7-13) estimated the phosphate resources contained in beds at least 3 ft thick and at or above the level of the local drainage to be 1.05 billion short tons with a grade of at least 18 percent $P_2O_5$. Of these resources 93 million tons contain more than 31 percent $P_2O_5$ (acid grade), 374 million tons contain between 24 and 31 percent $P_2O_5$ (furnace grade) and the remaining 585 million tons are between 18 and 24 percent $P_2O_5$ (beneficiation grade). The thickness of most beds that average at least 24 percent $P_2O_5$ ranges from 3 to 6 ft and beds that average 18 to 24 percent $P_2O_5$ are up to 12.4 ft thick. Since 1929 phosphate has been mined in the Garrison district 40 mi northwest of Butte by Cominco American, Inc. for the manufacture of fertilizer. Phosphate was formerly mined underground in the Melrose district 25 mi southwest of Butte and shipped to Stauffer Chemical Company's Victor Chemical Works west of Butte for the manufacture of phosphoric acid and elemental phosphorus. Since the mid 1960's, phosphate mined in an open pit in Idaho has supplied this plant.

Potash

Potash-bearing beds in the Middle Devonian Prairie Formation have been encountered during oil and gas drilling in northeastern Montana. Analyses by the Montana Bureau of Mines and Geology of core from the salt-bearing interval of this formation at a depth of 9918 to 10,120 ft from the Farmers Union Central Exchange-Jayhawk well #43X-30 Nelson located in NE 1/4 SW 1/4 sec. 30, T. 33 N., R. 56 E., Sheridan County showed the material to consist mainly of halite. The thickest sylvite-bearing interval is from a depth of 10,008 to 10,015 ft where the average content of water-soluble equivalent $K_2O$ is 4.3 weight percent. At a greater depth of 10,048 to 10,050 ft the equivalent $K_2O$ content is 6.96 weight percent.

At other localities in northeastern Montana this interval of the Prairie Evaporite Formation contains a greater concentration of sylvite (Reed, personal communication, 1989). However, compared to the large potash deposits mined from this same formation in southern Saskatchewan, the Montana deposits are deeper, thinner and of lower grade.

## Pumicite

Pumicite occurs in Tertiary sedimentary deposits exposed in the intermontane basins of southwestern Montana. Samples from six pumicite deposits were evaluated by the U.S. Bureau of Mines for suitability as pozzolanic raw material. Two of the samples, one from Big Horn County southeast of Billings, and the other from Powell County northwest of Butte, met the minimum requirements for pozzolanic material except that their reactivity with cement alkalies was too low (U.S. Bureau of Mines, 1969, p. 32 and 42). The most readily available source of pozzolanic raw material in Montana at the present time is fly ash produced by coal-fired generating plants. Deposits of pumice are not known in Montana.

## Rare Earth Elements

Minerals containing rare earth elements have been reported from a number of Montana localities. In southwestern Montana carbonatite bodies are exposed in southern Ravalli County, 95 mi south of Missoula, as well as adjacent areas in Idaho. The most abundant rare earths in those bodies that have been explored are cerium and lanthanum (Crowley, 1960, p. 3). Rare earth minerals from these deposits are monazite, ancylite, bastnasite and allanite (Heinrich, 1966, p. 364). The rare-earth-bearing fluocarbonate mineral parisite occurs associated with a carbonatite at the Snowbird mine, a fluorspar deposit 37 mi west of

Missoula (Lasmanis, 1977, p. 83-86).

Fergusonite? occurs in the Sappington pegmatite, a large pegmatite in Archean metamorphic rocks situated about 40 mi southeast of Butte (Heinrich, 1949, p. 24).

Other potential sources of rare earths are placer deposits in southwestern Montana known to contain concentrations of monazite (Overstreet, 1967, p. 171). Northwest of Great Falls concentrations of heavy minerals, most notably titaniferous magnetite, in the Virgelle Sandstone Member of the Eagle Formation and the Horsethief Sandstone, both of Cretaceous age, suggest a potential source of rare earths (Overstreet, 1967, p. 170).

Salt

Halite beds occur in the subsurface in eastern Montana on the west flank of the Williston Basin, a structural and stratigraphic basin whose center lies in western North Dakota. The Salt member of the Prairie Formation of the Middle Devonian Elk Point Group consists mainly of halite and is over 200 ft thick in northeastern Montana where it occurs at a depth of 6000 to 10,000 ft (Pierce and Rich, 1962, p. 51-56). (See the section on potash for a brief description of potash occurrences in the Prairie Evaporite Formation). Higher in the stratigraphic section, the Charles Formation of Mississippian age contains six salt beds whose cumulative thickness is greater than 300 ft in eastern Montana (Pierce and Rich, 1962, p. 56,57). The top of the salt beds ranges in depth from 7000 ft along the Montana-North Dakota border to approximately 2500 ft at their western limit 90 mi to the west. The Opeche Formation of Permian age also contains a salt bed which extends about 25 mi into eastern Montana (Pierce and Rich, 1962, p. 58). The maximum thickness of this salt bed in eastern Montana is slightly greater than 100 ft.

Sand, Gravel and Crushed Stone

Sand and gravel deposits are abundant in the mountainous western one third of Montana where igneous and metamorphic bedrock provide a source of durable material for high-quality sand and gravel. In this area fluvial deposits close to active rivers and streams provide a good source of sand and gravel. Also, older Quaternary and Tertiary gravel deposits exposed in terraces above the present flood plain provide additional resources (Larrabee and Shride, 1946). Sand and gravel derived from adjacent mountain ranges and forming terrace deposits northwest of Great Falls along the Rocky Mountain Front and also to the southeast are important sources of this commodity. In these areas as well as in eastern Montana, the underlying bedrock of the plains is shale and sandstone of Cretaceous and Tertiary age which generally do not yield sand and gravel deposits. The only widespread fluvial deposits in eastern Montana associated with an active river are those along the Yellowstone River (Larrabee and Shride, 1946).

North of the Milk River in north central Montana and north of the Missouri River in northeastern Montana gravel, sand and silt with local occurrences of marl and volcanic ash of the Tertiary Flaxville Formation cover a large area (Ross and others, 1955). Quaternary Wiota Gravels, glacial outwash, kame deposits and eolian sand deposits are also sources of sand and gravel (Colton, 1955 and 1963). Scoria formed by the metamorphism and partial melting of beds overlying burned coal in the Tertiary Fort Union Formation of southeastern Montana are used locally for road surfacing.

Crushed stone for railroad ballast is quarried at two localities, both in metasedimentary rocks of the Precambrian Belt Supergroup. Thirteen miles southeast of Missoula along the Clark Fork River, the Bonner Quartzite is quarried at the McQuarrie quarry. Fracturing related to movement along the nearby Clark Fork fault provides for easy quarrying of this quartzite. Quartzite from the Missoula Group is quarried at the Essex quarry 35 mi northeast of Kalispell near the southern boundary of Glacier National Park.

Silica

Quartz-cored pegmatites in the Boulder batholith between Butte and Helena are a silica resource. Since 1964 the Basin quarry (now inactive) about 25 mi southwest of Helena near the town of Basin has produced more than 250,000 tons of quartz containing 99.5 percent $SiO_2$ for metallurgical alloys (Peterson, 1976, p. 93,94). Chelini (1966) described two other quartz-cored pegmatites in the Boulder batholith south of Helena with purity greater than 99.5 percent $SiO_2$ and estimated reserves of 500,000 and 275,000 tons. Another quartz-rich pegmatite in the Idaho batholith south of Missoula contains 156,000 tons (Chelini, 1966, p. 12-14).

Numerous relatively pure quartz bodies, perhaps resulting from remobilization of quartz from quartzites, are present in the Proterozoic metasedimentary rocks of the Belt Supergroup northwest of Missoula. One such occurrence, the Petty Creek deposit, is estimated to contain 960,000 tons of quartz with analyses averaging 99.5 percent $SiO_2$ (Chelini, 1966, p. 30-32). Farther to the northwest the Haines Point deposit, also in rocks of the Belt Supergroup, is estimated to contain reserves of at least 100,000 tons of quartz with purity of 99.7 percent $SiO_2$ (Burlington Northern, 1972, p. 54-57).

The Pennsylvanian Quadrant Formation, mainly a quartzose sandstone, which is found throughout southwestern Montana is a significant silica resource. Eleven miles southwest of Dillon sandstone in this formation was quarried at Daly's Spur for smelter flux. Duplicate analyses of sandstone from this quarry indicate 98.9

and 97.5 percent $SiO_2$ (Carter and others, 1962, p. 21-23). The Detton silica deposit 42 mi south of Dillon, is reported to be sufficiently pure for use in glass (personal communication John Detton, Dillon, MT, 1989). This deposit also is in the Quadrant Formation. The Tensleep Formation exposed in southern Montana and Wyoming is equivalent to the Quadrant Formation and also is a potential source of silica.

Sandstone of Cretaceous age, although extensive in Montana, generally is feldspathic and thus does not have the high purity desired for most industrial uses. The same is generally true for the quartzite beds in the Belt Supergroup.

## Sillimanite Group Refractories

Of the three aluminosilicate polymorphs, kyanite, sillimanite and andalusite, sillimanite is the most abundant in Montana. At reported sillimanite occurrences in Archean metamorphic rocks of southwestern Montana this mineral occurs in biotite schist, in some instances accompanied by garnet (Heinrich, 1950, p. 20). Sillimanite also occurs in some pegmatites in Archean metamorphic rocks. The Placer Creek sillimanite deposit, 26 mi southwest of Bozeman in the Madison Roadless Area, is in Archean garnet-hornblende gneiss. This deposit is estimated to contain 21,000 tons of rock containing 84 percent sillimanite and 2 percent rutile with an additional inferred resource of 70,000 tons (Simons and others, 1983, p. 5). Kyanite occurs in quartzose pegmatites within Archean gneisses exposed about 13 mi southwest of Ennis. Although kyanite is locally abundant in and adjacent to these pegmatites where it constitutes as much as 20 percent of the rock, the occurrences are irregular and the total amount of kyanite may be small (Heinrich, 1948, p. 13).

Andalusite is not known to occur in significant quantities in Montana. Dumortierite, a boroaluminosilicate, occurs disseminated in quartz latitic welded tuff of Cretaceous age near Basin about 20 mi southwest of Helena (Ruppel, 1963, p. 96). Potential development of this deposit faces two obstacles: small deposit size and difficult beneficiation caused by the interlocking of dumortierite grains with other constituents of the rock.

## Sodium Sulfate

In northeastern Montana and western North Dakota numerous small lakes occupy depressions thought to have formed in ice-marginal channels in glacial till (Witkind, 1959, p. 73). Springs feeding these lakes contribute sodium sulfate which is concentrated sufficiently in some lakes to form permanent sodium sulfate beds. The largest deposit in Montana is in a small lake southeast of Brush Lake in Sheridan County where auger drilling by the U.S. Bureau of Mines intersected a bed of mirabilite or glauber's salt ($Na_2SO_4$ $10H_2O$) a few inches below the surface of the mud in the bottom of the lake. This bed ranges from 3.5 to 5.7 ft in thickness and is estimated to contain 2,710,000 tons of glauber's salt (Binyon, 1952, p. 18 and 27).

About 45 mi northeast of Great Falls a few intermittent lakes lie in the channel occupied by the Missouri River during Wisconsin stage glaciation. Four of these lakes contain significant concentrations of sodium sulfate which forms a white crust on the mud when the lakes are dry (Sahinen, 1956, p. 5 and 6). Further work is needed to determine whether or not permanent sodium sulfate beds occur within the mud on the bottom of these lakes. The largest of these lakes, appropriately named Big Lake, is about 2 sq mi in area (Sahinen, 1956, p. 6).

## Stone

Although Montana has a wide variety of rock types that are suitable for decorative stone, only a few have been quarried commercially in recent years.

The most important of these is travertine from deposits north of Yellowstone National Park which has been quarried since 1932 for facing. Color of this travertine ranges from white to ochre. Two other large deposits of travertine are present in the state, one southwest of Dillon and the other west of Lewistown (Berg, 1974, p. 20).

Gray granite has been quarried from the Cretaceous-age Boulder batholith in the Butte and Helena areas. Pink granite exposed south of Darby may be suitable for facing, but has not been quarried (Berg, 1974, p. 15). Marble, some unusually white, was formed by contact metamorphism next to granitoid plutons in southwestern Montana and also occurs in the Archean sequence exposed in the southwestern part of the state. Slate-like argillite from the Proterozoic Belt Supergroup is produced from a quarry near St. Regis in western Montana. The Flathead Formation, a Cambrian quartzite, has yielded an attractive facing stone from quarries east of Great Falls and from a quarry north of Thompson Falls.

A number of other rock types have been quarried, generally on a small scale or for only a few years. These include green Archean quartzite that contains green chromiferous muscovite, mottled limestone from the Cambrian Meagher Formation, dolomitic siltstone from the Triassic Chugwater Formation, flaggy limestone from the Bear Gulch Limestone Member of the Pennsylvanian Tyler Formation, and Tertiary volcanic rocks (Berg, 1974). Further development of stone deposits depends on aggressive out-of-state marketing and favorable transportation costs.

## Talc

In recent years Montana has led the Nation in value of talc produced. Deposits of high-purity talc, most of which can be mined by open pit methods, occur in Archean metamorphic rocks in the mountain ranges of southwestern Montana

(Berg, 1979). Although much still remains to be learned about the origin of these deposits, they appear to be Precambrian in age, their formation controlled in part by structure and in part by host rock lithology. Talc deposits are confined to dolomitic marble (Tysdal and others, 1987, p. A 17). Talc occurrences range in size from thin veinlets and disseminations to large bodies such as the one 95 ft thick at Pfizer's Treasure Chest mine in the Ruby Range (Olson,1976, p. 123). Sixteen miles east of Dillon just south of the Treasure Chest mine, Cyprus Industrial Minerals operates the underground Beaverhead mine. In the Gravelly Range 18 mi south of Ennis Cyprus mines talc at the Yellowstone mine and just to the west Montana Talc operates the Johnny Gulch mine. The greatest concentration of talc occurrences is in the Ruby Range, but talc has also been mined from deposits in the Tobacco Root and Greenhorn Ranges. In 1988 talc production from Montana deposits was estimated to be 339,000 tons (U.S. Bureau of Mines, 1988, p. 4). Talc from Montana deposits is used in paper, paint, ceramics, plastics and cosmetics. The high purity and lack of asbestiform minerals has enabled Montana talcs to compete effectively in the international market.

Vermiculite

Only one of the five known vermiculite deposits in Montana has been mined on a large scale. This deposit north of the town of Libby in northwestern Montana has been mined since 1925. The total vermiculite production from the Libby deposit is estimated to be several million tons (Bush, 1976, p. 151, 152). Vermiculite was formed by alteration of a biotitite core of a zoned Jurassic ultramafic complex that had intruded metasedimentary rocks of the Belt Supergroup. Alteration of biotite to vermiculite is thought to have been caused by weathering (Boettcher, 1966, p. 293-295).

The Hamilton vermiculite deposit, 45 mi south of Missoula, also was formed by the alteration of biotitic rocks in a pyroxenite body that intruded metasedimentary rocks of the Belt Supergroup (Perry, 1948, p. 28-30). Testing of samples of ore from this deposit by numerous methods and organizations shows that the content of asbestiform minerals is extremely low and that the average content of actinolite with an aspect ratio greater than 3:1 is 0.028 percent (State of Montana and U.S. Forest Service, 1988, p. 4). Plans are underway to mine this deposit.

The Pony vermiculite deposit is on the north flank of the Tobacco Root Mountains north of the small town of Pony 40 mi southeast of Butte. The vermiculite at this undeveloped deposit was formed by the alteration of Archean biotite schist interlayered with gneiss (Perry, 1948, p. 32, 33). Because the schist contains quartz, feldspar and garnet in addition to unalterred biotite, these minerals would have to be separated from the vermiculite. Perry (1948, p. 33) considered the reserves of vermiculite at this deposit to be "extremely large".

At the Elk Creek deposit 13 mi southeast of Dillon, vermiculite is concentrated at the contact between Archean gneiss and an ultramafic body (Desmarais, 1978). Exploratory drilling has indicated reserves of 3.5 million tons of rock containing an average of 11.4 percent vermiculite (Koehler Stout, personal communication, 1989). Several drill holes intercepted rock containing 28 percent vermiculite over a 25-foot cumulative thickness.

Vermiculite is associated with Tertiary syenite pegmatites in the Bearpaw Mountains of north central Montana (Heinrich, 1949, p. 45,46). This deposit appears to be much smaller than the others described and the biotite has not altered sufficiently to produce highly expandable material.

Zeolites

Although zeolites have not been mined in Montana, the abundance of Tertiary and Cretaceous volcanic rocks and a number of reported zeolite occurrences suggest the possibility of mineable deposits. Pearson (1989, p.8) reported clinoptilolite and mordenite in the Cretaceous-age tuff of Grasshopper Creek. Samples of this tuff collected along Grasshopper Creek 12 mi southwest of Dillon were estimated to contain 60 to more than 90 percent clinoptilolite on the basis of x-ray diffraction analysis. In another southwestern Montana occurrence a Tertiary tuff from Ryan Canyon 12 mi south of Dillon contains clinoptilolite (Sheppard, 1976, p. 75). Several miles to the north mordenite and heulandite occur in amygdales in tuffaceous rocks of Miocene age (Rose, 1972, p. 247).

Lens-like masses of zeolitized tuff 1 to 3 m long and 0.3 to 0.6 m thick occur in the Bootlegger Member of the Cretaceous Blackleaf Formation at the type section northwest of Great Falls (Cobban and others, 1976, p. 34). In the same area the Vaughn Member, also of the Blackleaf Formation contains clinoptilolite in a tuffaceous siltstone bed 0.5 m thick (Cobban and others, 1976, p. 29). Near the Dover tunnel 55 mi southeast of Great Falls, the Arrow Creek Bed contains concretionary masses that consist of quartz, clinoptilolite and calcite. This bed, which is largely bentonitic in this area, is also in the Bootlegger Member of the Blackleaf Formation.

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