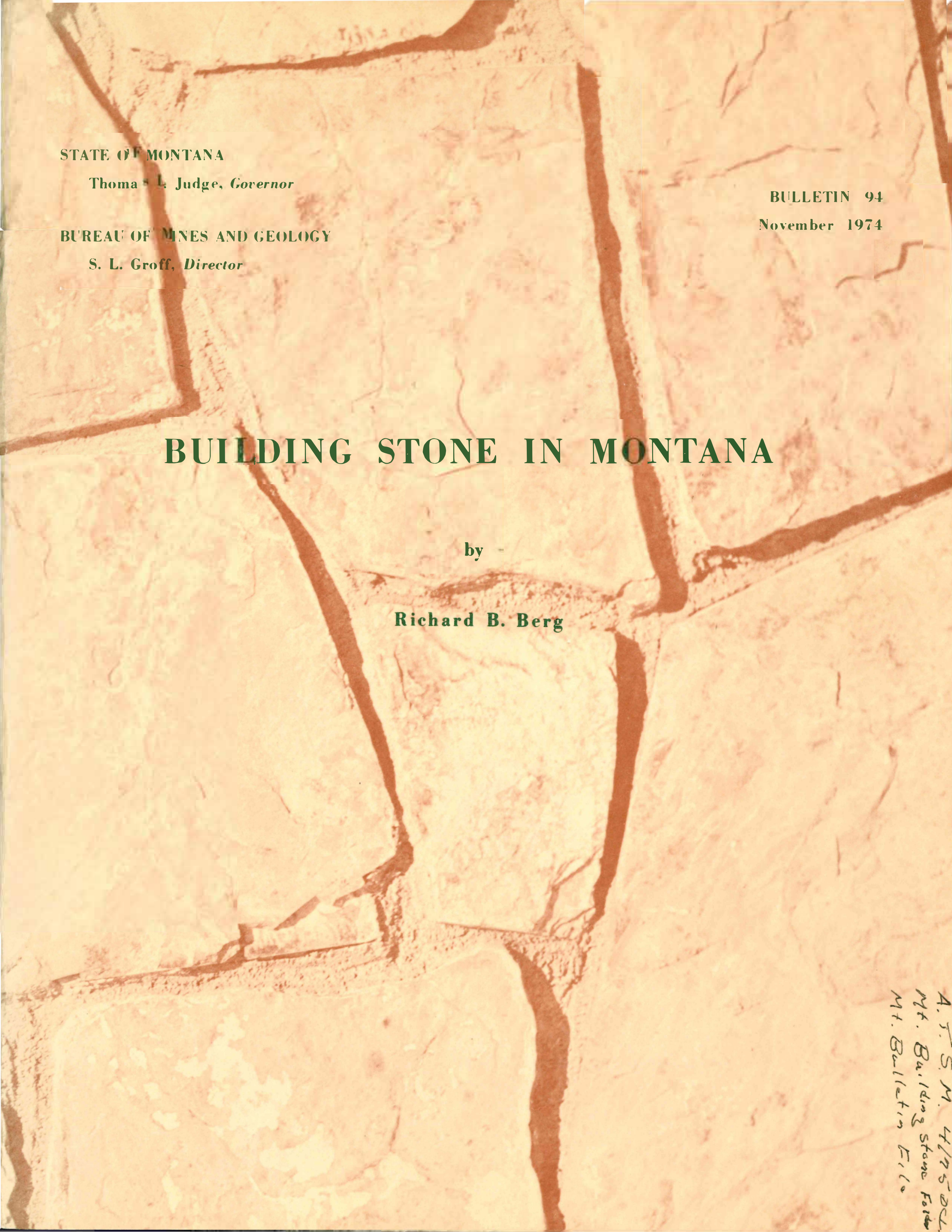

STATE OF MONTANA
Thomas L. Judge, *Governor*

BUREAU OF MINES AND GEOLOGY
S. L. Groff, *Director*

BULLETIN 94
November 1974

BUILDING STONE IN MONTANA

by

Richard B. Berg

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Mt. Bulletin File

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MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY
Butte, Montana
1974

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BUILDING STONE IN MONTANA

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ABSTRACT

Samples of stone from 41 of 67 described localities were tested for absorption and bulk specific gravity in accordance with American Society for Testing and Materials procedures. Petrographic descriptions of samples from 61 localities are included. Gray granite suitable for dimension stone can be quarried at several localities in the area south of Butte. Pink granite, also suitable for dimension stone, can be quarried south of Darby. Limestone, which can be used for flagging, ashlar, and rubble, is found near Lewistown, near Manhattan, and south of Billings. Large deposits of travertine occur near Lewistown, Gardiner, and Lima. In central and western Montana the Flathead Quartzite is a good source of ashlar and rubble. In northwestern Montana, argillite of the Prichard Formation is suitable for flagging.

INTRODUCTION

Many different kinds of rock are found in Montana, and over the years, several types of these rocks have been produced. Recently, stone quarried in Montana has been sold on both coasts and in Canada, indicating that the desirability of the stone can overcome the handicap of a long haul to market.

During this study of building stone, both abandoned and active quarries throughout the state were examined and sampled. A quarry, even though abandoned for tens of years, may be put back into operation relatively easily whereas a long-abandoned underground mine would require more effort. In addition, some abandoned quarries contain large leftover blocks of stone that may be workable by modern equipment and techniques. Furthermore, several deposits that had not been quarried were examined because published descriptions of the rock indicated that it might be suitable for use as building stone.

Absorption and bulk specific gravity of selected samples were determined according to procedures established by the American Society for Testing and Materials (ASTM). Mineralogy and texture were determined by examination of thin sections and polished slabs; mineralogy of a few samples was determined by x-ray diffraction analysis.

Specimens collected during this study are stored at the Montana Bureau of Mines and Geology where they are available for examination.

Deposits of rock suitable for use only as aggregate, riprap, road material, and similar products used in the construction industry were not examined during this investigation, but many of the deposits reported here would be suitable for constructional use. In selecting this type of stone, however, proximity to the building site is of greatest importance, and rock of this kind can be found close to most of the sites where it is to be used. Its selection is governed by factors different than the relatively exacting requirements considered in the selection of a quarry site for building or ornamental stone.

Published information on stone deposits in Montana consists of three publications. Rowe (1908) described Montana stone deposits in a fairly general manner and included information of historical interest on quarrying in the state shortly after the turn of the century. Mansfield (1933) provided detailed information on deposits of travertine near Gardiner and on a marble onyx deposit near Manhattan. Rector (1963) provided detailed information on a deposit of Flathead Quartzite north of Thompson Falls.

U. M. Sahinen offered information on quarry locations and undeveloped deposits. Mike Chapman performed much of the laboratory testing, and Jim Robson and Jeff LeFever prepared thin sections and polished slabs. Dariel McDonald, Mike Merritt, and Ken Patterson assisted with the field work.

VARIETIES OF BUILDING STONE

The distinction between rock and stone can be somewhat confusing. Rock is the naturally occurring material of which the earth is composed. Most kinds consist of a mixture of minerals, but a few varieties consist entirely of a single mineral. Rocks are classified by geologists on the basis of the contained minerals and the textures (relationship between individual mineral grains), which provide some information as to how the rock formed. For example, the correct identification and description of a rock usually requires the examination of a very thin slice (thin section) of the rock by use of a petrographic microscope. Rock names and descriptions given in the appendix are the result of such a microscopic examination of thin sections.

Users of stone classify stone by two criteria: the stone type, and the manner in which it is finished. Although rock names are used for stone type, the stone names are much more general. A great variety of rock types may be included under one name. Adjectives describing the color or an unusual feature of the rock are used to further distinguish between different varieties of the same stone.

The following terminology for building stone has been suggested by the American Society for Testing and Materials (1971, Part 12, p. 109-111).

GRANITE
1. True granite and other plutonic igneous rocks
2. Black granite (dark igneous rocks such as gabbro)
3. Gneiss (a metamorphic rock with banding)

LIMESTONE
1. Calcite limestone
2. Dolomite
3. Magnesian (dolomitic) limestone
4. Travertine

MARBLE
1. Calcite marble
2. Magnesian (dolomitic) marble
3. Onyx marble
4. Serpentine marble
5. Verde antique

GREENSTONE

SANDSTONE
1. Sandstone
2. Bluestone
3. Brownstone
4. Conglomerate
5. Freestone
6. Quartzite

SLATE

This classification will be used, in slightly modified form, in the arrangement of descriptions of specific stone deposits. In addition to the above categories, volcanic rock and miscellaneous categories have been added, and adjectives have been used where necessary to avoid confusion.

USE CLASSIFICATION OF STONE

Deposits of stone are classified on the basis of the lithology or composition of the rock. In addition, stone is classified on the basis of the use. For instance, a single type of stone, such as limestone, may be used in a variety of applications after preparation by different methods. Building stone from a specific quarry is likely to be finished in several different ways in an effort to capture variour segments of the building-trade market.

VARIETIES OF STONE WITHOUT MACHINE-FINISHED SURFACES

Field stone is used for architectural contrast where a rustic stone is desired. As its name suggests, it is stone found lying around on the surface of the ground. It has been derived from the underlying bedrock by natural weathering and frost action. Field stone formed naturally has a rough surface and is irregular. Furthermore, because field stone has withstood natural weathering, it should be durable. A rock variety that is not fairly resistant to weathering will not survive as blocks lying on top of the ground but will crumble into little pieces. Boulders and cobbles are also regarded as a variety of field stone. Glacial deposits, which contain boulders abraded by the moving glacier and by the erosive action of associated streams, are a source of easily obtained field stone. Stream deposits are another common source of boulders and cobbles.

Stone is also used purely for decorative purposes in landscaping. Large chunks of lightweight frothy volcanic rock are sold for this purpose. This variety of volcanic rock is favored because its light weight (about one fifth that of an equal volume of rock of other types) allows easier emplacement of large boulders of this rock than of the usual heavier varieties.

Boulders of field stone may be split in half to produce a fairly flat surface. The pieces are then so arranged that the flat surface forms the exterior face of the wall. Field stone covered with lichens has become popular in recent years. Some limestone and sandstone in Montana supports brown, red, yellow, and green lichens and is an attractive decorative stone.

Quarry operators can also produce rough stone in irregular shapes and sizes that resembles the naturally occurring field stone. A variety of rough stone having at least one relatively flat surface is termed rubble. This flat surface may be produced by splitting or by rough sawing of the rock. The rock may also be split in three directions so that the faces are approximately perpendicular.

Flagging or flagstone consists of slabs only a few inches thick but as large as several square feet in surface area. Besides its traditional uses as floor covering and for walkways and patios, it is commonly used as a facing. The amount of flagstone needed to cover a wall is significantly less than the amount of rough stone or rubble that would be used because of the great area of flagging relative to its thickness. Flagging emplaced so that the mortar produces a web-like pattern is called web-wall.

Ashlar is defined as a variety of stone that is produced in roughly rectangular blocks of uniform thickness but different lengths and heights. In common practice, the heights will be so related that two of the thinner blocks plus the mortar layer between will equal one of the thicker blocks. The exposed surface may be finished in various textures. Split face is produced by splitting the block in a guillotine-like rock splitter, which produces a relatively flat but rough, natural-appearing surface. Pitch-face ashlar is produced by breaking the surface in such a manner that the central part of the face projects slightly. A more ordered type of wall can be produced with ashlar than with rubble. Variety in ashlar facing is provided by mixing blocks of various sizes and by using contrasting rock types or different surface preparations in a single wall, thereby producing striking effects (Figure 3, A and B).

Travertine is an example of stone that can be used to produce ashlar although it has no significant natural cleavage. Large blocks of travertine are sawed into slabs, which are then broken by a stone splitter to produce split-face ashlar, the height of which corresponds to the thickness of the cut slabs.

VARIETIES OF STONE WITH MACHINE-FINISHED SURFACES

Polished granite and marble have been extensively used for facing buildings, especially public buildings and banks. Although in recent years polished stone has in part been replaced by the rougher and more rustic varieties, it is still in widespread use. Polished stone is, of course, extensively used in the monument industry.

Requirements of stone for polishing are more exacting than those for rubble or ashlar. Obviously, the stone must consist of minerals that will take a good polish. Most silicates such as quartz and feldspar can be polished, unless they contain impurities or have been altered to clay minerals. Many varieties of stone that contain large crystals and show significant variation in composition and texture, such as migmatites, produce very attractive stone when polished. If the rock is to be inscribed, however, a uniform texture without large crystals is desirable. Superior hardness of the constituent minerals in a rock is not necessary for a good polish. For example, calcite, the major constituent of marble, is much softer than the major constituents of granite, yet marble takes an excellent polish. Some stone is finished by honing—a process that smooths the saw cuts, but does not impart a polish to the stone.

During any quarrying operation there is bound to be much waste rock that is unsuitable for use in construction because of small size, discoloration, or impurities. Many quarry operators have been able to sell this otherwise waste material for a variety of uses, including chips for terrazzo floors, chips for exposed aggregate in pre-cast concrete panels, and granules for landscaping. Roofing granules represent an important market for some varieties of crushed rock.

DESIRABLE PROPERTIES OF STONE

Rock types considered for use as building stone are evaluated on the basis of their physical properties. Chemical and mineralogical composition are important only because of their effect on physical properties. For instance, a rock containing a significant amount of an easily weathered mineral, such as pyrite (FeS_2), would be judged unsuitable for exterior use because of the iron staining caused by the weathering of this mineral.

QUARRYABILITY

All rock can be quarried; only the maximum size of the blocks that can be quarried and the cost of quarrying distinguish a good quarry from a less desirable one. Both of these characteristics depend on the natural planes of weakness, which may be expressed as incipient fractures or actual breaks (joints) in the rock. A rock devoid of joints or fractures can be quarried, but this entails more cutting and wedging during quarrying. Although a definite aid to quarrying, fractures and joints limit the maximum size of blocks that can be removed and thus influence or decide the final use of the stone. The ideal situation would be uniformly spaced joints far enough apart to enable the quarry operator to remove blocks just the right size for the intended use. Some bedded sedimentary rocks and some metamorphic rocks that show prominent foliation or schistosity fulfill these conditions. Jointing nearly perpendicular to the natural cleavage of the rock provides an excellent opportunity for producing rubble or ashlar. Within a given quarry or natural outcrop, joints are likely to occur in two or more orientations, and these are likely to be nearly vertical and perpendicular to one another.

Some massive rocks, such as granite, possess a facility for breaking in certain directions. These are referred to as rift and grain in the granite quarry; in most quarries they are indispensable in producing large rectangular blocks. Subhorizontal joints (sheeting) in granitic rocks also facilitate quarrying. Well-developed sheeting can be observed in some of the roadcuts along Interstate 90 just east of Homestake Pass.

Few rock masses are uniform over distances of hundreds of feet. Slight variation in mineralogy can cause a difference in color; variation in texture or grain size may cause a difference in appearance. In addition, dikes of undesirable rock may cut the rock to be quarried. Areas where the rock has been altered by weathering or by processes operative when the rock was deeply buried must also be avoided in quarrying. These complicating features, as well as irregular fractures, all contribute to the waste rock produced during most quarrying.

STRENGTH

Strength and resistance to abrasion are important characteristics of stone that is to be used in certain applications. Because of the trend toward the use of stone simply as a veneer rather than as a supporting member of the structural framework, strength is not as important in the evaluation of building stone as it once was. Actually, the compressive strength of most stone greatly exceeds that required even for structural applications. Strength of a stone is thought by some to be an indication of durability of the stone when exposed to weathering. A texture and mineralogy that will produce a strong rock will also tend to produce a rock of low porosity and of consequent resistance to the spalling caused by freezing and thawing of water entrapped in the rock.

The American Society for Testing and Materials (1971, p. 144-146) has established procedures for measuring the compressive strength of natural building stone. The compressive strength is expressed in pressure per unit area (e.g., pounds per square foot), which is the minimum value at which the sample of stone will break. A block of stone within the size limits specified by ASTM is placed in a testing machine where the force exerted on it can be continually increased until the block breaks. It is essential that the top and bottom surfaces of the sample be as nearly parallel as possible. If the two surfaces are not parallel, the force is not applied uniformly to the entire specimen, thus the measured value of compressional strength will be less than the true strength of the sample.

Samples to be tested for compressional strength must be selected with care because the properties of a large mass of rock are to be inferred on the basis of what is really a very small part of the volume of that rock. The samples must be as nearly representative of the quarry or deposit as possible. Numerous samples should be tested, especially where the natural variation in the rock is obvious. This requirement, of course, applies equally to the determination of other physical properties of stone.

The modulus of rupture, a test less commonly applied than the compressive strength test, is also determined by following the ASTM procedures (1971, p. 96-98). Modulus of rupture is determined on specimens 4 x 8 x 2¼ inches laid with the smallest dimension vertical, supported near each end, and loaded at the center. The modulus of rupture is calculated on the basis of the force applied when the sample breaks after having been continuously loaded. Because of the importance of anisotropy (different strength in different directions) of the stone in this test, samples cut parallel to rift or bedding are tested and compared with samples cut perpendicular to bedding. In tests of compressive strength and of modulus of rupture, samples may be tested wet or dry. The values most frequently quoted are those for samples tested under dry conditions.

ABRASION RESISTANCE

Stone such as slate and flagging, which is to be used for floors or walkways, must be resistant to abrasion by foot traffic. The American Society for Testing and Materials (1971, p. 188-190) has specified a standard means of determining the abrasion resistance of stone subjected to foot traffic. The sample of stone, prepared in a specified manner, is held against a lap to which a specified abrasive is fed. The surface to be tested must be finished in the same way as the stone will be finished when in actual use. The weight loss of the sample as a result of the abrasion is used to calculate the resistance of the stone to abrasion.

The characteristic that makes a stone desirable for a specific use may also increase the cost of producing that stone in suitable form. Greater resistance to abrasion means added cost for cutting the stone with a wire saw, and greater strength means added cost for sizing or shaping the stone with a stone splitter. The economics of production may therefore dictate the selection of a stone that gives somewhat less than the maximum test values. For example, stone used for ashlar does not require great crushing strength, so a moderately soft stone that is easy and economical to finish is preferable to a stronger stone.

The workability of stone was of even more importance when stone was finished by hand. Some very soft stone was used in the past just because of its easy workability with hand tools. Now this stone cannot compete on the market because it lacks the durability of a harder stone, and because of the use of power tools, it does not have such an advantage over a harder stone in the finishing process.

DURABILITY

Stone facing is used on many commercial or government buildings to produce the impression of durability or timelessness. To maintain that impression, stone used for this purpose, or for any exterior decoration, must be able to withstand exposure to the elements for at least the life of the building. Although some of the physical properties of stone, such as the compressive strength, can be determined quantitatively, the durability or resistance to weathering is much more difficult to evaluate. Natural weathering processes acting on rocks may be either chemical or physical, and both should be carefully considered in the evaluation of building stone.

Chemical weathering includes those processes involving chemical reaction, such as the combination of the oxygen in the atmosphere with the iron in pyrite (FeS_2) to produce hematite (Fe_2O_3). This reaction is particularly disastrous to a building stone because the iron oxide causes an unsightly rust-colored stain, which is spread by water. Other iron minerals, such as pyrrhotite ($Fe_{1-x}S$) and marcasite (FeS_2) reacting in the same manner can also cause discoloration by oxidation of the iron, and if present in significant amount, preclude exterior use of the stone. Hematite (Fe_2O_3), limonite ($Fe(OH) \cdot nH_2$), and goethite ($HFeO_2$) can also cause difficulty, not because of chemical alteration but because these minerals tend to be pulverulent and can easily be dislodged and carried down the face of the stone by water.

Carbonates, such as calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)$), are slowly weathered if long exposed to water. A small amount of the carbon dioxide (CO_2) in the atmosphere dissolves in water to produce very weak carbonic acid (H_2CO_3), which slowly dissolves calcite and dolomite. This is the process that produces underground caverns in limestone. Because the chemical weathering of limestone and dolomite is not a serious problem unless they are subjected to unusual acid conditions, both are extensively used as building stone.

Silicate minerals, such as quartz, feldspar, micas, pyroxenes, and amphiboles, are the major constituents of the earth's crust and the major constituents of many building stones, such as granite, sandstone, volcanic rocks, and slate. Although some micas, pyroxenes, and amphiboles contain iron, they are not as susceptible to weathering as are the iron sulfides. In iron-bearing silicates, the iron is held tightly within the structure of the mineral and can oxidize very slowly, if at all, under normal weathering conditions. Silicate minerals, as a group, are very resistant to weathering. Although the feldspars in granitic rocks weather to form clay minerals, this process is so slow that it is of only minor consequence during the time that the stone in a building is exposed to weathering.

Physical weathering is related, either directly or indirectly, to temperature changes. If the pore space in a rock is full of water and the rock is subjected to freezing, the expansion that results when the water changes to ice will tend to weaken the stone. If the pores are not filled with water, freezing causes little damage, as space is available for the expansion, but if the pores are completely filled when the water freezes, the pressure exerted on the stone causes spalling and cracking. Spalling can also be caused by the crystallization of salts. When water containing dissolved mineral matter evaporates, crystallization of the mineral produces considerable force, which also causes spalling. This process is most harmful where salt, used on sidewalks or steps, is dissolved in water, which is then carried up into the stone by capillary action. The effects of salt on concrete are equally deleterious. Spalling caused by crystallization of salt can be seen on the lower courses of some porous stone where salt in solution has been absorbed by the stone. Theoretically, a salt solution (NaCl) that is oversaturated by a factor of two can produce a pressure of 650 atm (9,550 pounds per square inch) as a result of crystallization of the salt (Winkler and Singer, 1972, p. 3512).

Because the durability of a stone is a major factor in its evaluation, some effective method of determining this property is needed. The best method is to examine the stone where it has been in use on a building for 50 or 100 years, but this may be impractical. Stone that has long and successfully withstood conditions similar to those that can be expected to affect a proposed building will probably be satisfactory. Pollutants in the atmosphere must be considered, in addition to humidity and freezing and thawing.

Study of natural outcrops of the rock may also be instructive. A rock that forms bold, rugged outcrops or cliffs is obviously resistant to weathering under natural conditions in that locality and should be durable when placed on a building or used as a monument subjected to the same climatic conditions. The inverse, however, does not necessarily follow. A rock that does not form bold outcrops may nevertheless be sufficiently durable for use in a building where the exposure time is significantly less than that of a natural outcrop.

Knowledge of the mineralogy and texture of a rock should be helpful in judging its resistance to weathering. A rock containing easily weathered minerals, such as the iron sulfides, would be undesirable for exterior use; a rock free of such minerals and consisting of silicates would tend to be satisfactory for exterior use. Textural criteria that are useful in judging building stone are the abundance and size of pores and any pronounced planes of weakness, such as those in a schist, that may provide paths of ingress for water. Large grains may also tend to weaken the rock, especially those minerals that show well-developed cleavage.

The most direct method of determining the durability of a particular stone would be to reproduce the conditions under which it would be used but to increase the severity. For instance, a rock may be run through many freeze-thaw cycles under controlled conditions. On the basis of the amount of material lost from the sample by spalling, the resistance to freezing and thawing can be estimated.

Although no longer listed as a standard procedure, one method employed in the past was to soak the specimen in a concentrated solution of a salt such as sodium sulfate, then evaporate the water and crystallize the salt. After several cycles, the effects of the salt solution on the stone can be judged. In any test method involving speeded-up processes, interpretation of the results in relation to natural conditions may be somewhat uncertain.

The absorption of a stone can be determined according to procedures established by the American Society for Testing and Materials (1971, C-97). From a knowledge of the absorption of a specimen, possible effects of physical weathering can be estimated. For further discussion of the method, see the section describing test methods.

The compressive strength of a sample of stone gives some indication of resistance to physical weathering. A stone that has high compressive strength tends to have low porosity and also, because of superior strength, resists the pressure exerted by freezing water. More research is needed to develop suitable methods of testing that will evaluate the durability of the stone prior to production and use.

COLOR

Many of the important rock-forming minerals are colorless or white when pure, yet most rocks do have some coloration. Colorless or light-colored minerals may contain impurities of another mineral that imparts a specific color to the host. Pink and red granites are colored by potassium feldspar, a major constituent of true granite, which is some shade of red because of inclusions of microscopic grains of red hematite. Not all potassium feldspar is red, however. Granites that lack pink or red feldspar are white or various shades of gray; the exact shade depends on the abundance of dark minerals (most of which are biotite or an amphibole). The so-called black granites, actually far removed from granite in a geologic sense, are dark because of an abundance of pyroxene, biotite, or amphibole.

Several green minerals—chlorite, epidote, and actinolite—have been derived from other minerals by metamorphism or by other types of alteration far below the surface of the earth, or by weathering. Black biotite may be changed to green chlorite; white or colorless plagioclase feldspar may be changed to one or another of the minerals of the epidote group. But during the useful life of a building, white granite will not change to green granite. Although these changes do occur under natural conditions, they proceed very slowly over thousands of years and under geologic conditions far different from those that affect a slab of stone on the side of a building.

Rocks may be colored green also by iron, more specifically in the form of the ferrous ion (Fe^{++}). The red, brown, or yellow colors typical of many rocks are produced by ferric iron (Fe^{+++}) compounds, for example, limonite, hematite, and goethite. Iron in the ferrous (Fe^{++}) state can, when exposed to the atmosphere, slowly oxidize to form the ferric compounds that impart a red or brown color to the rock.

In summary, the color of a rock can be caused by small concentrations of deeply colored minerals. If these are silicate minerals (or inclusions therein), the color probably will not change after the rock is quarried.

ECONOMIC CONSIDERATIONS

After the turn of the century most towns in Montana had a local stone quarry, but now only a few quarries are operating in the state, and most of these are worked only on an intermittent basis. What is the reason for this change, paralleled by a similar decrease in the number of brick plants over the last 50 years? In both the stone and brick industries, this decrease has resulted mainly from competition from other materials. Many of the stone quarries in operation fifty years ago produced inferior stone, which was still competitive at that time for local use but which could not continue to compete with other construction materials. Those quarries have since been abandoned. Stone that has unusually desirable properties can be marketed even in areas distant from the quarry.

A quarry operator in Montana who hopes to market his product over a wide area outside the state must have good stone of unusual character, one that the consumer cannot find elsewhere and for which he will therefore pay the high transportation cost. Average figures for the value of building stone at the quarry or mill are variable, but ashlar or rubble suitable for facing might average $35 to $40 a ton in the mountain states. Shipping to the east coast would nearly double the cost. Obviously, the Montana stone must be distinctive or superior to any stone that can be quarried much closer to the potential consumer.

Not only must a quarry operator be able to produce a competitive stone at a competitive price, but he must be able to assure his customers that he will be able to provide matching stone thirty years hence. The efficient quarrying and finishing of the stone is only half the picture; efficient marketing of the stone is equally important. Unless architects and owners are familiar with the quality and beauty of a particular stone, they will not specify it for use in a particular building. Developing a market is just as important as developing an efficient quarrying operation, but this takes time. Thus, an individual investing his capital in the quarrying of a stone must be assured of continued access to the deposit for many years, either by long-term lease or by valid mining claim.

OWNERSHIP OF BUILDING STONE DEPOSITS

The method of acquiring the right to quarry a deposit of building stone depends on the ownership of the land, or more accurately, the ownership of the mineral rights, which need not belong to the owner of the surface rights. To quarry building stone on land owned by the State of Montana, the operator must obtain a lease from the State Land Board. Application for the lease should be submitted to the Department of State Lands, Helena. Leasing is also the common method of obtaining the right to quarry a deposit that is privately owned. A royalty is paid by the quarry operator on each ton of stone quarried. Leasing of either private or state land is relatively straightforward. Assurance of continuous access to the deposit for many years necessitates a long-term lease, say 25 to 50 years. Because much of the success of a stone producer depends on the establishment of a market built up over a period of years, investing the capital necessary to put a quarry in operation is not justified if there is a risk of losing the right to quarry the stone.

Quarrying on public lands is considerably more complicated. Some public land, such as campgrounds and administrative sites, is withdrawn from all mineral location. In those areas open to location, the General Mining Law of 1872 applies, as amended by the Building Stone Placer Act of 1892, which provides for the location of placer claims specifically for building stone. Public Law 167, The Multiple Surface Use Act of 1955, further modifies the General Mining Law by stating that deposits of common varieties of sand, stone, etc., cannot be obtained by location. Common varieties are to be sold by the U.S. Department of Interior. Since 1955, cases involving mining claims located for stone have provided some information on what is a common variety. Unfortunately, uncommon varieties have not yet been clearly defined.

In an April 22, 1968, decision, Alfred Coleman vs. the United States, the Supreme Court held that the "marketability test" can be used to help determine the validity of a mining claim. This test, they concluded, was a logical extension of the "prudent-man test", which has been used in the interpretation of the Mining Law of 1872. Since the Coleman case, the marketability test has been used in those decisions dealing with building stone claims. To establish marketability of a stone, the claimant must show that he can quarry the stone and sell it at a reasonable profit. Several cases have been decided against the locator of the claim because only a slight profit or none had been shown. The marketability test has been especially important in those decisions involving claims located prior to the Multiple Surface Use Act of 1955. Claims located prior to this date need not satisfy the uncommon varieties stipulation but they must survive the marketability test. This is true for unpatented claims only; claims already patented are private property and not subject to these restrictions.

Claims located after 1955 must pass the marketability test and the claimant must also demonstrate that the stone possesses unique properties that enhance its value. A unique chemical composition of a rock, for example, would not necessarily classify it as an uncommon variety. This unique chemical composition must make the stone more desirable than competitive materials for a specific use in order to qualify it as uncommon. Also, the deposit must be of such small areal extent that it is unique because of limited supply.

An operator who has located a mining claim on a building stone deposit must be able to substantiate his claim. The locator can do nothing about the uniqueness of the deposit; this has been decided over millions of years by geologic processes. Nonetheless, careful records of the quantity of stone removed from each quarry, as well as the usual records that good business practice requires, will be useful in demonstrating the marketability of the stone. If a stone deposit on public land does not fulfill the requirements for a valid mineral discovery, the potential producer can apply for the purchase of the stone. If the deposit is on National Forest Land, the prospective buyer must enter into a contract with the U.S. Forest Service. A contract for purchase may be negotiated if only one producer is interested in the deposit, but if more than one producer is interested, then the sale must be open to competitive bids. Terms of the sale are readjusted periodically, such as every three years. Conceivably the sale might continue over many years—ideally for the life of the deposit.

If the stone deposit is on land administered by the U.S. Bureau of Land Management, the procedure is essentially the same, competitive bids being required if more than one producer is interested in the deposit, but the sale period is two years. At the close of this period, a new contract must be written.

The foregoing comments, although valid as of 1974, may require modification in later years. In dealing with governmental agencies the prospective operator should study the latest regulations, laws, and court decisions.

LABORATORY PROCEDURES

Absorption and bulk specific gravity were determined in accordance with procedures set forth by the American Society for Testing and Materials (1971, C97-47, part 12, p. 93-95). The usual procedure was to test four specimens of a sample, but for a few samples as many as six specimens were tested, and for some samples, fewer than four specimens were tested. Determination of specific gravity of different specimens from the same locality produced similar results; the variation between different determinations on specimens from the same locality was less than 1 percent for most samples. Determinations of the absorption were erratic, especially for those specimens that showed high absorption values. In several samples, the variation of specific gravity between specimens was slight and variation of absorption by three of the four specimens tested was also slight, but the fourth speciman showed much greater absorption, probably the result of small natural fractures in this one specimen.

The weight per cubic foot of dry stone can be calculated by multiplying the specific gravity by 62.4 lb. (the weight of one cubic foot of water). Cubes approximately 2 inches (5 cm) on an edge were cut from the sample by diamond-blade saw. Specimens of thinly laminated rock from which these cubes could not be sawed were tested according to ASTM procedures for determining the water absorption of slate (1971, C121-48, part 12, p. 115, 116). Specimens approximately 4 by 4 inches (10 by 10 cm) and less than 1 inch (2.5 cm) thick were cut for this test. The cubes or slabs were dried for 24 hours at 105°C, then cooled in a desiccator and weighed. Next, the cubes were submerged in water for 48 hours, removed, wiped with a damp cloth, and weighed. Absorption was calculated as percent increase in weight after soaking. Bulk specific gravity was computed by measuring the submerged weight and dividing the dry weight by the difference between dry weight and submerged weight.

Bulk specific gravity and absorption were not determined for a few specimens. Because absorption is more likely to be a problem with porous rock such as sandstone and volcanic rocks, these were tested more thoroughly than the granitic rocks.

Color of both broken and sawed surfaces was determined by comparison with the Rock Color Chart of the National Research Council (Goddard and others, 1951). Color of coarse-grained specimens was determined by blending together the colors of individual minerals by placing the specimen on a rotating platform.

Mineralogy of specimens was determined by thin-section examination, x-ray diffraction analysis, and for a few specimens by polished-slab examination.

DESCRIPTIONS OF STONE DEPOSITS

The following descriptions are arranged according to a slightly modified version of the nomenclature given for natural building stone by ASTM (1971, part 12, p. 109-111). Two additional categories, volcanic rocks and miscellaneous, have been added to the ASTM designations granite, limestone, marble, sandstone, and slate (argillite). Although these divisions are based on lithology, they do not correspond to the standard rock nomenclature used in the petrographic descriptions in the appendix. In the discussions of most of the deposits, the geological age of the rock is mentioned. The absolute age, in millions of years, of the various geological periods is given in Table 1. Definitions of other geological terms are given in the glossary. Information, including possible uses, on specific deposits is summarized in Table 2, and localities of deposits are shown on Figure 1.

Table 1. Geological time scale.
(Harland and others, eds., 1964, p. 260-262)

Era	System or Period	Age estimate (in millions of years)
Cenozoic	Quaternary	1.5-2
	Tertiary	65
Mesozoic	Cretaceous	136
	Jurassic	190-195
	Triassic	225
Paleozoic	Permian	280
	Pennsylvanian	320
	Mississippian	345
	Devonian	395
	Silurian	430-440
	Ordovician	about 500
	Cambrian	570
Precambrian		

GRANITE

The category of building stone called granite includes all of the relatively coarse-grained igneous rocks, some fine-grained igneous rocks in which the individual mineral grains cannot be recognized without microscopic examination, and the metamorphic rock known as gneiss. For the sake of discussion, all igneous rocks included in this section are grouped together without regard to composition, although many of these rocks are actually in the quartz monzonite-granodiorite range (see Appendix).

The Boulder batholith, which contains all of the granite quarries in the Butte-Helena area, includes a dozen or more plutons, which crystallized between 78 and 72 m.y. (million years) ago (Robinson and others, 1968). The batholith crops out over a total area of 2,200 square miles and trends southwest from the Helena valley to the Silver Star area south of Butte. One pluton, the Butte quartz monzonite, occupies more than 75 percent of this area. Much of the granite produced in the Butte area has been quarried from the Butte quartz monzonite for use in the construction of numerous buildings in western Montana. Black inclusions, a few inches in maximum dimension, are prominent in much of the granite quarried from the Boulder batholith.

Helena Area

HARRISON QUARRY (Locality 1)

The abandoned Harrison quarry is west of Helena, close to U.S. Highway 12, in the SW¼ NE¼ sec. 34, T. 10 N., R. 5 W., Lewis and Clark County. The quarry is cut into the side of a hill of massive granitic rock of the Boulder batholith. The distance from the lowest point in the quarry to the highest point where granite has been produced is approximately 75 feet (23 m) and the quarry is approximately 200 feet (60 m) long. The most pronounced joint set trends N. 70° E. and is vertical; the joints are spaced 2 to 3 feet (0.6-1 m) apart. Less prominent, but also important in quarrying, is a joint set trending N. 25° W. and inclined 60° NE. Most of these joints are spaced 2 to 4.6 feet (0.6-1.4 m) apart, although in some places they are as much as 10 feet (3 m) apart. The attitude of sheeting is N. 45° W., 30° SW.,* and roughly parallels the surface of this granite as it was before quarrying was begun. The subhorizontal sheeting joints are spaced 2.8 to 3.6 feet (0.8-1 m) apart. Granite blocks of 2 to 3 feet (0.6-1 m) in least dimension could easily be quarried here.

As with so much of the rock in the Boulder batholith, ovoid black inclusions are abundant, and sizable blocks free of these inclusions would be difficult to obtain. The rock contains light-brownish-gray (5 YR 6/1) K-feldspar megacrysts set in a groundmass of feldspar, quartz, biotite, and hornblende. The average specific gravity is 2.65 and average absorption is 0.4 percent.

A large amount of the granite in this quarry could probably be quarried in sizable blocks. It is a durable rock, as indicated by the rounded knobs cropping out adjacent to the quarry. The abundance of black inclusions might make this stone undesirable for some decorative uses.

***The bearing given first here is the strike, and the angle following it is the angle of dip. See the Glossary for definitions of these terms.**

Table 2.–Summary of information on specific deposits of building stone

Locality no.	Name of quarry or deposit	Locality	County	Formation	Geologic age	Petrographic name	Sp.Gr.	No.of dets.	Absorption, %	No.of dets.	Possible uses	Locality no.
				GRANITE								
1	Harrison quarry	West of Helena SW¼ NE¼ sec. 34, T. 10 N., R. 5 W.	Lewis and Clark	Boulder batholith	Cretaceous	quartz monzonite	2.65	6	0.4	6	dimension stone	1
2	Schimpf quarry	West of Helena SE¼ SW¼ sec. 25, T. 10 N., R. 5 W.	Lewis and Clark	Boulder batholith	Cretaceous	quartz monzonite					dimension stone	2
3	Kain quarry	West of Clancy SW¼ NE¼ sec. 7, T. 8 N., R. 3 W.	Jefferson	Boulder batholith	Cretaceous	quartz monzonite					dimension stone	3
4	natural exposure	West of Canyon Ferry Lake SE¼ sec. 15, T. 10 N., R. 1 W.	Lewis and Clark		Tertiary?	monzonite	2.66	4	0.3	4	dimension stone	4
5	quarry	South of Boulder S½ NW¼ sec. 33, T. 5 N., R. 4 W.	Jefferson	Boulder batholith (Butte qtz. monz.)	Cretaceous	granodiorite					dimension stone	5
6	quarry	East of Butte NE¼ NW¼ sec. 15, T. 1 N., R. 6 W.	Jefferson	Boulder batholith (Rader Cr. pluton)	Cretaceous	granodiorite	2.72	1	0.1	1	dimension stone	6
7	quarry	East of Butte SE¼ NW¼ sec. 15, T. 1 N., R. 6 W.	Jefferson	Boulder batholith (Rader Cr. pluton)	Cretaceous	granodiorite					dimension stone	7
8	Dumos quarry	East of Butte NW¼ SE¼ sec. 15, T. 1 N., R. 6 W.	Jefferson	Boulder batholith (Rader Cr. pluton)	Cretaceous	granodiorite					dimension stone	8
9	Grace quarry	East of Butte NE¼ NE¼ sec. 26, T. 1 N., R. 6 W.	Jefferson	Boulder batholith (Rader Cr. pluton)	Cretaceous	granodiorite					dimension stone	9
10	Welch quarry	East of Butte SE¼ sec. 10, T. 2 N., R. 6 W.	Jefferson	Boulder batholith	Cretaceous	quartz monzonite					dimension stone	10
11	Feely quarry	South of Butte SW¼ sec. 21, T. 1 N., R. 8 W.	Silver Bow	Boulder batholith (Burton Park pluton)	Cretaceous	granodiorite					dimension stone	11
12	Ringing Rocks stock	Northwest of Whitehall sec. 4 and 9, T. 2 N., R. 5 W.	Jefferson	Ringing Rocks stock	Cretaceous or Tertiary	mafic monzonite	2.87	3	0.04	3	*dimension stone	12
13	quarry	East of Sula sec. 17, T. 1 N., R. 18 W.	Ravalli	?	?	quartz diorite	2.74	4	0.4	4	dimension stone	13
14	natural exposures	South of Darby NW¼ sec. 5, T. 1 S., R. 21 W.; SW¼ NE¼ sec. 26, T. 1 S., R. 22 W.	Ravalli	?	Tertiary?	granite					dimension stone	14
15	natural exposure	Southwest of Deer Lodge SE¼ NW¼ sec. 33, T. 7 N., R. 11 W.	Powell	Mt. Powell batholith	Tertiary	orbicular granite					none	15
16	natural exposure	North of Anaconda W½ sec. 9, T. 5 N., R. 11 W.	Deer Lodge		Tertiary	quartz monzonite	2.59	3	0.4	3	dimension stone	16
17	natural exposure	Northeast of Townsend sec. 16, T. 8 N., R. 3 E.	Broadwater		Cretaceous?	granodiorite					dimension stone?	17
18	quarry	East of Townsend sec. 20, T. 7 N., R. 5 E.	Broadwater		?	andesite	2.68	7	0.3	7	dimension stone?	18
19	road cut	East of Perma NE¼ SW¼ sec. 31, T. 19 N., R. 23 W.	Sanders		Precambrian	metagabbro	2.97	3	0.1	3	rubble	19
				LIMESTONE								
20	quarry	Northeast of Manhattan sec. 30, T. 2 N., R. 4 E.	Gallatin	Lahood Formation	Precambrian	silty micrite	2.63	4	0.7	4	flagging	20
21	quarry	Southwest of Grass Range sec. 33, T. 14 N., R. 22 E.	Fergus	Bear Gulch Limestone	Pennsylvanian or Mississippian	sparite	2.59	12	0.67	12	flagging, ashlar, rubble	21
22	Deadman quarry	West of Yellowtail Reservoir sec. 36, T. 7 S., R. 28 E.**	Carbon	Chugwater Formation	Triassic	silty sparite	2.55	4	3.4	4	dimension stone, split face, rubble	22
23	road cut	South of Yaak NW¼ of the Turner Mtn. quadrangle	Lincoln	Wallace Formation (Belt Supergroup)	Precambrian	silty dolomite	2.77	2	0.3	2	flagging, rubble	23
24	road cut	East of Nyack N½ sec. 26, T. 31 N., R. 17 W.	Flathead	of Belt Supergroup	Precambrian	argillaceous dolomite					flagging, rubble	24
25	Sieben Ranch quarry	North of Helena SE¼ sec. 26, T. 13 N., R. 5 W.	Lewis and Clark	of Belt Supergroup	Precambrian	silty limestone	2.68	4	0.13	4	flagging, rubble	25
				MARBLE								
26	quarry	Northeast of Radersburg NE¼ sec. 4, T. 5 N., R. 1 E.	Broadwater	Meagher Limestone	Cambrian	limestone					dimension stone, flagging	26
27	Limekiln quarry	South of Butte SW¼ NE¼ sec. 22, T. 1 N., R. 7 W.	Silver Bow	metamorphosed Paleozoic limestone		marble	2.56	2	0.9–4.6	2	light-gray granules	27
28	quarry	North of Anaconda NW¼ SW¼ sec. 10, T. 5 N., R. 11 W.	Deer Lodge	metamorphosed Paleozoic dolomite		dolomitic marble	2.85	3	0.09	3	white granules	28
29	natural exposures	Northwest of Deer Lodge NW¼ sec. 10, T. 8 N., R. 11 W.	Powell	metamorphosed Madison Limestone		marble	2.58	4	0.9	4		29
30	quarry	North of Manhattan sec. 14, T. 2 N., R. 3 E.	Gallatin			onyx marble	2.71	4	0.1	4	dimension stone?, rubble	30
31	White Angel quarry	East of Twin Bridges W½ sec. 27, T. 3 S., R. 5 W.	Madison		Cenozoic	onyx marble	2.72	4	0.05	4	rubble, granules	31
				TRAVERTINE								
32	Gardiner quarries	North of Gardiner sec. 14, T. 9 S., R. 8 E.	Park		Quaternary	travertine					dimension stone, sawed ashlar, rubble	32
33	Park deposit	North of Lewistown T. 17 N., R. 17, 18 E.	Fergus		Quaternary	travertine	2.53	2	1.0	2	dimension stone, sawed ashlar, rubble	33
34	quarry	Southwest of Lima sec. 19, 20, 29, 30, 31, T. 15 S., R. 9 W.	Beaverhead		Tertiary	travertine					dimension stone, sawed ashlar, rubble	34

				SANDSTONE (includes quartzite)								
35	quarry	North of Manhattan NW¼ SE¼ sec. 27, T. 2 N., R. 3 E.	Gallatin	Lahood Formation Belt Supergroup	Precambrian	arkose	2.64	4	0.52	4	rubble	35
36	natural exposure	East of Stryker NW¼ NW¼ sec. 31, T. 34 N., R. 24 W.	Lincoln	Grinnel Formation (Belt Supergroup)	Precambrian	orthoquartzite	2.56	1	0.4	1	rubble	36
37	quarry	North of Radersburg NW¼ NW¼ sec. 27, T. 6 N., R. 1 E.	Broadwater	Flathead Quartzite	Cambrian	orthoquartzite	2.64	4	0.25	4	flagging, ashlar, rubble	37
38	Monarch quarry	Southeast of Monarch SW¼ SW¼ sec. 24, T. 15 N., R. 7 E.	Cascade	Flathead Quartzite	Cambrian	orthoquartzite	2.33	4	2.7	4	flagging, ashlar, rubble	38
39	Kings Hill quarry	5 miles southeast of Neihart	Cascade	Flathead Quartzite	Cambrian	orthoquartzite	2.37	12	2.7	12	flagging, ashlar, rubble	39
40	Fishtrap quarries	North of Thompson Falls NE¼ sec. 26, T. 24 N., R. 28 W. N½ sec. 23, T. 24 N., R. 28 W.	Sanders	Flathead Quartzite	Cambrian	orthoquartzite	2.55	3	0.94	3	flagging, ashlar, rubble	40
41	quarry	East of Great Falls SW¼ SW¼ sec. 6, T. 18 N., R. 7 E.	Cascade	Swift Formation	Jurassic	orthoquartzite	2.37	12	3.9	12	limited decorative use, very soft	41
42	quarry	South of Great Falls SE¼ SE¼ sec. 30, T. 20 N., R. 4 E.	Cascade	Kootenai Formation	Cretaceous	orthoquartzite	2.30	3	2.75	3	dimension stone, flagging, rubble–soft	42
43	adjacent to Fields clay mine	South of Great Falls SW¼ SW¼ sec. 28, T. 20 N., R. 4 E.	Cascade	Kootenai Formation	Cretaceous	orthoquartzite					dimension stone, rubble–soft	43
44	quarries	Southeast of Lewistown NW¼ sec. 23, T. 15 N., R. 18 E.	Fergus	Kootenai Formation	Cretaceous	orthoquartzite	2.19	3	7.72	3	dimension stone, rubble–soft	44
45	quarry	North of Columbus NE¼ NE¼ sec. 21, T. 2 S., R. 20 E.	Stillwater	Lennep Sandstone	Cretaceous	subarkose	2.15	4	7.17	4	dimension stone, rubble–soft	45
46	quarries	South of Big Timber SW¼ SW¼ sec. 23, T. 1 N., R. 14 E.	Sweet Grass	Livingston Group	Cretaceous to Eocene	feldspathic subgraywacke	2.50	4	3.33	4	dimension stone, rubble–soft	46
47	Dalys Spur quarry	Southwest of Dillon NW¼ NW¼ sec. 1, T. 9 S., R. 10 W.	Beaverhead	Quadrant Formation	Pennsylvanian	orthoquartzite					dimension stone, rubble–soft	47
48	quarry	South of Ennis SW¼ SW¼ sec. 3, T. 9 S., R. 1 W.	Madison		Precambrian	quartzite	2.65	4	0.29	4	flagging?, rubble	48
49	natural exposures	South of Ennis in the vicinity of Johnny Gulch	Madison		Precambrian	iron-bearing quartzite					flagging	49
50	prospect pit	South of Superior along Trout Creek	Mineral	Belt Supergroup	Precambrian	siltite	2.61	10	0.4	10	rubble? (fractured)	50
				SLATE (includes argillite)								
51	quarry	South of Plains NE¼ sec. 14, T. 18 N., R. 26 W.	Sanders	Prichard Formation (Belt Supergroup)	Precambrian	argillite					flagging	51
52	quarry	South of Plains SE¼ sec. 2, T. 19 N., R. 26 W.	Sanders	Prichard Formation (Belt Supergroup)	Precambrian	argillite	2.75	9	0.3	9	flagging	52
53	quarry	Northeast of Plains NE¼ NW¼ sec. 2, T. 20 N., R. 25 W.	Sanders	Prichard Formation (Belt Supergroup)	Precambrian	argillite	2.75	4	0.06	4	flagging	53
54	road cut	Northeast of Plains N½ sec. 31, T. 21 N., R. 24 W.	Sanders	Prichard Formation (Belt Supergroup)	Precambrian	argillite					flagging	54
55	road cut	North of Perma NW¼ sec. 25, T. 21 N., R. 24 W.	Sanders	Prichard Formation (Belt Supergroup)	Precambrian	argillite					flagging	55
56	road cut and railroad cut	West of Libby SW¼ SE¼ sec. 15, T. 31 N., R. 33 W.	Lincoln	Wallace Formation (Belt Supergroup)	Precambrian	argillite	2.71	6	0.2	6	flagging	56
57	quarry	Southwest of Kalispell SE¼ SW¼ sec. 13, T. 28 N., R. 22 W.	Flathead	Siyeh Limestone (Belt Supergroup)	Precambrian	argillite					flagging	57
58	quarry	Southwest of Kalispell NE¼ NW¼ sec. 22, T. 28 N., R. 22 W.	Flathead	Piegan Group (Belt Supergroup)	Precambrian	dolomitic siltite	2.71	2	0.8	2	flagging	58
				VOLCANIC								
59	Josephine mine	North of Basin SW¼ NE¼ sec. 26, T. 8 N., R. 6 W.	Jefferson		Tertiary	felsite	2.37	4	3.7	4	rubble	59
60	quarry	South of Helena NW¼ NE¼ sec. 10, T. 9 N., R. 3 W	Jefferson		Tertiary	volcanic breccia	2.34	2	1.0	2	dimension stone	60
61	Flathead Sunset quarry	Northwest of Niarada NW¼ NE¼ sec. 34, T. 25 N., R. 24 W.	Flathead		Tertiary	lithic tuff	1.98	5	8.4	5	decorative stone, interior use	61
62	quarry	West of Dillon, sec. 14, T. 7 S., R. 11 W.	Beaverhead		Tertiary	vitric tuff	2.16	4	2.2	4	flagging, rubble	62
63	Montana onyx	Southwest of Alder SE¼ sec. 4, T. 9 S., R. 5 W.	Madison		Tertiary	tuff	2.44	3	0.9	3	granules, decorative items	63
64	natural exposure	Northwest of Whitehall SW¼ sec. 19, T. 3 N., R. 4 W.	Jefferson	Elkhorn Mountains Volcanics	Cretaceous	vitric welded tuff					rubble, flagging?	64
65	deposit	South of Bozeman NW¼ NE¼ sec. 21, T. 7 S., R. 4 E.	Gallatin		Tertiary	subarkose					rubble	65
66	Frying Pan Basin deposit	Northwest of Dillon NE¼ NW¼ sec. 28, T. 6 S., R. 9 W.	Beaverhead		Tertiary	vitric tuff					dimension stone?	66
				MISCELLANEOUS								
67	Bitterroot Valley Stone Co. quarry	Northwest of Darby SW¼ sec. 7, T. 4 N., R. 21 W.	Ravalli		Cretaceous?	blastomylonite					rubble	67

*Withdrawn from mineral location
**Location of stone yard; several quarries in this area.

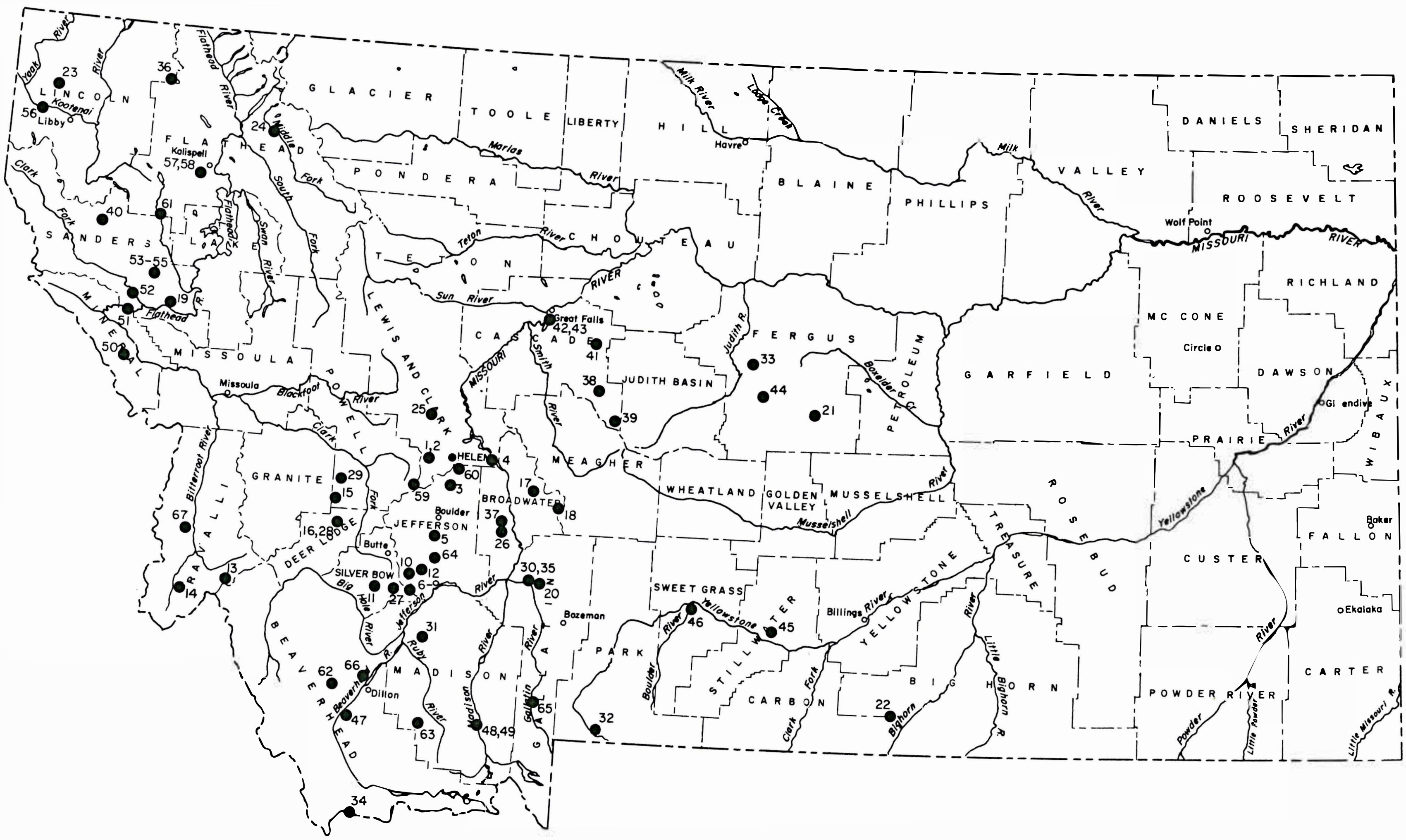

Figure 1.–Deposits of building stone. See Table 2 for additional information.

SCHIMPF QUARRY (Locality 2)

The abandoned Schimpf quarry is about 2 miles (3.2 km) east of the Harrison quarry in the SE¼ SW¼ sec. 25, T. 10 N., R. 5 W., Lewis and Clark County. It is considerably smaller than the Harrison quarry and consists of an excavation into the side of a granite knob. The most prominent joint set is oriented N. 65° E., 50° SE.; the less prominent set is oriented N. 15° W., 65° NE. Blocks of several feet in least dimension can be quarried here, but black inclusions are even more abundant here than at the Harrison quarry. The texture of the granite is similar to that of the granite at the Harrison quarry; light-brownish-gray (5 YR 6/1) K-feldspar megacrysts are set in a groundmass of feldspar, quartz, biotite, and hornblende.

KAIN QUARRY (Locality 3)

The Kain quarry, now abandoned, is west of Clancy in the SW¼ NE¼ sec. 7, T. 8 N., R. 3 W., Jefferson County. Granite from this quarry was used in construction of the wings of the State Capitol. The quarry is in the Butte quartz monzonite, which in this area has been referred to as the Clancy granodiorite (Knopf, 1963). This quarry, like the two described above, was cut into the side of a granite knob and made use of the natural jointing in the granite. The result is a quarry that resembles a large notch cut into the knob; the greatest height of the cut is 34 feet (10 m) and the horizontal distance across the base of the cut is 60 feet (18 m).

Two perpendicular sets of widely spaced joints oriented N. 10° E., 75° SE., and N. 80° W., 75° NE., permit the quarrying of blocks having a minimum dimension of 5 feet (1.5 m). Sheeting is oriented N. 45° W., 20° NE., and is much less pronounced than the steeply inclined joints. Black inclusions are abundant; in one quarry face their areal density is 70 per 100 square feet (9.3 m^2). Some are only faintly recognizable, however, and would not detract from the appearance of the granite.

Of the three quarries examined in the Helena area, this one presents the best opportunity for removal of large blocks of granite. Nonetheless, black inclusions are prominent in the granite at this location also.

Area Between Helena and Butte

MONZONITE WEST OF CANYON FERRY LAKE (Locality 4)

This rock is exposed just west of Canyon Ferry Lake where natural outcrops were examined in the SE¼ sec. 15, T. 10 N., R. 1 W., Lewis and Clark County. An abandoned quarry near the old Canyon Ferry Dam was flooded by the rise in the reservoir level when a new dam was constructed farther downstream. The most striking feature of this rock is the abundance of tabular K-feldspar megacrysts that, because of their resistance to weathering, project above the fine-grained groundmass on exposed surfaces. On an unweathered surface the rock is medium gray; average specific gravity is 2.66 and average absorption is 0.3 percent. Because of its unusual texture, this rock might be desirable for some decorative uses.

The crumbly, weathered outcrops suggest that fractures are abundant. If the rock proved to be more massive at depth, however, it might be suitable for quarrying.

GRANITE QUARRY SOUTH OF BOULDER (Locality 5)

Granite from the Butte quartz monzonite has been produced at two small quarries west of the Whitehall-Boulder road in the S½ NW¼ sec. 33, T. 5 N., R. 4 W., Jefferson County. The rock is similar to that described from other Butte quartz monzonite quarries; K-feldspar megacrysts are prominent, as are dark inclusions that have been caught in various stages of assimilation by the enclosing rock.

Vertical joint sets are oriented N. 40° E. and N. 40° W.; no sheeting was observed. Blocks 2 by 2 by 4 feet (0.6 by 0.6 by 1.2 m) have been quarried here.

Butte Area

Several granite quarries south and east of Butte have provided much of the stone used in the older buildings in Butte and in some other western Montana cities. Four of these quarries are within the Rader Creek pluton, one is within the Butte quartz monzonite, and one is within the Burton Park pluton (all are plutons of the Boulder batholith). The four granite quarries in the Rader Creek pluton are east of Butte near the Nineteen Mile. All are relatively small and all are now abandoned.

SMALL QUARRIES EAST OF BUTTE

Granite of the Rader Creek pluton has been quarried at two localities along a small unnamed tributary of Little Pipestone Creek. The northernmost quarry is in the NE¼ NW¼ sec; 15, T. 1 N., R. 6 W., Jefferson County (locality 6). A prominent vertical joint set trends N. 80° E.; much less prominent is the perpendicular set trending N. 10° W. Some epidote occurs along the prominent joint set. The quarry is a small cut into granite exposed along the side of a small gully. The rock, in striking contrast to the

Butte quartz monzonite, is relatively uniform in grain size and texture. Color on a broken surface is medium gray (N 5); dark inclusions are rare. Specific gravity is 2.72 and absorption is 0.1 percent. The rock is dense, uniform-textured granodiorite and can be quarried in blocks suitable for dimension stone.

The other small quarry along the tributary of Little Pipestone Creek is farther south in the SE¼ NW¼ sec. 15, T. 1 N., R. 6 W. (locality 7). Granite of the Rader Creek pluton has been quarried from the side of a small knob. The working face was approximately 35 feet (11 m) high by 40 feet (12 m) wide. Pronounced vertical joint sets trend N. 40° W. and N. 70° E. The rock is identical to that described from the quarry farther upstream. Dark inclusions are rare, and spacing of joints permits the removal of blocks having a least dimension of 5 feet (1.5 m).

DUMOS QUARRY (Locality 8)

The abandoned Dumos quarry, also in the Rader Creek pluton, is nearby but south of U.S. Highway 10 in the NW¼ SE¼ sec. 15, T. 1 N., R. 6 W., Jefferson County. The quarry is a shallow rectangular excavation 15 feet (4.5 m) deep, 17 feet (5 m) wide, and 35 feet (11 m) long. The long walls are joints of a set trending N. 65° to 80° E., and inclined 65° to 75° SE. Joint surfaces are coated with a thin layer of epidote. Sheeting strikes N. 70° E. and dips about 20° SE. Dark inclusions are rare in this medium-dark-gray (N 4) rock. Granite blocks having a least dimension of 3 feet (1 m) can be removed from this quarry.

GRACE QUARRY (Locality 9)

Granite from the Rader Creek pluton has also been quarried in the NE¼ NE¼ sec. 26, T. 1 N., R. 6 W., Jefferson County. A small quarry in a saddle between two knobs has produced most of the rock, but several blocks have been removed from exposures along the south side of one knob. The granite is medium gray (N 5), slightly lighter in color than that at the Dumos quarry, and contains rare dark inclusions. Conditions for further quarrying seem favorable. This quarry would be a good source of uniform-textured gray granite free from inclusions or other objectionable impurities.

WELCH QUARRY (Locality 10)

The largest granite quarry in the Butte area is the Welch quarry approximately 2 miles (3.2 km) northeast of Homestake Pass in the SE¼ sec. 10, T. 2 N., R. 6 W., Jefferson County. This quarry, reportedly in operation for 40 years but now abandoned, supplied much curbing, paving blocks, and dimension stone for construction in Butte, including the stone used in the County Courthouse. Granite (Butte quartz monzonite) has been quarried at three sites here; the two largest quarries are adjacent to an abandoned railroad grade. Sheeting, which is the most pronounced structural feature in the eastern quarry, is subparallel to the topographic surface. Spacing between sheeting planes in the east and west quarries was carefully measured (Table 3). Figure 2A shows the well-developed sheeting which, in conjunction with the wide spacing of vertical joints, must have been advantageous to the quarrying of stone for curbing. Near-vertical joint sets trend N. 70° E. and N. 15° W.; a much less pronounced set is oriented N. 50° E., 75° NW. In much of the quarry, prominent joints are spaced 20 feet (6 m) apart or farther. The western quarry, because of more widely spaced sheeting, is the better source of large blocks.

Table 3.–Spacing between sheeting planes in Welch quarry.

West quarry	East quarry
surface	surface
3.0 ft (0.9 m)	0.8 ft (0.2 m)
5.7 ft (1.7 m)	0.9 ft (0.3 m)
7.5 ft (2.3 m)	0.5 ft (0.2 m)
bottom of quarry	0.6 ft (0.2 m)
	0.9 ft (0.3 m)
	1.2 ft (0.4 m)
	1.1 ft (0.3 m)
	1.0 ft (0.3 m)
	0.8 ft (0.2 m)
	0.8 ft (0.2 m)
	1.6 ft (0.5 m)
	1.1 ft (0.3 m)
	0.8 ft (0.2 m)
	1.0 ft (0.3 m)
	1.2 ft (0.4 m)
	0.9 ft (0.3 m)
	0.7 ft (0.2 m)
	bottom of quarry

Dark inclusions, typical of the Butte quartz monzonite, are abundant at this site and would be prominent in any stone quarried. They are subrounded and vary in their degree of assimilation by the enclosing granite; some can be recognized only by careful examination of the rock whereas others can be recognized at a considerable distance. Within a 100-square-foot area (9.3 m^2), 26 inclusions were counted; in another, 45 were counted. Only 9 of the 45 counted in the second area were greater than 2 inches (5 cm) in greatest dimension. Only two aplite dikes were recognized in the quarry. The granite is light brownish gray (5 YR 6/1), but in some areas the K-feldspar megacrysts give the rock a pinkish cast.

Differences in spacing of joints and sheeting at this location make it possible to quarry blocks of a wide range of shapes and dimensions, but sizable blocks free of abundant dark inclusions cannot be quarried. The weathering of this rock indicates that the dark inclusions do not constitute a structural defect affecting the strength or durability.

FEELY QUARRY (Locality 11)

The Feely quarry, south of Butte in the Highland Mountains in the SW¼ sec. 21, T. 1 N., R. 8 W., Silver Bow County, has been abandoned for some time and is filled with water to a reported depth of 40 feet (12 m). Quarrying the granite produced a cut extending approximately 50 feet (15 m) above the surface of the water and about 50 feet (15 m) wide. Several hundred tons of large blocks are piled adjacent to the quarry. Presumably these blocks were set aside because they were awkward to shape by hand, as was necessary when this quarry was in operation. The rock is medium dark gray (N 4), uniformly textured, and almost devoid of dark inclusions.

RINGING ROCKS STOCK (Locality 12)

Ringing Rocks stock is northwest of Whitehall in sec. 4 and 9, T. 2 N., R. 5 W., Jefferson County. This area has recently been withdrawn from mineral location and probably will be maintained as a recreational site. The stock is roughly circular, about half a mile in diameter, and has a quartz monzonite core rimmed on the south and west by mafic monzonite (Prostka, 1966, p. F-15). Best exposures of the mafic monzonite are in the center of the NW¼ sec. 9, T. 2 N., R. 5 W., where large blocks of talus have accumulated on the side of a hill. These blocks, rusty on weathered surfaces, have many irregular protuberances. The most unusual aspect of this rock is its ability to ring like cast iron when struck with a hammer, hence the name Ringing Rocks stock.

Blocks from this talus pile have been crushed and the granules have been used in filter beds for the catalytic cracking of crude oil and also in terrazzo.

In 1970, a claim located on this deposit was declared to be null and void because rock quarried here is a common variety and therefore not locatable. Although the rock here is unusual in its ability to ring, the uses for which this rock was quarried did not require this unusual property, and, in fact, other stone could fulfill these requirements as well as the stone from the Ringing Rocks stock.

The color of this rock on a weathered surface is moderate brown (5 YR 3/4), but on a fresh surface it is dark gray (N 3). Average specific gravity is 2.87 and average absorption is 0.04 percent. Large blocks could be easily quarried, but the brown discoloration on a weathered surface might be undesirable for exterior use.

Other Areas in Western Montana

Western Montana abounds in igneous rocks, many of which the stone industry would classify as granite. Most of these igneous rocks are geologically young, about the same age as the Boulder batholith. With one exception, the following granite deposits have not been quarried commercially although a few blocks have been removed because of their unusual color and texture.

QUARTZ DIORITE NEAR SULA (Locality 13)

Quartz diorite is a relatively common igneous rock that consists of quartz, plagioclase feldspar, K-feldspar, biotite, and hornblende. The quartz diorite exposed east of Sula in sec. 17, T. 1 N., R. 18 W., Ravalli County, is unusual because of black hornblende crystals surrounded by light-colored quartz and feldspar. The quartz diorite forms a steeply inclined pod about 30 feet (9 m) thick where exposed in an exploration cut. The pod is surrounded by granitic rock and can be traced uphill from the base of the cut for only about 30 feet (9 m). Average specific gravity is 2.74 and average absorption is 0.4 percent. Because of its unusual appearance, this rock might be used as a decorative stone. The small size of the deposit, however, would preclude development as a major source of granite.

GRANITE SOUTH OF DARBY (Locality 14)

Most of the granite of southwestern Montana is some shade of gray, but pink granite is exposed south of Darby along the West Fork of the Bitterroot River. This granite forms cliffs around the dam at Painted Rocks Lake (so named because of the colorful lichens growing on the granite). Pink granite extends more than a mile (1.6 km) east of Painted Rocks Lake (Fisk, 1969) and 5 miles (8 km) to the north. Specimens were collected from an outcrop in the NW¼ sec. 5, T. 1 S., R. 21 W., and from a roadcut in the SW¼ NE¼ sec. 26, T. 1 S., R. 22 W., Ravalli County.

The granite is moderate orange pink (5 YR 8/4) and seems uniform within individual outcrops. Small cavities about 1 mm across are numerous, but the granite seems otherwise sound. No detrimental weathering effects were observed in outcrop. Although the jointing was not studied in detail, joint spacing would apparently facilitate the quarrying of blocks several feet in minimum dimension.

ORBICULAR GRANITE, SOUTHWEST OF DEER LODGE (Locality 15)

An unusual rock is exposed on a cliff face on the south side of Dempsey Creek in the SE¼ NW¼ sec. 33, T. 7 N., R. 11 W., Powell County. Spheroidal masses (orbicules) within the granite give this rock its name. The orbicules are composed mainly of quartz and feldspar, as is the rest of the rock, and are as much as 15 cm in diameter (Allen, 1969). Although the rock is unusual, it is not suitable for use as a building or decorative stone, because the orbicules tend to break out of the rock. Furthermore, the small amount of exposed rock is relatively inaccessible on the side of a cliff, so quarrying is almost impossible and would certainly not be economical.

GRANITE FROM LOST CREEK CANYON NORTH OF ANACONDA (Locality 16)

Granite exposed north of Anaconda along Lost Creek Canyon was examined in the W½ sec. 9, T. 5 N., R. 11 W., Deer Lodge County. Although the exposures examined lie within Lost Creek State Park, the same granite is exposed on the south side of Lost Creek outside the park. The most prominent structural feature at this locality is the well-developed sheeting, which is inclined toward Lost Creek. The granite is pinkish gray (5 YR 8/1) and is generally free of inclusions or other impurities. Average specific gravity is 2.59 and average absorption is 0.4 percent. This granite is even textured and has an attractive color; it could be quarried in large blocks, but the general scarcity of steeply inclined joints might make quarrying more difficult than where jointing is more pervasive.

GRANITE NORTHEAST OF TOWNSEND (Locality 17)

Granite is exposed along Gurnett Creek in the Big Belt Mountains. Exposures north of Gurnett Creek were examined near the center of sec. 16, T. 8 N., R. 3 E., Broadwater County. The rock here is yellowish gray (5 Y 8/1) to very light gray (N 8) and forms bold outcrops. When struck by a hammer, this granite produces a dull thud in contrast to the whack produced by most hard rocks. Because thin-section examination shows that the plagioclase feldspar has been extensively altered to a fine-grained layer silicate mineral, this rock is unsuitable for use in construction. According to Nelson (1963, p. J38), this granite is exposed over an area of approximately 7 square miles (18 km^2); it is possible that at other localities the feldspar is unaltered, and if so, the granite would make a good building stone.

ANDESITE PORPHYRY, DEEP CREEK CANYON EAST OF TOWNSEND (Locality 18)

Andesite porphyry is exposed in roadcuts and also in a small abandoned quarry along U.S. Highway 12 in Deep Creek Canyon, east of Townsend in sec. 20, T. 7 N., R. 5 E., Broadwater County. The andesite has been intruded into thin-bedded units of the Belt Supergroup. Where exposed, the andesite contains irregular fractures, which make it difficult to quarry large blocks; only small blocks and rubble would result from quarrying here.

The andesite consists of grayish-orange-pink (5 YR 7/2) plagioclase phenocrysts set in a dark-greenish-gray (5 G 4/1) groundmass. When polished, it would produce a decorative stone. Average specific gravity is 2.68 and average absorption is 0.3 percent.

METAGABBRO EAST OF PERMA (Locality 19)

Several metagabbro sills intrude the Prichard Formation of the Belt Supergroup (Precambrian) in the Perma area. One of these sills was examined in the NE¼ SW¼ sec. 31, T. 19 N., R. 23 W., Sanders County, where it is exposed in a roadcut along U.S. Highway 93. The metagabbro is discolored by iron oxides on some fractures, but is greenish black (5 GY 2/1) on a fresh fracture. Average specific gravity is 2.97 and average absorption is 0.1 percent. The abundance of irregular fractures at this locality precludes the quarrying of dimension stone. Discoloration along most of the fractures indicates that they were produced by natural processes and not by blasting during excavation. Perhaps this dense uniform-textured rock is less fractured and could be quarried in larger blocks at other localities.

GNEISS

The metamorphic rock, gneiss, is included in the commercial stone category of granite. The layers in the gneiss may be planar or they may be curved or folded. Although no deposits of gneiss were examined in conjunction with this study, this rock deserves mention as a decorative stone available in large quantities in western Montana. Gneiss, along with other metamorphic rocks, is exposed in many of the mountains of southwestern Montana. The Bitterroot Range, Highland Mountains, Ruby Range, Tobacco Root Mountains, Gravelly Range, Madison Range, Beartooth Range, and Little Belt Mountains all contain sizable areas underlain by gneiss. Because of its layering, gneiss tends to break into slabs that make a durable and decorative ornamental stone.

LIMESTONE

Although limestone quarries were numerous in Montana at one time, limestone is now quarried at only three localities for use as a decorative stone. For detailed information on carbonate rocks in Montana, see Montana Bureau of Mines and Geology Bulletin 44 (Chelini, 1965).

Limestone that accompanies argillite is included under argillite in the slate section.

FLAGSTONE NORTHEAST OF MANHATTAN (Locality 20)

Limestone has been quarried northeast of Manhattan in sec. 30, T. 2 N., R. 4 E., Gallatin County. The limestone, which is in the Lahood Formation (Precambrian), is exposed in low hills just north of the East Gallatin River (Spahn, 1967). Thin bedding and near-vertical joints permit the removal of thin slabs ideal for flagging. The total thickness of the deposit is unknown because of overburden, but it is at least 10 feet (3 m); bedding is inclined less than 20°. The color on the bedding planes is buff (10 YR 8/2) and on broken surfaces is pale brown (10 YR 6/2). Specific gravity is 2.63 and average absorption as determined for four samples is 0.7 percent. This limestone seems to be an excellent stone for both interior and exterior applications where thin slabs of an attractively colored rock are required.

BEAR GULCH LIMESTONE IN THE SNOWY MOUNTAINS (Locality 21)

The Bear Gulch Limestone member of the Tyler Formation (Pennsylvanian) is being quarried from a deposit on the northeast flank of the Snowy Mountains in Fergus County, sec. 33, T. 14 N., R. 22 E. Mr. Charles Allen of Beckett is the operator of this quarry, which produces flagging and a wide variety of blocks suitable for veneer (1971). Attitude of bedding is variable; the dip ranges from 5° to 20°; near-vertical joints that strike N. 65° E. and N. 50° W. permit the easy removal of slabs and blocks 2 feet (0.7 m) in maximum dimension as well as smaller slabs less than 1 inch (2.5 cm) thick (Figure 2B). An estimated 70 to 80 percent of the rock quarried is marketable. The exposed thickness of limestone at the quarry is 55 feet (17 m); the rock is also exposed in several other localities where it could be quarried.

Average specific gravity is 2.59 and average absorption is 0.67 percent (12 specimens tested). Color of bedding or joint surfaces ranges from light brown (5 YR 6/4) to yellowish brown (10 YR 5/4); on a freshly broken surface, the rock is pale yellowish brown (10 YR 4/2). Calcite coats some fracture surfaces.

In addition to attractive decorative stone, this quarry has yielded several geologically significant fossil fish and the remains of conodont-bearing animals (Melton, 1971).

DEADMAN QUARRY WEST OF YELLOWTAIL RESERVOIR (Locality 22)

The Pryor Mountain Stone Co. of Billings quarries a rock, described as dolomitic siltstone, from five quarries in the Chugwater Formation (Triassic) west of Yellowtail Reservoir in Carbon County. Stone is split and sorted in the stone yard, situated in sec. 36, T. 7 S., R. 28 E., and trucked to Lovell, Wyoming, for rail shipment. Two almost horizontal beds having a total thickness of 6 to 7 feet (1.8 to 2.1 m), which are reported to be approximately 100 feet (30 m) below the top of the Chugwater Formation, are quarried. Widely spaced near-vertical joints facilitate the removal of large blocks. The attractive coloration of stone from both beds is caused by differences in the iron oxide content of the thin laminae (Figure 2C). These laminae, which are parallel to bedding, seem not to constitute planes of significant weakness, as shown by the fact that this stone can be cut into slabs less than 1 inch (2.5 cm) thick oriented perpendicular to bedding. The lower bed is generally gray, and the upper bed is pale reddish brown (10 R 5/4) on bedding surfaces but slightly lighter reddish brown on surfaces sawed or broken perpendicular to bedding. Honed surfaces cut parallel to bedding show an attractive mottled coloration. Average specific gravity as determined on four samples from the upper bed is 2.55 and the average absorption of these samples is 3.4 percent.

Table 4.—Chemical analyses and physical properties of dolomitic siltstone from Deadman quarry (Chugwater Fm.). Analyses provided by Pryor Mountain Stone Co.

	Upper bed	Lower bed
SiO_2 (insoluble)	25.20%	42.80%
FeO, Fe_2O_3, Al_2O_3	2.04%	13.30%
$CaCO_3$	42.75%	24.10%
$MgCO_3$	29.62%	19.36%
	99.61%	99.56%
Compressive strength perpendicular to bedding	11,400 psi	12,400 psi
Absorption	6.0%	5.0%
Bulk specific gravity	2.30	2.34

DOLOMITE SOUTH OF YAAK (Locality 23)

Silty dolomite of the Wallace Formation of the Belt Supergroup (Precambrian) is exposed along a logging road between Big Foot Creek and Seventeenmile Creek in the northwest quarter of the Turner Mountain 7½-minute quadrangle, Lincoln County. Some of this dolomite can be broken into slabs suitable for flagging and into blocks suitable for rubble. Prospecting throughout this area might reveal more accessible deposits of equally good stone in the Wallace Formation. The silty dolomite is light greenish gray (5 G 8/1) on an unweathered surface, but is grayish orange (10 YR 7/4) on a weathered surface. Average specific gravity is 2.77 and average absorption is 0.3 percent.

DOLOMITE EAST OF NYACK (Locality 24)

Argillaceous dolomite of the Belt Supergroup (Precambrian) is exposed in a large roadcut along U.S. Highway 2 in the N½ sec. 26, T. 31 N., R. 17 W., Flathead County. Bedding is oriented N. 40° W., 60° NE., and is cut by numerous joints. Some rubble and flagging could be obtained where some of the beds are thinly laminated. Unweathered surfaces are greenish gray (5 GY 6/1), weathered surfaces stained by iron oxide are olive gray (5 Y 4/1).

SIEBEN RANCH QUARRY NORTH OF HELENA (Locality 25)

Silty limestone, also of the Belt Supergroup, has been quarried from exposures along Little Sheep Creek north of Helena. The quarry, variously referred to as the Sieben Ranch quarry or Picture Stone No. 1 quarry, is in the SE¼ sec. 26, T. 13 N., R. 5 W., Lewis and Clark County. The dip of bedding varies within the quarry but does not exceed 25°. A well-developed joint set is oriented N. 70° E., 70° SE.; a less pronounced vertical joint set trends N. 35° W. Figure 2D shows the difference in bed thickness that permits removal of thin slabs for flagging as well as thicker blocks for ashlar or rubble. Black pyrolusite (MnO_2) dendrites on bedding surfaces produce an attractive fern-like design. Color of the silty limestone ranges from olive gray (5 Y 4/1) to greenish gray (5 GY 6/1); average specific gravity is 2.68 and average absorption is 0.13 percent.

A large amount of this stone could be quarried in this area, but only a small part would show black dendrites.

MARBLE

Included under this commercial classification are marble, onyx marble, travertine, and one deposit of limestone. Marble occurs in two geologic environments in Montana: interlayered with other Precambrian metamorphic rocks such as gneiss and schist, and adjacent to granitic plutons where the heat from the magma caused recrystallization of a carbonate sedimentary rock to produce the marble. In the Butte, Anaconda, and Helena areas, the marble quarried from the latter type of deposits was used in smelting ore. Several of these abandoned quarries were examined. Most of the quarries would not yield large blocks suitable for dimension stone but would provide crushed rock of high reflectivity excellent for use in exposed aggregate panels, landscaping, terrazzo, or roofing granules.

BLACK AND GOLD MARBLE QUARRY NORTHEAST OF RADERSBURG (Locality 26)

The Meagher Limestone (Cambrian) is exposed at several localities in western and central Montana but has been quarried at only one locality in the Limestone Hills northeast of Radersburg in Broadwater County (NE¼ sec. 4, T. 5 N., R. 1 E.). The quarry was operated by the Vermont Marble Co. between 1928 and 1930 and for a few months in 1937. This gray limestone is mottled with yellowish-orange spots and has been marketed as Montana "black and gold marble". Attitude of bedding at the quarry is N. 10° W., 85° SW., and prominent joints trend N. 60° E., 75° NW. The quarry walls are parallel to joints and bedding. The surface dimensions of the quarry are approximately 30 by 50 feet (9 by 15 m), and depth is 60 feet (18 m). Waste blocks as large as 5 feet (1.5 m) in maximum dimension are piled next to the quarry. Most of the limestone is massive and suitable for dimension stone, but some is thin bedded and could be split into slabs only a few inches thick.

Freeman and others (1958, p. 492) reported that the yellowish-orange spots are composed of dolomite and some silt whereas the dark part of the rock is entirely fine-grained calcite.

LIMEKILN QUARRY SOUTH OF BUTTE (Locality 27)

Marble for use as flux in smelters has been produced at the Limekiln quarry south of Butte in the Highland Mountains, in the SW¼ NE¼ sec. 22, T. 1 N., R. 7 W., Silver Bow County. The marble at this quarry was formed by the metamorphism of Paleozoic limestone adjacent to the Boulder batholith. Relict bedding, still recognizable in the marble, strikes N. 20° E. and dips 80° SE. The most pronounced joint set is oriented N. 90° E., 80° S. The many irregular fractures cutting the marble in this quarry are too closely spaced to permit removal of blocks suitable for dimension stone. The total vertical distance from the bottom of the lower cut to the top of the marble exposure is 73 feet (22 m); the lower cut is 50 by 40 feet (15 by 12 m).

Color ranges from light gray (N 7) to bluish white (5 B 9/1). Moderate-yellowish-brown (10 YR 5/4) spots and streaks are caused by hematite stain. Average specific gravity is 2.56; absorption ranged from 0.9 percent for one specimen to 4.6 percent for another sample that contained a hematite-stained porous layer. Although this marble quarry might be a source of light-colored granules, other quarries contain lighter-colored marble.

LOST CREEK CANYON NORTH OF ANACONDA (Locality 28)

Another long-abandoned marble quarry is north of Anaconda near the mouth of Lost Creek Canyon (NW¼ SW¼ sec. 10, T. 5 N., R. 11 W., Deer Lodge County). Here a Paleozoic dolomite has been metamorphosed by a granite stock. The semicircular quarry has a diameter of

120 feet (36 m) and a maximum height of 60 feet (18 m) at the face. Because of many irregular fractures, only small chunks of marble could be efficiently quarried. The white color (N 9) and high reflectivity of this marble make it a good choice for use as a white aggregate or for any other application where granules of a light-colored stone are required. Average specific gravity is 2.85 and average absorption is 0.09 percent.

PIKES PEAK CREEK NORTHWEST OF DEER LODGE (Locality 29)

Marble has been produced northwest of Deer Lodge in the Flint Creek Range (Mutch, 1961), where the Royal stock has metamorphosed the Madison Limestone (Mississippian). Although marble may be widespread in this area, only the exposures along Pikes Peak Creek (NW¼ sec. 10, T. 8 N., R. 11 W., Powell County) were examined. At this locality, the marble shows many fractures and does not seem likely to yield large blocks. Perhaps at other localities where marble has been produced by contact metamorphism adjacent to the Royal stock, fracturing may be less deleterious. Marble specimens from this locality range from white (N 9) to medium bluish gray (5 B 5/1); average specific gravity is 2.85 and average absorption is 0.9 percent.

ONYX MARBLE QUARRY NORTH OF MANHATTAN (Locality 30)

This quarry, in the center of sec. 14, T. 2 N., R. 3 E., Gallatin County, was just being developed in 1932 (Mansfield, 1933, p. 2), but seemingly was abandoned before much stone had been removed. A large near-vertical vein of onyx marble 30 feet (9 m) thick within the Madison Limestone trends N. 20° E. Pronounced layering, along which the onyx marble breaks, is concordant to the limestone contact. Mansfield (1933, p. 3, 5) reported that the vein extends for 0.75 mile (1.2 km); a drill hole about 20 feet (6 m) deep showed that the onyx marble extended to this depth below the bottom of the quarry. Color of the onyx marble ranges from white to very pale orange (10 YR 8/2); average specific gravity is 2.71, and average absorption is 0.1 percent.

Where examined at the abandoned quarry, this deposit would yield numerous blocks suitable for rubble. With much care, blocks of dimension stone could be quarried. Granules and fist-size blocks could be produced in large quantity.

WHITE ANGEL QUARRY EAST OF TWIN BRIDGES (Locality 31)

A deposit of honey-colored onyx marble, on the west flank of the Tobacco Root Mountains east of Twin Bridges, has been quarried by the American Chemet Corp. at two sites in the W½ sec. 27, T. 3 S., R. 5 W., Madison County. The deposit is now owned by the Utah Calcium Corporation. The onyx marble was used in various ways: large pieces were used for facing; crushed stone for terrazzo, exposed aggregate panels, and roof granules; stone chips for landscaping; and fine waste for poultry feed supplement, as a white sand in plaster, and several other minor uses. Rounded pebbles were produced by tumbling rough chunks of stone 1 to 3 inches (2.5 to 7.5 cm) in diameter with water for 24 hours in an old truck mixer body.

The onyx deposit is near a steeply dipping fault that juxtaposes the Jefferson Dolomite (Devonian) with the Meagher Limestone (Cambrian) (Johns, 1961, Pl. 1). Presumably the calcite was deposited by movement of ground water, the flow pattern having been related to brecciation along this fault. Solution of the adjacent carbonate units may have provided the calcium carbonate that was deposited to form the onyx marble. In some areas of the quarry, fractures are too closely spaced to permit the removal of large blocks, but waste blocks lying around at the quarry indicate that blocks several feet in maximum dimension could be produced. Prominent banding consists of grayish-orange (10 YR 8/2) to white (N 9) layers, many of which are only a few millimeters thick. Average specific gravity is 2.72 and average absorption is 0.05 percent. This deposit has significant reserves of onyx marble.

TRAVERTINE

GARDINER QUARRIES (Locality 32)

Travertine from Gardiner has a more widespread reputation than any other stone now produced in Montana. Travertine from this deposit, about 1 mile (1.6 km) north of Gardiner, has been quarried since 1932 and sold for a variety of decorative uses. Stone from these quarries, now operated by the Livingston Marble and Granite Works, is provided in polished panels as well as split-face ashlar. Quarried blocks are hauled to Livingston where they are gang sawed into slabs that are then either broken into ashlar blocks or polished (Figure 3A).

Color of travertine from these quarries includes pale yellowish orange (10 YR 8/6), mottled grayish red (10 R 4/2), white (N 9), and numerous intermediate colors; many are attractively variegated. Production from several quarries ensures continued availability of these colors. Cavities in the travertine, as exposed in the quarry, range from only small pores, in some areas where the travertine is dense, to openings more than a foot across.

Three chemical analyses of the travertine from Gardiner reported 99.74, 99.47, and 98.92 percent $CaCO_3$. Absorption was measured as 1.23 percent for a cube 6 inches (15.2 cm) on a side immersed in water for 24 hours, and specific gravity of a specimen of "rather coarsely crystalline" travertine was 2.69 (Mansfield, 1933, p. 8). Chelini (1965, p. 12) cited an estimate made by Sahinen in 1961 of 8,423,500 tons of travertine on the property of Montana Travertine Quarries. Their property covered only about one fourth of the area of this deposit.

PARK DEPOSIT NORTHWEST OF LEWISTOWN (Locality 33)

Another large deposit of travertine northwest of Lewistown on the south flank of the North Mocassin Mountains covers 6 square miles (15 km^2) in sec. 1, 2, 11, and 13, T. 17 N., R. 17 E., and in sec. 5, 6, 7, 8, 17, and 18, T. 17 N., R. 18 E., Fergus County. The maximum thickness is reported to be 250 feet (75 m). The area underlain by the travertine deposit is named the Park because of its flat surface and lack of timber. Although not exposed within the Park, the travertine can be seen at its south edge, where layering is about horizontal and color ranges from moderate orange pink (10 R 7/4) to grayish orange (10 YR 7/4). Average specific gravity of two samples is 2.53 and average absorption is 1.0 percent.

A smaller deposit of travertine, about 4 miles (6.4 km) to the south, on the northeast flank of the South Mocassin Mountains (Miller, 1959, Pl. 1), was not examined.

Two major deposits of travertine occur on the south flank of the Judith Mountains (Calvert, 1909, Pl. 1). One is at Flat Mountain and includes parts of sec. 31 and 32, T. 16 N., R. 20 E., and sec. 5 and 6, T. 15 N., R. 20 E., Fergus County. The other is a few miles farther south and includes part of sec. 20, 21, 28, 29, 32, and 33, T. 15 N., R. 20 E. These two deposits were not examined.

LANDUSKY AREA

Mansfield (1933, p. 21) reported banded limestone or possibly travertine on the west flank of the Little Rockies probably in the SW¼ sec. 18, T. 25 N., R. 23 E. Although the area was searched, no rock resembling this description was found.

LIMA AREA (Locality 34)

Two related deposits of travertine occur in this area within the Tendoy Mountains. One deposit of massive white travertine in Clark County, Idaho, several miles south of the state line, is now being quarried by Idaho Travertine Corp. Large blocks of the stone are trucked to Idaho Falls where they are cut into slabs for facing. The quality of the rock is good and the reserves seem to be large.

The second deposit is astride the state line and covers an estimated area of 2 square miles (5 km^2) including parts of sec. 19, 20, 29, 30, and 31, T. 15 S., R. 9 W., Beaverhead County, Montana. The Idaho portion of this deposit covers parts of sec. 32, T. 14 N., R. 32 E., and sec. 4, 5, and 6, T. 13 N., R. 32 E. Some stone has been quarried at the west end of this deposit but otherwise the deposit is undeveloped. Although layering in the travertine is variable, it is within 10° of horizontal. In this deposit the layering is more pronounced than in the deposit farther south in Idaho. Thus slabs of travertine may be obtainable here, but quarrying of large blocks may be more difficult. Color ranges from white (N 9) to very pale orange (10 YR 8/2). The thickness is estimated to be 200 feet (60 m) where the travertine is well exposed south of the state line. This plateau of travertine is capped by a layer of Tertiary rhyolite (Witte, 1965). The travertine was assigned to the Medicine Lodge basin beds, tentatively dated as Miocene (Witte, 1965, p. 36).

Not enough development work has been done on this travertine deposit to permit evaluation of its potential. On the basis of brief examination, however, it seems to be a good-sized deposit of an attractive stone.

SANDSTONE

Many abandoned sandstone quarries in western and central Montana attest to a large demand for sandstone many years ago. The only sandstone quarries active in 1972 were in the Flathead Quartzite (Cambrian). This relatively hard, light-colored sandstone makes a fine ashlar or rubble for decorative use, and quarrying of this unit will undoubtedly continue (Figure 3B). Other sandstone units previously quarried in the state are younger (Jurassic to Cretaceous) and considerably softer and less durable than the Flathead Quartzite. When dimension stone for construction was in large demand, these softer sandstone beds provided an easily worked stone for local use. Despite transportation cost, stone is now shipped to out-of-state markets and must compete with a wide variety of natural stones as well as other building materials. The sandstone that could be inexpensively quarried for a local market but was of inferior quality is no longer in a competitive position. The abandoned Montana quarries in the Jurassic and Cretaceous sandstone beds probably will not be reopened for building stone as long as superior stone such as the Flathead Quartzite is available.

LAHOOD FORMATION NORTH OF MANHATTAN (Locality 35)

The Lahood Formation of the Belt Supergroup (Precambrian) was quarried north of Manhattan along Nixon Gulch (NW¼ SE¼ sec. 27, T. 2 N., R. 3 E., Gallatin County). The rock is massive dark-greenish-gray (5 GY 4/1) sandstone, which contains some fine-grained layers (Figure 3C). Attitude of bedding is N. 80° E., 20° NW.; joints are oriented N. 60° W., 80° SW. and N. 10° W., vertical. Joints are too closely spaced for large blocks to be quarried, but many blocks 4 to 10 inches (10 to 25 cm) in size could easily be pried from the exposed face. Exposed thickness of the massive beds is approximately 20 feet (6 m). Average specific gravity is 2.64 and absorption is 0.52 percent This abandoned quarry is a suitable source of small, decorative sandstone blocks of unusual color.

SANDSTONE NEAR STRYKER (Locality 36)

Sandstone in the Grinnell Formation of the Belt Supergroup (Precambrian) crops out to the east of Stryker in the NW¼ NW¼ sec. 31, T. 34 N., R. 24 W., Lincoln County. Although this deposit would yield some blocks of rubble, it would not be a good source of flagging. Maroon claystone clasts are abundant and form parting surfaces. Color of the sandstone ranges from pale red purple (5 RP 6/2) to brownish gray (5 YR 4/1). Specific gravity is 2.56 and absorption is 0.4 percent.

FLATHEAD QUARTZITE IN THE LIMESTONE HILLS NORTH OF RADERSBURG (Locality 37)

The Flathead Quartzite (Cambrian) has been produced for use as smelter flux from a small quarry in the Limestone Hills north of Radersburg. The quarry is in the NW¼ NW¼ sec. 27, T. 6 N., R. 1 E., Broadwater County. Bedding thickness of the sandstone ranges from 2 to 6 inches (5 to 15 cm), and the attitude of bedding is N. 20° W., 80° SW. The most prominent joint set is oriented N. 40° W., vertical; a much less prominent joint set trends N. 80° W. and dips 25° SW. (Figure 3D). Spacing of joints ranges from about 1 foot (0.3 m) to several feet; thickness of the easily quarried sandstone is approximately 60 feet (18 m). Although considerable waste would result, slabs 4 inches (10 cm) thick and as much as 4 feet (1.2 m) in maximum dimension could be quarried. The sandstone from this quarry ranges from pale red (5 R 6/2) to pinkish gray (5 YR 8/1) and is well cemented as shown by the low absorption, 0.25 percent. The average bulk specific gravity is 2.64. This quarry is a good source of sandstone flagging, rubble, and ashlar in colors ranging from buff to pale red. The Flathead Quartzite is exposed for approximately 7 miles (11 km) in a north-south direction (Freeman and others, 1958), so a large amount of this sandstone could probably be quarried in this area.

MONARCH AND KINGS HILL QUARRIES, LITTLE BELT MOUNTAINS (Localities 38, 39)

Montana Stone, Inc., produces rubble, ashlar, and flagging from two quarries in the Flathead Quartzite in the Little Belt Mountains.

The Monarch quarry is 4 miles (6.4 km) southeast of Monarch in Cascade County, and the Kings Hill quarry is adjacent to U.S. Highway 89 about 3 miles (4.8 km) north of Kings Hill Pass, southeast of Neihart.

The predominant type of rock at the Monarch quarry is sandstone, some of which is crossbedded, but minor conglomerate and siltstone layers are included. The beds are only slightly tilted (S. 50° W., 5° NW.). One set of vertical joints trends N. 10° E. to N. 40° E.; the other prominent joint set strikes N. 60° W. and dips 70° SW. Most of the stone has been quarried from a layer of sandstone 28 feet (8.5 m) thick, which is overlain by siltstone (Figure 4A). Although the general tone is very light brown (5 YR 7/4), thin reddish-brown laminae provide an attractive color contrast. Average specific gravity is 2.33 and average absorption is 2.7 percent. Attitude of bedding at the Kings Hill quarry is N. 90° W., 10° S.; prominent vertical joint sets trend N. 45° E. and N. 40° W. Color averages grayish red (5 R 4/2) but is not uniform. Crossbedding is prominent, and some conglomerate layers are present. Average specific gravity is 2.37 and average absorption is 2.7 percent.

FISHTRAP QUARRIES NORTH OF THOMPSON FALLS (Locality 40)

The Fishtrap quarries, also in the Flathead Quartzite, were operated by Mr. U. C. Campbell of Thompson Falls (1968), and are adjacent to Fishtrap Creek north of Thompson Falls in Sanders County. One quarry is in the NE¼ sec. 26, T. 24 N., R. 28 W., and the other is in the N½ sec. 23, T. 24 N., R. 28 W. Ashlar, rubble, and flagging are produced from these quarries. Rector (1963) reported that the Flathead Quartzite is only about 25 feet (7.5 m) thick here and dips westward 30 to 35°, and his map shows that the Flathead Quartzite extends slightly more than 12 miles (19 km) along the strike. Sandstone from these quarries ranges from pale yellowish brown (10 YR 6/2) to grayish red (5 R 4/2). Average specific gravity is 2.55 and average absorption is 0.94 percent. Relatively large reserves of durable stone that can be quarried in thin slabs showing attractive colors indicate that this deposit can be an important source of decorative stone.

SWIFT FORMATION EAST OF GREAT FALLS (Locality 41)

An abandoned quarry east of U.S. Highway 89 at Armington Junction in the SW¼ SW¼ sec. 6, T. 18 N., R. 7 E., Cascade County, is in the Swift Formation (Jurassic). Bedding is oriented N. 75° W., 5° NE., and two vertical joint sets trend N. 30° W. and about N. 85° E. The thickness of the massive sandstone exposed in the quarry is about 35 feet (11 m), and delicate black cross laminations, some containing pyrite, are abundant. The sandstone is light olive gray (5 Y 6/1); average specific gravity is 2.37, and average absorption is 3.9 percent. Because the stone is relatively soft and porous, it would not be desirable for exterior facing.

KOOTENAI FORMATION SOUTH OF GREAT FALLS

Sandstone has been quarried from massive beds near the base of the Kootenai Formation (Cretaceous) at two localities south of Great Falls. Both quarries are on the sandstone ridge north of Sand Coulee Creek. The westernmost quarry is in the SE¼ SE¼ sec. 30, T. 20 N., R. 4 E. (locality 42). The bed has an exposed thickness of 15 feet (4.5 m) and is horizontal. Two vertical joint sets trend N. 65° W. and N. 20° E. Flaggy sandstone overlies the massive sandstone. The uppermost 1 foot (0.3 m) could yield flagging; blocks having a minimum dimension of 1 foot (0.3 m) could be quarried from the lower part of the bed, but because of prominent crossbedding and irregular fractures, a large amount of waste would have to be removed. This sandstone is pinkish gray (5 YR 8/1), average specific gravity is 2.30, and absorption is 2.75 percent.

The same sandstone bed has also been quarried 1.5 miles (2.5 km) farther east in the SW¼ SW¼ sec. 28, T. 20 N., R. 4 E. (locality 43), adjacent to the Fields clay mine where fireclay has been mined from a clay bed below the massive sandstone. Bedding is horizontal, and vertical joints trend N. 70° W. and N. 10° E. The exposed thickness of the massive sandstone bed is 10 feet (3.3 m); the massive sandstone grades upward into more thinly bedded sandstone (Figure 4B). The total thickness is 20 to 30 feet (6 to 9 m). Sandstone slabs could be more easily removed from the thinly bedded section in this quarry than in the one farther west. Absorption and bulk specific gravity were not determined for samples from this quarry, but values should be similar to those for samples from the quarry to the west.

KOOTENAI FORMATION IN THE LEWISTOWN AREA (Locality 44)

Three quarries south of Lewistown in the NW¼ sec. 23, T. 15 N., R. 18 E., produced stone from the Kootenai Formation (Cretaceous) and were doing a good business shortly after the turn of the century (Rowe, 1908, p. 46) but are now abandoned. The sandstone bed quarried is at least 15 feet (4.5 m) thick and bedding is horizontal. The largest of the three quarries extends about 275 feet (84 m) along bedding. The rock is massive, but in some areas of the quarry, many small fractures prevent the removal of large blocks. Crossbedding is well developed in this quarry. Red clay and silt have been washed down from the overlying beds and have colored the surface of the sandstone reddish brown. Color on a fresh surface is grayish orange (10 YR 7/4), average specific gravity is 2.19, and average absorption is 7.72 percent. The stone is soft and friable; together with the high absorption, these qualities make the stone less desirable for exterior use than the sandstone from the Kootenai Formation in the Great Falls area.

COLUMBUS QUARRY (Locality 45)

The Lennep Sandstone (Cretaceous), which is probably equivalent to the Fox Hills Sandstone, has been quarried just north of Columbus in the NE¼ NE¼ sec. 21, T. 2 S., R. 20 E., Stillwater County. This sandstone has been used in numerous buildings, including the State Capitol in Helena. Bedding at the quarry is horizontal; joint sets are oriented N. 80° E., 75° NW., and N. 15° W., vertical. The quarry has been partly filled, leaving only 6 feet (2 m) of the massive sandstone exposed. Color is diverse; fine-grained layers, probably containing a fair amount of clay, are grayish orange (10 YR 7/4), but coarse-grained layers are moderate yellowish brown (10 YR 5/4). Average specific gravity is 2.15 and average absorption is 7.17 percent. Although this stone has been used satisfactorily in many buildings, its high absorption value would suggest caution in using it where it may be subjected to the combinations of abundant moisture and repeated freezing and thawing.

BIG TIMBER QUARRIES (Locality 46)

Sandstone has been quarried from the Livingston Group (Cretaceous or Eocene) south of Big Timber in the SW¼ SW¼ sec. 23, T. 1 N., R. 14 E., Sweet Grass County. The sandstone is soft; the rounded outcrops adjacent to the quarry indicate that it is easily eroded (Figure 4C). The massive nature of the sandstone makes attitude of bedding difficult to determine accurately, but a dip of 15 to 20° is estimated; vertical joint sets trend N. 65° E. and N. 40° W. The bed that has been quarried is about 10 feet (3 m) thick. The sandstone is brownish gray (5 YR 4/1) and has an average specific gravity of 2.50 and an average absorption of 3.33 percent. Because this sandstone is so easily eroded, it seems not to be a good choice for exterior use.

DALYS SPUR QUARRY SOUTHWEST OF DILLON (Locality 47)

The Quadrant Formation (Pennsylvanian) forms cliffs along the Beaverhead River in the vicinity of Dalys Spur where sandstone of good quality has been quarried (Rowe, 1908, p. 44). This stone was used in buildings in Butte, Dillon, and Salt Lake City. The quarry has more recently been a source of silica for smelter flux.

The quarry is in the NW¼ NW¼ sec. 1, T. 9 S., R. 10 W., along the Union Pacific Railroad in Beaverhead County. Past production is estimated at 100,000 tons or more (Carter and others, 1962, p. 22). The most prominent structural feature of the quarry is a fault striking N. 10° E. and dipping 45° SE. Lowell (1965, p. 5) attributed the brecciation of the sandstone at the quarry to a fault several hundred feet farther east, which has about 1,000 feet (305 m) of displacement.

This friable, very light gray (N 8) sandstone consists almost entirely of quartz. Duplicate chemical analyses made on a sample from this quarry show 98.9 and 97.5 percent SiO_2, 0.41 and 0.45 percent Al_2O_3, and 0.05 and 0.049 percent Fe_2O_3 (Carter and others, 1962, p. 23). Extensive fracturing combined with the friable nature of the sandstone make this quarry a good source of easily crushed quartz sandstone for smelter use but a poor source of building stone. No blocks larger than 2 feet (0.6 m) in maximum dimension could be quarried here.

QUARTZITE

The distinction between sandstone and quartzite (or metaquartzite) is based on the degree of recrystallization. The quartz or feldspar grains in quartzite are held together so tightly that when the stone is broken, individual grains are broken; in sandstone, however, the grains are not held together as tightly, and the stone breaks between grains. This distinction may be ignored in the building stone industry, and a rock that is geologically identified as quartzite may be marketed as sandstone. Because of the recrystallization, most quartzite is harder and more resistant to mechanical weathering than sandstone. Some deposits in which quartzite is closely associated with argillite are included in the slate category.

GREEN QUARTZITE SOUTH OF ENNIS (Locality 48)

The American Chemet Corporation of Helena has marketed a green Precambrian quartzite quarried in the foothills of the Gravelly Range south of Ennis (SW¼ SW¼ sec. 3, T. 9 S., R. 1 W., Madison County). The quartzite bed is 6 to 10 feet (2 to 3 m) thick and has been quarried for 250 feet (75 m) along strike. Attitude of the bedding and parallel schistosity is N. 30° E., 40° NW.; the most prominent joints are oriented N. 55° W., vertical. The overlying rock is schist. The quartzite tends to break along micaceous layers that show well-defined schistosity, which produces a shiny green surface. Hematite stains joint surfaces, and quartz veinlets are numerous. The quartzite is fractured to such an extent that slabs larger than 2 feet (0.6 m) in maximum dimension would be difficult to quarry. Color of the quartzite on the surface parallel to schistosity is dark yellowish green (10 GY 4/4), average specific gravity is 2.65, and average absorption is 0.29 percent.

BROWN QUARTZITE SOUTH OF ENNIS (Locality 49)

Iron-rich quartzite beds south of Ennis in the vicinity of Ruby Creek (Hadley, 1969) were not reexamined during this study. Pete Womack of Ennis has sold slabs of this rock for use as a decorative stone (1973). The iron-rich quartzite is interlayered in Precambrian gneiss and schist and can be quarried in slabs 1 to 2 inches (2.5 to 5 cm) thick and several feet in maximum dimension. Color of a weathered surface is grayish brown (5 YR 3/2) to dusky yellowish brown (10 YR 2/2).

SILTITE NEAR SUPERIOR (Locality 50)

Siltite, which differs from quartzite only in being finer grained, is included with quartzite because it closely resembles quartzite in appearance and use. Siltite in the Belt Supergroup (Precambrian) is exposed on the southeast side of Trout Creek at the confluence of Cement Creek, 17 miles (27 km) along a dirt road south from Superior. Bedding is oriented N. 55° W., 55° NE.; one joint set is oriented N. 50° E., 55° NW., the other is almost horizontal. This very brittle rock contains many irregular fractures in addition to the joints and thus cannot be easily quarried in blocks of uniform shape or size. Color ranges from white to pale red (10 R 6/2) and to grayish orange pink (5 YR 7/2) in specific layers. These layers are offset along small rehealed faults. Layering and irregular white patches and veinlets produce an interesting decoration. Average specific gravity is 2.61 and average absorption is 0.4 percent.

SLATE (ARGILLITE) AND ASSOCIATED ROCK TYPES

None of the deposits herein described are true slate; most are argillite, which is included with slate in the classification of building stone. Argillite is a metamorphic rock which, like slate, splits into slabs, but the surfaces along which the rock can be split are neither as flat nor as close together as in slate.

In addition to the argillite, one deposit of dolomite and one of siltite are described in this category. In northwestern Montana, all three rock types are closely associated in the deposits. These rocks are contained in the Belt Supergroup (Precambrian), a very thick and extensive sequence of sedimentary rocks that has been slightly metamorphosed. Johns (1970) presented a geologic map of most of the area containing the described deposits; the formational names are taken from his work.

PLAINS AREA (Localities 51, 52, 53)

Argillite in the Prichard Formation has been quarried at three localities in the vicinity of Plains, Sanders County, and probably could be quarried at other localities in this area.

One quarry along the Clark Fork River is almost due south of Plains in the NE¼ sec. 14, T. 18 N., R. 26 W. (locality 51). Figure 4D shows the slabby nature and jointing in this argillite where it is exposed in the quarry. The bedding, along which the argillite can be broken into thin slabs, is oriented N. 25° W., 65° SW. The two most prominent joint sets are oriented N. 25° E., 45° SE., and N. 85° W., 55° SW.; two much less prominent joint sets are oriented N. 50° W., 30° NE., and N. 35° W., 30° NE. Slabs of flagging an inch or two thick and as large as 1 square foot (0.09 m^2) in area could easily be quarried here. Iron oxide coats all natural fracture surfaces and produces moderate-brown (5 YR 3/4) to moderate-yellowish-brown (10 YR 5/4) coloration. Freshly broken surfaces are olive gray (5 Y 4/1). Bedding surfaces show small pits as much as 1 mm across. Presumably these were formerly occupied by iron sulfide minerals that were leached and oxidized to produce the abundant iron oxide coating on natural surfaces.

Although the iron oxide coating produces a pleasing color, it would tend to run on exposed surfaces and to discolor the mortar. The attractive brown color and the availability of thin slabs, however, should make this stone suitable for interior decoration.

Argillite of the Prichard Formation has also been quarried on the property of Gordon Koenig south of Plains in the SE¼ sec. 2, T. 19 N., R. 26 W. (locality 52). A combination of steeply dipping beds and fairly abundant joints cutting across the bedding permit easy quarrying of relatively thin argillite slabs for flagging. Some iron oxide coats the fractures, but it is much less abundant than at the previously described quarry; it probably would not cause any problem. Color on a weathered surface ranges from grayish orange (10 YR 7/4) to moderate brown (5 YR 3/4), and on a freshly fractured surface the color is medium light gray (N 6). Average specific gravity is 2.75 and average absorption is 0.3 percent. Some of the stone from this quarry has been marketed on the West Coast as Montana Slate.

A small amount of argillite from the Prichard Formation has been quarried northeast of Plains in the vicinity of Rainbow Lake in the NE¼ NW¼ sec. 2, T. 20 N., R. 25 W., Sanders County. Some large talus blocks have been drilled and split, evidently by feather and wedge, to produce smaller blocks. This locality yields good rubble; perhaps with some difficulty blocks can be carefully split along bedding planes to produce flagging, but at other localities in this area, such as those previously described, flagging can be quarried more easily. Color on a weathered surface is olive gray (5 Y 4/1) and on a fresh surface dark gray (N 3). Average specific gravity is 2.75 and average absorption is 0.06 percent.

NORTHEAST OF PLAINS (Locality 54)

About 1 mile (1.6 km) northeast of Rainbow Lake, in the N½ sec. 31, T. 21 N., R. 24 W., Sanders County, argillite of the Prichard Formation is well exposed in road cuts along Montana Highway 28. Some of this rock is suitable for flagging and small (less than 1 foot in maximum dimension) pieces of rubble. Cleavage in some of this rock intersects bedding at an angle of 15°. Because the rock breaks along bedding as well as cleavage, it is impossible to break out large slabs. The attitude of bedding in these road cuts varies considerably; dip angles are as much as 45°. Color is diverse; representative specimens are dark greenish gray (5 GY 4/1), greenish gray (5 GY 6/1), and brownish black (5 YR 2/1). Iron oxides coat some fracture surfaces.

The argillite exposed in these road cuts is too fractured to quarry for flagging or rubble. It is unlikely that larger pieces of stone could be quarried at this locality even below the zone of frost wedging.

NORTH OF PERMA (Locality 55)

Argillite in the Prichard Formation is exposed north of Perma in a road cut along Montana Highway 282 at Markle Pass (NW¼ sec. 25, T. 21 N., R. 24 W., Sanders County). The most prominent surface of fracture (bedding?) is oriented N. 80° E., 15° SE. Although the lateral extent of the exposure of this argillite in the road cut is only 60 feet (18 m), the rock probably extends under thin cover to the west. Color on a fresh surface is light olive gray (5 Y 6/1). On the basis of the exposure in this road cut, it is believed that the amount of rock suitable for flagging is large.

WEST OF LIBBY (Locality 56)

Argillite of the Wallace Formation is exposed in road cuts and in a railroad cut near Kootenai Falls on the Kootenai River west of Libby (SW¼ SE¼ sec. 15, T. 31 N., R. 33 W., Lincoln County). Orientation of bedding is N. 10° W., 75° NE.; ripple marks and mud cracks are common on bedding planes. Prominent joints of variable attitude would facilitate quarrying of flagging from this relatively thin-bedded argillite. It is estimated that as much as one-third of the rock exposed here could be quarried for flagging.

Color on an unweathered bedding plane is greenish gray (5 GY 6/1) and on a weathered surface is moderate yellowish brown (10 YR 5/4). Average specific gravity of the argillite is 2.71 and average absorption is 0.2 percent.

KALISPELL AREA (Localities 57 and 58)

A quarry in argillite of the Siyeh Limestone of the Belt Supergroup southwest of Kalispell in the SE¼ SW¼ sec. 13, T. 28 N., R. 22 W., Flathead County (locality 57), has been abandoned. Bedding is gently inclined (N. 45° E., 10° SE.) and is cut by near-vertical joints. Mud cracks and ripple marks are common, and small lenticular solution pits oriented parallel to bedding occur on some weathered surfaces. Slabs for flagging could be quarried here, but few pieces of stone larger than 1 foot (0.3 m) in maximum dimension could be recovered. Except for brown coloration caused by iron oxide coatings along some fractures, the color of this rock is generally greenish gray (5 GY 6/1) to olive gray (5 Y 4/1).

Another abandoned quarry is southwest of Kalispell in the NE¼ NW¼ sec. 22, T. 28 N., R. 22 W., Flathead County (locality 58). Dolomitic siltite within the Piegan Group of the Belt Supergroup has been quarried here. Bedding is oriented N. 60° W., 25° NE.; the rock is broken by numerous joints approximately perpendicular to the bedding. The quarry is a small excavation, about 30 by 30 feet (10 by 10 m), in the side of the hill. This rock is more thickly bedded than the argillite in the deposits just described. Blocks several inches thick and as wide as 3 feet (1 m) could be quarried here. The rock breaks along clay partings. Color on a weathered surface ranges from yellowish gray (5 Y 7/2) to moderate yellowish brown (10 YR 5/4) and on an unweathered surface, light greenish gray (5 GY 8/1). Average specific gravity is 2.71 and the average absorption is 0.8 percent.

VOLCANIC ROCK

Rocks formed by several different mechanisms, all related to volcanic activity, are included in this category. Some volcanic rocks formed when molten lava was extruded on the surface of the earth. Because of the flowage of the viscous magma, banding (lamination) is common in these rocks. This banding may provide planes of weakness along which the rock can be broken into slabs. The rhyolite at the Josephine mine is a good example of a rock in which flow banding is well developed.

Ash flow tuff results from the rapid expulsion of volcanic ash from volcanoes. The ash is mixed with hot gases and moves rapidly as a dense cloud until the small ash particles settle out to form an ash deposit. In many deposits, the heat and the weight of overlying ash produce compaction and weld the ash fragments together to form a dense rock called welded tuff. If welding of an ash deposit has not occurred, the rock is simply called tuff.

In addition, volcanic sandstone consists of fragments of volcanic material that have been transported significant distances by water. All of these volcanic rocks have been used as building stone; most tend to split into slabs but some of the more massive rocks may break into blocks. They may have interesting textures.

JOSEPHINE MINE NORTH OF BASIN (Locality 59)

Tertiary rhyolite has been quarried west of the Josephine mine in the SW¼ NE¼ sec. 26, T. 8 N., R. 6 W., Jefferson County, from claims of the Josephine group owned by H. G. McClernan of Butte. Frost wedging of rhyolite on a knob west of the Josephine mine has produced a large accumulation of talus that has been a source of decorative stone. Figure 5A shows the nature of blocks and slabs obtainable at this locality.

Pronounced flow banding in this rhyolite produces a pleasing texture, which in some specimens resembles the grain in wood. Color on a freshly fractured surface ranges from pale red (5 R 6/2) to the dominant yellowish gray (5 Y 8/1); weathered surfaces are slightly darker. Average specific gravity is 2.37 and average absorption is 3.7 percent.

The absorption is caused by elongate cavities, generally less than 1 mm wide, that parallel the flow banding. Because of the density of the intervening bands, as seen in thin section, the stone is believed to be suitable for exterior use despite its absorption. In addition, the angular blocks on the talus accumulation show little effect from prolonged weathering.

QUARRY SOUTHEAST OF HELENA (Locality 60)

Tertiary volcanic breccia has been quarried southeast of Helena in the NW¼ NE¼ sec. 10, T. 9 N., R. 3 W., Jefferson County. The quarry, which is on the side of a small knob, is approximately 120 by 70 feet (36 by 21 m) and has a working face 35 feet (11 m) high. Several other excavations have yielded small amounts of stone. Joints, some of which are coated with chalcedony, trend N. 50° W. and are vertical. In addition to the jointing, many irregular fractures make it difficult to quarry blocks longer than 2 feet (0.6 m). The quarry can provide abundant rubble, however.

The rock consists of angular fragments, some as large as 8 cm, ranging from brownish gray (5 YR 4/1) to pinkish gray (5 YR 8/1) set in a fine-grained pale-grayish-red (10 R 5/2) matrix. Average specific gravity of this rock is 2.34 and average absorption is 1.0 percent.

FLATHEAD SUNSET QUARRY NORTHWEST OF NIARADA (Locality 61)

The Flathead Sunset quarry, northwest of Niarada in the NW¼ NE¼ sec. 34, T. 25 N., R. 24 W., Flathead County, produces a fairly well indurated tuff. Iron compounds have colored the rock maroon and yellow. Rubble is produced from this quarry, which is owned by Harry Pennoyer. Figure 5B shows pallets of stone ready to be shipped. The quarry consists of three benches on a relatively steep hillside. Most quarrying has been completed in the second bench, which is 25 to 30 feet (7.5 to 9 m) high and approximately 70 feet (21 m) long. The rock breaks along the bedding, which is oriented N. 55° W., 25° NE. Although no well-developed joints appear in this rock, numerous widely spaced fractures of irregular orientation permit the removal of blocks several feet in maximum dimension. This rock is very pale orange (10 YR 8/2) to pale red purple (5 RP 6/2) and shows pale-yellowish-orange (10 YR 8/6) banding in some pieces. Average specific gravity is 1.98 and average absorption is 8.4 percent. The absorption value dictates caution in using this stone where it may be subject to excessive moisture and repeated freezing and thawing.

A related deposit of volcanic sandstone has been quarried in the SW¼ NW¼ sec. 13, T. 24 N., R. 24 W., Sanders County, where it is exposed at Sullivan Point. Although this rock is obviously too porous and friable to make a good building stone, one sample was tested and examined in thin section. The specific gravity is 1.55 and average absorption is 18.9 percent (the highest value of any sample tested). This rock might be suitable for interior decoration where the rough texture and the medium-gray (N 5) pebbles in a pinkish-gray (5 YR 8/1) matrix would provide a pleasing effect.

BADGER PASS WEST OF DILLON (Locality 62)

Volcanic rock identified as tuff has been quarried in sec. 14, T. 7 S., R. 11 W., Beaverhead County. This quarry, near Badger Pass west of Dillon, has produced some good flagging. Bedding is oriented N. 40° E., 35° SE. Joint sets are oriented N. 40° E., 30° NW., and N. 65° W., vertical. Iron oxides and dendrites of pyrolusite coat the first joint set. Because of lack of exposure, the total thickness is unknown, but 3 feet (1 m) of slabby tuff is exposed. Flagging an inch or two thick and as much as 2 feet (0.6 m) in maximum dimension can be quarried. Color on the bedding surface is grayish yellow (5 Y 8/4), and on a freshly broken surface perpendicular to the bedding it is slightly lighter yellowish gray (5 Y 8/1). Color along joint surfaces ranges from almost black to light brown (5 YR 5/6). Average specific gravity is 2.16 and average absorption is 2.2 percent.

MONTANA ONYX SOUTHWEST OF ALDER (Locality 63)

A decorative stone known locally as Montana onyx has been quarried from a deposit southwest of Alder, along Sweetwater Creek in the SE¼ sec. 4, T. 9 S., R. 5 W., Madison County. This rock attracts attention because of its color banding in various shades of yellow, brown, and purple formed by the deposition of iron compounds as water moved along fractures and joint surfaces. The color banding tends to parallel the edges of the block and produces a distinctive coloration (Figure 5C). The rock originally consisted of interbedded tuff and tuffaceous sandstone, but as a result of silicification, it is now harder and much more resistant to erosion. Some brecciation of this rock indicates the presence of faults that may have provided channels for the movement of the solutions that deposited the silica and iron. Attractively colored rock crops out on two knobs. Jointing attitude is diverse, and fractures are so closely spaced that no blocks larger than 1 foot (0.3 m) in maximum dimension can be quarried. Average specific gravity is 2.44 and average absorption is 0.9 percent.

Unavailability of large blocks limits the use of this attractive stone to such things as terrazzo chips, exposed aggregate panels, and small decorative items such as bookends.

WELDED TUFF NORTHWEST OF WHITEHALL (Locality 64)

Platy welded tuff exposed northwest of Whitehall, in the SW¼ sec. 19, T. 3 N., R. 4 W., Jefferson County, is in the basal part of Unit C, which is assigned to the middle member of the Elkhorn Mountains Volcanics (Upper Cretaceous), (Prostka, 1966, p. F4). Because this platy bed is underlain and overlain by more massive beds of tuff and welded tuff, the exposure at this locality is poor. The platy bed breaks into thin slabs 1 to 3 inches (2.5 to 7.5 cm) thick; the uneven surfaces are brownish gray (5 YR 4/1). This unit was investigated as a possible source of flagging because of its platy nature. Where examined, however, the uneven fracture surfaces and the small amount of exposed platy rock suggest that this volcanic unit would be a poor source of flagging.

TUFF SOUTH OF BOZEMAN (Locality 65)

Attempts have been made to quarry a pastel-tinted tuff south of Bozeman in the vicinity of Porcupine Creek (E. Bond, personal communication, 1970). A small prospect pit had been excavated in the Tertiary rocks in the NW¼ NE¼ sec. 21, T. 7 S., R. 4 E., Gallatin County. The operation seemingly was intended to include sawing the tuff into slabs for decorative use. No tuff was being quarried when the area was visited in 1970, however. The rock exposed here is yellowish-gray (5 Y 8/4) to dusky-yellow (5 Y 6/4) tuffaceous sandstone that tends to split into uneven platy slabs. The irregular shape of the slabs would discourage use of this rock as a decorative stone.

FRYING PAN BASIN NORTHWEST OF DILLON (Locality 66)

Tertiary sedimentary rocks that contain much volcanic material are exposed on the east side of Frying Pan Basin, a topographic swale occupying nearly 5 square miles (8 km^2) northwest of Dillon. This volcanic sediment has been quarried along Frying Pan Gulch in the NE¼ NW¼ sec. 28, T. 6 S., R. 9 W., Beaverhead County. The quarry was producing building stone during the early part of the century (Rowe, 1908, p. 51). More recently, rock from the same deposit was used as a lightweight aggregate for the manufacture of concrete blocks, but the quarry has been abandoned since the 1950's.

The most massive bed, approximately 35 feet (11 m) thick, is oriented N. 10° E., 20° SE. The somewhat irregular fractures would not aid the quarrying and would probably not allow blocks more than 1 foot (0.3 m) in maximum dimension to be removed (Figure 5D). This friable rock is very light gray (N 8) but has a faint yellowish-green color along some fracture surfaces. Because of the fracturing and the friability of this rock, it may seem unsuitable for building stone, but a residence in Butte constructed of this stone before 1908 (Rowe, 1908, p. 51) shows little evidence of deterioration after more than 60 years of exposure.

MISCELLANEOUS

QUARTZ NORTHWEST OF DARBY (Locality 67)

Massive white quartz for use both as a decorative stone and as a source of quartz chips is quarried by the Bitterroot Valley Stone Company of Darby. The deposit is northwest of Darby along the east edge of the Bitterroot Range in the SW¼ sec. 7, T. 4 N., R. 21 W., Ravalli County. Because the quartz has been strongly sheared, the origin (sedimentary or igneous) of the rock is obscure. Prominent cleavage is subhorizontal, and vertical joints are oriented N. 10° E. and N. 75° W. at the quarry. Joints and cleavage permit the production of slabs a few inches thick and more than a foot in maximum dimension. Johns (personal communication, 1972) reported pyrite near the base of the quartz mass; he estimated the deposit to contain 23,000 tons (22,000 metric tons) and to range from 2 to 5 feet (0.6 to 1.5 m) in thickness.

CONCLUSIONS

Montana has a wide variety of rock types suitable for building or decorative stone. Some of these, such as the travertine from Gardiner, have been quarried for many years and enjoy a widespread reputation. Others, for instance the argillite from the Prichard Formation, have been quarried on a much smaller scale but are, nonetheless, worthy of widespread use. Because of the distance to major market areas and the resultant transportation cost, Montana stone is at an economic disadvantage. For this reason, only the operator efficiently producing high-quality stone can compete on a regional basis.

An unusually good stone is the sandstone from the Flathead Quartzite, currently being quarried at several localities in western Montana. The argillite beds in the Belt Supergroup are also desirable for flagging or facing. Some of the granite from the Butte area is equal in quality to that produced from eastern quarries. Dolomitic siltstone from the Deadman quarries is an unusual stone that can be used for rubble and ashlar as well as for sawed and polished slabs. Onyx marble from the Sheridan area can be used where an unusual decorative stone is desired. Pleasing coloration and slabby nature of some of the volcanic rocks make them suitable for facing.

Other rock types of unusual color or texture might also be considered as possible sources of building stone.

GLOSSARY

Definitions designated by page and * are quoted directly from the A.G.I. Glossary of Geology, edited by M. Gary, R. McAfee, Jr., and C. L. Wolf.

batholith—a large, generally discordant, plutonic mass that has more than 40 square miles (100 km^2) in surface exposure and is composed predominantly of medium- to coarse-grained rocks of granodiorite and quartz monzonite composition (p. 62*).

dike—a tabular igneous intrusion that cuts across the planar structures of the surrounding rock (p. 197*).

dip—the angle that a structural surface, e.g., a bedding or fault plane, makes with the horizontal, measured perpendicular to the strike of the structure (p. 198*).

foliation—a general term for a planar arrangement of textural or structural features in any type of rock. It is most commonly applied to metamorphic rock (p. 272*).

inclusion—a fragment of older, previously crystallized rock within an igneous rock to which it may or may not be genetically related (p. 357*).

joint—a surface of actual or potential fracture or parting in a rock, without displacement; the surface is usually plane and often occurs with parallel joints to form part of a joint set (p. 380*).

megacryst—a mineral grain that is significantly larger than the surrounding mineral grains in the rock.

migmatite—a composite rock composed of igneous or igneous-looking and/or metamorphic materials which are generally distinguishable megascopically (p. 453*).

pluton—a term that embraces all intrusive bodies of igneous rock (Turner and Verhoogen, 1960, p. 66).

schistosity—the foliation in schist or other coarse-grained, crystalline rock due to the parallel, planar arrangement of mineral grains of the platy, prismatic, or ellipsoidal types, usually mica (p. 634*).

sheeting—subhorizontal, generally closely spaced joints in granite.

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APPENDIX

PETROGRAPHIC DESCRIPTIONS

The following brief petrographic descriptions provide information on the mineralogy, textures, and alteration of representative samples from the described stone deposits. Rock names used in these descriptions are based on mineralogy and are not necessarily the same as the commercial names used by the stone industry. Most modal percentages are based on point counting thin sections using a spacing of 1 mm. Some thin sections were stained for K-feldspar by the sodium cobaltinitrite method (Reid, 1969, p. 11). Opaque minerals in some specimens were identified by examination of polished slabs, and several minerals were identified by x-ray diffraction analysis.

1. Porphyritic quartz monzonite (Boulder batholith)–Harrison quarry west of Helena.

The estimated mode based on 500 points is plagioclase, 34.6 percent; K-feldspar, 27.4 percent; quartz, 29.6 percent; biotite, 4.4 percent; hornblende, 2.4 percent; magnetite, 0.6 percent; sphene, 0.6 percent; and apatite, 0.4 percent. Quartz is interstitial and shows a wide range in size, from 0.04 to 2.5 mm. Subhedral to euhedral grains (0.6 to 3 mm) of andesine have prominent oscillatory zoning and develop some myrmekitic intergrowths where in contact with K-feldspar. Microperthitic K-feldspar is anhedral, dusty, and ranges from 0.4 to 4 mm. Biotite and hornblende are associated and range from 0.4 to 1.6 mm in maximum dimension. Pleochroism of biotite is from light tan to dark-brownish-olive drab, that of hornblende is from green to yellowish tan. Apatite is associated with biotite and sphene, and magnetite with biotite and hornblende. Zircon is a trace constituent. Specific zones in andesine grains have been replaced by calcite, which also occurs as thin (0.06 mm) veinlets. Biotite is partly altered to chlorite and epidote.

4. Porphyritic monzonite west of Canyon Ferry Lake.

Tabular and perthitic K-feldspar megacrysts contain numerous grains of the other constituents and are as long as 3 cm. Euhedral to subhedral plagioclase (0.5 to 1.5 mm) is strongly zoned and has been partly altered to a fine-grained layer silicate. Pleochroism of biotite is from yellowish tan to very dark brown; that of hornblende is from pale tan to olive drab to bright green. Quartz is a relatively minor constituent of this rock and occurs interstitially. Zircon, apatite, and sphene are present in trace concentrations.

6. Granodiorite (Rader Creek pluton of the Boulder batholith)–East of Butte.

The estimated mode based on 680 points is plagioclase, 47.1 percent; K-feldspar, 17.3 percent; quartz, 21.0 percent; biotite, 5.9 percent; hornblende, 7.3 percent; and opaque minerals, 1.3 percent. Quartz is interstitial and averages about 0.5 mm in maximum dimension. Some separated quartz grains in optical continuity cover an area 4 mm across. K-feldspar grains average 2 mm across, and string perthite is abundant. Plagioclase laths, ranging from euhedral to subhedral and from 0.03 to 5.0 mm in size, exhibit pronounced normal zoning and are in the andesine compositional range. Plagioclase cores show some incipient alteration. Biotite (0.3 to 1 mm) is anhedral and pleochroic from yellowish tan to very dark dirty brown. Hornblende (1 to 2 mm) is subhedral and pleochroic from pale yellowish tan to green. A mineral tentatively identified as a pyroxene is associated with some of the hornblende. Zircon, apatite, epidote, and an opaque mineral occur in trace concentrations. Figure 6A is a photomicrograph of this specimen.

8. Porphyritic granodiorite (Rader Creek pluton of the Boulder batholith)–Dumos quarry east of Butte.

Estimated mode based on 1,000 points is andesine, 49.0 percent; K-feldspar, 18.4 percent; quartz, 17.4 percent; hornblende, 10.7 percent; biotite, 3.6 percent; and magnetite, 0.9 percent. Most andesine grains are subhedral, exhibit pronounced oscillatory zoning, and range between 0.4 and 3.5 mm. Perthite megacrysts are anhedral (3 to 4 mm) and include other mineral constituents. Biotite, averaging 0.4 mm, forms clusters of anhedral grains and is pleochroic from very light tan to dirty greenish brown. Euhedral to subhedral hornblende (0.05 to 3 mm) is strongly pleochroic (yellowish green to green). Apatite, zircon, and magnetite are accessory minerals. The cores of some plagioclase grains have been replaced by calcite.

9. Granodiorite (Rader Creek pluton of the Boulder batholith)–Grace quarry east of Butte.

The estimated mode based on 800 points is plagioclase, 44.2 percent; microcline, 14.2 percent; quartz, 21.4 percent; hornblende, 11.2 percent; biotite, 5.8 percent; magnetite, 1.4 percent; apatite, 0.3 percent; and secondary minerals, 1.5 percent. Euhedral to subhedral laths of andesine range from 0.3 to 2.5 mm in length and exhibit prominent zoning. Microcline microperthite is anhedral and reaches a maximum size of 5 mm. Some quartz grains (interstitial) are as large as 5 mm. Biotite (grain size 0.8 to 3 mm) is pleochroic from light yellowish tan to dark brown, and hornblende (grain size 0.3 to 2 mm) from pale yellowish tan to green. Some plagioclase grains are extensively altered to a fine-grained layer silicate; cores of some grains have been replaced by calcite. Biotite is partly altered to chlorite, and an epidote-group mineral is associated with the hornblende.

10. Porphyritic quartz monzonite (Boulder batholith)–Welch quarry east of Butte.

Estimated mode based on 300 points is andesine, 45 percent; K-feldspar, 25 percent; quartz, 23 percent; biotite, 4 percent; hornblende, 2 percent; and epidote and an opaque mineral, 1 percent. Andesine megacrysts range from 0.5 to 8 mm, are euhedral to subhedral, and most exhibit prominent zoning. K-feldspar grains are anhedral, range from 0.4 to 6 mm, and contain string perthite. Quartz is interstitial and contains numerous minute fractures. Subhedral grains of hornblende (pleochroism green to pale yellowish tan) are 1 to 3 mm long; biotite (pleochroism pale yellowish tan to dark muddy brown) grains are 0.5 to 1.5 mm long. Magnetite and sphene are minor accessory minerals. K-feldspar is partly altered to a fine-grained layer silicate; plagioclase to a mixture of a fine-grained layer silicate and an epidote-group mineral; and biotite is partly altered to pennine.

11. Granodiorite (Burton Park pluton of Boulder batholith)–Feely quarry south of Butte.

The estimated mode based on 500 points is plagioclase, 41.0 percent; K-feldspar, 13.6 percent; quartz, 22.2 percent; hornblende, 12.4 percent; biotite, 9.6 percent; and magnetite, 1.2 percent. Scanty estimates of plagioclase composition suggest a considerable compositional variation within the andesine range. Most plagioclase is subhedral, 1 to 4 mm in length, and zoned. Myrmekitic intergrowths are produced in some places where plagioclase is in contact with K-feldspar. Quartz and K-feldspar grains ranging from 0.2 to 2.5 mm are interstitial to the plagioclase. Pleochroism of biotite is pale yellowish tan to very dark brown, and that of hornblende is pale yellowish tan to green. Small grains of a mineral tentatively identified as a clinopyroxene form the cores of a few hornblende crystals. Magnetite is associated with biotite and hornblende; apatite and zircon occur in trace concentrations. The only alteration recognized is the partial replacement of some plagioclase by a fine-grained layer silicate mineral.

12. Mafic monzonite–Ringing Rocks stock northwest of Whitehall.

Estimated mode based on 730 points is plagioclase, 21.8 percent; K-feldspar, 28.1 percent; clinopyroxene, 21.2 percent; biotite, 10.8 percent; quartz, 7.5 percent; hornblende, 5.6 percent; olivine, 0.4 percent; and accessory minerals and products of alteration, 5.1 percent. Anhedral to subhedral andesine laths range from 0.1 to 0.3 mm in length; a few are cloudy and euhedral. Euhedral to subhedral clinopyroxene grains range from 0.6 to 2.4 mm, and some are rimmed by an amphibole. Olivine forms the core of some pyroxene grains and also occurs as individual grains; alteration of olivine to serpentine, magnetite, or iddingsite is common. K-feldspar and quartz are interstitial. Apatite, zircon, and magnetite occur in trace concentrations.

13. Quartz diorite–East of Sula.

Hornblende (pleochroism tan to green) megacrysts, as much as 20 mm across, are surrounded by andesine grains, which in some specimens produces a crude orbicular texture. Quartz is interstitial to these orbicules. Minor constituents are biotite, epidote, muscovite, sphene, magnetite, zircon, and apatite. Much of the biotite occurs as oriented intergrowths in the hornblende. Some biotite is partly altered to chlorite; some plagioclase is strongly altered to a fine-grained layer silicate mineral.

14. Granite–Painted Rocks Lake area south of Darby.

The estimated mode based on 100 points is K-feldspar, 50 percent; quartz, 34 percent; and albite, 16 percent. Anhedral K-feldspar averages 1.5 mm, exhibits well-developed string perthite, and contains some albite blebs. Most quartz grains show mosaic extinction, range from 0.5 to 1.5 mm, and are subrounded. Albite generally forms small (0.5 mm) euhedral to subhedral grains; most of these are dusty because of an unidentified alteration product. Muscovite and greenish-brown biotite are very sparse. Miarolitic cavities several millimeters across are common.

16. Porphyritic quartz monzonite–North of Anaconda.

Estimated mode based on 640 points is quartz, 47.0 percent; albite, 29.4 percent; microcline, 21.2 percent; biotite, 2.3 percent; and an opaque mineral, 0.1 percent. Large (average 5 mm) composite quartz grains are the most obvious feature in this specimen; boundaries between adjacent quartz grains are sutured, and individual grains show strong undulose extinction. Subhedral albite grains average 0.6 mm in length; microcline in anhedral grains (2 to 6 mm) is interstitial to albite. Many of the microcline grains are broken into segments of slightly differing optical orientation. Biotite (1 mm) is anhedral and is pleochroic from very pale yellowish tan to green. Fluorite, zircon, hematite, and limonite occur in trace concentrations.

17. Granodiorite–Northeast of Townsend.

This specimen is estimated to consist of plagioclase, 50 percent; K-feldspar, 13 percent; quartz, 28 percent; biotite, 7 percent; and accessory minerals, 2 percent. Euhedral to subhedral plagioclase (oligoclase) ranges from 0.6 to 5 mm in length, exhibits prominent oscillatory zoning (more than 70 individual zones in one phenocryst), and is partly altered to fine-grained layer silicates. Some plagioclase phenocrysts have myremekitic intergrowths of K-feldspar along the borders. Quartz and K-feldspar are interstitial to plagioclase. Biotite is pleochroic from yellowish tan to almost black and is partly altered to chlorite. Minor constituents are epidote, muscovite, sphene, apatite, zircon, and magnetite.

18. Andesite porphyry–Deep Creek Canyon east of Townsend.

Euhedral plagioclase phenocrysts 2 to 5 mm across constitute an estimated 30 percent of this specimen. Plagioclase is extensively altered to a mixture of calcite and a fine-grained layer silicate. Phenocrysts of either an amphibole or a pyroxene have been altered to a fine-grained mixture of chlorite, calcite, limonite, and an epidote-group mineral. Sheafs of colorless mica extend into a former cavity now filled with calcite. Sphene, apatite, and quartz are minor constituents. The groundmass is extensively altered to a mixture of a fine-grained layer silicate and calcite.

19. Metagabbro–East of Perma.

The estimated mode of this thin section is plagioclase, 30 percent; cummingtonite, 60 percent; and zoisite, 10 percent. Plagioclase (0.3 to 1.5 mm) laths generally have somewhat ragged boundaries and faint zoning; composition is approximately An_{50}. Cummingtonite (0.3 to 1.5 mm) is very faintly pleochroic (colorless to pale green) and somewhat fibrous. Small (0.1 mm) anhedral to subhedral grains of zoisite are scattered throughout the rock. Trace constituents are biotite (pleochroism colorless to pale reddish brown), sphene, and chlorite.

20. Silty micrite–Northeast of Manhattan.

Calcite grains constitute an estimated 85 percent of this specimen and range in size from 3 to 40 μm (average about 10 μm). Most of the other 15 percent of this specimen is made up of quartz grains (average size 20 μm). Very small hematite grains and an unidentified mineral of very low birefringence occur in trace concentrations. Only quartz and calcite were detected by x-ray diffraction analysis.

21. Sparite (Bear Gulch Limestone member of the Tyler Formation)–Southwest of Grass Range.

Calcite constitutes 95 percent of this specimen and ranges in grain size from <2 μm to 100 μm (average about 40 μm). Lenticular masses of fine-grained calcite give one part of the thin section a shredded appearance. Very small grains of an unidentified opaque mineral occur in trace concentrations.

22. Silty sparite (Chugwater Formation)–Deadman quarry west of Yellowtail Reservoir.

An estimated 60 percent of this specimen consists of calcite and dolomite ranging in grain size from 0.02 to 0.25 mm. X-ray diffraction analysis showed calcite and dolomite in approximately equal proportions. The greater part of the detrital constituent is subangular to angular grains of detrital quartz (average 0.04 mm); amounts of plagioclase, microcline, and chert are minor. Delicate layering is caused by differences in the hematite content.

23. Silty dolomite (Wallace Formation)–South of Yaak.

This very fine grained rock consists of dolomite (10 μm), 60 percent; angular quartz (0.02 mm), 30 percent; and muscovite (0.05 mm), 10 percent. Albite, having an estimated composition of An_5, dolomite, and pyrite (now replaced by limonite) form a small veinlet 0.7 mm thick.

24. Argillaceous dolomite (Belt Supergroup)–East of Nyack.

Dolomite is the major constituent of the entire thin section, but in some layers angular quartz grains (0.05 mm) and fine-grained colorless mica predominate. Minor constituents are plagioclase, microcline, muscovite, goethite, and hematite.

25. Silty limestone (Belt Supergroup)–North of Helena.

Angular quartz grains (0.05 mm) occur in a fine-grained matrix of clay and of calcite. Calcite also forms masses elongate parallel to the bedding. The estimated mode is calcite, 70 percent; quartz, 20 percent; and muscovite, 10 percent; and traces of zircon, dolomite, biotite, plagioclase, and goethite. No K-feldspar was recognized, but the section was not stained for K-feldspar.

27. Marble–Limekiln quarry south of Butte in the Highland Mountains.

Calcite grains averaging 3 mm constitute an estimated 95 percent of this granulose-textured marble. Diopside (0.05 to 0.3 mm), scapolite? (0.05 to 0.2 mm), calcic plagioclase, and magnetite? form irregular patches and trains throughout the thin section.

28. Dolomitic marble–Lost Creek Canyon north of Anaconda.

Dolomite grains produce a granulose texture and range in size from 0.2 to 2.5 mm (average 1 mm). Small grains of phlogopite? border some dolomite grains. A very fine grained carbonate forms veinlets.

29. Marble–Pikes Peak Creek northwest of Deer Lodge.

Calcite grains, ranging from 0.2 to 6 mm, form a granulose texture. A few grains of muscovite and of quartz, both less than 0.1 mm in longest dimension, are scattered throughout the thin section.

30. Onyx marble–Quarry north of Manhattan.

This rock consists predominantly of elongate calcite crystals as long as 2 cm that are perpendicular to the layering. Most of these crystals consist of many subindividuals with slightly divergent orientation. Thin (0.2 mm) layers of fine-grained carbonate (2 μm) are darker than the coarse-grained calcite; alternation of these light and dark layers produces banding.

31. Onyx marble–White Angel quarry east of Twin Bridges.

Large calcite crystals as long as 5 mm are perpendicular to layering and consist of numerous subindividuals, which differ slightly in optical orientation. Layers of fine-grained calcite (0.01 mm) are darker because very small grains of an unidentified mineral are included. Small opaque inclusions are abundant in the calcite underlying the layers of fine-grained calcite. Calcite was the only mineral detected by x-ray diffraction analysis.

32. Travertine–Gardiner quarries.

Both of the specimens examined in thin section are of granular texture and have calcite grains that range in size from 5 μm to 0.5 mm. Small cavities, some only 0.02 mm across, are surrounded by coarse-grained calcite. Trace concentrations of reddish-brown and opaque grains approximately 5 μm across produce the various shades of rose and yellow seen in much of this travertine.

33. Travertine–Park deposit north of Lewistown.

Structureless ovoid masses (0.1 to 0.4 mm across) consist of very fine grained calcite (1 to 3 μm) and are surrounded by coarser-grained calcite (as large as 60 mm). Banding in the rock is caused by difference in grain size of the calcite. Small voids are prevalent, and a few calcite veinlets were observed. Hematite forms a few minute blebs about 7 μm across. Calcite and a trace of quartz were the only minerals detected by x-ray diffraction analysis.

34. Travertine–Southwest of Lima.

A. This travertine is a mosaic of calcite grains in the size range of 0.02 to 0.8 mm. Numerous calcite crystals are euhedral and contain abundant very fine inclusions in their cores. Voids several millimeters in maximum dimension are common. Differences in abundance of inclusions and in grain size produce banding.

B. Calcite is the only mineral detected by x-ray diffraction analysis of this specimen. The calcite is fine grained (5 to 10 μm) and is dusty because of very small inclusions. Voids 1 to 10 mm long are common, and a few patches of radial coarse-grained calcite were recognized.

C. X-ray diffraction analysis showed this specimen to contain mainly aragonite and only a trace of calcite. Banding is caused by very small opaque grains in specific layers. The aragonite is extremely fine grained (<2 μm), but when it is viewed at low magnification, a fibrous texture perpendicular to the banding is recognizable. A few carbonate veinlets 0.05 mm thick are present.

D. This specimen consists almost entirely of anhedral carbonate (calcite or aragonite) grains 0.04 to 0.2 mm. Irregular voids average 0.8 mm in maximum dimension. A trace of limonite is present.

35. Arkose (Lahood Formation)–North of Manhattan.

Angular grains of quartz, plagioclase, and microcline range in size from 0.05 to 2 mm. Muscovite, apatite, chlorite, zircon, and an opaque mineral occur in trace concentrations. Interstices between large grains are filled with calcite, chlorite, and a very fine grained material that appears isotropic in thin section (Figure 6B).

36. Orthoquartzite (Grinnel Formation)—East of Stryker.

Rounded quartz grains (0.1 to 0.6 mm) exhibit undulose extinction, deformation lamellae, and quartz overgrowths. Minor amounts of fine-grained mica, plagioclase, and chlorite occur between quartz grains. Claystone clasts, as long as 1 cm, consist mainly of fine-grained mica (flakes 10 μm across) and quartz.

37. Orthoquartzite (Flathead Quartzite)—Limestone Hills north of Radersburg.

This rock consists essentially of quartz in subrounded to well-rounded grains (0.06 to 0.4 mm), many of which show pronounced undulose extinction and some of which contain deformation lamellae. Although the range in grain size is fairly great, each individual layer is well sorted. Small and more angular quartz grains occupy interstices between large grains in some layers. Trace constituents are tourmaline, colorless mica, zircon, and an epidote-group mineral. Hematite borders some grains.

38. Orthoquartzite (Flathead Quartzite)—Monarch quarry southeast of Monarch.

Most of the quartz grains (0.07 to 1 mm) are subangular and show prominent undulose extinction; sorting is poor. Interstices are filled with clay, hematite, and finer grained quartz?

39. Orthoquartzite (Flathead Quartzite)—Kings Hill quarry southeast of Neihart.

This poorly sorted sandstone consists mainly of subangular to subrounded quartz grains (0.15 to 1.2 mm) that exhibit undulose extinction. Rounded cores are recognizable in many quartz grains, and a few composite grains were seen. Interstices are filled with fine-grained quartz, clay, and hematite. X-ray diffraction analysis of fine-grained material separated from this specimen showed illite as the predominant clay; a trace of a 7Å-layer silicate, presumably either chlorite or kaolinite, was also detected.

40. Orthoquartzite (Flathead Quartzite)—Fishtrap quarries north of Thompson Falls.

Except for trace amounts of colorless mica, zircon, magnetite, and hematite, this rock consists entirely of quartz grains (0.06 to 0.4 mm, 0.2 mm average) in an interlocking mosaic texture (Figure 6C). Minute inclusions are concentrated along numerous deformation lamellae. Most quartz grains exhibit pronounced undulose extinction. Rounded cores are faintly outlined by very small inclusions; layering is produced by differences in grain size.

41. Orthoquartzite (Swift Formation)—Armington junction east of Great Falls.

Subrounded to subangular quartz (0.03 to 0.15 mm) is the major constituent; chert, chlorite?, muscovite?, and apatite constitute the rest of the detrital material. Although the cementing material is both calcite and dolomite, x-ray diffraction analysis shows more dolomite. A mineral tentatively identified as one of the zeolites is interstitial to the detrital grains.

42. Orthoquartzite (Kootenai Formation)—South of Great Falls.

This well-sorted orthoquartzite consists mainly (95 percent of detrital portion) of subangular to rounded quartz grains averaging 0.1 mm. Subrounded chert grains, a few colorless mica grains, and a trace of hematite constitute the rest of this rock. Extinction of quartz grains ranges from straight to extremely undulose; a few reworked quartz grains can be recognized by a rounded core surrounded by quartz overgrowth. This rock is very porous.

43. Orthoquartzite (Kootenai Formation)—South of Great Falls.

More than 95 percent of the detrital component of this moderately well sorted sandstone consists of subangular quartz grains (0.05 mm average size), many of which exhibit undulose extinction. Minor detrital constituents are chert, colorless mica, zircon, and tourmaline; limonite has been deposited in much of the pore space.

44. Orthoquartzite (Kootenai Formation)—Southeast of Lewistown.

An estimated 80 percent of the coarse detrital component of this moderately well sorted sandstone consists of subrounded quartz grains that average 0.1 mm; numerous grains exhibit pronounced undulose extinction. Some reworked quartz is present. The rest of the coarse-grained detrital material is subangular chert. The matrix consists of clay, limonite, and possibly some fine-grained quartz.

45. Subarkose (Lennep Sandstone)—Columbus quarry.

Detrital grains range in size from 0.05 to 0.25 mm (0.1 mm average) in this poorly sorted sandstone. Angular to subrounded quartz is the major constituent; minor constituents are chert, plagioclase, muscovite, microcline, glauconite?, biotite?, tourmaline, chlorite, garnet, and lithic fragments. Limonite is deposited between detrital grains.

46. Feldspar subgraywacke (Livingston Group)–South of Big Timber.

Although quartz is the most abundant detrital component, plagioclase, chert, clinopyroxene, composite quartz grains, and a serpentine-group mineral occur in appreciable concentrations. Grain size ranges from 0.05 to 0.3 mm, and shape ranges from angular to well rounded. Minor constituents are chromite, hematite, and garnet. The rock is estimated to contain 30 percent calcite cement.

47. Orthoquartzite (Quadrant Formation)–Dalys Spur southwest of Dillon.

This specimen consists mainly of subrounded to angular 0.2 to 0.3 mm quartz grains. A few chert and composite quartz grains form the rest of this rock. Because the amount of quartz cement is small, much pore space remains between detrital grains.

48. Quartzite (pre-Belt)–South of Ennis.

Quartz, estimated as constituting 85 percent of this specimen, produces a mosaic texture. The quartz grains exhibit relatively straight extinction, and grain size averages about 0.1 mm. Schistosity is defined by elongation of masses (as much as 0.3 mm) of fine-grained chromiferous muscovite, much of which surrounds rounded grains of a nonmagnetic opaque mineral.

The chromiferous muscovite causes the green coloration of this quartzite. Apatite, zircon, and limonite occur in trace concentrations.

49. Quartzite (pre-Belt)–South of Ennis.

Quartz grains (0.05 to 0.2 mm) have straight boundaries and exhibit only slightly undulose extinction. An estimated 30 percent of the thin section is composed of quartz grains. Magnetite and hematite are intergrown in grains as large as 0.3 mm; hematite is more abundant than magnetite. Layering is caused by differences in quartz content. A minor constituent is an unidentified mineral that forms small (2 by 30 μm) reddish-brown needles and shows a tendency toward alignment parallel to the layering.

50. Siltite (Belt Supergroup)–South of Superior.

Quartz grains (5 to 40 μm) have serrated grain boundaries. Minor constituents are plagioclase, muscovite, and a mineral tentatively identified as rutile (2 μm to 0.05 mm), which occurs in prismatic crystals, some of which are elbow twins. Rutile? is most abundant in finer-grained layers. Differences in quartz grain size produces laminae, which are offset by numerous small fractures.

51. Argillite (Prichard Formation)–South of Plains.

The estimated modal composition based on 500 points is quartz (0.01 to 0.02 mm), 54 percent; fine-grained colorless mica of random orientation (0.02 mm), 30 percent; and biotite (0.02 to 0.1 mm), 14 percent. Pleochroism of the biotite is colorless to greenish brown. Tourmaline (dichroism colorless to dirty green), chlorite, limonite, and an epidote-group mineral constitute the other 2 percent of this thin section. Coarse-grained areas, 0.5 to 1.5 mm across, consist of biotite, muscovite, quartz, and the epidote-group mineral.

52. Argillite (Prichard Formation)–South of Plains.

Quartz (nearly 50 percent of this specimen) ranges in grain size from 15 μm or smaller to 0.1 mm and exhibits straight extinction. Biotite (30 percent) is pleochroic from very pale tan to reddish brown and forms irregular flakes of random orientation that average about 0.1 mm in maximum dimension. Small grains (about 10 μm) of a colorless mica, presumably muscovite, make up the other 20 percent of this thin section. Tourmaline (dichroism very pale yellow to bluish green or brown), apatite, magnetite, hematite, and an epidote-group mineral are minor constituents. Laminae are prominent and are caused by differences in grain size and in quartz content; the coarse-grained laminae consist mainly of quartz and biotite.

53. Argillite (Prichard Formation)–Northeast of Plains.

This specimen consists mainly of subrounded to subangular grains of quartz and colorless mica. The mica ranges from extremely fine grained material to flakes 0.05 mm in length, which are identified as muscovite. Biotite, chlorite, plagioclase, pyrrhotite?, and chalcopyrite occur in trace concentrations. Coarse-grained patches (0.25 to 0.65 mm across) contain biotite, quartz, muscovite, chlorite, and an opaque mineral.

54. Argillite (Prichard Formation)–Northeast of Plains.

Almost 70 percent of this thin section is quartz (0.05 to 0.3 mm); most of the other 30 percent is fine-grained colorless mica (15 μm). Minor constituents are plagioclase, tourmaline (dichroism colorless to bluish green), biotite (pleochroism very pale yellowish green to dirty yellowish green), zircon, magnetite?, and hematite. Biotite occurs in small crystal clusters (about 0.05 mm long) of subparallel orientation. Small mica grains tend to be aligned in a plane inclined to bedding. Figure 6D is a photomicrograph of this specimen.

55. Argillite (Prichard Formation)–North of Perma.

Estimated modal composition is colorless mica, 40 percent; quartz, 35 percent; biotite, 20 percent; and tourmaline and an epidote-group mineral, 5 percent. Average grain size of the quartz is 0.02 mm, of muscovite is 0.02

mm, and of biotite (pleochroism very pale yellowish green to reddish brown) is 0.07 mm. Grains of magnetite? and hematite are nearly equidimensional (0.05 to 0.1 mm).

56. Argillite (Wallace Formation)–West of Libby.

This rock consists mainly of quartz (30 percent) and mica (70 percent). The quartz grains range from 5 μm to 0.1 mm but average about 0.05 mm. These grains are angular to subidioblastic and exhibit straight extinction. Colorless mica, too fine to identify optically, forms the matrix between larger quartz grains; in some areas of the thin section, a crude herringbone pattern is produced by the fine-grained mica. Muscovite flakes as large as 0.1 mm across are crudely aligned parallel to the bedding. Minor constituents are tourmaline (dichroism very pale green to dirty yellowish green), goethite, plagioclase, chlorite?, and a mineral of the epidote group. No K-feldspar was identified; perhaps if the thin section had been stained for K-feldspar some might have been recognized.

57. Argillite (Siyeh Limestone)–Southwest of Kalispell.

Fine-grained mica and quartz are the major constituents of this rock; minor constituents are dolomite, muscovite, apatite, tourmaline, and goethite. Difference in grain size causes distinct laminae; dolomite is more abundant in the coarse-grained layers. Angular quartz grains (10 μm to 0.1 mm) exhibit weak undulose extinction.

58. Dolomitic siltite (Piegan Group)–Southwest of Kalispell.

Angular to subangular quartz grains (0.02 mm) and dolomite (0.01 to 0.03 mm) are the major constituents; minor constituents are plagioclase, muscovite, tourmaline, and an unidentified opaque mineral. Laminae are produced by differences in dolomite content.

59. Felsite–Josephine mine north of Basin.

Prominent flow banding, marked by differences in grain size of the matrix, is accentuated by differences in the hematite content.

Quartz (0.1 mm and smaller) is an abundant constituent. Euhedral tourmaline (dichroism colorless to olive drab) forms in some layers of coarser-grained quartz. Magnetite is a trace constituent in this specimen. Most of the mineral grains are too small for optical identification.

60. Volcanic breccia–South of Helena.

Angular to subrounded fragments of quartz porphyry and rhyolite as large as 6 cm are contained in a matrix consisting mainly of glass and very fine grained material. The matrix also contains crystal fragments of quartz, K-feldspar, and plagioclase. Magnetite and hematite concentrations are minor. Small cavities are partly filled with radial masses of chalcedony, layers of opal, and very small rhombs of what seems to be a feldspar.

61. Volcanic sandstone and lithic tuff–Northwest of Niarada.

A. Fragments of euhedral plagioclase crystals exhibiting prominent zoning are the major crystal type in this specimen; fragments of round quartz grains are less abundant. Plagioclase and quartz grains range from 0.04 to 3 mm; the matrix between grains consists of glass and pumice fragments. Lithic fragments are as large as several centimeters and are mainly volcanic, although one quartzite fragment was recognized.

B. Lithic fragments, which are the predominant constituent of this rock, are subangular and range from 0.06 to 2 mm. These fragments consist mainly of glass or of a very fine grained material that appears isotropic. X-ray diffraction analysis of clay removed from this specimen indicates that it is kaolinite. A mixture of very fine grained components as well as angular fragments of quartz and plagioclase occupy the interstices between lithic fragments.

C. In addition to lithic fragments, angular fragments of quartz and perthite constitute the coarse-grained fraction of this specimen. Crystal fragments range from 0.03 to 1 mm, but lithic fragments, most of which are subrounded, range from 0.8 mm down to the very fine material in the matrix. Because of the very small grain size of matrix material, individual grains were not identifiable. Hematite and limonite color this specimen.

62. Vitric tuff–West of Dillon.

A. An estimated 10 percent of this specimen consists of fragments of quartz and plagioclase grains (0.15 to 0.3 mm). The groundmass is composed of partly devitrified glass. Layering is produced by differences in abundance and size of crystal fragments.

B. Crystal fragments range from 0.07 to 0.4 mm and constitute an estimated 10 to 20 percent of this specimen. The fragments are of anhedral quartz and euhedral plagioclase crystals. Lithic fragments and partly devitrified glass constitute the groundmass. Layering is produced by differences in the abundance of crystal fragments.

63. Tuff–Southwest of Alder.

A. Coarse-grained layers consist of angular fragments (0.01 to 1 mm) of quartz, microcline, and a trace of plagioclase. The groundmass consists of glass fragments and some fragments interpreted as devitrified glass. Fine-grained layers consist mainly of glass fragments. Limonite has extensively stained the rock, and some fine-grained secondary silica is seen throughout the thin section.

B. Angular fragments of quartz and microcline (0.03 to 2.5 mm) predominate; plagioclase and garnet are trace constituents. Some quartz grains exhibit pronounced undulose extinction and contain numerous vacuoles. The matrix, approximately 50 percent of this specimen, consists of very fine grained material, either devitrified glass fragments or fine-grained quartz. Numerous small fractures divide the groundmass into a mosaic of small "grains" (0.2 to 0.4 mm).

64. Vitric welded tuff (Elkhorn Mountains Volcanics)–Northwest of Whitehall.

Fragments of euhedral plagioclase (0.05 to 1.2 mm) and a few collapsed pumice fragments are set in a matrix of deformed and devitrified glass shards. Plagioclase is partly altered to calcite and constitutes approximately 15 percent of this specimen.

65. Subarkose–South of Bozeman.

Angular quartz and plagioclase grains (average about 0.07 mm) constitute about 80 percent of this thin section; biotite and zircon are minor constituents. A brownish matrix of fine-grained lithic fragments is presumably derived from rocks of volcanic origin.

66. Vitric tuff–Frying Pan Basin northwest of Dillon.

Fragments of euhedral quartz and K-feldspar crystals range from 0.1 to 2 mm. Glass shards, many partly devitrified, average about 0.2 mm in longest dimension and, together with fine-grained tridymite?, constitute almost 95 percent of the thin section. Both tridymite and cristobalite were identified by x-ray diffraction analysis.

67. Blastomylonite–Northwest of Darby.

Fluxion texture is produced by the alignment of quartz grains; one unusually elongate grain is 0.5 by 15 mm; most quartz grains are more nearly equidimensional and range from 0.05 to 0.2 mm in length. These grains exhibit pronounced undulose extinction. Although numerous planar features, oriented at large angles to fluxion texture, are easily recognized in hand specimens, they are not recognizable in thin section. Aside from a few small black grains, the specimen consists entirely of quartz.

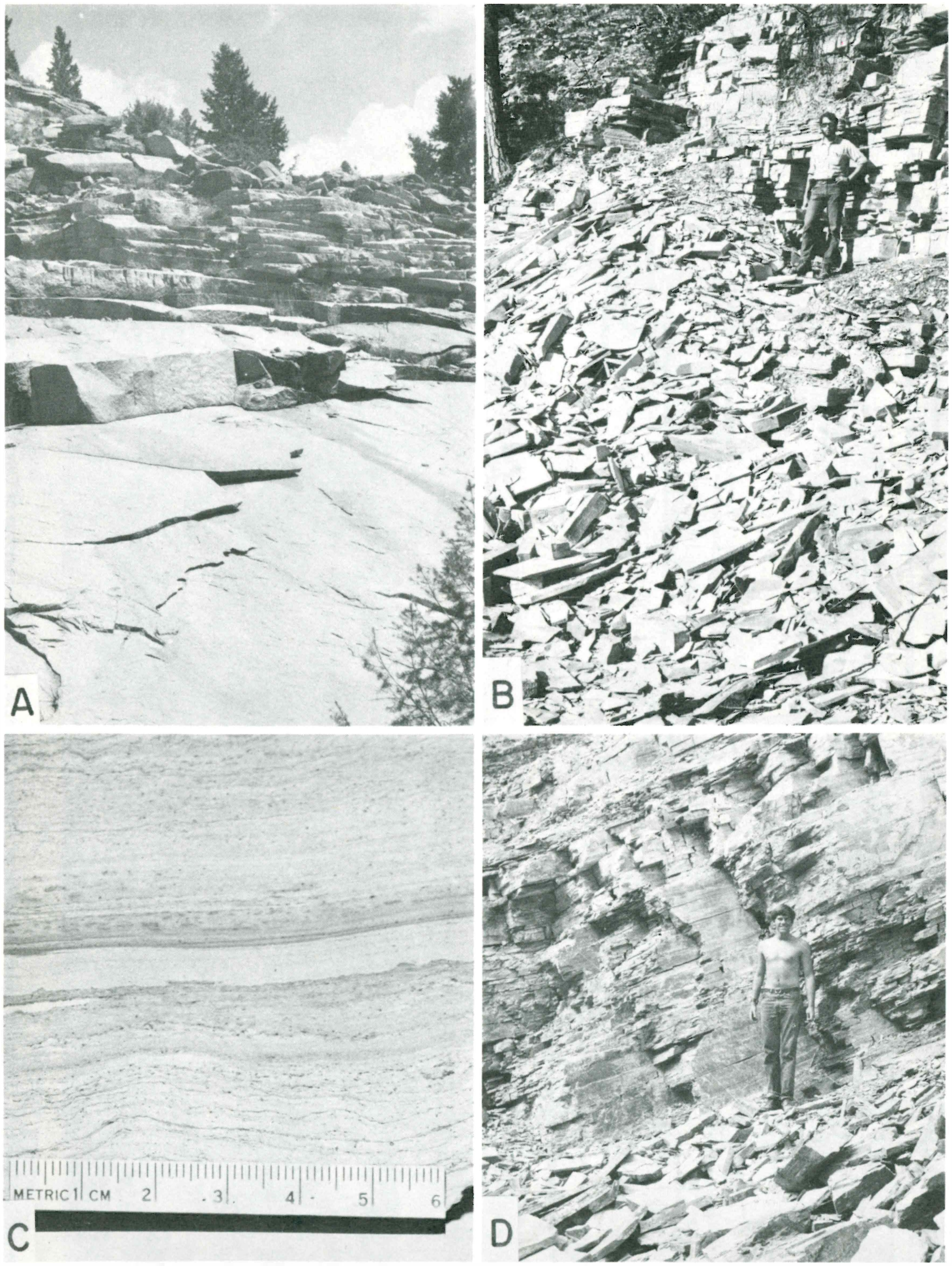

Figure 2.–Limestone and granite. A. Well-developed sheeting and near-vertical jointing in granite at Welch quarry (locality 10). B. Quarry in Bear Gulch Limestone (locality 21). Note range in thickness of slabs that can be quarried here. C. Dolomitic siltstone from Deadman quarry (locality 22). D. Sieben Ranch quarry (locality 25). Bedding is inclined to the left, and jointing is of near-vertical attitude.

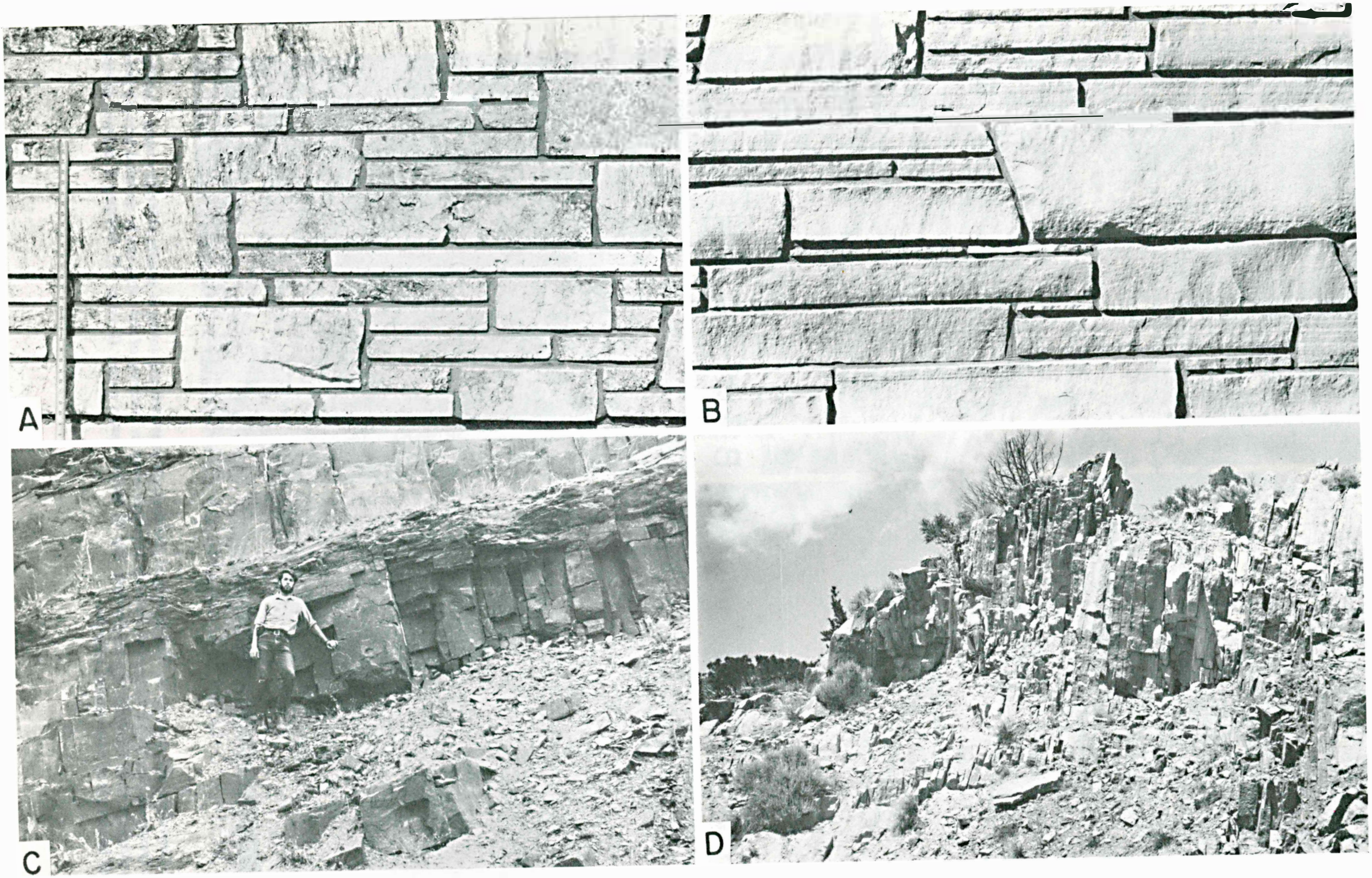

Figure 3.–Travertine and sandstone. A. Travertine ashlar. B. Ashlar of Flathead Quartzite. C. Blocky sandstone of Lahood Formation (locality 35). Note well-developed joints. D. Exposure of Flathead Quartzite, bedding steeply inclined to left (locality 37).

Figure 4.–Sandstone and argillite. A. Flathead Quartzite at Monarch quarry (locality 38). B. Massive sandstone bed in Kootenai Formation at locality 43. C. Natural exposure of Livingston Group at locality 46. Irregular surface of this outcrop indicates the easy erodability of the sandstone. D. Argillite of Prichard Formation (locality 51). Joints are nearly perpendicular to bedding, which is steeply inclined to right.

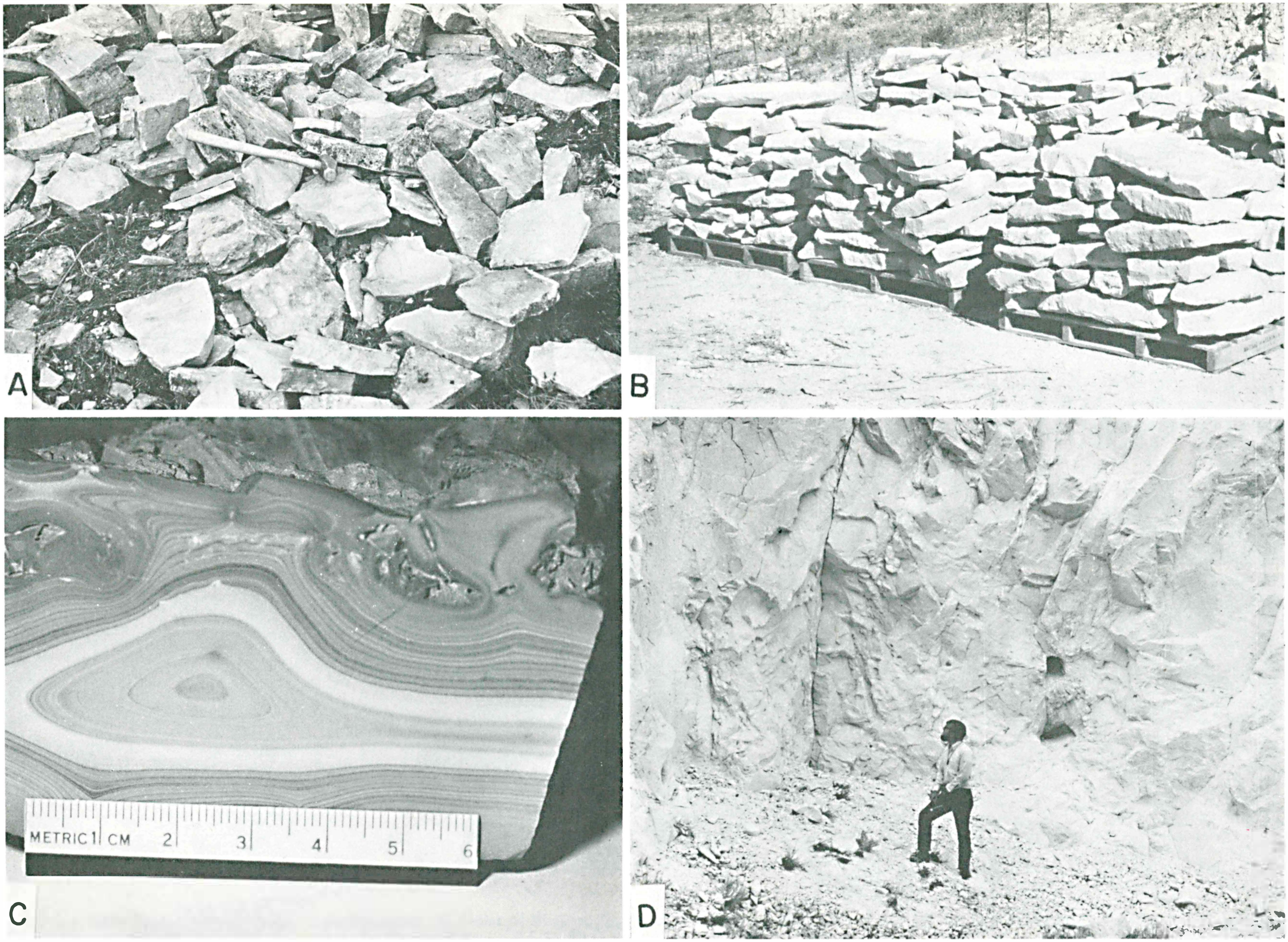

Figure 5.—Volcanic rock types. A. Slabs of rhyolite at Josephine mine (locality 59). B. Slabs of volcanic rock quarried at Flathead Sunset quarry (locality 61). C. Sawed surface of Montana onyx from locality 63. D. Abandoned quarry at Frying Pan Basin (locality 66).

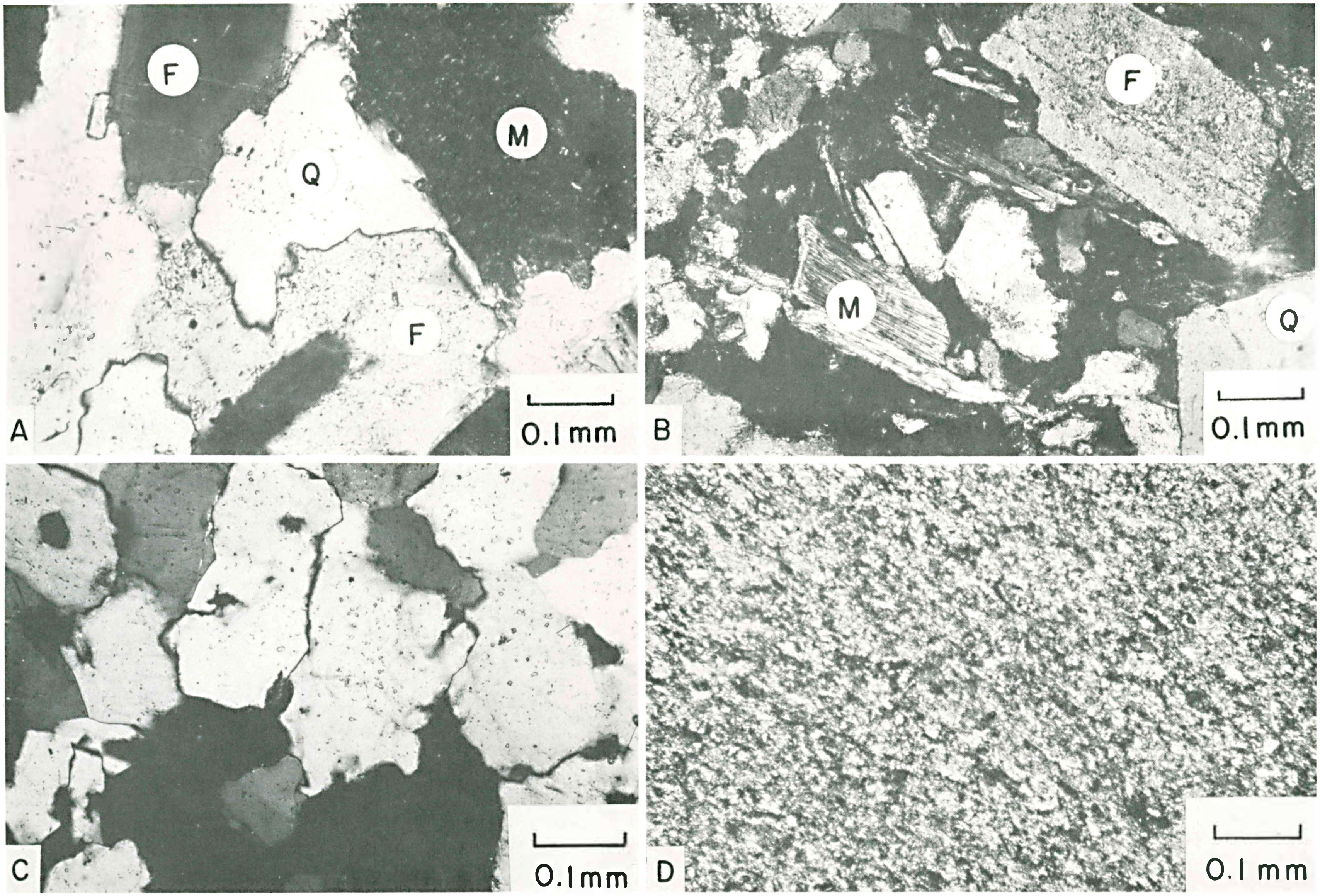

Figure 6.–Photomicrographs. All were taken with crossed polars, which causes some mineral grains to appear gray or black although they are actually transparent in thin section. A. Granodiorite from locality 6. Note how grains of quartz (Q), feldspar (F), and mica (M) are tightly intergrown. B. Lahood Formation from locality 35. Unlike Flathead Quartzite, which consists mainly of quartz, this sandstone contains feldspar (F), quartz (Q), and mica (M). C. Flathead Quartzite from Fishtrap quarries (locality 40). All large grains are quartz. D. Argillite of Prichard Formation (locality 54). Note small size of individual grains in this rock.

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