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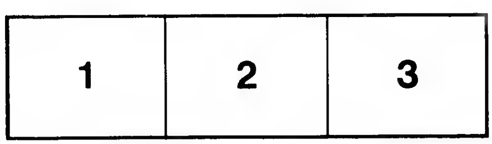

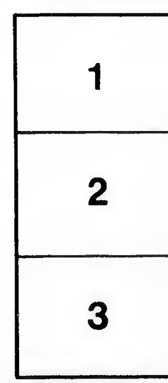

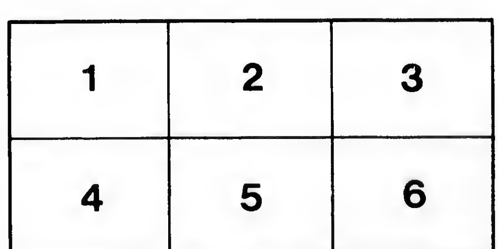

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Geological Department : McGill University.

Description of a Series of Thin Sections of Typical Rocks.

BY

FRANK D. ADAMS, Ph.D., F.G.S.
Logan Professor of Geology in McGill University.

MONTREAL:
1896.

Geol
A

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LIST OF MINERALS DESCRIBED IN THE SECTIONS.

NAME OF MINERAL.	NUMBER OF SECTION.
Andalusite	18
Apatite	3, 5, 15
Biotite	1, 7, 13
Calcite	6, 14, 22, 23, 25
Chlorite	1, 14
Epidote	2
Garnet	4, 5, 19
Graphite	19
Hematite	13
Hornblende	3, 4, 10, 13
Ilmenite	5
Leucite	16
Leucoxene	5
Magnetite	1, 17
Microcline	2
Muscovite	2, 17, 22
Nepheline	4
Nosean	4
Olivine	7, 8, 16
Orthoclase	1, 2, 3, 20
Plagioclase	1, 5, 6, 13, 16, 21
Pyrite	4, 7, 19
Pyroxene (Rhombic)	6
Pyroxene (Monoclinic)	4, 6, 7, 8, 13, 16
Quartz	1, 2, 3, 20
Rutile	19
Serpentine	6, 7, 14, 22
Sillimanite	19

Sphene	3, 4, 5
Tourmaline	18
Zircon	1, 10, 20
Zoisite	5

Glass	9, 10, 14, 16

STRUCTURES EXHIBITED IN THE SECTIONS.

STRUCTURE.	NUMBER OF SECTION.
Allotriomorphic	18
Amygdaloidal	14
Cataclastic	2, 20, 21
Cryptocrystalline	11
Epiclastic	23, 24
Foliated	19, 21
Fluidal	9, 11
Holocrystalline	1, 2, 3
Hypidiomorphic	7
Idiomorphic	13
Massive	1, 2, 3
Microcrystalline	13
Ophitic	15
Poikilitic	8
Porphyritic	11, 13, 16
Spherulitic	11, 12
Semicrystalline	16
Vesicular	11
Vitreous	9, 10

IGNEOUS ROCKS (PLUTONIC DIVISION).

(1). BIOTITE GRANITE—Baveno, Italy.

A typical granite, very extensively quarried, at Baveno, on the S.W. shore of Lago Maggiore, Italy.

Essential constituents	. . .	**Orthoclase, Quartz, Biotite.**
Accessory "	. . .	**Plagioclase, Zircon.**
Secondary "	. . .	**Chlorite, Magnetite.**

Biotite.—This mineral can be at once distinguished from the feldspar and quartz by its brown colour, these other constituents being colourless, or nearly so. It occurs in fairly good crystalline forms.

Two classes of sections can be recognized :—

(*a*) Those parallel to the vertical axis.—These are oblong in form, with one set of well-marked parallel cleavages running in the direction of the longer axis. Since the cleavage of mica is parallel to the base, it is evident that it is parallel to this plane the crystals are elongated. Examined between crossed nicols they are anisotropic, and become alternately light and dark four times during a complete revolution. Extinction (darkness) takes place when the cleavages marking the direction of one of the elasticity axes coincides with the vibration plane of one or other of the nicols; that is, with the hair lines in the ocular. That is to say, these sections show "parallel extinction."

Removing the upper nicol, thus employing the lower nicol alone, and revolving the stage, the sections are found to be pleochroic—*i.e.*, the light passing through them parallel to one axis of elasticity differs in colour from that passing through in the direction of the other. As this change is of the nature of a darkening of the yellow colour of the sections, owing to an absorption of the light passing through in one direction, this phase of pleochroism is referred to simply as absorption. The greatest absorption takes place when the cleavages coincide with the vibration plane of the lower nicol. The character and intensity of the absorption is represented as follows:—

$\mathfrak{a}$ = deep brown,
$\mathfrak{c}$ = pale yellowish brown, $\mathfrak{a} > \mathfrak{c}$

(*b*) Sections parallel to the base.—These are, of course, much less abundant, but a section at least approximately parallel to the base can usually be found. If parallel to the base, these sections will not change in colour on revolving the stage if the lower nicol alone be employed, but will remain of a uniform dark brown colour. When, however, they are examined between crossed nicols in convergent light, they show the black cross of a uniaxial mineral, which, when examined by means of a quarter undulation mica plate, or gypsum plate showing red of the first order, will show a negative sign. On revolving the stage when this black cross is visible, the latter will usually be found to separate into two black hyperboles, which, however, always remain very close to one another. This is due to the fact that biotite is really biaxial, but the axial angle being very small the optical properties of the mineral closely resemble those of a uniaxial mineral·

These sections, being parallel to the base, show no cleavage. They are also more or less irregular in outline, showing that the mineral, while occurring in tabular individuals, is not bounded by well-defined faces in the prismatic zone.

The biotite is frequently altered to **Chlorite**, its most common decomposition product. This, like the biotite, is doubly refracting, and has parallel extinction, but is distinguished from the latter by its green colour and lower double refraction. This alteration may be observed in all its stages.

The chlorite is a typical example of a secondary constituent. Oxide of iron, in the form of **Magnetite**, is often separated out during the alteration and lies embedded in the chlorite.

Orthoclase.—Easily distinguished from the quartz by its turbidity, due to incipient alteration. Most sections are anisotropic, but isotropic sections also occur, and these, being at right angles to an optic axis, show the revolving bar of a biaxial crystal. The mineral possesses good cleavages, especially well seen at the edge of the section. Its crystalline form is less perfect than that of the biotite, which it often encloses. Between crossed nicols, decomposition products in the form of little flecks having a different orientation from their host are frequently seen.

Plagioclase.—Associated with the orthoclase in small amount. Distinguished by its polysynthetic twinning.

Quartz.—In clear fresh grains, without crystalline form, occupying the space between the grains of biotite and feldspar. In places, slightly turbid from the presence of little inclusions, often arranged in little lines or bands, many of which, when examined with a high power, are seen to consist of little cavities, often containing a moving bubble. It is distinguished from the orthoclase not only by its freedom from decomposition products, but also by the absence of cleavage, and by the fact that when isotropic sections are examined between crossed nicols in convergent light the mineral is seen to be uniaxial and negative.

Zircon.—A few little crystals or grains, colourless. Very high index of refraction, giving an appearance of high relief, and also very high double refraction, causing the mineral to polarize in brilliant colours. Occurs as inclusions in all the other constituents.

Note that the constituents have crystallized out in the following order—Zircon, Biotite, Feldspar, Quartz, as indicated by the fact that each mineral contains inclusions of those which precede it in this list, and that this is the order in which the minerals stand in respect of perfection of their crystalline form.

Note, also, that the texture of the rock is **Holocrystalline, Massive,** and **Granitoid.**

(2). BIOTITE MUSCOVITE GRANITE—Stanstead, Province of Quebec, Canada.

A granite occurring as a large intrusive mass cutting strata of Lower Palæozoic age. It is extensively quarried, and used as paving stone in the City of Montreal and for various other purposes elsewhere.

Essential constituents	. . .	**Orthoclase, Quartz, Biotite.**
Accessory "	. . .	**Microcline, Plagioclase.**
Secondary "	. . .	**Muscovite, Epidote.**

Orthoclase—like that in the Baveno granite. It is, however, fresher, and hence clearer, and more transparent. Its cleavages and biaxial character serve to distinguish it from the quartz. Its place is taken to a certain extent by the triclinic form of the molecule, characterized by a very fine cross-hatched structure, produced by a double set of polysynthetic twins, and which is known as **Microcline**. This feldspar is especially abundant in granites and similar rocks which have been submitted to great pressure. Its presence would suggest such pressure in the present case, a suggestion strengthened by a study of some of the other constituents.

A considerable quantity of ordinary **Plagioclase** is also present as an accessory constituent.

Quartz—possesses the various properties described in No. 1. Almost every grain, however, shows an uneven extinction; that is to say, a single individual, when revolved between crossed nicols, does not extinguish simultaneously over its whole surface. This is owing to the fact that the grain has, subsequent to the consolidation of the rock, been twisted by great pressure to which the rock has been subjected. In some cases the movements have been so intense that an individual can be observed to have been broken into several smaller grains, and an incipient **Cataclastic Structure** thus developed. This structure is especially well seen in gneisses and similar rocks, many of which are merely crushed granites.

Biotite.—See No. 1.

Muscovite.—This mica differs from the biotite in being colourless. It is also biaxial, with a large axial angle, hence an isotropic section; *i.e.*, one cut at right angles to an optic axis will show the revolving bar of a biaxial crystal. Granites containing primary muscovite are extremely rare, and there is good reason to believe that the muscovite in this Stanstead rock is all secondary, having been derived in part from the alteration of the biotite and in part from the orthoclase. An ordinary decomposition product is not taken into consideration in naming a rock, but the muscovite does not belong to this category, as it was probably produced deep in the crust of the earth by the same forces which turned the orthoclase to microcline and crushed the quartz; hence it has been considered in naming the rock. It occurs in the feldspar as skeleton crystals, the various parts of which, in the plane of the section, are often completely separated from one another, but which were probably united either above or below, the muscovite individual being in fact in the form of a sponge growing in the feldspar. The separated portions, often mere shreds, are recognized as belonging to the same individual by the fact that they extinguish simultaneously when revolved between crossed nicols. The muscovite is occasionally accompanied by other secondary minerals as epidote, or by a feldspar having a slightly different orientation from the rest of the orthoclase, but it is usually embedded in perfectly fresh and unaltered feldspar, affording a remarkable example of the growth of a new mineral in a solid rock when this latter, in the crust of the earth, has been submitted to conditions differing from those under which the rock originated.*

Epidote.—Nearly colourless. High index of refraction, and high double refraction. Occurs in small amount. Like the muscovite, it is a secondary product.

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* Adams, F. D.: "On some Granites from British Columbia and the adjacent parts of Alaska and the Yukon District."—Canadian Record of Science, September, 1891.

3. HORNBLENDE SYENITE—Plauensche Grunde, near Dresden, Germany.

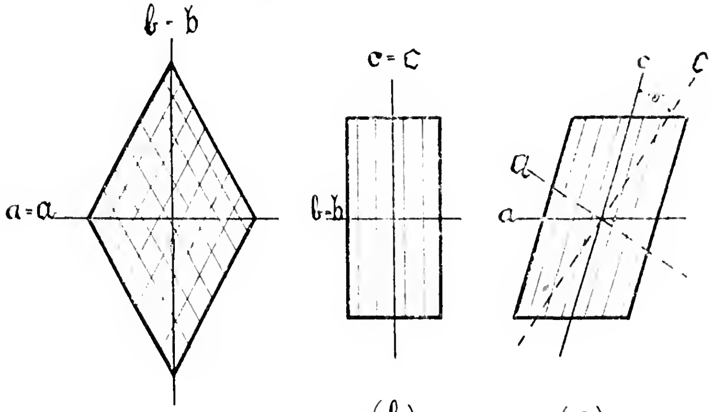
A typical and very celebrated syenite occurring as a large intrusive mass on the outskirts of the city of Dresden, where it is extensively quarried.

Essential constituents . . .	**Orthoclase, Hornblende.**
Accessory " . . .	**Plagioclase, Quartz, Sphene, Magnetite, Apatite.**

Orthoclase.—See Nos. 1 and 2.—Abundant. Often twinned. Associated with it is a certain amount of **Plagioclase**, as in the case of granites

Hornblende.—Abundant. Often with rude crystalline form. Pleochroic.

Three classes of sections will be noted (see accompanying cut), having approximately the following positions :—



SECTIONS OF HORNBLENDE.

(*a*) Parallel to O P.—These show two sets of cleavages crossing one another at angles of about $124\frac{1}{2}°$. Strongly pleochroic. $\mathfrak{a}$ = pale yellow, $\mathfrak{b}$ = dark yellowish-green. Absorption = $\mathfrak{b} > \mathfrak{a}$.

(*b*) Parallel to $\infty P \bar{\infty}$. One set of parallel cleavages, with parallel extinction. Pleochroic, but not very strongly so. $\mathfrak{b}$ = dark yellowish-green, $\mathfrak{c}$ = deep green. Absorption = $\mathfrak{c} > \mathfrak{b}$.

Sections possessing these characters are less abundant than those of the two other classes.

(*c*) Parallel to $\infty P \grave{\infty}$.—One set of parallel cleavages, as in the case of those parallel to $\infty P \bar{\infty}$, but with inclined extinction, the extinction angle being about 18°. Strong pleochroism. $\mathfrak{a}$ = pale yellow, $\mathfrak{c}$ = deep green. Absorption = $\mathfrak{c} > \mathfrak{a}$.

The absorption of the mineral, as determined from these several sections, would therefore be $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

Plagioclase.—Distinguished by its polysynthetic twinning (See No. 5). Present in considerable amount.

Quartz.—Few grains. By an increase in the amount of quartz present, this Plauen syenite, in another part of the area, changes into a granite.

Sphene.—In large individuals, usually presenting the wedge-like forms, often very perfect, from which the name is derived. Brown in colour. With high index of refraction, causing it to have the appearance of standing up from the field; also high double refraction.

The mineral, crystallizing in the triclinic system, is biaxial, so that any section cut at right angles to an optic axis, and therefore isotropic, will show the revolving bar of a biaxial crystal. It is very common in hornblende rocks.

Apatite.—In colourless crystals, usually rather small. These, when cut parallel to the vertical axis, give sections which are oblong in shape, while sections parallel to the base have a hexagonal outline. It has rather a high index of refraction, which causes it to stand up from the field, although the appearance of relief is not very pronounced.

The mineral is uniaxial, and has a very low double refraction, which causes it to polarize in very dull tints. The extinction is parallel in the case of the oblong sections, while the hexagonal sections, being at right angles to the optic axis are isotropic. The revolving bar, however, is not well seen except under the most favourable circumstances, on account of the very low double refraction which the mineral possesses. It occurs sometimes in the form of little irregular grains.

The structure is identical, in all respects, with that of granite.

Magnetite.—A few opaque black grains, often embedded in the hornblende ; often partially altered to hematite, which is transparent and red in colour.

(4). ELAEOLITE SYENITE—Corporation Quarry. Montreal, Canada.

A typical elaeolite, or nepheline syenite, forming a portion of Mount Royal, and extensively quarried for road metal.

Essential constituents	.	**Orthoclase, Elaeolite, Hornblende.**
Accessory "	.	**Plagioclase, Pyroxene, Garnet, Sphene.**
Secondary "	.	**Nosean, Magnetite, Pyrite.**

Orthoclase.—Colourless. Polarizes in dull blue tints. Possesses same characters as in granites (See Nos. 1, 2, and 3). It is often intergrown with the **Plagioclase**, which is present as an accessory constituent, and can be recognized by its polysynthetic twinning. It has been found to be, in part at least, oligoclase.

Elaeolite.—This is also colourless, polarizes in very dull blue tints, and resembles the orthoclase so closely that it is difficult to distinguish the two minerals. It is, however, uniaxial, and if a good basal (isotropic) section can be found, will show a cross instead of a revolving bar, which cross will when tested by a gypsum plate showing red of the first order, prove to be negative. The most satisfactory method of ascertaining how much of the colourless mineral is elaeolite would be to remove the cover glass and etch the slide with hydrochloric acid and then stain with fuchsine, when all the elaeolite would appear red, while the feldspar would remain unacted upon.

Hornblende.—Deep green in colour, showing the same cleavages and general characters as that in No. 3. It has, however, a somewhat larger extinction angle and a remarkably small axial angle. It is very rich in iron, and in composition probably resembles closely the remarkable hornblende which occurs in the nepheline syenite from Dungannon, Ontario.* It is in places intergrown with some pyroxene, rather paler in colour, and distinguished by the fact that the two sets of cleavages cross at right angles, as well as by its much larger extinction angle. (See No. 7).

Garnet.—Occurs in occasional large grains of a brown colour and very irregular shape. It is transparent, and when

* Adams, F. D.: "On a new Soda Hornblende from the Nepheline Syenite of Dungannon, Ontario."—American Journal of Science, March, 1895.

examined between crossed nicols is found to be perfectly isotropic. It also possesses a high index of refraction, which causes it to stand up from the field. It contains many inclusions of other minerals, especially of hornblende and nosean, which shows that it must have crystallized out after these constituents, which is not usually the case, garnet being, as a general rule, in rocks of this class, one of the first constituents to separate out.

Sphene.—In numerous little crystals of a pale yellow colour, with the characteristic wedge-like form and high index of refraction. (See No. 3).

Nosean.—This mineral is present in considerable quantity in the form of colourless grains which at the first glance might be mistaken for the nepheline or orthoclase. An examination between crossed nicols, however, shows that they are quite isotropic. The grains possess good crystalline form, and towards the centre are usually filled with minute, opaque, black particles of magnetite, while the borders of the grains are quite clear and free from inclusions. These inclusions make it easy to recognize the nosean grains even before polarized light is employed in the examination. This mineral is rarely found in nepheline syenites, but is common in certain other classes of nepheline rocks.

Magnetite.—A small amount, associated with a little **Pyrite.**

(5). HORNBLENDE DIORITE—Halsbrücke, Kingdom of Saxony,

Essential constituents	. . .	**Hornblende, Plagioclase,**
Accessory "	. . .	**Garnet, Apatite, Iron Ore,**
Secondary "	. . .	**Leucoxene, Zoisite, etc.**

Hornblende.—As in syenite. (See No. 3).

Plagioclase.—Colourless, clear and transparent, except when decomposed, it being then grey and turbid. Its cleavages can be readily seen, especially about the edge of the section. It can be readily recognized by the polysynthetic twinning, according to the albite law, which results in the development of a series of parallel bands of colour crossing the grains. These, of course, can only be seen when the section is examined between crossed nicols. These bands are so arranged that the alternate bands of the series in any grain extinguish simultaneously as the stage is revolved. In this way the whole grain is never black at any time during a complete revolution, for while one set of bands are light the other set are dark. If the mineral is cut parallel to the twinning plane, these twin lines will not, of course, be seen; so that the absence of twinning is not a proof that the mineral is not plagioclase. In some instances furthermore, although these are rare, the plagioclase occurs in untwinned crystals, and therefore does not show the banding described. In this section there is a considerable amount of untwinned feldspar, which in this way may really be plagioclase; or there may be a certain amount of orthoclase associated with the plagioclase in the rock, as an accessory constituent. In order to decide this, a separation by means of a heavy solution would have to be made.

The turbid, almost opaque, lath-shaped forms, now consisting of an aggregate of minute grains of zoisite and other minerals, are probably also decomposed plagioclase; perhaps more basic than the rest of the plagioclase, and hence more readily decomposed. The **Zoisite** is colourless, and is recognized by its high index of refraction and low double refraction, polarizing in very dull blue colours.

Garnet.—In almost colourless grains, usually of irregular shape. High index of refraction. Perfectly isotropic. Traversed by numerous cracks. Sometimes encloses grains of hornblende as well as little grains of zoisite. (See No. 4).

Apatite.—Some slides contain a considerable amount; in rather large, colourless grains of rounded outline. (See No. 3).

Titanic Iron Ore.—Opaque grains, black by reflected light.

Leucoxene.—The iron ore is usually surrounded by a narrow zone of a transparent mineral, having a very high index of refraction and also a very high double refraction. This is a decomposition product of the iron ore, and is a silico-titanate of lime, called leucoxene, being in fact merely a variety of sphene. Its presence here proves that the iron ore is at least titaniferous, if not a true ilmenite. It is very commonly found associated with the iron ore of gabbros, especially when these rocks are much decomposed.

(6). ANORTHOSITE—Four Miles East of Ste. Agathe, Province of Quebec, Canada.

This rock (Anorthosite) is a variety of gabbro in which the plagioclase preponderates almost to the exclusion of the other constituents.

This specimen of anorthosite is typical of the rock as developed in the great intrusions which cut through the Laurentian in various parts of Canada, and often occupy areas of several thousand square miles. The slide represents the rock near the centre of what is known as the Morin intrusion, which has an area of about one thousand square miles, and shows the rock as it appears when it has not been crushed or granulated by pressure. Section 16 shows the same rock from the margin of the area, where it has been completely granulated by the great pressure to which it has been submitted.

Essential constituents	.	**Plagioclase, Augite, Hypersthene.**
Accessory "	.	**Ilmenite, Biotite, Pyrite.**
Secondary "	.	**Serpentine, Chlorite, Calcite.**

Plagioclase.—The polysynthetic twinning, explained in the description of No. 6 is excellently seen. The rock is composed almost exclusively of plagioclase, and almost every grain is twinned. Occasionally a second set of twin lines are seen cutting the first, approximately at right angles. These are due to the fact that the individual showing them is twinned according to the Pericline as well as to the Albite law. The feldspar is filled with minute dust-like inclusions, with some larger rod-like inclusions which run in certain definite directions through the crystals. They are opaque, or nearly so. They belong to the class of what Professor Judd* has called "Schillerization Products"—for it is their presence that gives to many feldspars as well as other minerals, the peculiar "Schiller" or play of colours which they often exhibit. They are found principally, if not exclusively, in rocks which have been deeply buried, and Professor Judd believes that they are secondary and fill minute cavities which are developed along certain planes ("solution planes") in a mineral, when it is subjected to great pressure, without being actually crushed, in the deeper portions of the earth's crust. They sometimes have the appearance of partially filling cavities, as can be seen in this section if it be examined under a high power. The inclusions in the case of the

* "The Tertiary and older Peridotites of Scotland."—Q. J. G. S., August, 1895.

present rock probably consist for the most part of titanic iron ore.*

The plagioclase is either a basic labradorite or bytownite.

Augite.—As this mineral occurs much more abundantly in the olivine gabbro (No. 7), its optical properties will be there described in detail.

It is pale green in colour, not pleochroic, and has an extinction angle of over 40°. It usually contains, more or less abundantly, dark schillerization products similar to those described in the feldspar, but is present in much smaller amount than the feldspar.

It is often much decomposed, the chief alteration product being a rhombohedral carbonate, either **Calcite** or dolomite, recognized by the peculiar silvery tints which it presents between crossed nicols, and an almost isotropic pale green **Chlorite.**

Hypersthene.—Intergrown with the augite is a rhombic pyroxene, probably bolonging to the species hypersthene. When fresh it is recognized by its lower double refraction, its parallel extinction, and faint pleochroism in pale green and pale reddish tints. It is, however, more easily decomposed than the augite, and is here seldom seen in a fresh state, being represented chiefly by decomposition products retaining the form of the original grains, and consisting chiefly of **Serpentine** or bastite and a carbonate like that above described.

Ilmenite.—A few grains, sometimes partly decomposed to hematite and sometimes to leucoxene.

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* Adams. F. D.: "Ueber das Norian oder Ober-Laurentian von Canada."—N. J. für Min., etc., Beil. Bd., VIII. 1893, Translated in Can. Rec. of Sc., Vol. VI., 1895. See p. 169.

Biotite.—A few grains in some slides. Deep brown in colour and showing the usual pleochroism and absorption.

Pyrite.—A very few grains.

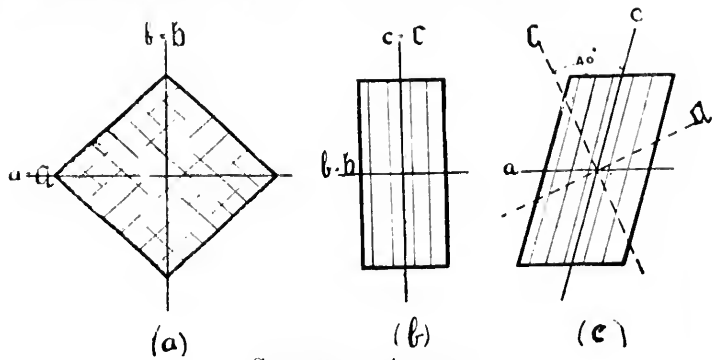
(7). OLIVINE GABBRO—Mount Washington River, New Hampshire, U.S.A.

A typical olivine gabbro, occurring in large intrusive masses.

Essential constituents	. .	**Plagioclase, Augite, Olivine.**
Accessory "	. .	**Biotite, Iron Ore, Apatite, Pyrite.**
Secondary "	. .	**Serpentine.**

Plagioclase.—See Nos. 5 and 6.—The plagioclase in this rock has been analyzed and found to be labradorite.

Augite.—Large amount. Pale brownish in colour. As in hornblende (see No. 3) there are three classes of sections, having approximately the following positions :—



SECTIONS OF AUGITE.

(*a*) Parallel to O P—These show two sets of cleavages, intersecting nearly at right angles, and not so perfect as those of hornblende. The direction of extinction bisects the angles made by the intersection of these cleavages. By determining the position of the plane of the optic axes, in sections cut at right angles to an optic axis, these cleavages can be proved to be prismatic.

(*b*) Parallel to $\infty P \bar{\infty}$. One set of parallel cleavages, and extinction coinciding with them.

(*c*) Parallel to $\infty P \breve{\infty}$. One set of parallel cleavages, but with inclined extinction, the angle of extinction being very large, reaching 45°.

Sections in intermediate directions and showing correspondingly intermediate characters are also, of course, present.

The mineral has no pleochroism. It is occasionally twinned.

Olivine.—Very pale green in colour, almost colourless, with higher index of refraction than the augite, giving it the appearance of possessing a rough surface, like ground glass, and also of standing out more prominently from the field. Its cleavage is indistinct and imperfect, but, where seen, the extinction is parallel to it. The mineral is, however, traversed by many large irregular cracks. It has a high double refraction, and thus in this section, which is thin, polarizes in brilliant colours. In some slides twin crystals are seen. It is usually more or less decomposed to **Serpentine**, which is developed along the cracks traversing the olivine, and is recognized by its green colour, low double refraction, and aggregate polarization.

Biotite.—See No. 1.—Occurs chiefly as borders about the grains of iron ore, and is especially well developed when the iron ore would otherwise come against the plagioclase.

Iron Ore.—Probably ilmenite or highly titaniferous magnetite. Considerable quantity. Black and opaque.

Apatite.—A number of grains.—(See No. 3).

Pyrite.—A few little grains. Recognized by its yellow metallic lustre when examined by reflected light.

The order of crystallization has been essentially as follows :

Iron Ore and Apatite, Olivine, Biotite, Augite, Plagioclase.

Structure—**Hypidiomorphic.**

(8). PERIDOTITE—Ile de France, Matawin River, Province of Quebec, Canada.

A large dyke-like mass, cutting Laurentian Gneiss, and representing an extreme variation of the gabbro magma in one direction as anorthosite (see No. 6) does in another.

Essential constituents	. .	**Olivine, Augite.**
Accessory "	. .	**Biotite, Hornblende, Pyrite.**
Secondary "	. .	**Serpentine, Iron Ore.**

Olivine.—See No. 7.—Often altered along cracks to a mixture of serpentine and iron ore.

Augite.—See No. 7.—Nearly colourless. Resembles the olivine somewhat, but is distinguished by its cleavage and other characters already described.

Biotite.—See No. 1.—Strong pleochroism and good cleavage, with parallel extinction.

Hornblende.—See No. 3.—Brown in colour, but not so intensely coloured as the biotite, and much less abundant. Distinguished by its cleavage as well as by its inclined extinction and other optical properties. Often intergrown with the augite. This variety of Peridotite, composed essentially of olivine and augite, is called **Pikrite.**

In many sections of the rock a **Poikilitic Structure** is seen, produced by the presence in a single large individual of one mineral, *e.g.*, biotite, of a large number of grains of other constituents of the rock embedded quite without reference to the crystallographic orientation of their host or of one another.*

* Williams, G. H.: "On the Use of the Terms Poikilitic and Mikropoikilitic in Petrography."—Journal of Geology, February, 1893.

IGNEOUS ROCKS (VOLCANIC DIVISION).

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(9). OBSIDIAN—Yellowstone National Park, Wyoming, U.S.A.

Occurs as a cliff, from 150 to 200 feet high, forming part of a great surface flow of obsidian or volcanic glass.*

The rock consists of a nearly colourless isotropic **Glass**, through which are distributed immense numbers of minute **Microlites** and **Trichites.** The microlites are transparent, and about ·0002 inch in diameter, and occur either separately or strung like beads on little opaque threads. They are rudimentary crystals of **Augite.** The trichites are black hair-like bodies, and about ·000032 inch wide, and may be traced through different stages of growth into grains of magnetite, which in larger form are recognized in the glass as intimately associated with the augite, usually enclosed in a grain or crystal of the latter mineral. These trichites give the obsidian its black colour. Traces of **Flow Structure** can be seen in most sections. In some sections, little crystals and irregular spherulites are seen, which are composed of a micro-pegmatitic intergrowth of quartz and feldspar.

(10). PITCHSTONE—Arran, Scotland.

Occurs in the form of dykes, probably of Tertiary age.

A nearly colourless, isotropic **Glass**, filled with greenish, acicular **Microlites**, sometimes so minute and so numerous as

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Iddings, J. P.: "Obsidian Cliff, Yellowstone National Park."—Seventh Annual Report of the U. S. Geol. Survey, 1885-86.

to give merely a dusty aspect to the section when viewed with a low power, sometimes large enough to show crystallographic outlines. These are often aggregated together so as to form exquisite arborescent groups, resembling ferns or fir trees, and sometimes have the shape of dumb-bells, etc. Each group, having concentrated in itself the colouring matter from the immediate vicinity, is surrounded by a zone of clear glass. These microlites consist of **Hornblende**—the green colour and small extinction angle (about 15°) can often be observed in the larger individuals. In almost every section one or two rounded phenocrysts of **Quartz, Sanidine** or **Plagioclase** are met with, holding inclusions of the glassy base; also a grain or two of **Magnetite** and of a colourless transparent mineral, with high index of refraction and high double refraction, which is probably **Zircon**.

(11) RHYOLITE—Kremnicka, Hungary.

The product of one of a series of great eruptions of Tertiary age. In this slide the **Porphyritic Structure**, with well-marked distinction between phenocrysts and groundmass, which is the usual structure in volcanic rocks, is seen.

In rhyolite, as a general rule, phenocrysts of quartz, feldspar, and biotite are present. In this section the **Biotite** and **Feldspar** alone are found, quartz phenocrysts not being common in the rock. The biotite shows, in a more or less well marked manner, the absorption phenomenon, known as the **Opacite Rim** (See No. 13). Indications of **Flow Structure** can generally be seen. The groundmass is in a much more highly devitrified condition than in Nos. 9 or 10. It is for the most part **Cryptocrystalline**, consisting, probably, of an exceedingly fine-grained intergrowth of quartz and feldspar (See No. 9). Much of it has a rudely **Spherulitic** arrangement. The rock being somewhat **Vesicular**, a number of elongated irregular-shaped holes are seen in the slide.

(12). APORHYOLITE—Raccoon Creek, Pennsylvania, U.S.A.*

A rhyolite of pre-Cambrian age, being a representative of the great volcanic outbursts of this age which are found along the line of the Appalachian mountain chain from Gaspe to Georgia. The original glassy rock has in the lapse of ages become thoroughly devitrified. The phenocrysts are chiefly **Orthoclase**; some are of **Plagioclase**. These preserve their perfect crystalline outlines, and in many instances hold inclusions of the groundmass as in the case of modern volcanic rocks.

The **Groundmass** is a very fine quartz-feldspar mosaic, through which there is a certain amount of finely disseminated sesquioxide of iron. This mosaic is very largely the result of devitrification and recrystallization, but a portion of it may represent an original microgranitic groundmass. Numerous areas of a rounded or more or less irregular shape, and coarsely crystalline in character, are seen. These consist for the most part of quartz. Of these there are two kinds, representing two different structures in the original rock. One kind, usually irregular in shape, often long and narrow as if drawn out by movements in the liqu

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* Williams, G. H.: "The Volcanic Rocks of South Mountain in Pennsylvania and Maryland."—Amer. Jour. of Science, December, 1892.

Bascom, F.: "The Structures, Origin, and Nomenclature of the Acid Volcanic Rocks of South Mountain."—Jour. of Geology, Nov. 1893.

rock, with well-defined walls, were originally **Vesicles.** They often show a banded arrangement about their borders, following all the windings of the wall, representing deposits of secondary minerals in the vesicular cavities. Little spherulites or groups of crystals, originally of tridymite now converted into quartz, are often seen on the walls of the original cavities, precisely as in the case of modern lavas. The other kind are usually more rounded in shape and not so sharply defined against the groundmass; faint concentric markings can often be traced about them in the groundmass, and areas of the groundmass—in the centre of each of which one of these coarsely-crystalline mosaics occurs—are marked off from one another by a line of iron oxide, which lines form a species of network in the slide. These, it has been found, from the study of a large number of specimens, were originally **Spherulites,** which have been more or less completely obliterated by devitrification, the centre of each having been dissolved away and replaced by the mosaic in question.

The rock was therefore, originally, a vesicular spherulitic glassy rhyolite.

The prefix *apo* is employed to indicate the specific alteration known as devitrification: an aporhyolite is therefore a devitrified rhyolite.

(13). HORNBLENDE ANDESITE—Stenzelberg, Siebengebirge, Germany.

Essential constituents (in form of Phenocrysts),
Hornblende, Plagioclase.

Accessory constituents (in form of Phenocrysts),
Augite, Biotite, Magnetite, Hematite.

Groundmass.

The phenocrysts, being perfect crystals, are **Idiomorphic** and show good crystalline outlines. They show the cleavages and optical properties severally characteristic of them, as already described (See Nos. 1, 3, and 7).

The **Hornblende** and **Biotite** crystals are always surrounded by a dark border, known as the "**opacite rim**," which consists of a mixture of **Augite** and **Magnetite** in very minute grains. This is due to the corrosive action of the magma on these first-mentioned minerals after they had crystallized out. The corrosive action is sometimes seen to have gone so far that the hornblende or biotite have entirely disappeared, leaving only an aggregate of little black grains.

As augite is one of the products of this action, the augite grains themselves are not attacked, and have no border.

The **Plagioclase** usually shows growth rings, and is excellently twinned, often according to both laws, while both the hornblende and augite frequently show twinning also.

Many small irregular-shaped grains of **Magnetite** are scattered through the rock.

The **Groundmass** is essentially microcrystalline, and is made up chiefly of little lath-shaped crystals of plagioclase with minute grains of augite and magnetite, often showing distinct flow structure. A considerable amount of **Hematite**, bright red by reflected light, occurs finely disseminated through portions of the groundmass.

(14). MELAPHYRE—Oberstein, a.d. Nahe, Germany.

Occurs as sheets and flows, interstratified with rocks of Permian age.

A melaphyre containing phenocrysts of **Olivine** and **Augite** as well as phenocrysts of **Plagioclase**.

In this particular specimen, however, these minerals are less abundant than usual, olivine not being present in every slide and augite being rarely found; so that, judging from some of the sections, the rock might be classed as a labradorite porphyrite.

The **Olivine**, where originally present, is now always entirely altered to **Serpentine**, which still retains the form of the olivine grains, and is recognized by its pale green colour, fibrous structure, and aggregate polarization.

The transparent reddish-brown lines and bands which traverse the **Plagioclase** phenocrysts are due to **Oxide of iron** infiltrated into cracks in the crystals, and derived from the alteration of various ferruginous minerals in the rock. The same material, by its presence all through the groundmass, gives the rock its dark opaque character.

The **Groundmass** consists chiefly of minute lath-shaped crystals of plagioclase, but between them a certain amount of **Glass** filled with dark inclusions still remains, and can be recognized by its isotropic character.

The **Amygdaloidal Structure** of the rock is remarkably well seen. The smooth outline of the cavities will be noted, as well as the concentric arrangement of the minerals filling them. Some of these have a beautiful **Spherulitic** arrangement. They are **Calcite, Chlorite, Quartz,** often in the form of **Chalcedony**, and occasionally **Zeolites.**

Quartz is not found in all sections, and when it does occur is present only in very small amount.

The **Apatite** needles are often very long and slender. A few grains of **Pyrite** are usually present.

(15). OLIVINE DIABASE—Near Sudbury, Ontario, Canada.

Occurs in the form of a large dyke cutting rocks of Huronian age.

Essential constituents . . **Plagioclase, Augite, Olivine.**
Accessory " . . **Iron Ore, Biotite, Apatite, Quartz, Pyrite.**
Secondary " . . **Serpentine, Chlorite.**

A fresh and typical rock of this class, differs from No. 7 only in structure, the same minerals being present in both rocks.

This rock shows the "**Diabase**" or "**Ophitic**" **Structure,** the **Plagioclase** occurring in long lath-shaped crystals, running into the **Augite,** which crystallized later than the plagioclase.

(16). LEUCITE BASANITE - Mount Vesuvius, Italy.

A Vesuvian lava of the eruption of 1873.

Essential constituents (in the form of Phenocrysts), **Leucite, Plagioclase, Augite, Olivine.**
Accessory " **Magnetite.**
Groundmass or base.

The rock has a typical porphyritic structure.

The **Leucite** occurs in clear colourless crystals with polygonal outlines, of approximately circular shape. These are sections through tetragonal trisoctahedra or other allied forms of the isometric system. Between crossed nicols they appear isotropic, or show sets of parallel and very faint bands of colour crossing one another. These are probably due to a complicated system of twinning, and are seen more particularly in the large individuals—smaller ones being usually quite isotropic.

The **Plagioclase** occurs in well defined colourless lath shaped individuals having the usual polysynthetic twinning.

The **Augite** is pale green in colour, and occurs with good crystal outlines. It may be recognized by its cleavages and its optical properties.

The **Olivine** is also in good crystals, but is colourless, and possesses its distinctive optical properties. See No. 7.

Magnetite.—A few small grains.

The **Base** or **Groundmass**, in which these phenocrysts are embedded, is a brown isotropic **glass.**

METAMORPHIC ROCKS.

(17). SPOTTED CLAY SLATE—Andlau Valley, Vosges Mountains, Germany.

This rock, as well as No. 18, are taken from the celebrated Barr-Andlau Granite Contact Zone, made classical by the investigations of Prof. Rosenbusch.*

This section, which really represents a transition between what are known as the Spotted Clay Slate and the Spotted Mica Schist Zones, shows the clay slate in an incipient stage of alteration, while No. 18 shows it in its most altered condition.

The section presents a lighter coloured portion with numerous dark spots disseminated through it.

The **darker spots** represent portions of the original slate in an almost unaltered condition. Their presence is very characteristic of the outer and less altered portions of contact zones, in cases where the altered rock was originally a shale or slate. They are composed for the most part of the same minerals as the lighter coloured portion, but in much smaller individuals and with more carbonaceous pigment and much less muscovite.

The **lighter coloured portion** is the metamorphosed portion of the rock. When examined under a very high power it is

* "Die Steiger Schiefer und ihre Contactzone an den Graniten von Barr-Andlau und Hochwald." Abh. zur Geol. Specialkarte von Elsass. —Lothringen, Strassburg, 1877.

seen to be composed of minute shreds of **Muscovite** and **Kaolin** (which resemble one another very closely), minute grains of **Quartz**, some black **Carbonaceous Pigment**, with a few grains of **Tourmaline** and possibly a little chlorite. Crystals of **Magnetite** have also been developed all through the altered portion.

(18). ANDALUSITE HORNSTONE—Near Andlau, Vosges Mountains, Germany.

From same contact zone as No. 17 (which see), but nearer the granite, being produced by the recrystallization of the slate into a comparatively coarse grained aggregate of several minerals. Of these, **Quartz, Biotite, Muscovite** and **Magnetite** are abundant, and will be readily recognized. A portion of the opaque black mineral which looks like iron ore is graphite.

Andalusite is present in large amount. It is colourless and possesses a high index of refraction, but a low double refraction. The extinction is parallel. It also shows a faint but very characteristic pleochroism—pale red and pale green, the former in the direction of the vertical axis, the latter at right angles to it.

Tourmaline.—A few little grains, with high index of refraction, strong pleochroism, and deep greenish-black colour.

The minerals are perfectly **Allotriomorphic,** and grow through one another in an irregular manner, quite different from the orderly succession of crystallization found in igneous rocks.

(19). SILLIMANITE GNEISS—St. Jean de Matha, Province of Quebec, Canada.

Occurs in thick bands, interstratified with a white garnetiferous quartzite, the whole lying nearly flat, and forming part of the Grenville Series (Laurentian).

This gneiss has the chemical composition of an ordinary clay slate, and in all probability represents an extremely altered form of an ordinary sedimentary rock.*

Essential constituents . . **Orthoclase, Quartz, Sillimanite, Garnet.**

Accessory " . . **Pyrite, Graphite, Rutile, Biotite.**

Orthoclase.—See No. 1.

Quartz.—See No. 1.—This, as well as the orthoclase, usually shows some evidences of pressure in a slightly uneven extinction. Frequently in long and narrow grains, their long axes being arranged parallel to the foliation of the rock.

Sillimanite.—Abundant, and usually occurs in large individuals. It is colourless, and has both a high index of refraction and a high double refraction, which enables it to be readily distinguished from the quartz or orthoclase. It crystallizes in long, nearly square, prisms, with a single good cleavage parallel to a pinacoid. There are thus two sorts of sections to be observed :—

(*a*) Elongated sections, parallel to the vertical axis, which may or may not show a cleavage parallel to their length, according to the plane in which they lie. They show parallel extinction, and high polarization colours.

(*b*) Basal sections, nearly square in cross section, and showing a good cleavage bisecting two of the angles. These are nearly isotropic. In convergent light the mineral is seen to possess a very small axial angle and to be positive.

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* Adams, F. D. : "A Further Contribution to our Knowledge of the Laurentian."—American Journal of Science, July, 1895.

Garnet.—See Nos. 4 and 5.—In large irregular shaped colourless individuals. Perfectly isotropic. Often holds inclusions of sillimanite, rutile, etc., as if it had grown around them.

Pyrite.—See Nos. 4 and 7.—Very considerable amount. In irregular shaped little strings and grains. Probably appeared after the development of the other constituents, as it is frequently seen to occupy little cracks in the rock. It is associated, in some slides, with a little pyrrhotite. Hydrated sesquioxide of iron, reddish brown by reflected light, occurs as a decomposition product, running through the rock in cracks and along the cleavages of the various minerals.

Graphite.—In long and narrow opaque black strings or in scales.

Rutite.—In small, irregular shaped, deep brown grains; nearly opaque. High index of refraction.

Biotite.—A few grains, deep brown in colour.

(20). HORNBLENDE GNEISS—Trembling Mountain, Province of Quebec, Canada.

Trembling Mountain, whose summit is the highest point in the Laurentian plateau in this part of the Dominion, was was referred to by Sir William Logan as a typical occurrence of the Fundamental Gneiss. The rock possesses a distinct although not a very perfect foliated structure, and forms almost the entire mass of the mountain.

It has the chemical composition of a granite, and is nothing more than a hornblende granite of igneous origin, which by great earth movements has been squeezed into the form of a gneiss.*

* Adams, F. D.: "A Further Contribution to our Knowledge of the Laurentian."—American Journal of Science, July, 1895.

Essential constituents	. .	**Orthoclase, Quartz, Hornblende.**
Accessory "	. .	**Biotite, Magnetite, Zircon, Apatite.**

Orthoclase.—The rock consists principally of rather large and very irregular shaped orthoclase grains imbedded in a mass of finely granulated rice like material, also orthoclase for the most part. The large individuals show "strain shadows," and often a somewhat fibrous appearance, due to a very fine microperthitic intergrowth. The finely granulated material is formed by the peripheral granulation of the larger individuals.

Quartz.—A few large individuals, also irregular in shape and with uneven extinction, often much broken. Also, a number of smaller grains intermixed with finely granulated orthoclase.

Hornblende.—See No. 4.—Strings of small grains, green in colour.

Biotite.—A few grains.

Magnetite.—An opaque black iron ore, in irregular shaped grains, usually associated with the hornblende. There is also a hydrated oxide of iron, which occurs in small amount as a secondary product, and has found its way between the grains of the several minerals or into their cleavages, thus staining the rock.

Zircon.—See No. 1.—A number of minute prismatic crystals, with high index of refraction, high double refraction and parallel extinction.

Apatite.—See No. 3.—A few small grains.

The rock shows a **Cataclastic Structure**, the foliation having been produced by pressure.

(21.) FOLIATED ANORTHOSITE—Near Chertsey, Province of Quebec, Canada.

This is a finely foliated variety of No. 6, taken from the margin of the same area, the Morin anorthosite. Here, however, the rock has moved like a plastic mass under the influence of the great pressure to which it has been subjected, and the manner in which the movement has taken place is clearly seen in the slide. Both the **Plagioclase** and the **Pyroxene** individuals, while remaining unaltered in composition, have, under the influence of the pressure, been granulated, and the broken grains have moved in a direction at right angles to the pressure, and are often seen to be arranged in long strings or trails on either side of a remnant of the large original individual from which they were derived, which shows well-marked **Strain Shadows**, and can often be seen to be in the very act of shearing into two smaller individuals, very long and narrow, or to be gradually breaking down by peripheral granulation.

Whenever this granulation sets in the Schillerization products disappear. This slide show excellently one way in which a foliated rock is developed from a massive rock. It should be studied in connection with No. 6.

(22). SERPENTINE LIMESTONE—Near Rawdon, Province of Quebec, Canada.

A typical Laurentian crystalline limestone, occurring as a thick band interstratified with gneiss.

Essential Constituents . . .	**Calcite, Serpentine.**
Accessory " . . .	**Muscovite.**

Calcite.—High index of refraction and very high double refraction, causing the mineral to polarize in silvery tints.

The rhombohedral cleavage is very distinct. The mineral is in some places clear and transparent, while in other places it is turbid from the presence of numerous dust like inclusions. The same grain will sometimes be clear in one part and turbid in another. These turbid spaces are highly suggestive of obliterated fossil fragments. (See Section No. 25.)

Serpentine.—In rounded grains of a very pale green colour, embedded in the calcite. Has a very low double refraction and shows aggregate polarization.

Muscovite.—A number of rather large grains, usually somewhat bent or twisted. (See No. 2.)

AQUEOUS ROCKS.

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(23). ARKOSE—Campbellton, Prince Edward Island, Canada.

A highly feldspathic redsand stone of Permo-Carboniferous age.

Quartz.—Abundant. Often shows strain shadows, indicating that it has been originally derived, in part at least, from gneiss or some other quartzose rock which has been submitted to great pressure.

Orthoclase.—Much kaolinized.

Plagioclase.—A few grains.

Muscovite.—A few grains.

Calcite.—Chiefly in the form of large individuals serving as a cement.

A few composite fragments consisting of fine grained sandstone, etc., are present. A good deal of reddish hydrate oxide of iron also occurs coating the grains or scattered through the rock, giving to it its red colar.

The rock has a typical **Clastic Structure,** being made up of broken grains of various minerals with some composite rock fragments.

(24). SANDSTONE—Lachute, Province of Quebec, Canada.

A typical quartzose sandstone of Potsdam age. Made up almost exclusively of clear transparent quartz grains, more or less perfectly rounded in shape. The original outlines of the grains are marked by the lines of impurities which coated the surface of the original grains. The most interesting and important point to note in the section is that the original grains have in many cases become enlarged by the deposition of **Secondary Silica** in the little interspaces between the grains, the silica so deposited having the optical orientation of the adjacent quartz grain. A little space between, say, three grains, can often be observed which has thus become filled up with quartz, portions of which are orientated parallel to each of the three quartz grains, as can be ascertained by an examination between crossed nicols.

This process results in the formation of a quartzite from a sandstone.*

The rock process is a typical **Clastic Structure.**

(25). FOSSILIFEROUS LIMESTONE—Montreal, Province of Quebec, Canada.

A dark gray stratified limestone of Trenton age.

Composed exclusively of calcite, containing in places as an impurity a certain amount of a dark carbonaceous material in minute disseminated grains, which give to the limestone its dark colour.

A large part of this calcite, comprising almost all that darkened by the presence of the impurities above referred to, consists of the fragments of broken up fossils of several kinds. The forms can be readily recognized as of organic origin, and are quite different from anything seen in other sections of this collection. Among these fragments those of **Monticulipora** and **Ptilodictya** are most abundant, both made up of cells usually oval in section, the latter having the cells

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* Irving and Van Hise: "On Secondary Enlargements of Mineral Fragments in Certain Rocks."—Bull. U.S. Geol. Survey, No. 8, 1884.

in two rows, arranged either side of a central canal. Next in abundance are fragments of **Crinoids,** some of them annular cross sections of elements of the stalk; others of various shapes, according to the forms of the plates and the direction of the sections. A few long, narrow forms, showing little or no structure, are cross sections of **Brachiopod Shells.**

Between these fossil fragments and filling up their cells is a cement consisting of large clear calcite individuals, which show the perfect rhombohedral cleavage and various optical properties of the mineral (see No. 22). These can often be observed to form a clear border about a fossil fragment, while the latter can be recognized only by its darker color, due to the inclusions of carbonaceous matter. This is especially noticeable in the case of the crinoid fragments, for even in a living state each crinoid element is a skeleton crystal of calcite, and hence the secondary calcite is deposited in optical continuity with original calcite of the fragment, and the whole polarizes as a single individual. In such a composite grain the original fragment is seen as a more or less sharply defined dark inclusion, the boundaries in some instances, however being indistinct, the original fragment being represented merely by a turbid area in the interior of the grain, like that seen in some cases in Section No. 22, and in the description of that Section stated to be suggestive of an organic origin of the limestone.

Before consolidation this limestone must have been a material closely resembling the "coral sands" found about the coral reefs of the modern seas.*

* See Sir William Dawson: "On the Microscopic Structure of some Canadian Limestones." Can. Nat., June, 1859.

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