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GEOLOGIC FACTORS OF QUARRYING

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INTRODUCTION

It is not the intent here to deal in detail with the subject of geology, but rather to outline briefly certain basic principles which should be considered if a general understanding, or, at least, a practical knowledge, is to be gained of commercial rock production. Quarrying is successfully carried on by men who have had long experience in this work and who, without having a technical knowledge of geology, have nevertheless acquired a most useful working knowledge that serves their needs. The lack of such experience should be compensated for in part by as complete scientific and technical information as it is possible to obtain. The purpose of this Information Circular is to suggest these geologic essentials. It cannot be complete. The most that can be expected is that certain basic factors be set forth which may lead to a better understanding of the most pertinent phases of the subject, thereby stimulating a desire to obtain further and more detailed information through recourse to the many available textbooks and other published material.

In assembling this material, various texts have been freely drawn upon to supplement the observations of the authors. Specific citations are not indicated except where the original has been followed without change, in which case the work cited is indicated in parenthesis after the quoted material. These and other references may be referred to for further and more detailed information. Quarrying methods and the preparation of dressed and crushed stone are not dealt with, as information on these subjects--usually acquired through experience--can be obtained from comprehensive reports that are readily available.

Suggested References

1. Blackwelder, Eliot, and Barrows, Harlan H., Elements of geology, New York, American Book Co., 1911. An elementary but authoritative book on general geology, presenting in a very readable and understandable manner all the essential features of the subject for the beginner.
2. Bowles, Oliver, Sandstone quarrying in the United States: U. S. Bur. Mines Bull. 124, 1917. A comprehensive bulletin covering all phases of sandstone quarrying.
3. Bowles, Oliver, The stone industries, New York, McGraw-Hill Book Co., Inc., 1934. A very complete text covering the occurrences of stone, giving a full account of quarry methods for the production of dimension and crushed stone, and treating with the economics of the industry.

*Prepared as a basis for, and to supplement, a lecture on geology for men having no previous training in this subject; presented at the request of officers of the U. S. Army Engineer Training Section, Army Service Forces Training Center, North Fort Lewis, Washington, in charge of training army personnel in quarry operations and methods.

4. Branson, E. B., and Tarr, W. A., Introduction to geology, New York, McGraw-Hill Book Co., Inc., 1935. A general geology text, presenting some late concepts and emphasizing certain phases of the subject for the more advanced student.
5. Legget, Robert F., Geology and engineering, New York, McGraw-Hill Book Co., Inc., 1939. An excellent account of geology as applied to the engineering profession.
6. Von Bernowitz, M. W., and Hess, Frank, Cutting and polishing stones: U. S. Bur. Mines Inf. Circ. 7107, 1940. A brief report dealing with cutting and polishing procedure for ornamental stone production.

MATERIALS OF THE EARTH'S CRUST

Geology is the science which treats of the history of the earth and its life, especially as recorded in the rocks. Three principal branches or phases are usually distinguished: 1. Structural geology, treating of the form, arrangement, and internal structure of the rocks; 2. Dynamic geology, dealing with the causes and processes of geologic change; 3. Historical geology which, aided by other branches of geology, aims to give a chronological account of the events in the earth's history. Another division is economic geology, that branch of geology which deals with the applications of the science in industrial relations and operations. Mining geology, a subdivision of economic geology, is concerned with the application of geologic facts and principles to mining.

The crust of the earth is composed of various rock types which, in turn, are composed chiefly of only nine elements. These principal elements, making up about 98 percent of the crust's constitution, are conventionally reported chiefly as oxides. Their relative abundance in percent is: silica, SiO_2 , 59; alumina, Al_2O_3 , 15.3; ferric oxide, Fe_2O_3 , 3; ferrous oxide, FeO , 3.8; magnesium oxide, MgO , 3.5; calcium oxide, CaO , 5; soda, Na_2O , 3.8; potash, K_2O , 3.1; water, H_2O , 1.1; titanium dioxide, TiO_2 , 1.0. Subordinate elements and compounds present in amounts less than 1 percent are: zirconium oxide, ZrO_2 ; carbon dioxide, CO_2 ; chlorine, Cl ; fluorine, F ; sulphur, S ; sulphur trioxide, SO_3 ; phosphorous pentoxide, P_2O_5 ; chromium oxide, Cr_2O_3 ; vanadium trioxide, V_2O_3 ; manganese dioxide, MnO_2 ; nickel oxide, NiO ; barium oxide, BaO ; strontium oxide, SrO ; lithium oxide, Li_2O ; copper, Cu ; zinc, Zn ; lead, Pb ; carbon, C .

Definition and Classification of Minerals

The elements are combined to form natural inorganic chemical compounds called minerals, to which distinctive names are given. Minerals are characterized by a definite composition and crystal form, and usually show differences in structure, hardness, fracture, cleavage, color, luster, streak, fusibility, and specific gravity. They are commonly classified on the basis of chemical composition, as in the following examples:

Elements:	native gold; native copper; native silver; etc.
Oxides:	quartz, SiO_2 ; magnetite, Fe_3O_4 ; etc.
Sulphides:	pyrite, FeS_2 ; galena, PbS ; sphalerite, ZnS ; etc.
Carbonates:	calcite, CaCO_3 ; magnesite, MgCO_3 ; etc.
Sulphates:	mirabalite, $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$; barite, BaSO_4 ; etc.
Silicates:	olivine, MgSiO_4 ; hornblende, $\text{Ca, Mg, Fe, Al, SiO}_3$; etc.
Etc.	

More than a thousand minerals are known, of which some 300 are relatively common. Some predominate in and characterize ore deposits; others, known as rock-forming minerals, are those generally making up the rocks that form the earth's crust. The common rock-forming minerals, mostly silicates, may be roughly classified as follows:

- | | | |
|----------------------|---|--|
| Commonly light color | { | <p>Quartz.--irregular clear grains, glass-like fracture. (SiO_2)</p> <p>Feldspar.--usually lath-like, prominent cleavage.</p> <p> orthoclase: white to red. (KAl silicate)</p> <p> plagioclase: white to gray. (Na, CaAl silicate)</p> <p>Carbonate.--soft, commonly white. (CaCO_3)</p> |
| Commonly dark color | { | <p>Amphibole.--usually gray to green, forms <u>long</u> prisms. (Ca, Mg, Fe, Al, silicate + OH)</p> <p>Pyroxene.--gray to green, forms <u>short</u> prisms. (Ca, Mg, Fe, Al, silicate + OH)</p> <p>Mica.--easily split into <u>thin flexible</u> sheets.</p> <p> muscovite: colorless. (K, Al, silicate + OH)</p> <p> biotite: black. (K, Mg, Fe, Al, silicate + OH)</p> |

Definition and Classification of Rocks

A rock is defined as any mineral or aggregate of minerals, whether or not coherent, that forms an essential part of the earth, but in common usage is restricted to a consolidated or relatively hard material.

Most rocks, such as granite and basalt, are predominantly aggregates of minerals, though some may be made up of a single mineral as is limestone, a rock composed chiefly of calcite. Rocks are broadly classified in three types: igneous, sedimentary, and metamorphic. This is done on a basis of origin and does not take into account mineralogic composition or physical properties. The following table shows this broadest of classifications and provides the minimum of detail which is necessary to differentiate between the various principal rock types. Far more elaborate classifications on the basis of mineral or chemical composition and other features are available in standard texts for those who desire greater detail.

Igneous Rocks

Igneous rocks have been formed from molten material originating under high temperature and pressure at great depth in the earth's crust. The interior of the earth is considered to be solid, but it is under tremendous heat because of the pressure. At certain periods in the earth's history, and at certain places, particularly during mountain-making episodes, the pressure which keeps this high-temperature material from becoming liquid may be relieved, resulting in the formation of molten rock--rock in a liquid, fluid state. Other factors than pressure may contribute to the heat and fluidity, such as the presence of radio-active elements. This molten matter may be forced into the upper, cooler rocks of the earth's crust and, in fact, may be extruded on the earth's surface.

Batholiths.--The bodies of local molten igneous material (magma) may be of tremendous size and may cool and solidify without reaching the earth's surface. Under such conditions of slow cooling, a prominent crystal structure develops (see page 6, fig. 1). The resulting rocks are coarse grained and are termed plutonic. These large masses, measuring in some places hundreds of miles in length and having comparable widths, are known as batholiths. Granite is a common plutonic rock of batholithic origin and, after being exposed through the deep erosion of its original cover, may form the surface outcrops throughout many square miles.

Generalized Rock Types

Class	Occurrence	Texture	← Light colored → → Dark Colored →		
			rhyolite felsite	trachyte	andesite
1. Igneous.-- crystallized from molten material in earth's in- terior.	Extrusive.-- flows	Fine grained; in- dividual crystals difficult to dis- tinguish			basalt
	Intermediate intrusive.-- (hypabyssal) smaller bodies, <u>plugs</u> , <u>dikes</u> , <u>sills</u>	Large crystals, usually feldspar, in fine-grained to dense matrix	felsite porphyry; quartz fel- site porphyry	felsite porphyry	basalt porphyry
	Intrusive.-- (plutonic) large masses, batholiths; originating at <u>great depth</u>	Medium to coarse grained; minerals recognizable.	porphyritic granite; granite	syenite	diorite
Composition			Quartz and orthoclase; hornblende and/or mica	Plagioclase + quartz + hornblende and mica	Plagioclase + hornblende and/or pyroxene

2. Sedimentary.--
formed by disintegration
and decomposition of
rocks; particles carried
by wind, water, and/or ice
to place of deposition.

conglomerate.--rock fragments, pebbles, and boulders in sandy matrix; cemented;
coarse grained.
sandstone.--mineral and rock grains; cemented; granular; breaks around grains.
shale.--compacted clay, mud, and silt; very fine grained.
limestone.--calcium carbonate of chemical or organic origin; cemented; dense or
granular.
3. Metamorphic.--
recrystallized from ig-
neous and sedimentary
rocks, generally under
high temperature and
pressure.

quartzitic conglomerate.--formed from conglomerate; matrix may show cleavage.
quartzite.--formed from sandstone; breaks across grains; very hard.
slate, schist.--formed from fine-grained rocks (chiefly sedimentary); cleavage
prominent.
marble.--formed from limestone; medium to coarse grained; compact.
gneiss.--usually formed from coarse igneous rocks; banded.
greenstone.--formed from basic fine-grained igneous rocks; greenish; massive;
soft minerals developed.
serpentine.--complete reformation of basic igneous rock; greenish; soft.

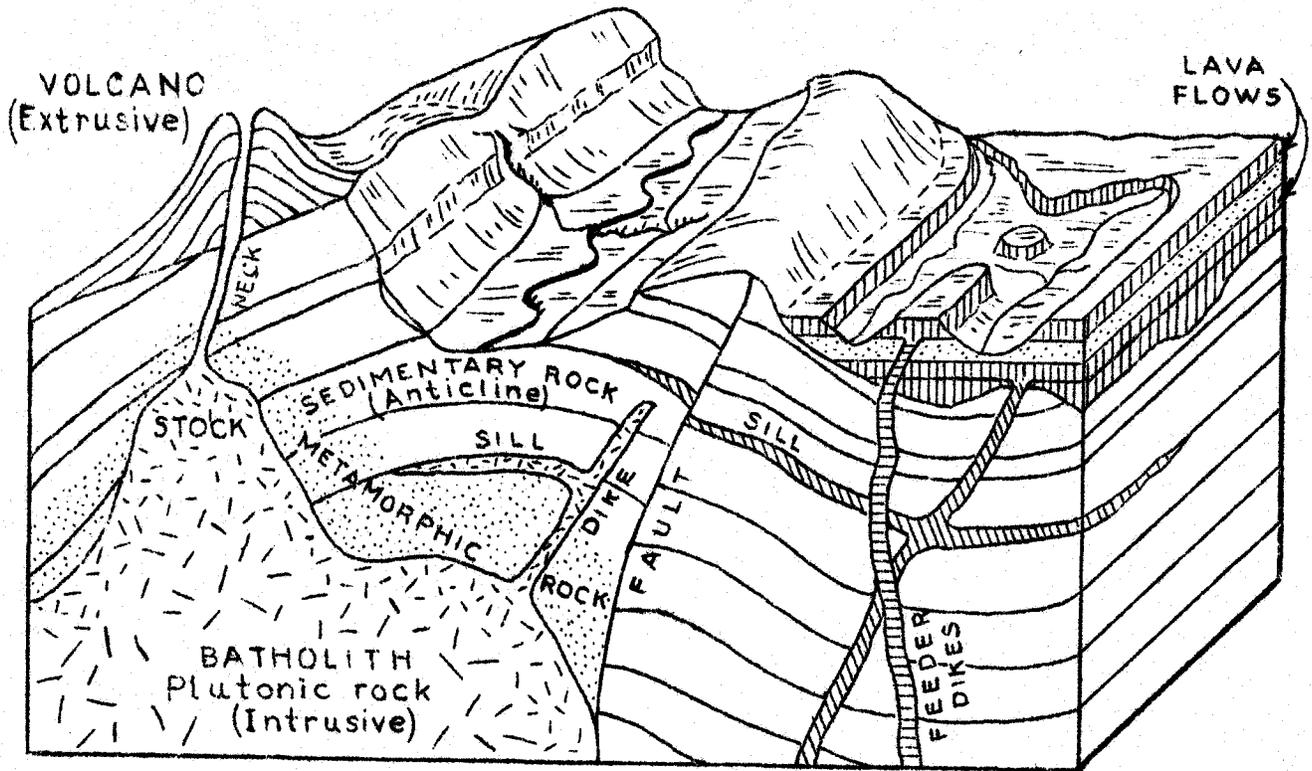


Figure 1.--Diagrammatic representation of certain rock structures and of the formation of various rock types and physiographic features.

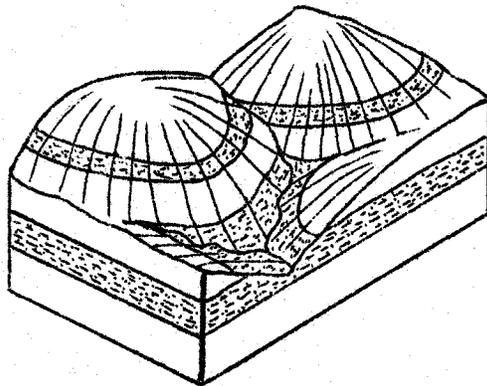


Figure 2.--Horizontal beds.

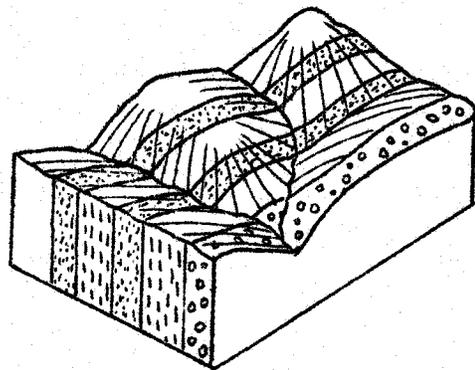


Figure 3.--Vertical beds.

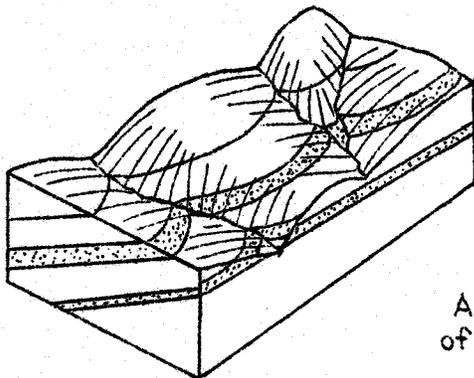


Figure 4.--Inclined beds.

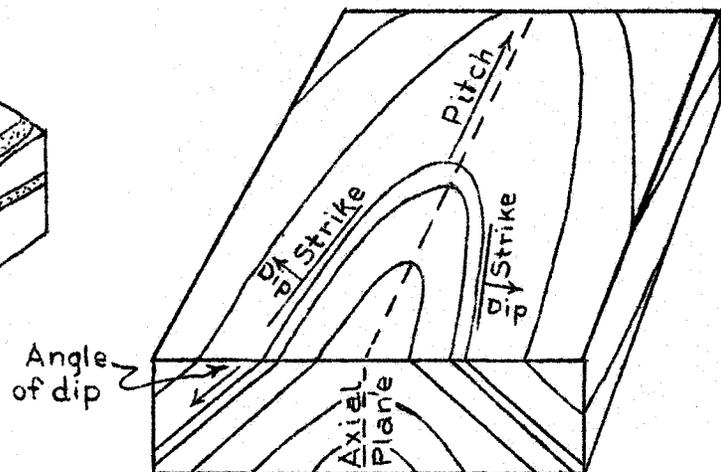


Figure 5.--Strike, dip, and pitch of plunging anticline.

Stocks and plugs.--Smaller intrusive bodies, commonly offshoots of deep-seated batholithic masses, are known as stocks and plugs. The rock may have a chemical and mineralogical composition similar to that of granite or other plutonic varieties but, owing to faster cooling, the texture, or grain size, is usually finer. Porphyries are common in such occurrences.

Dikes and sills.--Dikes and sills are similar in origin. Dikes are formed when molten rock--offshoots from larger igneous masses--is forced through fractures that traverse other already solidified igneous rocks or cuts across the bedding of sedimentary rocks. If the molten material follows the bedding of a sedimentary rock it produces a sill. The resultant rock mass may be less than a foot in thickness or it may be hundreds of feet thick; however, its lineal extent is many times more than its thickness, so the mass is commonly tabular. Under such conditions the molten material is quickly cooled, hence the grain size is small and the rock may be very dense. Basalt, andesite, aplite, and rhyolite are characteristic rock varieties formed in this way, and, if the mass is relatively thick, porphyritic phases of these rocks may result.

Flows.--Molten rock produces flows when it reaches the surface of the ground, flows out from the vent, and solidifies on the pre-existent surface. These commonly have great areal extent but the thickness may be only a few feet or tens of feet. As flows are quickly cooled, they are usually fine-grained or even dense rocks such as basalt, andesite, and rhyolite. In some places successive flows have built up to great thickness, as in eastern Washington where an aggregate of more than 4,000 feet has resulted from superimposed flows. In a cooling mass, under certain conditions, some minerals, usually of a definite kind, may crystallize and grow to a relatively large size while the rest of the mass is still molten; if the remaining molten portion is then quickly cooled, it will solidify as a relatively fine-grained rock in which the first-formed crystals (phenocrysts) show prominently. Rock so formed is termed a porphyry and is common in stocks, large dikes, sills, and even in some massive flows.

In the table (p. 5) it is important to understand that rocks grade into each other with respect to both texture and composition. Because of this, many varieties have been named; however, for sake of simplicity and clarity, only the commonly known, typical members of the igneous class are mentioned. It is apparent that the material which formed a granite, if having solidified at intermediate depths, becomes a felsite porphyry; and, if extruded on the surface, becomes a rhyolite. Broadly speaking, granite, felsite porphyry, and rhyolite represent the acidic (high in silica) end of the igneous rock series and are generally light colored; similarly, gabbro and its extrusive equivalent basalt represent the basic (lower in silica) end of the series and are heavier and darker in color.

Sedimentary Rocks

Sedimentary rocks are those formed through the disintegration and decomposition of other rocks. They are composed of boulders, pebbles, or grains that may include individual minerals or combinations of minerals. This material may be transported by wind, water, or ice, and redeposited as beds close to or far removed from its original position. Beds may range in thickness from a fraction of an inch to hundreds of feet and, depending on various circumstances of origin, may extend laterally for long distances--across whole States in some outstanding instances. Most sedimentary rocks are interstratified: that is, it is usual for various thicknesses of several varieties to be bedded one on another in a given exposure.

The process of sedimentary-rock formation may be seen in mud-laden streams which deposit their loads on flats or in lakes and seas. The unconsolidated material transported in this way, depending on its grain size and composition, is termed

gravel, sand, mud, or clay. Later, these beds may become buried under other beds or even under accumulations of other rock types such as lava flows; and then under conditions of long time and pressure, aided by cementing materials, the unconsolidated sediments may become compacted, giving rise to such rocks as conglomerate, sandstone, and shale. If the original unconsolidated material was largely calcium carbonate, formed either as chemically precipitated particles or as an accumulation of shell fragments or coral, the resultant consolidated rock is termed limestone. The cementing material for the sedimentary rocks may be clay, iron oxide, calcium carbonate, or silica, and upon the nature of the cement will depend the durability and hardness of the final rock.

Metamorphic Rocks

Under certain conditions of deep burial--with consequent high pressure and temperature, presence of cementing materials, and long time--the igneous and sedimentary rocks, particularly in mountainous areas, may become changed into other and distinct rock types known as metamorphic rocks. This change usually involves a recrystallization, mostly in a solid state, of the original rock or of certain constituents of that rock, and shows itself by the development of new minerals that are commonly of platy character. The platy characteristic and a general orientation of the newly developed minerals give many of the metamorphic rocks a characteristic cleavage or schistosity. This, together with a greater hardness or induration, serves to distinguish this group from the preceding igneous and sedimentary varieties. Certain exceptions to these characteristics may exist, as, for instance, in the development of greenstone and serpentine, formed through the metamorphism of basalt or other basic igneous rocks such as gabbro. In these instances pronounced cleavage may be lacking, and the chlorite and other soft minerals that result make the metamorphic equivalent of certain igneous rocks much softer and less durable than the original materials.

STRUCTURAL FEATURES OF ROCKS

The rocks of almost any region disclose the results of movements that have taken place, and there is evidence that movements are continually recurring. The earth is forever undergoing changes of many kinds which, after long lapses of time, produce profound results. These changes include crustal movements. Some of the movements are sudden like those that produce earthquakes, but most are extremely slow. Such changes cannot be detected while in progress, but their results over long periods of time are obvious. The effect may be grouped as fractures and folds.

Rocks in general are brittle substances and if quickly bent or squeezed will break. Both conditions exist, so rocks in some places are broken and in others bent or folded. If pressure is applied slowly, as in mountain-making movements, and especially if the rock layer is heavily weighted by thousands of feet of overlying rock, a bend may result instead of a break.

Partings in Rocks

Joints and fractures.--Joints, or cracks, result from the shrinkage of cooling igneous rocks; they also form, since rocks are brittle, when the crust of the earth is raised or lowered, or when strata are folded. In some exposures rocks may show a parallel system of cracks, usually upright when the beds have not been folded, but slanting when the beds are inclined. Joints commonly occur in sets trending nearly at right angles; though if deformation is pronounced, the joint system may be more complex. Some rock exposures are jointed so closely as to be unsuitable for anything

but crushed stone; at other places the joints that limit the size of quarriable blocks may be 50 feet or more apart. Joints are of major importance to quarrymen and determine the usability of the rock from any given exposure (see p. 16).

Lamination or fissility.--Under certain conditions of weathering and deformation rocks may develop a lamination or platiness that is not necessarily related to mineral orientation and is distinct from jointing. This may be a feature of any rock, but is particularly evident in some shales which part in layers as little as a fraction of an inch thick, parallel to the bedding. Even such hard rocks as basalt sometimes develop a thin, platy structure, also parallel to the bedding or, in this instance, the flow surface.

Cleavage.--Under more pronounced deformation and consequent development of new platy minerals a cleavage or schistosity may develop. This is a secondary feature not related to bedding. As a result, metamorphic rocks such as slate and schist develop a cleavage which permits the rocks to be split into thin layers or sheets usually at an angle to the original bedding.

Faults.--In most instances, fracturing does not involve displacement of the rock on either side of the break. At times, particularly when rocks are under stresses such as produce folds, blocks become tilted, shifted, and forced up or down so that the ends of broken strata no longer match. Such dislocations are called faults. The relative amount of movement, or displacement, may be only a matter of inches or it may be hundreds or thousands of feet. Individual faults differ widely, and to classify or interpret them may be a matter of much complexity. It is customary, however, to group most of them in two divisions: (1) normal faults--those resulting from tension, whereby one side of the broken block moves down with respect to the other, and (2) reverse faults--those resulting from compression, whereby one side is forced up, and even over the equivalent block beyond the break.

The direction of movement may be vertical, horizontal, or diagonal, and it may be sufficient in amount to impose serious problems in quarrying. A thin bed that is being quarried laterally may be found to end abruptly (be faulted) against another rock type. It is then a problem to find the missing continuation of the bed. It may have been let down, and so underlie exposed rock; or it may have been uplifted relative to the part being quarried, with the consequent possibility of removal by erosion.

In some places faults afford passageway for heated mineral-bearing solutions that may alter the adjacent rock, rendering it unfit for dimension stone or for road-surfacing use.

Folds

Bedded rocks (flows or sediments) may be flat, lying just as they originally formed, or they may be folded, or even intricately twisted and crumpled. Folds are classified as anticlines (upfolds) and synclines (downfolds). Limbs are the sides of folds, and between them is the axis or axial plane of the fold. Terms used to describe tilted beds are strike and dip, used also to describe the attitude of faults, joints, and oriented minerals. Strike is the direction of intersection of a horizontal plane with the plane of the inclined bed, fault, or joint. Dip is the angle of inclination from the horizontal, measured in degrees at right angles to the strike of the inclined bed. Pitch is the inclination from the horizontal of the crest or trough of a bed that is involved in a fold (see p. 6, fig. 5).

As an example of the use of these terms: Outcrops of some certain sandstone bed may show that the bed--originally flat--is now tilted. The bearing, as obtained by compass, of a horizontal line in the plane of the inclined bed shows the strike

here to be north 14° east. The angle of inclination from the horizontal, as obtained by clinometer, at this place shows the dip to be 20° , and the direction of dip to be southeast. As the dip is at right angles to the strike, the bearing of the dip direction is S. 76° E. At another place the strike might be N. 50° E. and the dip 30° NW, indicating that the bed is involved in an anticline, that the axis pitches to the northeast, and consequently that extension of the bed--under possibly a covered area--should be sought for in a N. 14° E. or S. 14° W. direction on one flank, in a N. 50° E. or S. 50° W. direction on the other flank, that a dip of 20° and 30° and that an undetermined pitch must be taken into account in prospecting.

Unconformities

A series of sedimentary rocks may be folded, faulted, or cut by intrusive bodies, then eroded to various degrees. Erosion, if carried on for sufficient time, could produce a relatively level surface in what formerly had been an area of marked relief. Later, under favorable conditions, a new series of rocks may be laid down on the eroded older series. The surface which separates the older from the younger series is called an unconformity and represents a lapse of time which may have been of great duration.

WEATHERING OF ROCKS

Weathering is a term applied to nearly all the processes which cause rocks to break up and decay. It prepares rocks for transportation by erosive agencies, and is essentially a static--at most an unobtrusive--process. It reduces rocks to pieces sufficiently small to be blown or washed away. Most of the material moved by wind and water is derived from bedrock in this way. Weathering consists of two processes, mechanical and chemical.

Mechanical Weathering

In this category are temperature changes, freezing and thawing, as well as the effects of plant growth and burrowing animals. Rocks are poor conductors of heat, so that by unequal expansion and contraction during temperature changes of they day and night, probably facilitated by unequal rates of expansion of individual minerals, an outer shell tends to become separated from the interior. This is called exfoliation, and is an effect particularly noticeable in granitic rocks. Mechanical weathering, involving temperature changes, is particularly effective in dry regions and at high altitudes and latitudes. In deserts and on bare mountains, therefore, slopes may be nearly covered by loose angular fragments. Pieces of rock loosened from steep slopes in this, or other ways, accumulate at the bottom to form piles of talus.

Water fills pores of rocks and occupies cavities. When it freezes it expands and exerts great force. As a result, cracks are enlarged and pieces are broken from the bedrock. The work of ice is favored by alternate freezing and thawing; accordingly, it is most effective in early and late winter in moist regions situated in high middle latitudes.

Chemical Weathering

The oxygen, carbon dioxide, and water vapor of the atmosphere are very active chemically. Chief among the rock substances with which the oxygen unites is iron. This process (oxidation) is illustrated familiarly by the rusting of iron objects exposed in damp weather, the rust being a chemical combination of iron, oxygen, and

water. The brick-red and yellow colors of many soils and rocks are due to the oxidized condition of their iron. Among the common minerals affected by the process are mica, hornblende, and augite--all complex rock-forming silicates containing iron. The union of the carbon dioxide (CO_2) of the atmosphere with certain rock materials (carbonation) is also an important and common process. For example, carbon dioxide may unite with the calcium and with the iron of minerals containing these elements to form calcium carbonate and iron carbonate. The chemical union of the water vapor in the air, or of water after it has fallen as rain, with rock material constitutes hydration. (Blackwelder and Barrows, pp. 100-104)

The rate at which weathering proceeds depends on the kind of rock, the climate, and the rate of removal of waste already formed. If rocks are not buried too deeply with soil and subsoil, they probably weather fastest in hot and moist climates. Thick accumulations of weathered rock occur in flat areas of the tropics, as in parts of Brazil where weathering may extend to a depth of 300 feet.

Water, in addition to its function in hydration, sinks below the surface and becomes ground water. It gives rise to springs, flowing wells, and geysers. It acts as a lubricant so that under certain conditions the weathered rock material, aided by gravity, may move, causing creep if slow, and landslide or slump if sudden. Underground water modifies the character of rocks by leaching, by deposition of new material in rock cavities, by substituting new material for old, and by forming new chemical combinations.

Effects of Weathering on Different Rocks

The resistance of rocks to weathering depends on the resistance of their components to weathering. Olivine, augite, hornblende, serpentine, plagioclase, orthoclase, biotite, muscovite, and quartz decrease in solubility in the order mentioned. Quartzite, therefore, being chiefly quartz, is among the most resistant of rocks; and, on the other hand, rocks rich in the iron-bearing minerals are readily weathered. Basalt ordinarily will weather faster than granite, granite faster than biotite schist, and schist faster than quartzite. As a result of weathering, surface and near-surface exposures of any rock commonly show a yellowish discoloration, due to the oxidation of iron-bearing minerals or to staining from iron-bearing ground water. At depth this staining ordinarily disappears although it may follow joints for a considerable distance into otherwise unaltered rock.

EROSION

Erosion is a dynamic process involving movement of the air (wind), of water (streams, and waves of the ocean), and of ice (glaciers). It includes those processes by which rock surfaces are broken up and the loosened material removed. Weathering is a part of erosion to the extent that the material is made ready for transportation by moving water and ice.

Wind action

Erosion by the wind is chiefly mechanical. Wind gathers up loose dust and sand, and with these it abrades as well as polishes all rocks with which it comes in contact. Its work is most characteristic in arid climates, where outcrops become rounded and sculptured by wind abrasion.

Stream Action

Streams roll material along their beds, and also carry it in suspension and in solution. The amount of material moved depends on the volume of water, its velocity, and the amount and nature of the material. For instance, the Mississippi River carries about a million tons of sediment per day into the Gulf of Mexico. The rate at which streams wear down their channels depends on the load carried and several conditions. Weak rocks with soluble cements favor rapid wear, whereas strong nonsoluble rocks retard it. Sedimentary rocks, in general, prove less resistant than massive rocks. Other things being equal, rocks with numerous joints and cracks are worn faster than unfractured rocks, because these openings are planes of weakness. Rapid streams do more work than slow ones. The velocity of a stream depends upon its slope, volume, load, and shape of its channel. Load retards velocity, therefore a stream flows fastest if clear, and slowest if loaded. The velocity of a stream is retarded also by the friction of the water with the bed and sides. There are many factors involved in the ability of a stream to erode, but it is probable that wear is fastest when only a partial load is carried. Most streams flow in definite valleys. In general, valleys correspond in size to their streams and, like the stream it contains, a given valley is smaller than the one it joins and larger than those which join it. All streams are engaged, with the help of the agents of weathering, in enlarging their valleys. It is a law of erosion that streams make their valleys--not that the valleys are ready made for the streams which occupy them.

Bedrock structure commonly influences the drainage pattern. For example, a stream may flow along the axis of a syncline or along the axis of an anticline, and so in this way establishes a pattern of drainage that is dependent on the character and attitude of the rock underneath. One may infer the character of rock to some extent by the drainage pattern shown on a topographic map. Horizontal sedimentary rocks usually have developed on them a dendritic drainage pattern. Folded sedimentary rocks may show a trellised pattern, that is, the main channels trend more or less parallel to each other with small, short tributaries entering at right angles.

Wave Action

Usually the rocks of the seashore are traversed by joints and, if stratified, by bedding planes. With the impact of strong waves, water is forced into the openings with great pressure, so rocks are broken and the openings enlarged. During storms the sea may be able to gather up sand, stones, or even large boulders which are hurled like battering rams against the shore. The rate of sea erosion depends upon size or strength of the waves. The rate of wear is influenced also by the character and structure of the rocks at the shore. Soft rocks wear faster than hard ones, soluble rocks faster than insoluble ones, and rocks with many joints and openings faster than rocks with few. A seacoast where waves are relatively weak may retreat as much as 15 feet in a single year. On the east coast of England, entire parishes have been washed away within a few centuries. To prevent this rapid erosion, riprap is commonly used to protect important coastal areas as it is to protect stream banks.

Ice Action

Like winds and rivers, glaciers wear the surfaces over which they move, transport rock waste, and deposit their loads to form characteristic land forms. Pure ice accomplishes little or no wear upon smooth firm surfaces; although thick ice moving over much-jointed surfaces sometimes quarries out blocks of rock by the process known as plucking. When ice is charged with rock fragments it becomes an efficient agent of erosion; included clay particles tend to smooth and polish, the sand grains and

hard pebbles to scratch (striate), and boulders to gouge and groove the bedrock. Glaciers tend to plane away the angularities of the surface, reducing and smoothing the slopes; in this way hilltops are worn and valleys are widened and deepened.

TOPOGRAPHIC EXPRESSION AND DISTRIBUTION OF OUTCROPS

Mountains

In mountainous areas outcrops are abundant, as erosion is active and the products of weathering do not, as a rule, accumulate to much depth. Hard, unaltered rock may be found in most places under scant soil and superficially altered rock, or it may form cliffs where weathered rock is virtually absent. Broken rock may accumulate as talus at the base of cliffs and is commonly an excellent source of easily mined rock that is usable with a minimum of crushing.

Hills

Weathered, softened rock usually occurs to considerable depth on hills, particularly if they are low, well rounded, and covered with vegetation. However, usable outcrops may occur along streams, and bedrock may be expected at shallow depth in the steeper-sided valleys and draws. Suggestions as to the occurrence of harder rock masses or beds are given by steepened slopes and by prominent, sharp ridges or spurs. Other information on the kind of bedrock underlying covered slopes may be obtained from soil characteristics, animal burrows, up-turned trees, and, in some places, by the kind of vegetation.

Mesas and Buttes

A high, broad, flat table-land bounded on one or more sides by steep slopes or cliffs that rise from lower land is termed a mesa. That it exists in this form is due to a protecting cap of hard rock (usually sandstone, limestone, or basalt) that is more durable than the material of lower elevation. A butte is a conspicuous isolated hill or small mountain, especially one with steep slopes. The fact that erosion has left these remnants indicates the presence of a more resistant rock than is usual in the immediate vicinity.

Plains

Relatively level land may result from the complete erosion of hills, in which case deeply weathered rock would be expected under a thick soil cover. Other plains exist because of the presence of underlying flat (unfolded) beds of sedimentary rock or flows of igneous rock; in this case an excavation--commonly shallow--may expose a usable material such as sandstone, limestone, or basalt. Still other plains are formed by unconsolidated sediments being spread by stream or ice action over whatever the pre-existent surface may have been; useful deposits of sand and gravel are usually found in such areas and may be developed by shallow pits.

GEOLOGIC HISTORY APPLIED TO QUARRY SITES

The age of the earth is not measured in years but in eras, periods, and epochs, the shortest of which may involve millions of years. During these immense intervals of time, mountain ranges have been repeatedly and slowly elevated and as slowly eroded away; seas have covered great areas of the land and then have withdrawn.

In fact, the surface of the earth has undergone constant change. Historical geology deals with the long chronological sequence of episodes that are recorded in the rocks formed during successive ages. The latest era of geologic time is the Cenozoic, probably of some 60-million-years duration; this is divided into Quaternary time, including Recent and Pleistocene or Glacial epochs, and Tertiary time, including Pliocene, Miocene, Oligocene, and Eocene epochs. Earlier eras (Mesozoic, Paleozoic, Proterozoic, and the most ancient, Archeozoic) also are subdivided into periods and epochs on a basis of life evolution or on the physical and structural features of the rocks of the time.

During the various geologic periods, as erosion was active in certain areas, thick beds of sedimentary material were being deposited in others, and also there were many recurring cycles of more-or-less intense igneous activity. In this way rock formations originated, which can be recognized by included remains of the life of that time (fossils) or by physical characteristics, and to which individual names have been given.

Stone of a definite economic value may characterize one period and not another, and some formations are important as a source of dimension stone, though others are chiefly valuable for road metal. For example, in Washington the Yakima basalt formation (Miocene) makes an excellent crushed rock for road surfacing, and the Puget formation (Eocene) produces valuable sandstone for architectural purposes. Such facts are useful in prospecting for quarry stone and in the preliminary evaluation of some rock types, particularly where geologic mapping has been done and the characteristics of the various formations are known.

SELECTION OF QUARRY SITES

Uses of Stone

The stone industry is broadly classed as to the uses for which the stone is intended: (1) dimension stone, for building purposes, paving blocks, curbstones, switchboards, blackboards, and monumental use; (2) crushed stone, for concrete aggregate, road metal, ballast, and riprap; (3) manufacturing stone, for portland cement, lime, refractories, and various chemical and metallurgical uses. Granitic rocks, limestones, marbles, slates, sandstones, and other types are used. Selection of a quarry site will depend on the need for a particular kind of stone and on the use for which it is intended.

Dimension stone.--Of the innumerable occurrences of rock throughout the world, only a small part are suitable for dimension stone. Freedom from cracks and lines of weakness within certain dimensions is essential. A rock that has irregular or closely spaced joints is unsuitable, for sound blocks of moderate to large size are required. The rock must have uniform texture and grain size, and usually a uniform and attractive color. For some purposes it should be adaptable to carving and polishing. It must be free from minerals that weather easily, forming stains. The rock must not be friable and must be of sufficient strength.

Crushed stone.--Although the dimension-stone industry is old, dating back many hundreds of years, the crushed-stone industry is scarcely more than 50 years old. The requirements for crushed stone are very much less severe than for dimension stone. The slow processes of cutting and wedging, and the careful use of explosives in dimension-stone quarrying contrast with heavy fragmentation blasting, power shoveling, crushing and screening, elevating, and conveying in the crushed-stone industry. Crushed stone is used chiefly for concrete aggregate, road metal, and railroad ballast. Limestone is a favored material, much more being used for crushing than is used of basalt, granite, sandstone, and other rocks combined.

The low price of stone, especially crushed stone, prohibits its being hauled very far, hence, the necessity of finding suitable material close at hand.

For concrete aggregate the stone should be clean, hard, and strong; it should be free from soft, thin, elongated pieces; and should be without coatings. Soluble minerals in the rock are particularly undesirable.

For road metal the requirements are less severe than for concrete aggregate, but the stone should be tough and hard, and it should break into chunky, sharply angular fragments. Soft stone and hard laminated stone are less suitable. The desirable features of stone for concrete aggregate and road metal are tabulated on page 13.

Riprap is heavy irregular rock fragments used chiefly for protecting the banks and shores of rivers and harbors. Other uses are in jetties, breakwaters, dikes, docks, and dam spillways. The rock must be resistant to the force of waves and strong currents. Nearly any kind of hard, sound stone may be used, but it must not be easily susceptible to alteration and weathering, as are volcanic agglomerates and some other rock varieties, and should be quarriable in relatively large blocks.

Manufacturing stone.--Chemical composition is the principal consideration in the selection of stone that is to be used for most manufacturing processes. Limestone of certain quality and adequate quantity is required for portland cement. Limestone for paper mills and for the sugar industry must be suitable as to quality and should be quarriable in sound pieces that do not break too small. For other industrial applications various specifications in composition and physical properties must be met, so the quarry site can only be selected after a thorough study has been made of all pertinent factors.

Urgency

The urgency of requirements will, to a large extent, govern the choice of stone and the location of quarry sites. As a rule, adequate time can be given to the selection of the best dimension stone in a given region and to laying out a quarry; also, transportation is not the critical factor that it is for crushed stone. Urgency is more vital in the matter of crushed stone and may determine the material to be used and the quarry site.

If a choice of stone for crushing is available, a hard tough rock will be selected in preference to one less durable. Emergencies may arise, however, when a road must be built for immediate short-time use and no choice of materials be available. In this case, what is at hand will be used. If time is not an item, one can go farther afield for a suitable material that will be durable.

If the road foundation is poor, attention must be given to the ballast, or base course, so that the road will be able to support the traffic for which it is designed. The ballast is not subject to direct wear, so a less resistant rock may be used with fair satisfaction if nothing else is available, particularly if a durable rock is obtainable for the surface or top course.

If relatively poor material must be used, also, for the surface course, the road will require more upkeep than would be the case otherwise. Even a sand, if kept moist, provides a usable surface in an emergency. Disintegrated granite is very satisfactory but, as with all materials of low durability, requires constant scraping. Broken shells or coral are commonly used in some places where nothing else is available. However, a few materials, such as argillite, serpentine, or rock high in chlorite, are unsatisfactory, particularly under moist conditions. Shale is not usable, though either shale or clay, when nothing else is available, may be sintered and so provide a fair top course.

Accessibility

A permanent quarry should be as close as possible to main highways, or, if there is necessity for rail transportation, to a railroad, or so located so that a spur could be built to the quarry site without undue expense. Temporary quarries commonly may be opened in the near vicinity of a road that is under construction, and abandoned when the specific needs have been met.

Ease of Quarrying

Overburden.--A desirable stone will usually have an overburden, or cover, that must be removed (stripped) before quarrying can be carried on. This may consist of soil, stained rock, decomposed rock, other rock varieties, or unconsolidated sedimentary material (alluvium), such as glacier- or stream-laid deposits. The kind and amount of overburden may determine the feasibility of the operation. A thick bed of stone will permit the economical removal of deeper overburden than will a thin bed. Under conditions of valuable stone and thick overburden, it may be more economical to resort to underground mining methods. In some places a relatively thin bed can be quarried successfully, without much stripping, by extending the working face laterally along the outcrop, rather than by driving deeply into the hillside. At Renton, Washington, 150 feet of overburden was stripped in order to mine an equal thickness of shale; however, 30 to 50 feet is, as a rule, as much as can be removed economically in order to extract common stone. At one place in Ohio a 22-foot horizontal bed of rock, having only a thin overburden, has been quarried from an area of more than a square mile.

Location.--Surface or near-surface occurrences of stone are usually selected, so that an open quarry can be developed with due regard to accessibility, economy of operation, drainage, and waste disposal. The site should preferably be opened on a moderate slope--not against a high cliff. An opening is gradually enlarged and deepened, its size and shape depending greatly on the rock. Thin flat beds may be quarried laterally (as mentioned in the previous section); such quarries are common in the Middle West. Quarries opened on steeply inclined beds, as occur in most mountainous areas, may be narrow and deep--as much as 500 to 700 feet. High land values, restricting property lines, and heavy overburden may make deep quarrying necessary. If the rock to be utilized crops out a little above the level of the valley or surrounding country, drainage will present little or no problem; if the quarry is opened on a flat surface, pumping will be necessary. Pit quarries may need hoists, derricks, inclined tracks, ladders, and stairs, but if properly designed and equipped can be operated at costs that compare favorably with those opening into hillsides.

Heavy overburden, as mentioned previously, may make underground mining necessary. Many limestone and marble deposits, and a few granite and slate deposits, are successfully worked underground; this has one marked advantage, as work can be carried on without regard to weather. Gloryhole mining is adapted to crushed-stone production: a haulage tunnel is driven in under the bottom of the quarry, then a raise, to be used as a chute, is driven to the quarry floor; rock is blasted around the chute and funneled through it to the haulageway.

Drainage.--Ground water is seldom troublesome where quarries are opened above stream levels; if it is encountered, a properly planned floor will provide drainage for it and for surface water. Any pit operation will necessarily need to be drained by pumping.

Jointing, strike, and dip.--Quarries opened for dimension stone will need to be selected with care. The joints in the stone should be evenly spaced and wide enough apart to provide large blocks that may be sawed or split into whatever size

is desirable. Where joints are 2 to 3 or 4 feet apart, the rock may be used for certain building purposes requiring relatively small blocks. Where joints are 10 to 40 feet apart, they greatly facilitate the process of quarrying, particularly in such rocks as sandstones. The quarry should be opened to follow the vertical joint system if possible. Because of jointing, and sometimes bedding, a block may be found to split more easily in one direction than in another; this is called the rift and, in sedimentary rocks, is usually parallel to bedding. There may be a second direction of easy splitting called the run or grain, which is usually at right angles to the rift. A third direction of easy splitting sometimes occurs at right angles to rift and run; it is called hard way or head grain. These features may be persistent over wide areas and are of marked importance in all quarrying procedures.

In folded beds it is sometimes desirable to open a quarry so that a given member or series of members may be followed along the strike. In this way beds of certain color, texture, or composition may be selectively mined. This is particularly true of very thick steeply dipping beds but may not apply to thin beds that are interstratified with unwanted rock varieties.

Waste disposal.--The overburden, as removed, must be taken far enough not to interfere with future quarrying, or require a second removal. In dimension-stone quarrying there will be waste that will need to be piled, so the quarry site should be selected with this in mind.

Space for buildings and equipment.--Large operations probably will need space for buildings and equipment. Quarries opened in narrow canyons or along narrow banks of streams may afford small space, so attention should be paid to present or future needs in this regard whenever possible.

QUALIFICATIONS OF AGGREGATES FOR SURFACING AND CONCRETE

by

Bailey Tremper*

<u>Characteristic</u>	<u>Surfacing</u>	<u>Concrete</u>
Durability	reasonable durability essential	good durability essential
Hardness (toughness)	desirable	desirable but extreme hardness not necessary
Shape	angularity desirable. Thin slivers may puncture tires	rounded best but crushed material can be used if necessary
Surface texture	roughness desirable	fair degree of smoothness an advantage
Coatings	thin coatings of good characteristics acceptable	should be free of most coatings. Organic material bad.
Soil admixtures	limited amount of good binder acceptable. Avoid organic top-soils.	should not be present
Extraneous materials	avoid excess of wood, bark, etc.	should not be present
Size of largest particles	not over three-fourths of thickness of course	usually not over 3 inches. Smaller in thin, reinforced members
Grading	well graded. Particularly avoid shortage of sand in course directly on a clay subgrade	well graded. Particularly avoid excess of "pea gravel"

Guard against segregation in handling prepared materials.

Test for organic matter in sand: Put 2-inch layer of sand in small bottle. Add test solution to depth of 1 inch above sand. Let stand 24 hours. Color should be straw or lighter.

Test Solution: Dissolve one ounce (1 tablespoon) of caustic soda or ordinary lye in one quart of water.

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