CHAPTER I.

COMPOSITION AND KINDS OF STONE.—ROCK STRUCTURES.

INTRODUCTION.

In order to understand thoroughly the relative value of different stones used for building, monumental, or other purposes, one should be familiar with the more common mineral substances which compose the more important kinds of rock. He should understand not only their mineralogical composition, but he should also be familiar with the conditions under which they were formed, and the changes which they have undergone since their formation.

To the geologist an elementary discussion of this nature is entirely superfluous, but for the benefit of those who have little or no knowledge of geology, it is thought best to insert at this place, a brief account of the common minerals, giving their composition and physical properties, by means of which they may be distinguished from one another. Following the description of the minerals, the more important rock types are discussed and characterized.

Any general statements that are made in these pages with reference to the importance, abundance, hardness, durability, etc., of different minerals or rocks, unless otherwise stated, refer to building stones as a class, and not to rocks in general.

COMPOSITION AND KINDS OF STONE.

MINERALS.

Any rock which may be picked up for examination is composed, as a rule, of several different minerals in a state of aggregation. We may separate from this rock any one of the

minerals of which it is composed and by chemical means ascertain that it, in turn, is made up of two or more substances known as elements.   According to Dr. H. Erdman of Halle there are seventy-four known elements which combine in various ways to form all known matter.   The eight most important, in order of abundance, are as follows: oxygen, 47.13 per cent., silicon, 27.89 per cent., aluminum, 8.13 per cent., iron, 4.71 per cent., calcium, 3.53 per cent., sodium, 2.68 per cent., magnesium, 2.64 per cent., potassium, 2.35 per cent. Very few of the elements are found free or uncombined in nature.   They generally exist in combination with one another forming what is known as a mineral substance.   In the neighborhood of two thousand different combinations, known as mineral species, have been described and named.   Many of them are very rare and constitute a very inconsiderable part of the earth's crust.   More than 95 per cent. of the rocks considered in this report are composed of various combinations of fourteen minerals.

Minerals are distinguished from one another by their physical properties, crystallization, and chemical composition. The chemical composition can only be obtained by a chemical analysis.   Every mineral that separates from a solution or a molten magma under conditions where the growth is unobstructed, assumes a definite crystal shape.   All minerals, which occur in crystals, crystallize under one of six well defined systems. These systems are recognized, in individual minerals, by the number and relation of the plane surfaces which bound the crystals.   Thus, if we are able to make out in any way the number of faces and their relation to one another on any mineral, we have a means of determining the mineral itself.   As a rock constituent, however, it is seldom possible to determine the system to which a mineral belongs or its specie by the crystal faces. The crystal faces belonging to the minerals of most sedimentary rocks, are usually entirely wanting, and in many of the igneous rocks they are either very imperfect or entirely absent.   The mineral individuals are often so small that they can only be distinguished with the aid of a microscope.

The outward crystal form is an expression of a definite internal structure. On account of this structure each mineral possess certain optical properties by means of which one can, with the aid of a compound microscope, determine the system to which it belongs, and ordinarily the mineral itself. In the determination of the crystallization of the minerals of a rock the microscope is an indispensable auxiliary.

The physical properties, among which are color, luster, hardness, cleavage, and streak, are also valuable aids in the ready determination of minerals.

The hardness of a mineral is relatively constant. For convenience all minerals are referred to a scale of hardness of ten units, composed of common or well known minerals, which are as follows: (1) talc; (2) gypsum; (3) calcite; (4) fluorite; (5) apatite; (6) orthoclase; (7) quartz; (8) topaz; (9) sapphire; and (10) diamond. The hardness of any mineral is determined by its ability to scratch the members of this scale. The degree of hardness is expressed by the number of the mineral in the scale, and minerals of intermediate hardness are expressed by fractions.

The capacity which some minerals have to part more readily in certain directions than in others is known as cleavage. A mineral may possess cleavage in one or several directions. It may be well developed in one mineral, and poorly developed in others. The presence of cleavage, its perfection, and its relation to the different faces of the crystal often furnish a valuable means of identification.

The streak is the color of the mineral when powdered, and in the case of the softer minerals is obtained by scratching a piece of porcelain with the mineral which is to be identified. As a means of determining the minerals of building stones, this quality is not important except perhaps in two or three cases.

A mineral cannot always be determined by a single one of these properties, and for this reason they should be used in conjunction with one another.

The important minerals and groups of minerals to be considered in reference to building stone are quartz, feldspar, mica,

28

amphibole, pyroxene, chlorite, olivine, talc, calcite, dolomite, magnetite, hematite, limonite, and pyrite. The following is a short description of these minerals, giving the composition, physical characteristics and appearance of each.

QUARTZ.

The chemical composition of quartz is silicon dioxide (SiO_2) which is a combination of the two most abundant known elements, silicon and oxygen. It is one of the hardest of the common minerals, being seven in the scale of hardness. It will readily scratch glass and most of the other common minerals. It possesses no ready cleavage, having, as a rule a conchoidal fracture. As a rock-making constituent, quartz is generally colorless, but when found alone it is frequently brown, yellow, purple, milky white, or pink. When occurring alone or in crystal aggregates, the quartz individuals often have very perfect crystal faces, but as a rock-making constituent the individuals generally have round, oval, or irregular outlines.

Quartz is one of the most abundant minerals. The glistening sand which forms the bars in many of the larger rivers is mainly quartz. The white and yellow particles which are caught up by the wind and eddied here and there in small dunes over some of our farms, are mainly quartz. This loose sand is largely a result of the decomposition of sandstone, which is composed mainly of quartz. Quartzite, as the name implies, is composed essentially of quartz. Among the igneous rocks, such as granite, rhyolite, and gneiss, quartz is a prominent constituent. Rocks which do not contain more or less quartz are the exception rather than the rule.

Among all the common rock-forming minerals quartz is the most permanent. Hydrofluoric acid alone will dissolve it. It is very hard and resists, to a high degree, any attempt to break or crush it. As a result of weathering it is often broken into smaller particles, but it is decomposed and taken into solution only with exceeding difficulty.

FELDSPAR.

The feldspar group contains two series of minerals, under both of which are included several species and sub-species. Certain of the species differ in the elements which enter into their composition, while others differ merely in the percentage of such elements. The two series of minerals are known by the name of their most common member, as orthoclase and plagioclase. Orthoclase is composed of an admixture of potassium, aluminum, silicon, and oxygen, with occasionally a small percentage of sodium, $(K, Na)_2 Al_2 Si_6 O_{16}$ (Hintze). Plagioclase contains sodium, calcium, aluminum, silicon, and oxygen, with either one of the following or some intermediate formula: $Na_2Al_2Si_6O_{16}, —Ca_2Al_4 Si_4O_{16}$. The two series differ not only in chemical composition but also in their habit of crystallization. The former crystallizes in what is known as the monoclinic system, while the latter crystallizes in the triclinic system.

A few characteristics will suffice to distinguish them from other associated minerals. The color is generally either pink or white. The hardness is six in the scale, being surpassed, among the common minerals, only by quartz. They have two very pronounced cleavages at right angles to each other, in consequence of which they generally have smooth, glistening faces. Feldspar is not as widespread or abundant a constituent of building stones as quartz. It is found mainly in the igneous rocks, although it is often a subordinate constituent of sandstone. It is an essential constituent of granite, gneiss, porphyry, and many of the allied rocks. In fact, it is seldom absent from any of the igneous rocks.

Feldspar is a compound which is decomposed and taken into solution with less difficulty than quartz, and is seldom found in the ancient rocks in a completely unaltered condition. Its ready cleavage permits of a more easy passage of water in and through its entire mass, presenting favorable conditions for slow chemical changes. The molecules are in some manner slowly broken down, and we have formed from the feldspar, by a rear-

rangement and recombination of the elements, a variety of different products, among which may be mentioned kaolin, quartz, chlorite, mica, epidote, zoisite, and calcite. Decomposition of the feldspar takes place wherever it is exposed to the action of percolating water or to the weathering action of the atmosphere. In some manner these alterations, however slowly they act, must eventually affect the strength and durability of the rock of which the feldspar forms a part.

MICA.

As in the case of feldspar, there are several varieties of mica differing from one another either in the combination, or in the relative amounts of the elements which compose them. The two most important species are muscovite and biotite. Muscovite contains various proportions of the elements hydrogen, potassium, aluminum, silicon, and oxygen, while biotite differs mainly in containing, in addition to the above named elements, magnesium and iron. The hardness of muscovite is 2–2.5, while that of biotite is 2.5–3. Mica is distinguished from other associated minerals by its easy and close cleavage. It has the appearance of being composed of very many exceedingly thin, glossy sheets, piled one upon another. Each sheet or folio can be scaled off with the blade of a pen-knife, or often with the finger nail. Biotite is generally black or very dark brown, owing to the iron in its composition. Muscovite is ordinarily distinguished from biotite by its white or silvery white color. The dark color of some rocks is largely due to the abundance of biotite in their composition, while many of the gray granites owe their color partially to the presence of muscovite.

Biotite is very slowly altered to other compounds by exposure to the atmosphere. The resulting products of decomposition are iron oxide, quartz, chlorite, and a mixture of the carbonates. On the other hand, muscovite, under the same conditions, decomposes more slowly than biotite. The alteration of biotite takes place along the cleavage planes or between the laminæ, which hasten decomposition by furnishing a larger working surface to the agents of decomposition.

Mica is an essential constituent of granite, gneiss, and many other igneous rocks. It also occurs to a less extent in certain of the sedimentary rocks, of which micaceous sandstone is an example.

AMPHIBOLE.

The mineral species included under the general name of amphibole are composed mainly of magnesium, calcium, silicon, iron, manganese, and oxygen, with or without aluminum. The most common species are actinolite, in which aluminum is wanting, and hornblende in which aluminum is present. The hardness of these minerals is about that of apatite or feldspar, being from 5 to 6 in the scale of hardness. Actinolite, as often found in the igneous rocks, occurs in long needle-shaped crystals, while hornblende is columnar. The color of these varieties is usually green, brown, or black. Other varieties of amphibole are colorless to silver gray. The minerals of this group differ from those of the pyroxene group, to be next described, only in their mode of crystallization. For this reason it is often difficult to distinguish them from each other. The prismatic cleavage is the most useful distinguishing characteristic. In the amphiboles the angles of intersection are 124° 30' and 55° 30', while in the pyroxenes the angles are uniformly nearly 90°. The cleavage faces have a vitreous to pearly luster.

Amphibole is an essential constituent of many granites, but more especially of the basic igneous rocks. It is also an abundant constituent of many schists and altered sedimentaries. The alteration products of amphibole depend upon the species under consideration, but they consist mainly of talc, calcite, chlorite, epidote, and quartz. These minerals, in turn, may be still further decomposed, as in the case of chlorite, which breaks up into "a mixture of carbonates, clay, limonite, and quartz." (Rosenbusch.) Under ordinary conditions at the surface of the earth, actinolite is a more stable compound than common hornblende. It must be understood that all the changes referred to take place very slowly.

PYROXENE.

The composition of the mineral species included under the general name of pyroxene is nearly the same as that of the species included under the amphibole group. The individuals of this group are ordinarily composed of one or more of the elements magnesium, calcium, iron, manganese, sodium, and lithium, in combination with silicon and oxygen, with the addition in certain of the important species, of aluminum, as an essential constituent. The hardness varies from 5 to 6, but in some of the less common species reaches as high as 7. The color and luster of the cleavage faces are essentially the same as in the preceding amphibole group. As has been previously observed, it is difficult to distinguish the members of this group from those of the preceding. The only ready means is through a determination of the cleavage angles, or a knowledge of the crystal forms. The most important rock-forming member of this group is augite, which name is often used synonymously with pyroxene.

Pyroxene is mainly a constituent of igneous rocks, being an important constituent of many of the granites, gneisses, and especially of the more basic rocks.

Through the weathering processes pyroxene is slowly decomposed, altering into chlorite, calcite, and epidote. Under given conditions pyroxene weathers somewhat more rapidly than amphibole, and for this reason is considered a less stable compound.

CHLORITE.

This group of minerals, in which is included a number of species, is composed of various combinations and proportions of magnesium, iron, manganese, and aluminum, with hydrogen, silicon, and oxygen.

The hardness of the minerals of this group ranges from 2 to 2.7. The members of the chlorite group are characterized by their green color, which is common to silicates containing ferrous iron. In itself, chlorite is generally an alteration product of some other mineral. It occurs in fibers and folia in many of the old igneous rocks known as "greenstone," in which case it is

generally an alteration product of amphibole, pyroxene, feld-
spar, or mica. Chlorite alters to a mixture of carbonates, clay,
limonite, and quartz.

OLIVINE.

The olivine group is now more correctly known as the chryso-
lite group. The different species differ somewhat in composi-
tion, being composed of varying proportions of magnesium, cal-
cium, iron, and manganese, in combination with silicon and
oxygen. The hardness ranges from 6 to 7. The predominant
color is what is commonly known as olive green. The luster is
vitreous. Olivine is a constituent, mainly, of the more basic
igneous rocks, such as diabase and gabbro. It alters very ex-
tensively to chlorite, talc, and serpentine.

TALC.

Talc is composed of hydrogen, oxygen, iron, magnesium,
aluminum, and silica, united in different proportions. It is
usually foliated, but frequently massive or fibrous. Talc has a
peculiar greasy feel which furnishes, as a rule, a ready means of
distinguishing it from associated minerals. The color varies
from apple green to white or silvery white. The luster is often
pearly on cleavage faces. Talc is widely disseminated through
the igneous and metamorphic rocks.

CALCITE.

Calcite is composed of the elements calcium, carbon, and oxy-
gen. It is more accurately known as calcium carbonate,
($Ca\,C\,O_3$). The hardness is 3. Calcite is sometimes clear
and transparent, but is more often white or cloudy. It some-
times contains impurities which impart a brown or pink color.
It has a perfect cleavage in three directions, by means of which
it breaks into small six-sided pieces, with inclined faces, called
rhombohedrons.

Calcite is often mistaken by the inexperienced for quartz.
The color of the two minerals is almost identical, but if one will
bear in mind that the hardness of calcite is 3 and that of quartz

7, there can be little danger of confusion. Furthermore, calcite has the perfect cleavage, above mentioned, which is not present in quartz. Calcite is an essential constituent of all limestones and many sandstones. It is also a constituent of many of the igneous rocks, being an alteration product of other minerals. The only important alteration product of calcite is gypsum or the sulphate of calcium. According to Geikie, sulphate of calcium frequently forms as an outer crust on marble tombstones, due to the action of sulphuric acid. It is not known how general this product may be, but it appears very probable that the efflorescence observed on many limestones may be due to the formation of calcium sulphate.

DOLOMITE.

Dolomite is composed of calcium, magnesium, carbon, and oxygen, and has the formula: $(Ca\ Mg)\ CO_3$. Its hardness is from 3.5 to 4, which is slightly above that of calcite. It may be distinguished from calcite by this quality, but more easily by the fact that it does not dissolve in cold, dilute hydrochloric (muriatic) acid, while calcite does. Dolomite is found abundantly as a constituent of the dolomitic limestones. The main alteration is to the sulphate which is commonly found at or near the exposed surface of dolomitic limestone.

MAGNETITE.

Magnetite is commonly known as magnetic iron ore. It is composed of iron and oxygen and has the formula: Fe_3O_4. The hardness is 5.5 to 6.5.

Magnetite is one of the commonest constituents of the igneous and metamorphic rocks, and is most often present in small grains or crystals scarcely visible to the naked eye. When present in larger individuals it is easily recognized by its brilliant black luster and the property which it has of being readily attracted by the magnet. Magnetite is not only widely disseminated in grains, crystals, and irregular patches through the igneous and metamorphic rocks, but it also occurs in large beds, constituting a valuable iron ore. Magnetite alters slowly to

yellowish brown limonite "which impregnates the surrounding rock."

HEMATITE. (Red hematite.)

Hematite, or iron sesquioxide, is likewise composed of iron and oxygen, but the proportion of the two elements is different from that in the magnetite. The chemical composition of hematite is Fe_2O_3. It has a metallic luster. The streak is red. The color is generally steel gray to iron black but as a rock constituent it is often found in minute blood-red flakes. Besides occurring as a rock constituent, it is often discovered in massive beds, forming one of the most valuable iron ores. It often occurs as a cementing material in sandstone, binding together the individual grains, and with limonite is generally the cause of the brown and red color of the sedimentary, igneous, and metamorphic rocks. Hematite hydrates very slowly to limonite.

LIMONITE. (Brown hematite.)

The chemical composition of limonite is the same as that of hematite, with the exception that it contains water in addition to iron and oxygen, $(Fe_2O_3\ 1\frac{1}{2}\ H_2O)$. It is found in all kinds of rocks—eruptive, sedimentary, and metamorphic. It results mainly from the decomposition of other minerals rich in iron. As a staining or coloring agent, it is probably more abundant than red hematite. It also occurs in large masses, and furnishes a valuable iron ore.

PYRITE.

The chemical composition of pyrite is iron and sulphur $(Fe\ S_2)$. The hardness is 6 to 6.5. Common pyrite, or pyrite proper, is recognized by its cubical shape and bright yellow color. The less common form of iron sulphide, known as marcasite, has a much lighter, almost gray color, and is softer than common pyrite. The occurrence of iron sulphide in both forms is very wide spread, being found alike in eruptive, sedimentary, and metamorphic rocks. Both compounds decompose rather

readily, but pyrite proper is less affected by atmospheric conditions than marcasite. This is due to the fact that much of the iron in the marcasite exists in the ferrous state, while that in the pyrite is more largely in a ferric condition.[1]   Under the same conditions, the ferric compounds are much more stable than the ferrous, and hence the greater readiness with which the marcasite decomposes. The decomposition products of the two minerals also differ to some degree. The decomposition of pyrite results, as a rule, in the formation of limonite and free sulphur, while that of marcasite results in the formation of ferrous sulphate, although when under water limonite is also largely formed.

ROCKS.

A rock is ordinarily defined as a mineral aggregate. It consists of individuals of one or more mineral species in which the particles are either cemented together or otherwise consolidated. Rocks are ordinarily classified, on the basis of their origin, into igneous, aqueous (or sedimentary), and metamorphic. This basis of classification is not altogether satisfactory to the student of geology, but is convenient for the purposes of this volume.

The important rocks from an economic standpoint, which are found in this state, may be classified as follows:

IGNEOUS.

    Granite.

    Rhyolite.   (Quartz porphyry.)

    Greenstone.

SEDIMENTARY.

    Sandstone.

    Limestone.

    Dolomite.

METAMORPHIC.

    Quartzite.

    Gneiss.

It must be understood that this classification is very general, and that between the few kinds of rocks mentioned, many differ-

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[1] Mr. A. P. Brown, Proc. Amer. Phil. Soc., Vol. XXXIII., 1894, p. 225.

ent varieties have been distinguished and named. There exist all gradations between the rocks of the sedimentary series as well as between the rocks of the igneous series. Each rock type passes by insensible gradations into the adjacent type of the series to which it belongs. Likewise, there are all gradations between the igneous, aqueous, and metamorphic rocks.

IGNEOUS ROCKS.

Igneous rocks, as the name implies, are those rocks which have had their origin in the cooling and consolidation of molten material. Provided we accept the hypothesis that the earth was at one time a molten mass, which has subsequently cooled, igneous rocks may be either a result of the downward cooling of the earth's crust, or a result of the consolidation of molten material which has been pushed up from below into or through the already cooled crust.

These rocks exhibit many different characteristics. The different conditions under which the molten material solidifies and differences in the chemical composition of the original magma are the main, controlling factors in producing differences in the mineralogical composition and the size and arrangement of the grains. Upon these differences in mineralogical composition and size and arrangement of the individual grains, several different classifications of igneous rocks have arisen. None of these classifications has been generally accepted as satisfactory. It would be entirely out of place to describe all of the many different kinds of rock included in any one of these classifications. It is thought that only a description of the more important kinds found in the state of Wisconsin, which are now used for economic purposes, is necessary. These are granite, rhyolite, and greenstone.

Granite.

Granite is supposed to form deep below the surface of the earth, under peculiar conditions of heat and pressure, whereby the elements of the molten magma are allowed to enter into various combinations, forming minerals having definite char-

acteristics. The rock thus formed is completely crystalline, and composed of the essential constituents quartz, orthoclase feldspar, and plagioclase feldspar, with one or more minerals from the mica, pyroxene, or amphibole series. Magnetite, pyrite, zircon, apatite, and a number of less important microscopic minerals are present as accessory constituents. The minerals, as a rule, have irregular outlines and interlock in a very intricate manner, each of the individuals having very much the appearance of being irregularly dove-tailed into those adjacent. This interlocking character of the minerals accounts for the fact that, as a rule, an individual can only be separated from the mass of the rock by severing it at some part. This characteristic of igneous rocks also accounts, in part, for their strength and the difficulty which stone cutters experience in working them.

In certain of the granites the essential mineral constituents are very small, being distinguisable only by the aid of a lens. Such a granite is generally designated as fine grained. In others the essential constituents are often as much as a quarter or even a half an inch in diameter. These are spoken of as being either coarse or very coarse grained. Between the two extremes there are all degrees of coarseness (or fineness). Frequently a granite is found in which certain of the feldspar individuals are very large and stand out boldly in a fine grained groundmass. Such a rock is called a porphyritic granite.

Granites are discriminated from one another by the predominant ferro-magnesium mineral among their constituents, and are known as biotite-granite, muscovite-granite, hornblende-granite, augite-granite, etc.

The color of granite differs greatly in different localities. The color depends, not alone upon the color of the individual minerals composing the rock, but also upon the size and distribution of the constituents. With respect to color, granites may be classified as red and gray. Whether a granite belongs to the first or second class will depend upon the red or white color of the feldspar. Many granites contain both red and white feldspar, but so long as the red variety is sufficiently abundant to impart a reddish tone to the rock, it is called a red granite.

The most brilliant red granites have a preponderance of medium-sized red feldspar individuals. As the individuals become finer grained and biotite, amphibole, or pyroxene become more abundant, the color is subdued and we have a dull red granite.

The gray granites are dark or light colored, depending upon the size of the individual minerals and the amount and kind of the ferro-magnesian minerals present. The lightest colored granite has a preponderance of white feldspar and contains muscovite as the main ferro-magnesian mineral. The darker gray granites contain less feldspar and a greater abundance of biotite, hornblende, or pyroxene. Occasionally one finds a granite which has a peculiar iridescent hue, which is due to the presence of one of the plagioclase feldspars, usually labradorite.

Granite is generally massive, but occasionally one finds a quarry in which the rock splits in one direction much more readily than in others. This direction is known by quarry-men as the rift. When it becomes very pronounced and wavy the granite is known as a gneiss, and should be classified under the metamorphic series.

Granite is fresh or altered, depending upon the state of preservation of the mineral constituents. The more common alterations to which the various rock forming minerals are subject have been mentioned above. One can readily see that the alteration and decomposition of the individual minerals would, in time, result in a breaking down or crumbling of the rock itself. The degree of alteration and the alteration products as they affect the durability of a rock will be considered later.

Rhyolite.

The rocks which have been placed under this subdivision have essentially the same chemical composition as granite. They differ mainly in texture and mineralogical composition, occasioned by the entirely different conditions under which they have been formed. In contra-distinction to the granites, which are formed deep below the surface, these rocks are formed at or near the surface of the earth.

Porphyritic rhyolite, commonly known as quartz porphyry, is the only variety of this kind of rock which we have occasion to consider. In this rock, quartz and feldspar are the first minerals to crystallize out from the magma, and constitute the porphyritic elements in the rock. Sometimes feldspar alone is present, and again both quartz and feldspar are found among the porphyritic individuals. The remainder of the magma is supposed to have cooled so rapidly as to permit of only fine grained or partial crystallization. The rock, as a rule, has a dark, dense background, through which are disseminated numerous large, lustrous crystals of feldspar or quartz, or frequently both. These porphyritic constituents of rhyolite generally differ from those of granite in having well defined crystal outlines. The matrix of porphyritic rhyolite, as it now occurs, is often composed of a dense mass of microscopic crystals of quartz and feldspar. In other instances the matrix may be entirely or in part amorphous.

The color of the Wisconsin rhyolites used for building stone ranges from yellowish brown to black. A very pleasing effect is sometimes produced by a black groundmass through which are promiscuously scattered porphyritic crystals of pink and white feldspar and clear, translucent individuals of quartz. Rhyolite is an exceedingly hard and brittle rock, often breaking with a conchoidal or splintery fracture. The rock very often exhibits a tendency to split more readily in one direction than in others. Frequently there are two directions of easy parting, one being better developed than the other. The direction of easiest parting is known by quarrymen as the "rift;" the direction of next easiest parting has been designated the "run." The third direction is known as the "head." The rift may be the result of flowage planes developed before the rock was completely solidified; it may have been occasioned by alterations since the formation of the rock; or it may be a result of both. The rift and run assist very materially in quarrying the rock, but the rift is often a serious obstacle to satisfactory polishing. The rift side is the direction of the longest axis of the flattened minerals, and the exceptional closeness of the parting planes is a cause for the difficulty experienced in polishing the rock with the rift.

Greenstone.

In the nomenclature of igneous rocks the name "greenstone" has no definite significance, having been applied to almost any rock which has a green color. The main kinds of greenstone in Wisconsin which might be used as building material are known as diabase, gabbro, and basalt. These rocks have, as their main constituents, plagioclase feldspar, amphibole, mica, and pyroxene. All of the three last may or may not be present. To these essential constituents may be added from ten to twelve accessory minerals, some of which are present in each kind of rock.

Diabase is one of the most abundant and widespread igneous rocks in Wisconsin, being found in huge bosses, dikes, and sills. It is formed originally within the crust of the earth, and is distinguished from the other members of the family by the texture known as ophitic. This texture may be either macroscopic or microscopic. The rock is usually fine to medium grained, and seldom has a porphyritic texture. It is generally compact and thoroughly homogeneous. The color of diabase is decidedly somber, being dark green and sometimes almost black.

The gabbro member of the family is distinguished from diabase by its granolithic texture, which is always microscopic. The mineralogical composition, color, and occurrence are quite analogous to that of diabase.

Basalt is commonly a volcanic rock. It is sometimes completely crystalline and at other times partly glassy. The texture at times approaches microgranolithic. The mineralogical composition and color correspond quite closely with the two previously described members.

It will be noted that the constituents of the greenstones are among the more readily decomposed and disintegrated minerals. For this reason, and on account of the dark, somber color of the rock, they are not generally sought after as building stones.

AQUEOUS OR SEDIMENTARY ROCKS.

The sedimentary rocks have their origin in chemical or organic precipitation and mechanical deposition from water. If it were possible to trace back the history of the material com-

posing the sedimentary rocks to its original source, one would find that a large part had its origin in the igneous rocks of long ago. The rivers are constantly transporting millions upon millions of tons of finely comminuted material from the land into the sea. Millions of tons are also being carried in solution. The waves, beating upon the shore, are steadily wearing it back by breaking down the rocks along the coast. The shore currents, waves, and tides assort the material which is worn from the coast and that which is brought into the ocean by the rivers, depositing it over the bed of the ocean near the land. The coarsest material is dropped nearest the shore, while the finer material is carried into deeper water. The ocean is inhabited by myriads of animals and plants that are continually extracting calcium carbonate and silica from the water, to build their shells and skeletons. As these creatures die their shells are added to the accumulations at the bottom of the ocean, and in many places they become so abundant that they form a large part of the deposit.

Beside calcium carbonate and silica, which are the substances mainly used in building the shells of marine animals, the water carries in solution many other soluble mineral substances. These are also often precipitated to the bottom of the ocean, mingling themselves with the mechanical sediments and organic remains. Through these various agencies four principal kinds of sediments are formed—conglomerate, sandstone, shale, and limestone or dolomite. These deposits are not sharply separated from one another, but between them every possible gradation may be found.

Conglomerate.

Close to the shore line the coarser pebbles and boulders, which have been worn away from the cliffs of the adjacent coast, are laid down. These pebbles are generally well rounded and in the spaces between the individuals finer material settles until the whole becomes a compact, solid mass. This interstitial material is known as the matrix, and is generally either sand or clay. When such a deposit has been buried underneath many thousand feet of other sediments, it becomes consolidated and

forms rock conglomerate. After many centuries, through elevation and subsequent wasting away of the land, the conglomerate thus formed may emerge again at the surface as a part of the continental land mass.

Where the pebbles are comparatively uniform in size conglomerate is sometimes used for economic purposes. But as a rule the decided difference in texture and hardness between the different pebbles and between the pebbles and the matrix, is a fatal objection to its use as a building stone. It sometimes serves as a beautiful stone for inside ornamental work, where it is protected from the destructive action of the weather. There are no conglomerates in this state of recognized economic value, and we shall therefore pass them without further discussion.

Sandstone.

The next distinct deposit beyond the conglomerate belt and in deeper water is that composed of small particles of sand. After the sand is deeply buried beneath later sediments and the interstices become filled or partly filled with materials deposited from percolating waters, the incoherent sand is transformed into a rock known as sandstone.

The composition of sandstone varies quite largely, but in all cases the preponderant original constituent is round to subangular grains of quartz. Feldspar or calcite may constitute a considerable portion of the rock, in which case it is called either a feldspathic or calcareous sandstone. Clay may be so intermingled with the quartz grains as to give the rock the name argillaceous sandstone. Mica may also be abundant, and the rock is then called a micaceous sandstone.

The original grains which compose the rock generally have roundish outlines, owing to their having been water-worn. The individuals, therefore, do not interlock as in the case of the igneous rocks. When first deposited small spaces exist between the grains, but due to consolidation from superincumbent pressure, these spaces may be reduced in size, and through cementation they are either partly or wholly filled by material from extraneous sources.

29

The kind of cementing material which binds together the grains will depend largely upon the mineral matter carried in solution by the water, which has percolated through the rocks, although the mineral particles composing the rock may contribute largely to the force which occasions precipitation of the cementing material. The more important cementing materials are calcium carbonate, iron oxide, and silica.

It is evident that the hardness of a rock depends upon the state of aggregation, as well as upon the hardness of the individuals composing the rock. The hardness of quartz is 7, but this is not the hardness of a rock composed entirely of an aggregate of quartz grains. The hardness of the rock will depend more upon the manner in which the grains are cemented, or united, and the character of the cementing material. The efficiency of the cement will depend not only upon its inherent characteristics, but also upon the affinity which exists between the grains and the cement. The hardest and most durable cement is silica. A sandstone in which the individuals are completely cemented with silica is one of the hardest and most durable rocks. Sandstone in which the cementing material is calcium carbonate is softer and less durable than the former. Calcite is one of the softest of the important minerals of building stone and breaks very readily into small pieces, due to its cleavage. It is also quite readily dissolved in carbonated waters. A sandstone in which the individuals are cemented with iron oxide is less strong than one cemented with either silica or calcite. As a rule, iron oxide is the least important of the three cements. Writers are constantly classifying iron oxide as a more durable cement than calcite, probably drawing their conclusions from the durability of the brown sandstone. But the most durable brown sandstone, such as occurs in Wisconsin, is mainly cemented with silica and not iron oxide. The value of the iron oxide is mainly in imparting to the rock the beautiful shades of red and brown, for which much of the Wisconsin sandstone is noted. Thus it happens that errors have frequently been made concerning the relative importance of silica, calcite, and iron oxide as cementing materials.

Any estimate of the hardness or durability of a rock should take into consideration the conditions of cementation. In comparing the hardness and durability of sandstone, the relative amount of cementing material, the size of the grains, and the completeness with which the cement has filled the interstices, as well as the kind of cement and mineral constituents, should be taken into consideration.

Alterations of sandstone are mainly the result of additions or subtractions of mineral matter, usually silica. Quartz, as has been previously stated, does not alter, although small amounts may be taken into solution and carried away by percolating water. The cementing materials and the subordinate constituents, such as feldspar, mica, calcite, and iron oxide (or sulphide), are alone subject to alteration in the sense of decomposition. Feldspar and mica break down into their various alteration products, and calcite is often dissolved and reprecipitated as the sulphate. Ordinarily iron oxide, in the form of hematite, is reasonably stable; in the form of the carbonate or sulphide, it is readily decomposed and becomes a source of unsightly discoloration.

Shale.

In deeper water but mainly in the shallows of the ocean, beyond the sandstone belt, still finer sediments are deposited in the form of clay. These deposits, after passing through the ordinary process of consolidation, are also transformed into a rock, which is known as shale. These rocks have no economic importance in Wisconsin and will not be further considered.

Limestone and Dolomite.

Beyond the clay there occurs a deposit of calcium carbonate or calcium magnesium carbonate ($CaCO_3$ or $CaMgCO_3$). This deposit is composed largely of the shells of marine animals in conjunction with calcium carbonate resulting from chemical precipitation. This deposit, as in the case of those previously described, is consolidated and transformed into rock through the pressure of superincumbent deposits and the addition of

cementing material from percolating water. This rock, like the former, may be brought to the surface as a part of the land and is known either as limestone or dolomite, depending upon the percentage of magnesium carbonate present.

The method of formation of the dolomitic limestone has been the subject of a great deal of discussion. Some authorities attribute it entirely to secondary processes after the limestone is deposited, while others assert that it can only be accounted for by contemporaneous chemical precipitation and the extraction of $(CaMg) CO_3$ by living organisms. The probability is that both original and secondary processes have contributed to its formation. In one place chemical precipitation may have been the chief agent, while in another it may have been the result of secondary processes. In other places both agencies may have been equally operative.

The chemical composition of pure limestone is calcium carbonate, a combination of the elements calcium, carbon, and oxygen. It is seldom that limestone occurs in the pure state among the rock formations of Wisconsin. Magnesium, silica, clay, iron oxide, and bitumen are all of common occurrence. By far the most abundant of these accessory constituents is magnesium in the form of dolomite $(Ca Mg) Co_3$.

Owing to the presence of magnesium in large quantities in certain of the limestones, authors have been accustomed to apply the name dolomite to limestone, which contains a certain percentage of $Mg CO_3$, ranging from 18 per cent. to 40 per cent., depending upon the writer. The term dolomite has such a varied meaning and has been used so loosely by different authors, that it would avoid confusion if some definite usage for it was established in the nomenclature of rocks. For scientific as well as practical purposes, it would be best, as far as possible, to distinguish limestone and dolomite as different kinds of rock. If the rock is essentially pure calcium carbonate, it should be called a limestone. If the rock is essentially calcium-magnesium carbonate, it should be termed a dolomite. If the dolomite becomes important, but not predominant, the limestone should be known as dolomitic or magnesian limestone. If the

percentage of calcium carbonate is less than that of the calcium magnesium carbonate the rock should be called a calcareous dolomite.

There are all gradations between the rocks in which the chemical composition is pure limestone, calcium carbonate, and those in which the chemical composition is pure dolomite. The stone may be a limestone, a dolomitic limestone, a calcareous dolomite, or a dolomite. Either may be qualified by affixing the name of the most abundant subordinate constituent. If this subordinate constituent chances to be clay, the rock would be an argillaceous limestone or dolomite; if iron, a ferruginous limestone or dolomite; if bitumen, a bituminous limestone or dolomite. Silica often occurs either as original grains of quartz or as a product of infiltration. It may be almost equal in importance to that of calcium carbonate and in such case the rock might with equal propriety be called an arenaceous limestone or a calcareous sandstone. Iron is frequently a subordinate constituent, either as the carbonate, oxide, or sulphide. If present in any considerable quantity the rock is known as a ferruginous limestone. Iron is a cause of the discoloration of many of the limestones, after being placed in the walls of the buildings. Oxide, in the ferric form, is not liable to cause discoloration after the stone is placed in the wall, but when the iron is present as the carbonate of sulphide, it may, in the case of limestone, not only be a source of discoloration, but also injure the texture of the rock. The sulphide of iron, as previously mentioned under the description of mineral species, is found in the form of pyrite and marcasite. Hopkins, in his report on the marbles of Arkansas (p. 60) says: "The sulphide of iron is more liable to decomposition when it is in the form of marcasite than in the form of yellow pyrite, and is less destructive in dry places than in moist ones, as in the presence of moisture it not only forms the oxide known as iron rust, but it at the same time produces sulphurous and sulphuric acids which act on the lime, changing it to sulphate of lime or gypsum. Often the only effect of iron, if present in very small quantities, is to mellow the stone, producing a yellow tint with age."

Clay may occur in the limestone either as thin laminæ between the layers, as segregations, or disseminated in fine particles throughout the stone. An admixture of clay has a tendency to soften the limestone, thereby making it less durable. If present in thin laminæ or in pockets it will soon be noticeable by the greater rapidity with which it weathers. The surface will weather unevenly and soon become ragged and pitted.

Bitumen, either as petroleum or carbonaceous matter, is often an accessory constituent and imparts to the rock a black color and a fetid odor. The injurious effect of bitumen depends largely upon the amount present. It is objectionable, in any considerable quantity, on account of its odor and the discoloration which it occasions. Frequently limestone formations are reservoirs of great mineral wealth. Lead, zinc, copper, and mineral fuels are found in limestone formations. These minerals sometimes furnish qualitative names to the limestone, such as the "Galena" limestone.

Abysmal Deposits.

In the abysmal parts of the ocean, various deposits of ooze are now being formed, but it is thought that these have never contributed to the formation of the rocks of the continent.

METAMORPHIC ROCKS.

The metamorphic rocks are modified equivalents of the rocks of both the igneous and sedimentary series, which have been profoundly altered through dynamic and other agencies since they were first formed. Every rock in the igneous and aqueous series has its equivalent in the metamorphic series. Among these rocks may be mentioned gneiss, which may be an alteration product of either igneous and aqueous rocks, quartzite, which results from the induration of sandstone, and marble which is the metamorphosed equivalent of limestone.

The metamorphic rocks used as building stone in Wisconsin are mainly gneiss and quartzite. Certain of the limestones and dolomites approach very close to marble, but they have not been classified separately in this report. The gneiss and

quartzite have both been used to a limited extent for ornamental and constructional purposes, but the abundance of much more suitable materials among the unmetamorphosed rocks has retarded their development.

Quartzite.

When sandstone has been subjected to metamorphic processes, through many years, it is transformed into either a quartzite or a quartz schist. Quartz schist results from alteration combined with mechanical deformation, by which a cleavage or schistosity is developed. Quartzite is composed almost entirely of quartz, and differs from quartz schist simply in the absence of the laminated or schistose structure. In these rocks the grains of sand have largely lost their original, roundish shape, and now interlock in an intricate manner, much after the fashion of the grains of an igneous rock. Quartzite is composed essentially of quartz, and the cementing material is silica. Iron oxide is often present, imparting to the rock a red or brown color. Frequently other very subordinate constituents are associated with the quartz. The color varies through white, gray, red, blue, or brown.

Quartzite is an exceedingly refractory stone, and is worked only with the greatest difficulty. This quality, combined with its always numerous joints, almost wholly prevents its economic use, except for road construction.

Gneiss.

Gneiss is the general term applied to a series of schistose rocks having the constituents of granite. The rock may originally have been either igneous or aqueous. In some of the gneisses, the metamorphic process has only progressed far enough to produce a decided lamination, without obliterating evidences of the origin of the rock. In others all traces of the original rock have been removed.

Wisconsin possesses an abundance of gneissic rocks of all kinds, but owing to the great abundance of non-foliated rocks,

they are seldom quarried. Nevertheless, when polished they are often very pretty, and are more durable than many of the rocks ordinarily used.

ROCK STRUCTURES.

ORIGINAL STRUCTURES.

The original structures in sedimentary rocks are those which are produced through changing conditions of sedimentation or alternation of sediments. Through the alternation of sediments, there is formed a structure which I propose to call stratification. Originally the sedimentary rocks possess no actual planes of parting, but merely the stratification planes, which are planes along which the rock has a natural capacity to part most readily. The more abrupt the change in sediments, the greater will be the capacity for the rock to part along the sedimentary planes.

The igneous rocks formed below the surface of the earth are originally massive and homogeneous, and without original parting planes. Igneous rocks which have solidified at or near the surface often have developed an original flowage structure, which resembles, in some respects, the stratification planes of the sedimentary rocks and has frequently been mistaken for them. Such rocks have a capacity to part most readily along the flowage planes.

SECONDARY STRUCTURES.

One ordinarily thinks of the rock envelope at the surface of the earth as being one continuous, unbroken mass of rock. But when closely examined it is found at the surface to be composed of a mass of various sized, polygonal blocks, to all appearances perfectly fitted to each other. These polygonal blocks have a wide range in size. Often, they do not exceed several inches in cross-section, while occasionally they are fifty or even several hundred feet in each of the three dimensions. Blocks of all intermediate sizes may be found. It is known that the parting planes which bound these polygonal blocks are not original, but

that they have been produced since the consolidation of the rock. The most important of these parting planes are known as joints. Joints develop in the sedimentary and igneous rocks as the result of stresses, requiring a readjustment of the earth's crust in conformity with new conditions. Relief generally takes place where there is least resistance. In the sedimentary rocks the planes of sedimentation are the planes of weakness, and along these planes where originally there existed merely a capacity to part, actual parting takes place. These planes might consistently be called joints but I propose to call them *bedding,* in distinction from those that are normal or inclined to the plans of stratification. Other parting planes besides these may be developed in two or more directions, normal or inclined to bedding. Such fractures are known as joints, although ordinarily spoken of by quarrymen as vertical or inclined seams. Joints, normal or inclined to bedding, generally occur in sets almost at right angles to each other. They are ordinarily classified as "dip" joints and "strike" joints, depending upon whether they correspond in direction with that of the strike or dip of the rocks. A better classification would be that of tension joints and compression joints as proposed by C. R. Van Hise.[1] The first classification is unsatisfactory, in so much as it does not provide for the possible cases, and is often misleading. The latter classification is based on the origin of the joints, and is decidedly more satisfactory. Yet the classification is not of sufficient importance to quarrymen to warrant giving it serious attention.

Joints are known by quarrymen as "major" and "minor," depending upon how well they are developed, and for quarrying purposes this appears to be the most practical classification. The major joints are those seams which continue for a considerable depth and for long distances. The minor joints are those seams which originate and die out within short distances, often within the same quarry. The least of the minor joints are often known as "dry" or "incipient" joints. Often the larger
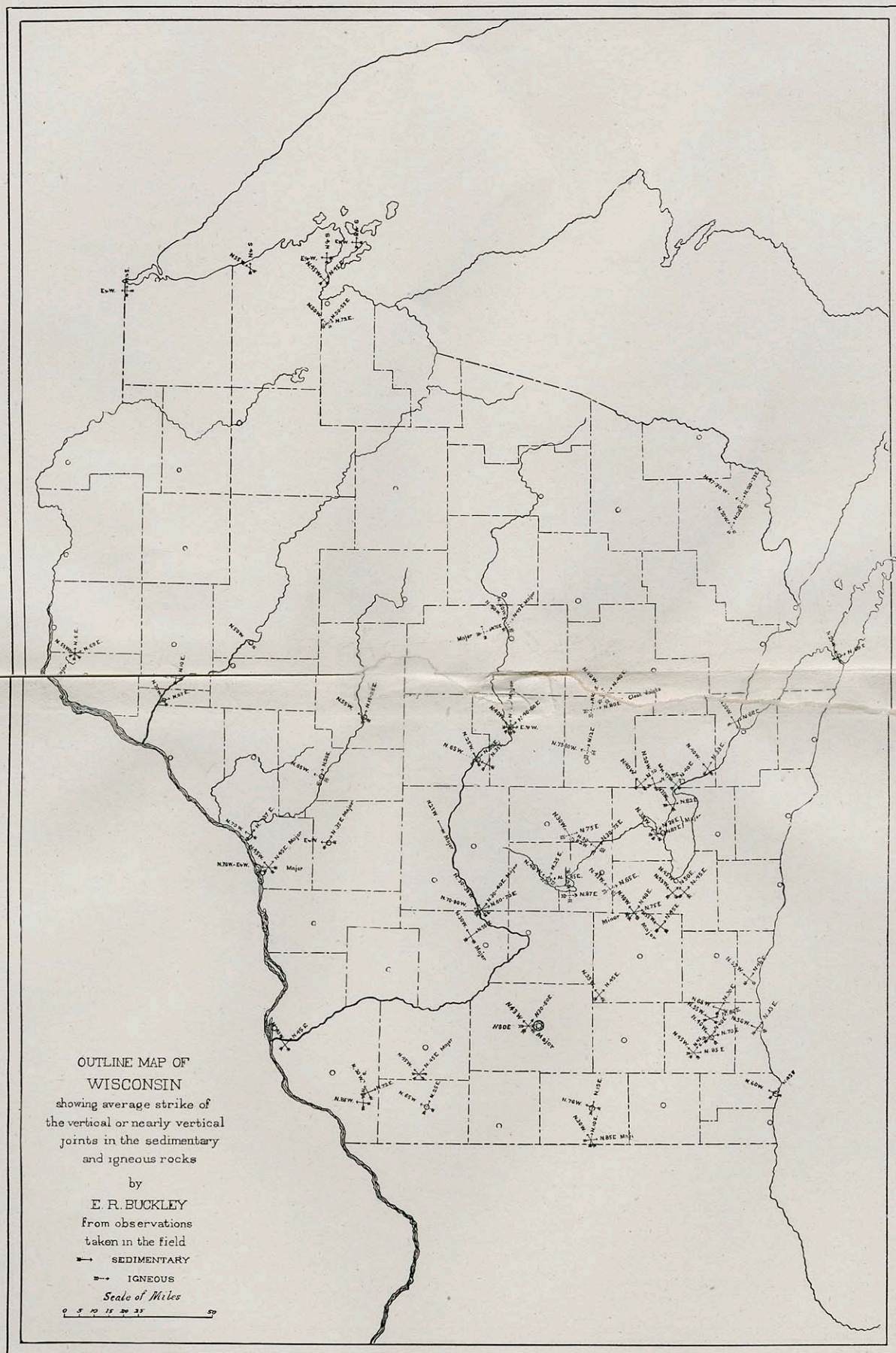
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[1] Principles of North American pre-Cambrian Geology, by C. R. Van Hise: 16th Ann. Rep't, U. S. Geol. Survey, 1896, pp. 668–672.
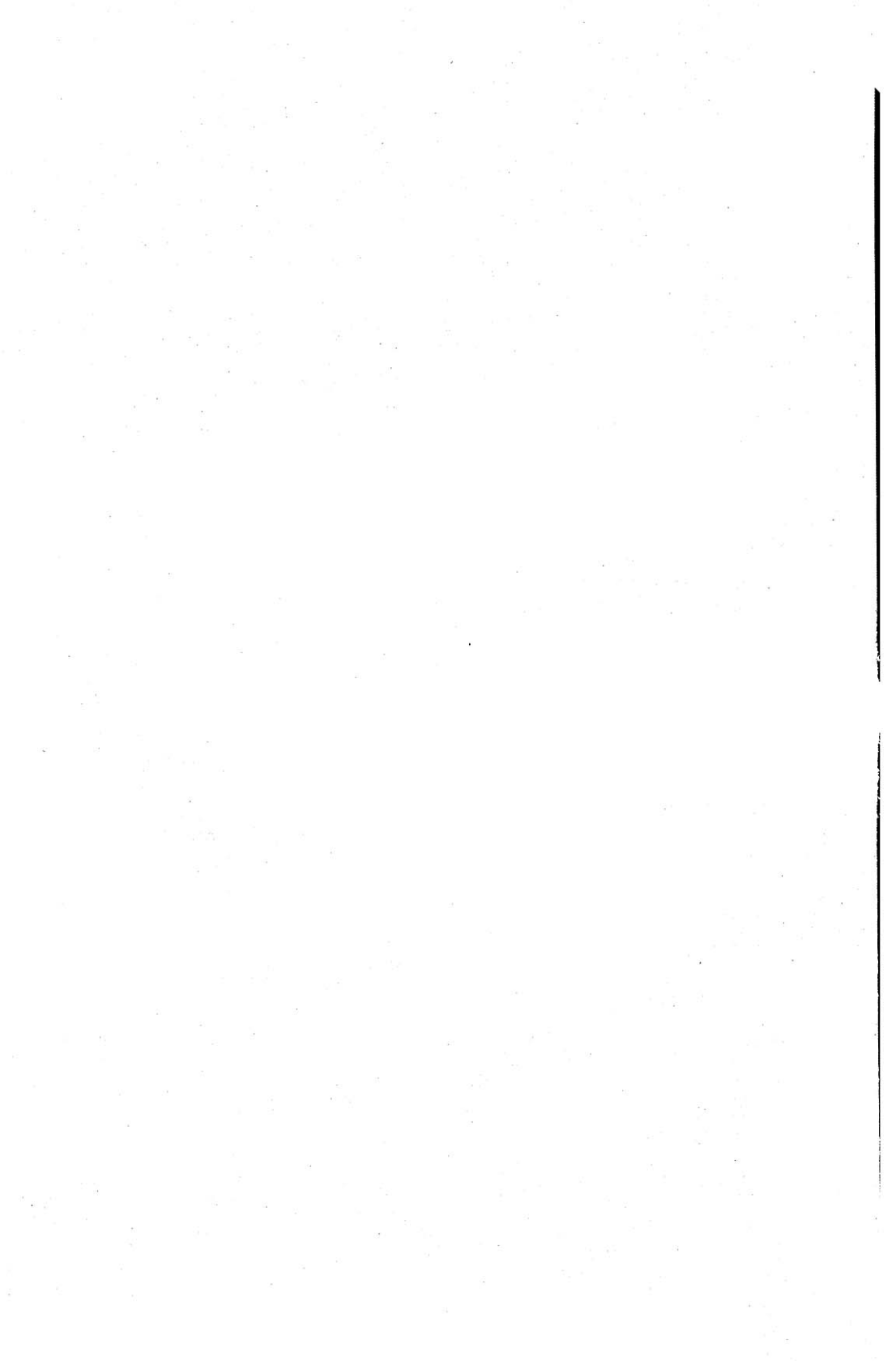
joints near the surface, have developed into narrow V-shaped trenches, sometimes 20 feet in depth. These are often filled with mud and clay, and are known by the quarrymen as "mud seams."

The advantages and disadvantages of these natural seams are well known to the quarrymen. The parting planes may be so distributed as to furnish dimension blocks of the most convenient size, or they may be so few in number as to make the expense of quarrying too great for economical working. Or again, they may be so abundant that the rock masses are fragments too small for dimensional purposes. Rock which is thus badly broken up may be most economically handled for road purposes. Where the stone is desired for heavy constructional work, the presence of numerous jointing planes is a source of great annoyance and expense to the quarrymen. In quarries where the jointing is uncertain, it is occasionally necessary to work over a large section of the quarry before finding blocks of the required dimensions.

Several hundred observations were made on the jointing of the rocks as it occurs in the different quarries throughout the state. These observations included a determination of the strike and dip of each set of joints, and a record of the most prominent sets. The results are embodied in the map, Pl. XLIX.

The jointing in the sedimentary rocks is quite different from that in the igneous rocks, being much more complex, as a rule, in the latter than in the former. In the sedimentary rocks bedding always occurs, and the jointing is mainly vertical, dipping only a few degrees in either direction. As a rule, the sets of joints occur in pairs striking nearly at right angles to each other. In most places two pairs of sets can be distinguished, each set striking at an angle of about 90° from the two adjacent sets. Two of the four sets are often equally well developed, while the third and fourth sets may or may not be equally well developed. The two sets that are best developed in one part of an area may be superseded in another part by the other two sets. The joints are often very abundant in one part of a quarry and sparse in another. Curved joints occur in the formations

OUTLINE MAP OF
WISCONSIN
showing average strike of
the vertical or nearly vertical
joints in the sedimentary
and igneous rocks

by

E. R. BUCKLEY
from observations
taken in the field

⊢━▶   SEDIMENTARY

⊢━▶   IGNEOUS

Scale of Miles

0 5 10 15 20 25   50

through the eastern part of the state, and occasionally faulting has occurred.

As will be seen in the accompanying map, the joints of the sedimentary rocks strike in four main directions. The prevailing general direction of the joints is NE. and SW. The other directions are NW. and SE., E. and W., and N. and S.

The joints in the igneous rocks are more numerous than in the sedimentary, owing to the greater length of time through which they have been subjected to dynamic action. The joints are partly vertical, but many of them are inclined or even approximately horizontal. The observations are recorded on the map, Pl. XLIX., along with those of the sedimentary rocks.

There may also be produced in rocks another structure parallel, inclined, or normal to stratification, known as cleavage. Cleavage is a capacity which a rock may possess to split readily into thin laminæ or folia. It is somewhat homologous to stratification, but is distinguished by being a secondary and not an original structure. The parting along cleavage planes is sometimes smooth, and at other times wavy. The former is known as slatiness and the latter as schistosity. Prof. Van Hise[1] has also made a distinction between fissility and cleavage. He defines cleavage "as a capacity present in some rocks to break in certain directions more easily than in others." Fissility is "defined as a structure in some rocks, by virtue of which they are already separated into parallel laminæ in a state of nature."

Thus in the sedimentary rocks one may recognize stratification, bedding, jointing, schistosity, fissility, and cleavage. In this report no attempt has been made to distinguish cleavage from fissility, although the author appreciates the necessity of such a division for scientific accuracy.

The rocks are sometimes variously folded and plicated, and the strata bent into domes and basins. These structures are observed mainly in mountanious regions and are not characteristic of the unaltered sedimentary rocks.

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[1] Principles of North American Pre-Cambrian Geology, by C. R. Van Hise: 16th Ann. Rep't, U. S. Geol. Survey, 1896, p. 623.

The igneous rocks exhibit analogous structures to those of the sedimentary rocks. Horizontal or nearly horizontal bedding is often found, either along the flowage planes of surface lavas, or in the originally structureless deep-seated rocks. Joints are developed in directions inclined or normal to bedding, as in the sedimentary rocks. In mountainous regions the rocks are often folded and plicated in a complicated manner, while fissility, cleavage, and schistosity, which generally accompany folding, are also usually developed. Slatiness and schistosity are especially characteristic of the oldest rocks, known as the Pre-Cambrian gneiss, and often occur over extensive areas.

In certain of the igneous rocks there has developed, either originally or secondarily, a differential parting capacity in three directions. This is exhibited mainly in certain of the rhyolites, in which the large porphyritic individuals have been elongated and flattened in a common direction. The plane of flattening is the direction of easiest parting, and is known as the "rift." The plane normal to this, and extending in the direction of elongation is designated the "run." The third plane, normal to the other two, is known as the "head." These structures do not commonly occur together in the same stone, although they are characteristic of the rhyolite from several of the important quarries in Wisconsin.

In general, it should be noted that the igneous rocks have structures which are in many respects analogous to those of the sedimentary rocks. It is important that one who is working in a quarry should be familiar with all the above structures, as it will often greatly facilitate the work of extracting the stone.