

CRYSTALLINE LIMESTONES AND ASSOCIATED ROCKS OF
THE NORTHWESTERN ADIRONDACK REGION

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(Read before the Society December 28, 1894)

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INTRODUCTION.

Since the publication of the report of Emmons on the geology of the second district of New York, the northern and western portions of the Adirondack region have received little more than casual mention in geologic literature. This is even more markedly true than in the case of the eastern counties, though little enough has been done there until quite recently.

Having spent some time in the contiguous portions of Saint Lawrence, Jefferson and Lewis counties, the writer has ascertained certain facts which may be taken as a starting point for an inquiry into the geologic relations of the region. Although but little more than a beginning has been made, it seems expedient to present some of these facts with the conclusions drawn from them, particularly to establish a basis of comparison between the phenomena exhibited in different portions of the Adirondack region. With this end in view it is proposed to give a condensed description of the limestones themselves, with a more detailed account of those other crystalline rocks of the region whose character and relations to the limestones are pretty clearly established.

EXTENT AND CHARACTER OF THE LIMESTONES.

There is a marked contrast in the extent of the limestones between the region described by Professor Kemp in the preceding paper and that now under consideration. In Essex county they form rather limited patches, while in Saint Lawrence, Jefferson and Lewis counties they constitute extended belts many square miles in area. For instance, a limestone belt begins near the village of Antwerp, and extends eastward across the township of that name, across Rossie and Gouverneur, into Hermon. This belt has been traced more than twenty miles along the strike, while the average width is perhaps six miles. A narrower belt extends across Fowler into Edwards township, and is distinguished by containing extensive talc deposits. Farther to the south, a third belt of limestone, that appears from beneath superficial deposits which probably hide an extension westward, begins just west of the village of Natural Bridge, Jefferson county. This belt crosses the townships of Diana, Lewis county, and Pitcairn, Saint Lawrence county, with an average width of two or three miles, narrowing toward the east and passing into Edwards. No extended belt is known farther south, though this may be due to the fact that in this direction there is a dense and unfrequented forest; but scattered patches of limestone have been noted in various portions of

Herkimer and Hamilton counties. Similar patches occur in the region under consideration, in addition to the extensive belts.

The limestone in all of these belts is highly crystalline, rather coarse, and usually light gray or white, though darker gray portions occur. Of the disseminated minerals phlogopite, graphite, pyroxene and tremolite are most common. They may be evenly distributed or segregated in lumps, the tendency toward the latter mode of occurrence being less marked than in the eastern section.

In general the limestone is very massive, so that it is difficult to ascertain the strike and dip with any degree of accuracy. When observable, the former is generally northeast, the latter northwest, though exceptions to the rule are common.

Intimately associated with the limestones are several varieties of gneiss, which may be roughly divided into garnetiferous and micaceous on the one hand and pyroxenic and hornblendic on the other. Of the former group some are distinctly interbedded with the limestones, while others are of doubtful relation. Among the pyroxenic and hornblendic rocks many have the appearance of interbedded members, but others, both in composition and in structure, closely resemble somewhat modified intrusions.

Wherever these hornblende and pyroxene rocks appear they show a great amount of crumpling and crushing. This ranges from slight plication to most elaborate contortion, followed by crushing of the rock until, in extreme cases, it is reduced to a mass of angular fragments held together by a paste of limestone. In this way remarkable breccias are produced, whose origin might be obscure but for the fact that every step in the process of their formation is shown. In all such cases the limestone displays little or no sign of structural change, having the appearance of a plastic mass in which the contained layers could be twisted to any extent. It must be noted, however, that a large amount of crushing and distortion in the limestone might be completely obscured by subsequent recrystallization. These facts make it apparent that when the limestone is free from gneissic layers it may present a massive and undisturbed appearance, and yet have been subjected to intense mechanical strains.

This is a matter of importance in considering the question of the metamorphism of the series, for while the character of the limestone as a whole might be thought to point to an absence of any considerable mechanical disturbances, the phenomena of the crushed gneiss show that, as a matter of fact, the series has been subjected to intense pressure. The plastic nature of the limestone must also be taken into account in all efforts to work out the structure of the series, as it is liable to introduce complications which may be the cause of much inaccuracy.

The marked resemblance of the limestone series to the Grenville series of Canada has been noted by Van Hise,* with the suggestion that they are equivalent. The difficulty of establishing such equivalency leads the writer to prefer a local designation for these rocks, and he has elsewhere † suggested the term Oswegatchie series.

GNEISSIC AREAS.

The areas intervening between the belts of limestone are occupied by gneisses whose origin and relation to the limestone series constitute one of the most important problems presented by this region. In many cases the portions of these gneisses immediately adjacent to the limestone closely resemble the interbedded garnetiferous gneisses and doubtless should be regarded as members of the limestone series. These varieties usually pass somewhat gradually into more massive gneisses of plutonic aspect, and cases are not few where the latter are in direct contact with the limestones. It is difficult to resist the impression that these massive gneisses are, at least in part, of igneous origin, and that this is sometimes the case will be shown below, but whether or not it may be accepted as a general explanation it is impossible to say at present. To the writer it seems probable that absolute proof as to the origin of many portions of the gneiss will never be found.

IGNEOUS ROCKS.

The rocks of undoubted igneous origin may be classed, with few exceptions, as granite, diorite, gabbro and diabase. Of these the first two have been in part described by the writer in another paper,‡ so that a brief summary of the facts then stated will suffice.

GRANITE AND DIORITE.

A more or less interrupted ridge of granite extends across the townships of Antwerp, Rossie and Gouverneur, and has not been traced to a limit on the east. Besides this, there are numerous isolated masses scattered irregularly about. It is a biotite-granite or granitite, whose intrusive nature is shown at many points where it breaks through the limestone. The structure of these contacts admits of no doubt of their character, but metamorphism, while not absent, is hardly as extensive as might be expected. Diorite appears as a basic phase of this granite, with a

* Bull. 86, U. S. Geological Survey, p. 508.

† Report to State Geologist of New York (unpublished).

‡ Trans. New York Acad. Sci., vol. xii, p. 203.

gradual passage from one to the other perfectly exhibited. This area of the granite with associated diorite is clearly defined, being surrounded by the older limestone, with the relations between the two perfectly distinct. Except at a few points, there could hardly be any confusion between it and the gneisses of doubtful origin, although the granite is itself sometimes prominently gneissoid.

A more complicated case is presented by a series of granitic rocks extending along the northern boundary of the limestone belt of the townships of Diana and Pitcairn. In this instance the granites are quite variable in character, ranging from a rather fine grained to a coarse porphyritic variety, containing feldspar phenocrysts an inch or more in length. At the same time the color varies, showing white, gray and red.

The microscope shows much variation in the feldspar of the rocks, as plagioclase quite often preponderates over orthoclase. The amount of quartz is also variable, but the dark mineral is quite constantly biotite. These variations suggest that the rocks can hardly belong to a single intrusion; but for present purposes they may be classed together under the head of granite.

Only one good contact with limestone has been found along this belt, but this shows abundant evidence of intrusion, with decided contact metamorphism, resulting in the formation of a zone composed of pyroxene, scapolite, titanite and garnet.

The igneous nature of the granite is not, however, dependent upon this single locality for its proof. On the contrary, there is a high cliff extending two-thirds across Pitcairn township, which contains most abundant evidence of the intrusive nature of the rock. This cliff is made up of finely laminated gneiss, such as occurs interbedded with the limestone (and which is therefore regarded as a member of the limestone series), cut through and through by granite. At some points the granite sends many tongues and veins into the gneiss, while at others the gneiss is wholly cut out by the intrusion. As a result, the cliff at some places consists entirely of gneiss, at others of a mixture of gneiss and granite, and at still others of granite alone (see figure 1). Wherever the granite

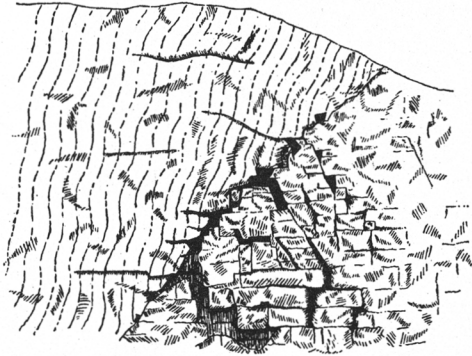


FIGURE 1.—Granite Cutting laminated Gneiss.

The drawing is from photograph taken half a mile north of Harrisville.

is in small tongues or veins there is a marked tendency for them to follow the lamination of the gneiss, producing structures precisely like those described and figured by Lehmann* in the case of similar intrusions occurring in Saxony (see figure 2). At many of the exposures abundant inclusions of gneiss in granite give further evidence of intrusion.

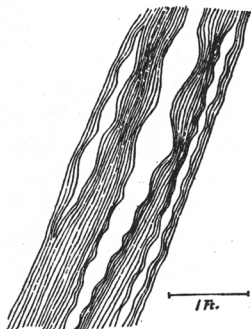


FIGURE 2.—Granite Veins parallel to Lamination of Gneiss.

The drawing is from field sketch made one mile north of Pitcairn Forks.

While these relations are most extensively shown in Pitcairn, indications of the same sort may be found in Diana, particularly just north of Harrisville, north of Indian lake, and two miles east of Natural Bridge, on the Bonaparte road.

Thus it is evident that the limestone belts of Antwerp-Gouverneur and of Diana-Pitcairn are separated by a gneissic area whose southern border is made up largely of intrusive rocks. How much of this area is but a continuation of the intrusions can be determined only by very close and careful study, and perhaps not even then; but the facts at hand are certainly suggestive and seem to point out a fruitful line of inquiry.

GABBROS.

FIRST VARIETY.

Area of Occurrence.—Of gabbros there are three varieties, the most important being of somewhat exceptional character, which renders its affinities rather uncertain. The most typical gabbro occupies an area of hardly more than a square mile, just east of the village of Pitcairn, or, as it is called more commonly by the inhabitants, Geers. The southern edge of this area is marked by a steep cliff, like that formed by the granite and gneiss just described. The two cliffs are almost in line, though not continuous, and the structural relations of both are very

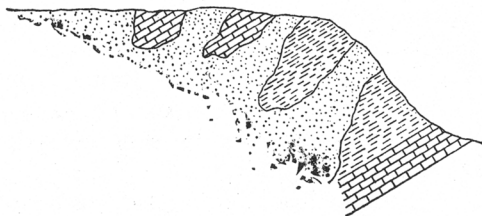


FIGURE 3.—Basic Gabbro cutting Limestone and Gneiss.
Diagrammatic section of exposure at Pitcairn.

*J. Lehmann: Untersuchungen über die Entstehung der Altkrystallinischen schiefer Gesteine, p. 20.

similar. On the other sides the gabbro area falls off more gradually. The section at the cliff shows at the base limestone dipping under the next higher member, laminated gneiss. Above this again there is limestone, largely cut out by gabbro, which also intersects the gneiss (see figure 3.) The structural relations are perfectly clear and admit no doubt of the intrusive nature of the gabbro, which is further shown by a conspicuous amount of contact metamorphism.

Macroscopic Characteristics.—The most pronounced feature of the gabbro as seen in the field is the great variation from point to point in composition and structure. On the one hand the constituents may be less than a millimeter in diameter, while on the other they may reach an inch or more in their greatest dimension. Naturally, the finer portions are more conspicuous near the margin, but there are abundant exceptions to this rule. In composition there is a range from a nearly black rock, composed almost wholly of ferro-magnesian minerals, to a rock consisting chiefly of white feldspar, with a few prismatic pyroxenes. The latter is the least abundant variety, the bulk of the rock being rather dark-colored. It is surprising how many varieties of the gabbro may appear in a small area, the passage between the most extreme phases often taking place within five or six feet. Such variations are, of course, very common in basic igneous rocks, but it is probable that there is nowhere a more striking example of the phenomenon.

Mineralogic Composition and Characteristics.—The microscope shows the rock to consist of plagioclase feldspar, pale green augite, hornblende, apatite, pyrite and alteration products. All of the minerals, save the apatite, are allotriomorphic, though in the feldspathic variety the augite has an imperfect prismatic habit. The augite is normally the prevailing ferro-magnesian constituent, though it may be replaced by hornblende. The relation between the two is interesting, for if it is ever safe in the absence of idiomorphic boundaries to say that massive hornblende is derived from pyroxene, it may be stated in this case. Every stage of the process is clearly shown, beginning with the appearance of small spots of deeper color scattered through the light green of the pyroxene and ending with a complete substitution of hornblende. The change does not begin in any particular portion of the pyroxene, but at numerous points scattered through the mass. Professor Iddings* has pointed out the need of caution in accepting such an explanation of the origin of hornblende, but in the present instance the facts are very strong in its support.

The extinction angles of the feldspar indicate the prevalence of an acid

* Twelfth Ann. Rep. U. S. Geol. Surv., p. 610.

labradorite, but in portions of the rock having an abnormally small amount of ferro-magnesian minerals and containing some quartz there is a much more acid plagioclase and probably some orthoclase. The feldspar of all specimens is entirely free from the fine inclusions so common in the feldspar of most gabbros.

The feldspar is often much altered to kaolin and to muscovite, more rarely, to scapolite. This latter change is interesting, recalling the group of scapolite-diorites and "gefleckter gabbros." It is also suggestive in connection with the scapolite rock of Gouverneur previously described by the writer.* A peculiar feature of the gabbro, considering its rather basic character, is the almost complete absence of magnetite and ilmenite, these minerals being rarely seen in microsections.

Effect of Contact.—The contact phenomena are important only where the gabbro cuts the limestone, as it has little or no effect upon the gneiss. The limestone is converted into a coccolitic mass, chiefly green pyroxene, but containing considerable quantities of garnet, scapolite and sphene, the latter often in perfect, though very small, crystals, the other minerals being in grains. This change is shown both on the border of the mass and in inclusions, some of which are changed throughout to the aggregate described.

Relation of the Gabbro to Granite Intrusions.—As the gabbro occurs in the line of granite intrusions above described, the relation between the rocks is a matter of interest. If the acid granites of Gouverneur pass into quartz-free diorites it might be thought that the gabbro is a basic phase of these more basic granites. That this is not the case is conclusively proved by a contact between the gabbro and the granite. The contact is sharp, with no transition, and clearly irruptive. The structure of the contact does not, however, prove the relative age of the intrusions, but the extreme fineness of the gabbro and its exceptional aspect under the microscope indicate that it is the later of the two rocks.

The Gabbro as a Basis of Comparison.—This gabbro is of particular interest in affording a basis of comparison for rocks from other portions of the region, where the field relations are less clear. The black gneiss from southern Hamilton county, recently described by the writer,† affords an instance. This rock was referred to as probably belonging to the gabbro series, although no positive proof of this was at hand. While not, of course, affording such proof, the Pitcairn gabbro gives great support to the supposition named, as there is a strikingly close resemblance between many portions of the rocks, though the Hamilton county rock

* Trans. New York Acad. Sci., vol. xii, p. 215.

† On Gabbros in the southwestern Adirondack region. Am. Jour. Sci., vol. xlviii, p. 54.

has certain features connecting it more closely with the pyroxene-granulites.

SECOND VARIETY OF GABBRO.

Area of Occurrence.—A second variety of gabbro occurs on both sides of the road about midway between Oswegatchie Settlement and Diana Center. The field relations of the rock are not so clear as in the case just described, but they indicate an intrusion of no very great extent, cutting the third variety of gabbro, to be considered below.

Description of the Rock.—The rock may be sufficiently described by the statement that both in the hand specimens and in microsections it is practically identical with the hypersthene-gabbro of southern Hamilton county described in the paper referred to above.

Relations and Origin.—As the two localities are about 60 miles apart, it would seem at first sight rather strange that there should be such identity in the character of the rocks, which occur in quite inconspicuous masses. The explanation of the fact doubtless lies in the suggestion made in the paper cited, namely, that these small bodies of fine grained gabbro have an intimate connection with the great gabbro intrusions of the region. They are products of the differentiation of the magma, which was the source of these wide spread intrusions, and are alike because derived from the common source. The region is regarded as a petrographic province in which the igneous rocks bear most intimate genetic relationships to each other; and many facts indicate that this is the case. If this supposition be correct, it is to be expected that the fine gabbros may be found anywhere in the vicinity of the large intrusions.

THIRD VARIETY OF GABBRO.

Chief Characteristic.—These great intrusions seem to be represented in the region under consideration by a rock of so much interest in its relation to the limestones and gneisses as to merit rather extended consideration. It is the third variety of gabbro previously referred to, and, as there stated, is of somewhat unusual character. This fact appears in the variable nature of the feldspar, ranging from highly twinned plagioclase to a finely fibrous micropertite, while there is a corresponding change in chemical composition. Thus, different specimens of the rock require, from a strictly petrographic point of view, different names, ranging from gabbro and anorthosite to augite-syenite, but it will for present purposes be considered as a whole under the term gabbro, its geologic relationships rather than its petrographic affinities being the main object of investigation.

Area of Occurrence.—A band of this rock stretches across Diana, with a course somewhat north of east, forming the southern boundary of the

Diana-Pitcairn limestone belt. The line of junction of these two rocks is clearly defined, but such is not the case on the other sides of the gabbro, as the rock undergoes decided modification, which renders its delimitation a matter of difficulty. The clearly recognizable mass of the rock has been traced from near Natural Bridge to a point three or four miles east of Harrisville, a distance of nearly or quite twenty miles. On account of the modifications mentioned the southern boundary of the mass is uncertain, but an average width of about four miles may be taken as a minimum.

Appearance in the Field.—Over a large proportion of the gabbro belt outcrops are abundant. The rock surface usually presents flowing contours, with something the aspect of roches moutonnées. This is particularly true in the eastern part of the belt, where the gabbro rises into considerable hills. In the vicinity of Natural Bridge the surface is flatter.

In many cases it is not easy to distinguish a weathered portion of the gabbro from coarse gneiss, but, as a rule, it is more massive and shows the prevalence of large feldspars. The most favorable exposures for an examination of the surface are those which have been smoothed by glacial action and since preserved from decay. Such a surface is usually a very light drab or gray, and has a somewhat porphyritic aspect; that is to say, the rock appears to consist largely of distinct feldspar individuals, ranging from a fraction of an inch up to an inch or more in diameter, held together by a varying amount of finer material.

In some cases the appearance of the surface recalls a rather fine conglomerate of great uniformity of grain and composition. Usually on such surfaces no constituent other than the feldspar can be determined, although dark minerals are shown in small grains.

Characteristics of the Feldspar.—In form the feldspar grains may be rounded or nearly rectangular, approaching their crystallographic outlines. A zonal structure is often shown, the marginal portion being nearly white, while the interior is gray or brown. The white band is about one-fourth as wide as the individual and the passage into the dark core is rather abrupt. There is a marked difference in the resistance offered to decay by these two portions of the feldspar. The dark area decomposes much the more readily, so that on glaciated surfaces which have been slightly weathered the feldspar grains have a depression in the central portion, surrounded by a rim of the white material. This mode of weathering is a great help in determining the true nature of doubtful exposures. Where the rock has been recently blasted it has a decided gray color, sometimes with a greenish tinge. Occasionally it becomes pink or red without deviating otherwise from the normal character. As is natural, such a surface has a more granular aspect than those which

have been glaciated, but the cleavage faces of the large feldspars are plainly seen. Other minerals, as a rule, are not determinable, but at some points there are considerable quantities of magnetic iron ore.

At most outcrops careful inspection shows a certain amount of parallelism in the arrangement of the feldspars. On the one hand this is very obscure, while on the other the rock becomes distinctly gneissoid.

Microscopic Characteristics and mineralogic Composition.—Microscopic sections show that the rock, as indicated in the hand specimens, consists chiefly of feldspar. The more typical specimens have cores of well twinned plagioclase, surrounded by a margin usually composed of micropertthite. In such cases the fine tongues and spindles of the micropertthite correspond optically with the material of the core, while the inclosing feldspar is more acid, as indicated by its lower interference colors. The basic character of the core accounts for its more ready disintegration, as seen in the field, while its dark color is explained by the presence of inclusions of magnetite.

The same microsections generally show other feldspar individuals consisting wholly of micropertthite, and comparison of different sections shows that the micropertthite may increase till it becomes the only feldspathic constituent.

The low extinctions and interference colors of the feldspars, as well as a mean index of refraction lower than that of quartz, as measured by Becke's method, show that the plagioclase is near the albite end of the series. The high percentage of soda shown by the analysis points to the same conclusion. Anorthoclase may well be present, but its separation has not been attempted.

Of ferro-magnesian constituents, monoclinic pyroxene is largely predominant, hornblende filling a very minor role and biotite rarely present. The pyroxene is usually deep green and non-pleochroic. The diallagic parting is absent, though a fibrous structure is sometimes shown. The mineral is always in irregular grains, and usually in small amount as compared with the feldspar. Magnetite is generally seen, ranging from the small inclusions in the feldspar up to irregular masses of considerable size. These may constitute so large a proportion of the rock as to render it a considerable ore body. Slender prisms of apatite are not uncommon. Quartz also appears in a number of sections, but there is reason for believing that some of it is secondary. Other constituents of minor importance are more common in certain modified portions of the rock. They will be referred to in the sequel.

The most striking feature shown under the microscope is a beautifully developed cataclastic structure. This is never lacking, though varying in different specimens. When least marked, the feldspars are separated

by narrow bands of fragmental grains, while the large individuals have very strong undulatory extinction. From such cases there is a gradation up to a complete crushing of the rock to a mass of minute grains, with only here and there a small residual core.

Chemical Analyses.—The analyses given below show that the microperthitic variety is rather too acid to be classed as a member of the gabbro family, as might be expected from its mineralogic aspect in thin sections, but there is no doubt of its geologic continuity with the more basic phase. They are different portions of a single intrusive mass and owe their differences to magmatic variations. It is by no means easy to determine in the field which is the prevailing type, but the facts at hand point strongly to the preponderance of the basic rock; hence the use of the name gabbro for the intrusion. In fact, the employment of this term would be justifiable even were the acid phase more abundant in this particular mass, inasmuch as the presence of a large quantity of the basic phase points so strongly to the conclusion that the entire mass belongs to the great gabbro intrusions of the region.

	I.	II.
SiO ₂	57.00	65.65
Al ₂ O ₃	16.01	16.84
FeO.....	10.30	4.01
MgO.....	1.62	0.13
CaO.....	6.20	2.47
K ₂ O.....	3.53	5.04
Na ₂ O.....	4.35	5.27
H ₂ O.....	.15	.30
Totals.....	99.16	99.71

I. Average sample of the ordinary basic variety; from Natural Bridge.

II. Acid variety, in section, largely composed of microperthite; from near Harrisville.

RELATION OF GABBRO TO LIMESTONE.

Character of the Transition.—As previously stated, the northern boundary of the gabbro belt is clearly defined, being the line of its contact with the crystalline limestone series. It is not meant to imply that the precise location of this boundary has been determined throughout its entire length, for such is not the case, but merely that there is nothing like a transition between the two formations, the passage from one to the other being abrupt. As some portions of the gabbro might be taken for metamorphosed sediments, it is important to establish the true nature of this contact in order to justify the conclusion that the rock is igneous.

Character of the Contact.—Many absolute contacts have been examined, while in even more cases the two formations have been observed very

close together, although the line of junction was not exposed. These observations show that the contact is extremely irregular, presenting all the characteristic features produced by the intrusion of an igneous rock.

In the vicinity of Natural Bridge the contact is shown on a horizontal surface, forming a very irregular line, the gabbro sending out broad extensions into the limestone. Sometimes the latter rock cuts off portions of the gabbro from the main body, forming isolated patches. Narrow, sharply defined dikes of the gabbro have not been observed, the extensions being broad and irregular.

These contacts, however, though evidently irruptive, are not as striking as those presented in vertical sections. A most favorable locality for observing one of the latter is in a cliff on the west shore of Bonaparte lake. It is probable that this is the locality referred to by Van Hise* in his brief account of the region, as it corresponds closely to a description of the latter point given to the writer by the late Professor G. H. Williams shortly before his death. The gabbro here exposed may not be continuous on the surface with the main body; but if not, there is no doubt of their unity, so that the bearing of the facts remains the same in either event.

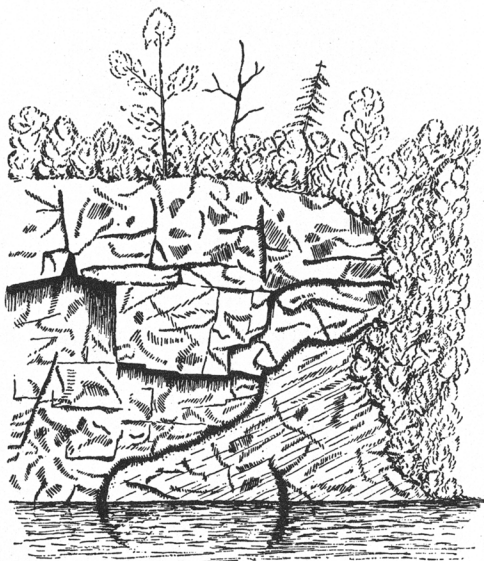


FIGURE 4.—*Gabbro-Limestone Contact. Lake Bonaparte.*
The drawing is made from a photograph.

The cliff referred to rises almost vertically out of the water to a height of sixty or seventy feet. Near its base the limestone is exposed clearly banded, but the mass of the cliff consists of gabbro, which cuts across the banding of the limestone in a sinuous line (see figure 4). At one point a wedge of limestone projects into the gabbro a distance of three feet. The limestone extends to the top of the cliff, but is cut off again by the gabbro a short distance along the face. These phenomena are repeated several times at this point and elsewhere along the lake shore, the gabbro cutting through the limestone again and

*Bulletin 86, U. S. Geol. Survey, p. 399.

again. It would be impossible to examine these outcrops without being convinced of the irruptive nature of the contact.

If any further structural evidence were needed to substantiate this view, it would be afforded by the presence of included masses of the older rocks in the intrusive. These are shown on a small scale near Natural Bridge, but a more instructive example occurs about a mile

southeast of Harrisville. Here the gabbro contains abundant inclusions of fine grained, laminated gneiss, such as occurs interbedded with the limestone. These inclusions vary from a few inches to several yards in diameter. The lamination in the different blocks has different directions. The outline is usually rather irregular and the boundary between the inclusion and the

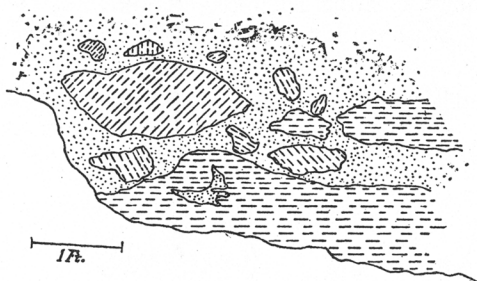


FIGURE 5.—*Inclusions of Gneiss in Gabbro.*

The drawing is made from photograph and field sketch procured one mile northeast of Harrisville.

gabbro is very sharp, with no trace of gradation between them (see figure 5). Sometimes the gabbro shows a banding near an inclusion and parallel to the side of the latter. There can hardly be a doubt that this is an original structure caused by the flowing of the molten magma around the solid inclusion (see figure 6). These facts clearly prove that the blocks of fine rock are inclusions and not of the nature of segregations. As they correspond in character to the gneisses of the limestone series, they furnish another proof of the intrusive character of the gabbro.

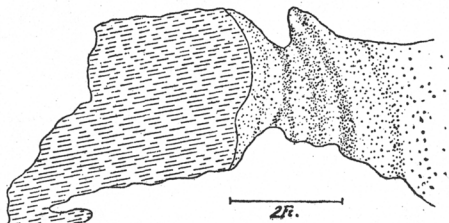


FIGURE 6.—*Banding of Gabbro parallel to Side of Gabbro Inclusion.*

Less conclusive, but of a confirmatory nature, is the fact that at varying distances north of the main belt of gabbro there are numerous bosses cutting the limestone, which seem to bear an important relation to the former rock. These are generally quite small, but sometimes attain considerable dimensions. The rock of these bosses is quite different from the ordinary gabbro, but closely resembles certain phases of the latter yet to be described.

This resemblance is such that there can be little doubt that the bosses are offshoots from the main mass of gabbro, which owe their modified character to the different conditions under which they have solidified. It should be noted, however, that some of these bosses may be offshoots of the granite which lies to the north.

Contact-metamorphism.—While the structural evidence is in itself sufficient to justify the conclusion that the gabbro is intrusive in the limestone, there is no lack of substantiation in the way of mineralogic changes. On the contrary, wherever the two formations are observed in actual contact there is seen a considerable amount of contact-metamorphism, both endomorphic and exomorphic.

These changes, though varying in minor details from point to point, are on the whole of a rather uniform character, so that some of them may be described as a whole and others may be represented by a few typical localities.

Endomorphic Changes.—When the gabbro is examined near the contact it is found to be finer grained than the normal rock, though this is a rule to which there are abundant exceptions. At the same time the feldspar often becomes bleached to a light gray or white, and there may be an increase in the amount of dark constituents. The result of these changes is a rock finer than the normal gabbro, and, as a whole, lighter colored, but dotted over with numerous black spots.

Microsections from these portions of the gabbro often have the pyroxene in larger grains than in the normal rock, and the grains are in many cases bordered by scales of green hornblende. This hornblende looks like a secondary product, but the evidence in support of such a supposition is not as strong as in the case already described. The most striking and characteristic feature of these marginal portions of the rock is the presence of titanite, often in very considerable quantity. This mineral is usually in irregular grains of small size, several of which may be aggregated, forming patches two or three millimeters in diameter. It is noticeable also that sections from this part of the rock show much less granulation of the minerals.

The phenomena shown in the marginal portions of the main body of gabbro are largely repeated in the bosses lying beyond its northern boundary, but they, on account of their small size, have the marginal character throughout. This accounts for the variation from the normal type shown by the rocks of these bosses, and emphasizes the probability of their being offshoots from the main body. These changes in the character of the gabbro might be regarded as an example of the variation from point to point so often shown by members of the gabbro family and other basic rocks, but this supposition is completely negated by the

fact that the changes always appear as the limestone is approached and have not been seen in any other part of the rock.

Exomorphic Changes.—Decidedly more marked than in the gabbro, are the mineralogic changes in the adjacent limestone. A good example is furnished by the contact, previously referred to, in the cliff on Bonaparte lake. The gabbro at this point shows the ordinary marginal character. The limestone at a distance from the contact is distinctly banded, but as it approaches within three or four feet of the gabbro the banding disappears and the limestone becomes a uniform white. Immediately adjoining the gabbro is a zone composed of a fibrous white mineral, with abundant grains of a green mineral. This zone varies in width from an inch up to a foot, and the relative proportions of the different minerals varies in different parts. The minerals sometimes show a banded arrangement which is wholly discordant with the original banding of the limestone, but is parallel to the line of contact. This zone is totally different from either of the rocks between which it lies, and is without doubt a product of the action of the heated intrusion upon the limestone. The contact-zone seems rather more closely linked to the intrusive rock than to the limestone; but it is doubtless to be regarded as an altered portion of the latter, or perhaps more accurately as a product of interaction, deriving some of its constituents from both rocks, and thus in a sense intermediate between the two. Sections from this zone show green pyroxene and wollastonite as prevailing minerals, with smaller quantities of titanite and garnet.

Similar contacts may be seen at several other places along the shore of Bonaparte lake, and at many points elsewhere in the region. They are particularly marked in the case of the small bosses lying to the north of the main gabbro body.

In most of these exposures the phenomena are somewhat obscured by weathering, but this difficulty is removed at several points about one mile east of Natural Bridge. The well known minerals from this locality are such as to suggest the possibility of the presence of a contact-zone, and, indeed, it has been stated* that they occur "near the juncture of crystalline and sedimentary rocks." As a matter of fact, the most important openings from which these minerals have been collected were found by the writer to be immediately on the contact of the gabbro and limestone. Some of these pits have been opened to a depth of ten feet or more, with a length of fifteen or twenty feet, and though several have been filled in with boulders gathered from adjacent fields, two or three are open to inspection and furnish very perfect sections of the contact, with an almost complete absence of weathering.

* Dana's System of Mineralogy, sixth edition, p. 1063.

In a pit on the Ashmore farm the best exposure occurs, showing both the limestone and gabbro. The latter rock has the same character as the marginal portions seen elsewhere, being comparatively fine, light colored and showing many black spots. Between the gabbro and the limestone there is, as at Bonaparte lake, an intermediate zone of contact-products, usually from one to two feet wide. This varies in precise detail in various parts of the pit, but where best shown there is, next to and grading into the gabbro, a layer containing much wollastonite. Next to this, on the other side, is a mixture of feldspar, pyroxene, scapolite, sphene, zircon, etcetera. Then comes coarse calcite with much pyroxene, and, finally, fairly pure, coarse calcite, which shades off into the ordinary limestone. The different layers are not at all distinct, but shade into each other and vary greatly in relative and absolute thickness. At another point the portion of the contact-zone next to the gabbro consists of almost pure scapolite instead of wollastonite. Irregular seams in the gabbro are abundant, and are lined with pyroxene, orthoclase and scapolite. Similar facts are presented in the other pits of the vicinity, but owing to the causes above named they are less clearly shown.

The position of this zone, following all the irregularities of the contact between the two formations, is sufficient proof that it has been formed by the action of the one upon the other. This action can be explained in no other way than as a case of contact-metamorphism resulting from the intrusion of the gabbro into the limestone. This conclusion is entirely supported by the mineralogic composition of the contact-zone, as the species named are all recognized contact-minerals, particularly in limestones.

No extended study of the minerals of the contact has been made, and their presence in most mineral collections renders unnecessary a detailed description, but it may be well to state some of their more important features.

Orthoclase occurs in implanted crystals and irregular masses in the limestone. The crystals are opaque white and range from very small size up to two inches in greatest diameter. They are tabular, parallel to the clinopinacoid, and measurements made with the hand goniometer show the presence of the following faces (using Dana's lettering): *b*, *c*, *m*, *n*, *o*, *z*, *y*.

The determination as orthoclase rather than microcline is based not upon measurement, but upon extinction angles and the absence of twinning in cleavage plates. Such examination does, however, show the presence of the micropertthitic intergrowth. It also shows in the orthoclase from one opening great quantities of fluid inclusions. These inclusions are arranged in rows, and the cavities are so close together that

with low powers these rows look quite like the rutile threads in quartz. Most of the rows are, in basal section, parallel to *b*. In the symmetry plane the rows are less regular, but usually parallel to *c* and *z*.

The irregular masses of orthoclase which lie imbedded in calcite differ from the foregoing in being semitransparent, with a bluish tinge. Cleavage fragments indicate that intergrown with the orthoclase there are parallel plates of plagioclase.

Pyroxene is extremely abundant, and is found both implanted in the fissures of the gabbro and imbedded in the adjacent limestone. In the latter position it sometimes forms individuals two or three inches long and one inch in diameter. The implanted crystals are usually smaller. The color is dark green or black. The faces on the material collected are so imperfect that measurements could not be made, but apparently the crystals are rather simple, probably combinations of *b*, *c*, *m*, *n*, and *o*.

Wollastonite has not been found with crystal form. It occurs in irregular fibrous masses, often several inches in greatest diameter, pure white, and with a pearly luster.

Scapolite may be in layer-like masses or distinct crystals. The masses are colorless, with a slightly fibrous appearance, on the vitreous cleavage surface. The crystals, which have not been found with a length of more than an inch, are either white, gray or pale blue. They show the forms *a*, *m*, *r* and *z*, some crystals showing clearly the pyramidal hemihedrism.

Titanite occurs both in the zone of mixed composition and imbedded in pure calcite. The crystals are very perfect, with bright faces and deep reddish brown color. They may be almost microscopic in size or as much as an inch in diameter. They belong to the variety *lederite*, and show the faces *c*, *m* and *n*. A specimen in the Hamilton College collection from this locality shows the polysynthetic twinning described by Williams* as occurring on titanite from the adjoining town of Pitcairn.

Zircon occurs in the same manner as the sphene. The crystals are simple, showing only *m*, *p* and *n*. They are often very long and slender. The best specimen obtained was imbedded in calcite; it is about an inch long and doubly terminated. The color in all the specimens inclines to lavender, which sometimes becomes very marked.

Other minerals, in particular phlogopite, are present, but as they occur disseminated through the limestone almost everywhere they cannot be regarded as contact-products. In this connection mention should be made of the gieseckite, of which fine specimens are found under and near the natural bridge. The large hexagonal crystals of this mineral compare very closely with the form of nepheline, as shown by Blum, who regards the gieseckite as a pseudomorph after the latter species. If this

* Am. Jour. Sci., third series, vol. xxix, p. 486.

conclusion is correct nepheline should probably be added to the list of contact-minerals, for the points where it occurs are very close to the contact, though not absolutely on it. It must be said, however, against such a supposition that there has been found neither gieseckite nor nepheline at the actual contacts examined. The question as to the origin of these minerals is thus still open, with the probabilities as just stated, but of the presence of contact-metamorphism there is not the slightest doubt.

Metamorphism of the Limestones as a Whole.—This brief consideration of contact-action in the limestones brings up the question as to how much of the general metamorphism of the limestone series has resulted from the intrusion of the great gabbro masses. That the crystallization of the rocks is a result of contact action on a large scale was first suggested by Van Hise,* and the idea has been referred to by Professor Kemp in the preceding paper. In Essex county, where the limestone occurs in isolated patches completely surrounded by gabbro, the inference seems quite justifiable; but great caution should be used in applying this explanation to the region here considered, where the conditions are very different, as shown in the foregoing. Instead of small patches, we have extensive areas of limestone, while the rocks of known intrusive nature are quite limited in area as compared with Essex county. So far as examination has been made, the limestone is thoroughly crystalline throughout, the degree of crystallization not depending upon the position in the belt nor the proximity of intrusives, except in the case of a narrow zone in close contact with the latter. If the metamorphism were caused by the intrusion we should expect to find a different state of affairs, a more complete crystallization in the neighborhood of the igneous rock; but even did such a relation exist it would seem very doubtful whether the igneous rock present would afford a sufficient cause for the complete crystallization of such extensive areas of limestone and imbedded gneiss. Should future investigation, however, prove a large percentage of the massive gneisses to be of intrusive nature, this difficulty would be considerably reduced. When the actual contact-zones are considered, their narrowness and sharpness of definition are striking. Instead of a gradual increase in crystallization and number of different minerals as the igneous rock is approached, there is no perceptible change till within a few feet or inches of the latter, and then there is a distinct zone of contact-products. Were the intrusion the cause of general metamorphism it would seem that the contact-zone would be much wider and would shade gradually into the ordinary limestone.

In this connection much interest attaches to an isolated patch of lime-

* Bulletin 86, U. S. Geol. Survey, p. 399.

stone which lies about two miles east of Diana Center and is entirely surrounded by gabbro. It might be expected that an intrusion capable of completely metamorphosing many square miles of limestone would convert this area of a few square rods into a mass of contact minerals, and yet the limestone of this patch differs in no considerable degree from that of the larger belts.

These facts appear to render very doubtful the hypothesis of contact-metamorphism on a large scale, although the intrusive rocks may have considerably aided the process of crystallization. It is a matter of great difficulty to determine the relative efficiency of different agents, and opinions will doubtless show much variance.

That the rocks of the limestone series have been subjected to intense mechanical strain with consequent plication and crushing has already been pointed out. It seems well within the bounds of probability to assign to this cause much, if not most, of the crystallization of the limestone series, while what has been called static metamorphism may have contributed to the final result.

RELATION OF GABBRO TO GNEISS.

Of great importance in unraveling the geology of the region is the relation subsisting between the gabbro and the adjacent gneisses which bound it on the west and south. This importance lies not so much in the phenomena presented as affecting this particular field, but rather in the clues afforded for solving problems in other parts of the Adirondack region.

In the vicinity of Harrisville considerable breaks in the series of outcrops between the gabbros and the massive gneisses to the south have thus far prevented a determination of their relations; but near Natural Bridge the conditions are more favorable. Between this village and Carthage, ten miles west, the country is occupied by a red gneiss, rather fine grained, and not, as a rule, strongly foliated. Starting from the normal gabbro at Natural Bridge and passing toward this red gneiss the natural expectation, based upon the appearance of the two rocks, would be to find the one cutting, or superimposed upon, the other; but such is not the case. On the contrary, about two miles west of the village the gabbro undergoes a conspicuous modification. It becomes gradually finer grained and gneissoid, and changes from gray to red. In other words, it passes gradually into the red gneiss, which must therefore be regarded as a modified portion of the gabbro.

The change, while gradual, as traced from one outcrop to another, is rather abrupt, as regards the width of the intermediate zone in comparison with the extent of the two varieties of the rock. This zone is

perhaps half a mile wide, though, in the nature of the case, not clearly defined.

The red gneiss has not been examined over any considerable area, but, so far as seen, the change in the gabbro at all points has been so considerable that no unmodified portions have been found in the red gneiss. Still, many specimens of the latter show traces of their origin, being augen-gneisses on a small scale, with augen of residual feldspar grains sometimes a quarter of an inch in diameter.

Sections of the red gneiss under the microscope differ from the ordinary gabbro only in a more complete granulation of the constituents, with the formation of a little finely divided hematite, which gives the red color to the rock, and often an increase in the amount of quartz present.

It seems, then, clearly established that this red gneiss in the town of Wilna is continuous with, and a modification of, the gabbro. South and east of Natural Bridge, in the vicinity of Oswegatchie Settlement, a similar transition is found, but differing somewhat in detail. The gabbro again passes into a reddish gneiss, but the latter is much coarser than that of Wilna, and contains a conspicuous amount of hornblende. The outcrops in this direction are less satisfactory than in the previous case and the evidence is not so conclusive. Still, the inference seems to be wholly justified that here again there is a gradual transition from normal gabbro into red gneiss, the two rocks being simply different phases of the same mass. In neither of the cases would it be possible to determine with any certainty the origin of the gneisses were the zone of transition hidden, and it is probable that, in the absence of this zone, the derivation of the gneiss from the gabbro would hardly suggest itself to an investigator in the field, though it might be indicated by microscopic and chemical examination.

This being the case, it is natural to infer that all of the gneiss which extends along the southern side of the gabbro belt may be a modification of the gabbro itself, although the absolute establishment of this inference as a fact may be a matter of great difficulty. These facts indicate how difficult it is to map accurately this and other portions of the Adirondack region, for as yet no method has been found for making an accurate distinction between the gneisses which may be modified portions of the gabbro and those of different origin.

DIABASE.

At widely scattered points in Diana several outcrops of diabase have been noted. It forms irregular bosses or sheets, more rarely clearly defined dikes, usually cutting the limestone or gabbro, only a single intrusion in granite having been found. The rock exists in such small

quantity as to be of little importance in itself, while the fact that it cuts all the other rocks renders it useless as a factor in working out their relations. In microsections it usually shows fairly perfect ophitic structure, with the augite in a granulitic condition, instead of in large masses. The only uncommon mineralogic features are the occasional presence of garnet, which seems to be an original constituent, and the occurrence of some hypersthene. When the latter is in considerable amount and, as is not uncommon, the ophitic structure disappears, there is a close resemblance between the diabase and the hypersthene-gabbro above described. This fact, combined with their field characters, suggests a close connection between the two rocks.

SUMMARY.

The region considered contains extensive belts of crystalline limestones with interbedded gneisses, constituting a series which can hardly be regarded as of other than sedimentary origin. Certain hornblendic and pyroxenic gneisses constantly associated with the limestone may be in part modified igneous rocks.

There are present several varieties of undoubted igneous rocks, granite and gabbro in large amount, with minor diorite and diabase. They are all younger than, and intrusive in, the limestone series, producing marked contact-metamorphism in the latter. The ages of these intrusions with reference to each other are not clearly determined except in the case of the diabase, which is evidently the youngest.

Besides these rocks whose origin is clear, there are wide areas of gneisses whose origin and relation to the other formations are largely a matter of doubt. Portions of these gneisses form the basal parts of the limestone series. Other portions are intrusive, as shown by the granitic boundary of one of the belts and by the passage of gabbro into a gneissoid form.

Whether all of the gneisses belong in the one or the other of these classes, or whether still other portions are older than, and unconformable beneath, the limestone series, it is as yet impossible to say. At present we have no absolute knowledge of any formation in the region which is older than the limestone series.

It has been suggested that the metamorphism of the limestone is a result of the intrusion of the gabbro masses which are so extensive in the Adirondack region; but the great extent of the metamorphosed series, the completeness of crystallization in all parts, the narrow and sharply defined contact-zones and the comparatively small quantity of known intrusive rocks combine to render the explanation rather improbable as applied to this particular area. On the other hand, the evidences of great mechanical disturbances justify the conclusion that the metamorphism is largely dynamic.