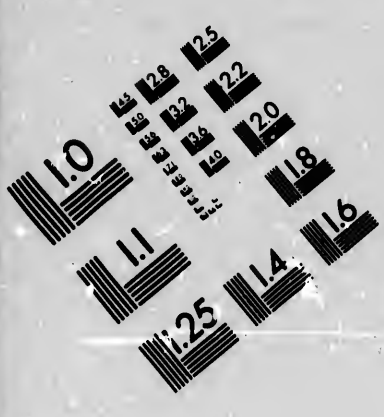

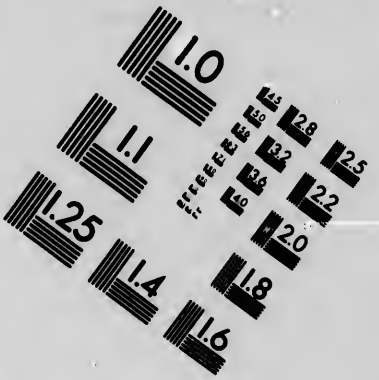

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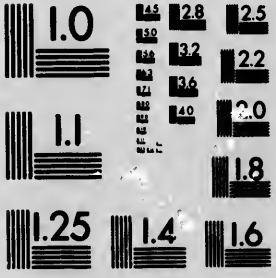

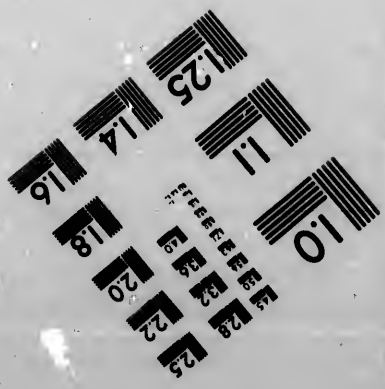

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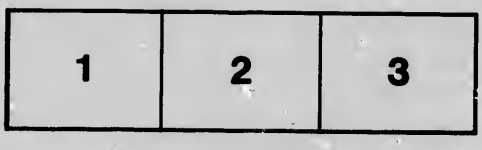

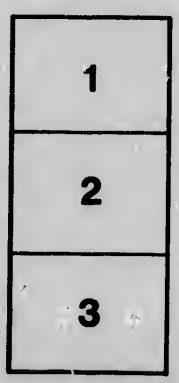

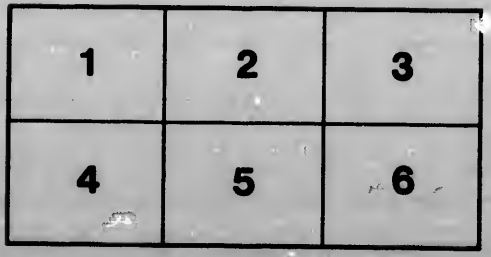

McGILL UNIVERSITY

PAPERS FROM THE DEPARTMENT

OF

GEOLOGY.

No. 8.—NODULAR GRANITE FROM PINE LAKE, ONTARIO.

BY

FRANK D. ADAMS, PH.D.

[Reprinted from the Bulletin of the Geological Society of America, Vol. 9, pp. 163-172, Pl. 11.]

MONTREAL, 1898.

FIGURE 1.—SEPARATE NODULES AND A VEIN
(About one-tenth natural size)

FIGURE 2.—LENTICULAR NODULES ARRANGED IN ROWS
(About one-tenth natural size)

FIGURE 3.—SEPARATE NODULES AND FORKED, VEIN-LIKE MASS

NODULAR GRANITE FROM PINE LAKE, ONTARIO

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 9, PP. 163-172, PL. 11 FEBRUARY 10, 1898

NODULAR GRANITE FROM PINE LAKE, ONTARIO

BY FRANK D. ADAMS

(*Read before the Society December 30, 1897*)

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INTRODUCTION

While engaged during the past summer in carrying out some work for the Geological Survey of Canada in the eastern portion of the province of Ontario, a somewhat remarkable occurrence of orbicular or nodular granite was met in the township of Cardiff, in the county of Peterborough, which, on account of some peculiarities it presents, seemed worthy of detailed study.

This part of eastern Ontario is underlain by rocks of Laurentian age, which here consist chiefly of crystalline limestones with rusty weathering gneisses and amphibolites, broken through by great intrusions of granite, the geological relations being very complicated and intricate, as the mapping of the area now in progress shows.

GENERAL DESCRIPTION OF THE OCCURRENCE

About halfway across the township of Cardiff and near its southern limits is Pine lake, a body of water some two miles long and averaging about a quarter of a mile in width. The bold rocky shores of the lake are formed of a rather fine grained reddish granite, except at the northern and near the southern extremity, where the granite is associated with a dark gabbro-like amphibolite, through which it apparently cuts. The granite is in many places quite massive, but usually shows a somewhat gneissic structure, marked chiefly by the presence of small and ill defined

but rudely parallel streaks, differing from one another somewhat in size of grain. Where this gneissic structure is seen, it coincides in direction with the strike of the associated amphibolitic rock, which in places is also foliated. Much of the granite resembles aplite in appearance, but in places it passes into a coarse pegmatitic development, holding large masses of black schorl. Its general character, except for these minor variations, is uniform over a very considerable tract of country, and its appearance is that of an undoubted igneous intrusion.

The nodules described in the present paper do not occur throughout the whole mass of the granite, but are confined to a portion of it, which, although situated toward the northern limit, is from 200 to 300 yards from its contact with the amphibolite, so that the nodular development cannot be regarded as a contact phenomenon. Along the contact, the granite is in fact free from nodules. The localities where the nodules have been found are all situated on Range III of the township of Cardiff, being chiefly on Lots 13 and 15, which lie opposite to one another on the north and south sides of Pine lake, respectively. They are also found to the northeast of the lake, at a point probably about Lot 18 of the same range. In these localities the nodules are abundantly disseminated through the rock, although not thickly crowded together as in many other similar occurrences elsewhere described. Where most abundant 200 were counted on a surface 36 square feet in extent. Elsewhere they are much less numerous.

They are usually spherical in form, but in some places have a more or less flattened or elliptical outline. This is more especially the case where the granite shows a tendency to foliation, the longer axes of the nodules in this case being parallel with the strike of the rock (see plate 11, figure 2). The nodules have a diameter of from one to eight inches, but usually measure from two to three inches across and can readily be broken out of the rock entire and almost free from the surrounding matrix. Those of them which have been cut across and smoothed by the glaciation of the country show the inner portion of the nodule to be lighter in color than the normal granite.

Being harder and more resistent than the granite, furthermore, they stand out a little from its somewhat disintegrated surface. Many of the nodules when thus ground flat by the action of the ice also exhibit a more or less distinct zonal structure, the central portion being somewhat different in composition from the exterior, although this is not always seen. There is, moreover, usually a little bunch or sponge of black tourmaline near the center, while large glistening poikilitic plates of muscovite are often seen.

Although throughout the greater part of the area in which they occur these nodules are scattered haphazard through the rock without any def-

inite arrangement, in one or two places they were found arranged in rows. The nodules in such rows vary somewhat in diameter, though not greatly, and are at first separated by an interval of two or three inches. On following along the line, however, they are found to come closer together and then to form a continuous string, touching one another, the long row of contiguous balls being here and there interrupted by spaces of the normal granite. Still further on, as indicated in figure 1, the

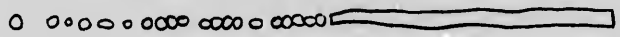

FIGURE 1.—*Vein passing into separate Nodules.*
One-fiftieth natural size.

nodules of the row are found to fuse or coalesce, at first into a series of sausage-like masses and then into a continuous band, having the width of a single nodule, a band which as exposed on the glaciated surface of the rock no observer would hesitate to regard as a true vein filling a fissure, could not its passage into the separate nodules be distinctly traced (see plate 11, figures 1, 2, and 3). These "veins," moreover, in some cases show a rude banding parallel to the walls, for the concentric structure of the nodules passes naturally over into the banded structure of the vein. The quartz which is more abundant in the outer portion of the nodules is thus more abundant on the sides of the vein, while muscovite and feldspar, being more abundant toward the center of the nodules, are also more abundant toward the middle of the vein. The relation of the "vein" to the series of spherical masses, moreover, is indicated by the successive little sponge-like bunches of tourmaline rounded in general outline, like those found toward the central part of the nodules, which are distributed along the length of the vein at more or less regular intervals (see figure 2). In some cases even traces of the medial line can be seen on the weathered surface, passing down the length of the vein and suggesting the meeting place of the combs in the combed vein (see plate 11, figure 1). These "veins" are well defined against the granite, although the boundary is not absolutely sharp, and occasionally they split and fork as other veins do, and pass into a row of nodules (see plate 11, figure 3). Their continuity in depth could not be so well studied, as they are exposed chiefly on horizontal surfaces. In one instance, however, on the face of a little cliff, one of them could be seen to extend vertically through the granite in a direction at right angles to its strike for a distance of three feet and then downward out of sight. It is certain

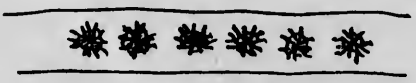

FIGURE 2.—*Sponge-like Bunches of Tourmaline.*
Arranged at intervals along a vein. One-fifth natural size.

from this and numerous other observations that these "veins" do not represent merely single lines of nodules, but rather sheets which fray out into separate nodules along their outer margins.

Whether irregularly disseminated through the rock, as is usually the case, or whether arranged in lines or sheets, as in certain rare instances, the nodules bear a striking resemblance, so far as mode of occurrence is concerned, to the spherulites, axiolites, and other similar structures seen in obsidian and other volcanic rocks, although, of course, on a very much larger scale (see plate 11, figure 2).

The several structures described can be duplicated on a small scale in many hand specimens of the obsidian from the Yellowstone park. The presence of tourmaline and muscovite is suggestive of the presence of mineralizers, which also play so important a part in the formation of spherulites. These nodules, however, differ in a marked manner from such spherulites in that their composition is not identical with that of the enclosing rock, while in the case of the spherulites there is a practical identity in this respect. That an abundance of mineralizer was present in certain parts of the granite magma is, however, indicated by the streaks or more or less irregular segregations of coarsely crystalline quartz and tourmaline found in places through the rock.

Microscopical Character of the enclosing Granite

The red granite from various parts of the area is found when examined under the microscope to be uniform in composition and microscopical character, although, as has been mentioned, varying somewhat in grain. Orthoclase and microcline preponderate largely, the former in untwinned grains, showing good cleavages, the latter presenting a well marked cross-hatched structure. Soda-lime feldspars are also present, although in very subordinate amount. The microcline, which is usually about equal to the orthoclase in amount, is in some places present in large grains with irregular boundaries and a marked micropoikilitic structure, the enclosed grains consisting of orthoclase, plagioclase, and quartz, with a few of biotite and iron ore. These inclusions, which are often very numerous, are more or less rounded in form, their outline being often nearly circular. They are also quite irregularly oriented. The microcline in these cases is evidently younger than the other constituents of the rock, with the possible exception of the quartz, as has been found to be the case with this mineral in a number of granites which have been recently studied.

The quartz is much less abundant than the feldspar and often occurs in subpolygonal or more or less rounded grains, instead of occupying the interstices between the other minerals as in a normal granite, a mode of occurrence which marks an approach in character to that seen in the

granite porphyries. Highly pleochroic biotite is present in considerable amount in the usual lath-shaped forms. A small amount of muscovite, often intimately associated or intergrown with the biotite, is also present. This mineral also occurs enclosed in the feldspars, either as well defined individuals or in grains having the peculiar feathery, fretted, or lace-like margins exhibited by it in certain other granites, and in such cases it often has an edging of quartz surrounding a portion of it. In some cases it was even observed enclosed in quartz. A few grains of iron ore and apatite complete the list of minerals found in the rock.

Microscopical Character of the Nodules

Six nodules were selected for microscopical study, and eight sections, comprising a whole nodule, were prepared. Three of these nodules, when cut across, showed a rather distinct concentric structure, the outer and inner portions differing somewhat in color, the former consisting chiefly of quartz and sillimanite and the latter chiefly of quartz and muscovite. The outer and inner portions, however, are not separated by a sharp line, but fade into one another, so that no satisfactory separation of them for purposes of chemical analysis could be effected. Many nodules also, as has been mentioned, when broken across, show a small sponge-like mass of black tourmaline toward the center. In the case of the other three nodules this zonal arrangement was merely suggested, the nodules being essentially uniform throughout. One of them, however, contained the tourmaline sponge, before referred to, near the center, and in two of them there was an indistinct tendency to a radial arrangement on the part of some of the constituents.

The absence of pronounced concentric or radial structure is one feature in which these nodules differ in a marked manner from the basic concretions, nodules, and varioles described in other granitic rocks. On passing from the granite to the nodule there is seen under the microscope an abrupt change both in grain and composition. The regular mosaic of the granite is replaced by a coarser grained and sometimes indistinctly radial or sheaf-like arrangement of the constituents; the biotite and microcline disappear entirely, while the quartz and muscovite, especially the former, become more abundant, and sillimanite makes its appearance, usually in large amount.

Quartz, muscovite, and sillimanite are the chief constituents of the nodules. Plagioclase and an untwinned feldspar, probably orthoclase, which are present in some nodules in considerable amount, but in others in very small quantity, with tourmaline in some cases and a few grains of iron ore and pyrite, complete the list of constituent minerals.

The quartz is uniaxial and forms a well defined mosaic of polygonal

grains, showing little or nothing of the tendency to develop rounded individuals seen in the granite itself. It often holds an abundance of sillimanite needles, although in it this mineral does not usually occur in such mats as in the feldspar. It frequently contains lines of minute cavities, some of which enclose moving bubbles. The muscovite occurs in large colorless plates, often of very irregular outline, extending in some cases completely across the central portion of the nodule, and holding many inclusions of quartz, sillimanite, and other constituents. The irregular and indented outline is quite distinct in appearance from the finely fretted or lace-like boundary presented by the muscovite of the granite, the outlines being quite sharp. It may, however, be regarded as this structure on a much larger scale. It has the eminent basal cleavage characteristic of this mineral, with the uniform extinction parallel to it.

The sillimanite occurs in long, slender, isolated needles with transverse partings and extinction parallel to their length, or as bundles or mats of such needles, felted into nearly opaque masses. It occurs penetrating both the quartz and muscovite, but, as has been mentioned, is especially abundant in the feldspar, which is usually crowded with needles of it. The sillimanite individuals are usually very small, and are irregular in cross-section. There is, however, a tendency to develop the nearly square or the eight-sided prismatic forms usually seen in this species, and the larger grains show the usual good cleavage in the direction of one pinacoid. The mineral is uniaxial and positive, and $c = \mathfrak{c}$.

In one or two instances an individual of muscovite could be seen at its extremity to pass into a bundle or brush of sillimanite fibers.

The occurrence of sillimanite in granite, except along sheer zones, is, so far as I am aware, unknown, but the mineral often abounds in the quartz which occurs in veins and irregular masses in highly altered rocks in the vicinity of granite intrusions and elsewhere. Whether such veins have any genetic relation to such occurrences as those described in the present paper is a question for future investigation to decide.

The feldspars are present in some nodules in a considerable amount; in others they are practically absent. When present they consist in part of well twinned plagioclase and in part of an untwinned feldspar, probably orthoclase. Microcline is never found in the nodules, although it may abound in the surrounding granite. The feldspar, especially the orthoclase, occurs in irregular shaped individuals having the feather-like forms seen in spherulites, often with an indistinct radial arrangement, and sometimes showing a granophyric intergrowth with the quartz. It is not especially abundant in any part of the nodule, and is crowded with bundles and mats of sillimanite needles. The iron ore, which is black and opaque, occurs in each nodule in the form of a few rather large grains. A grain or two of pyrite is also usually present. The tourma-

line, thus far found, occurs as a bunch of grains irregular in shape, dark in color, and with strongly marked pleochroism in pale gray and dark gray-blue tints. It is uniaxial and negative, and is associated with quartz and feldspar, and in one or two cases was seen to be penetrated by a few sillimanite needles.

Chemical Composition of the Granite and of the Nodules

In order to make a comparative study of the chemical composition of the granite and the nodules, a specimen was selected consisting of the typical granite in which there was enclosed a nodule spherical in shape and two inches in diameter. The specimen was broken up and the granite, excepting that immediately surrounding the nodule, was crushed and an average sample of it drawn. The nodule, after having been very carefully freed from the adhering granite, was broken across and one-half taken for analysis. The analyses were in each case carried out in duplicate, the figures given below representing the mean of two closely concordant determinations;*

	Granite.	*Nodule.*
Silica	78.83	81.43
Alumina	10.88	13.70
Ferric oxide	1.63	1.58
Lime	.22	.37
Magnesia	.35	.06
Potash	5.31	1.28
Soda	2.13	1.02
Loss on ignition	.32	.92
	99.67	100.36

Boracic acid was not looked for. The silica in a second nodule was found to amount to 79.19 per cent.

The analyses bring out the fact that the granite is a very acid one, and that the chief difference between it and the nodules is that the latter are richer in silica and alumina and poorer in alkalies than the granite itself. Among the minor differences is the marked preponderance of potash over soda and, owing to the presence of the biotite, the larger percentage of magnesia, in the case of the granite.

A study of thin-sections of this particular specimen of granite showed it to be composed chiefly of quartz and microcline, with a small amount of biotite, plagioclase, and an untwinning feldspar, probably orthoclase. Very small amounts of muscovite and iron ore were also present.

The exact composition of the several minerals present not being known, it is impossible to calculate the percentages in which they are found in

* They were carried out in the laboratories of McGill University by Mr Nevil Norton Evans.

the rocks. By neglecting, however, those constituents which do occur in very subordinate amount and having in view a feldspar in which the alkalies are present in the proportion indicated by the analysis, a rough calculation shows that the granite is composed approximately of 42 per cent of quartz and 58 per cent of feldspar.

Similarly, in the case of the nodule, if all the alkalies are calculated as feldspar and the excess of alumina is calculated as sillimanite, the percentage composition would be approximately: quartz, 68 per cent; feldspar, 15 per cent; sillimanite, 17 per cent. If muscovite be present this will alter the relative proportions of these constituents, although not greatly, as the muscovite present cannot amount to more than a few per cent.

Origin of the nodular Structure

Granites and allied rocks containing spheroidal or concretionary lumps or nodules are known from many parts of the world and some of these occurrences are widely celebrated, as, for instance, the concretionary granite from Fonni in Sardinia, the "pudding granite" of Vermont, and the orbicular diorite of Corsica.

The origin of these structures is not, however, in all cases thoroughly understood; but in a recent and elaborate memoir* on the subject von Chrustschoff has presented the results of a very detailed comparative study of a large number of such occurrences and believes them to be genetically divisible into four groups.

1. Concentric, spheroidal, and concretionary growths about foreign inclusions.

2. Nodular growths about fragments of secretions or inclusions, which latter are often partially or wholly redissolved.

3. Group of the so-called pudding granites, where the structure is due to a simple concretionary action set up in the magma during its normal crystallization.

4. Primary structural forms of the magma or endomorphic contact products.

In the Pine Lake occurrence we evidently have to do with the case of primary magmatic differentiation, for although in the case of the occasional vein-like forms the mode of occurrence is such as to suggest a development subsequent to the crystallization of the granite, the fact that these pass into spherical nodules precisely identical with those which occur scattered as isolated individuals through the rock far and wide, and which are far more abundant than the streaked or vein-like forms, proves that they are both identical in origin and are derived from the crystallization of a magma which was free to gather itself into rounded

* Memoires de l'Academie Impériale des Sciences de Saint Pétersbourg, vii série, tome xlii, no. 3, 1894.

drop-like forms which the isolated portions of such a liquid would take, but which could not be developed in a magma when crystallization was far advanced. The constituent minerals of the nodules furthermore are not identical with the last formed constituents of the granite, as they should be if the nodules represented the last products of the crystallization of the granite magma. Microcline, which is abundant and one of the last minerals to separate out of the magma in the case of the granite, is entirely absent from the nodules, while sillimanite, which is never found in the granite, is one of the most abundant constituents in the nodules as well as one of the first of the constituents to crystallize.

The peculiarity of the present occurrence lies chiefly in the fact that the portion of the magma which thus separated out was more acid than the magma as a whole and richer in alumina, which is very unusual. It must be remembered, however, in this connection that the granite itself is more acid than usual.

Magmatic differentiation has been put forward by Bäckström to account for the origin of the nodular granite found at Kortfors, in Sweden,* in which, however, the nodules are more basic than the granite itself, as well as to account for other allied occurrences. He thinks that "it is in many cases evident that the inclusions were *soft*, and then the simplest view is that they were drops or portions of a partial magma, which, at the temperature existing immediately before crystallization, could no longer be held in solution by the principal magma but separated out."†

This seems to be the only satisfactory explanation of the Pine Lake occurrence, the history of whose development seems to have been as follows: In the original magma there were certain "schlieren" richer in silica and alumina than the rest of the magma, and containing also a certain amount of boracic acid. How these came into existence, whether by segregation or separation from the immediately surrounding magma, or whether brought into their present position from another part of the mass by movements in the molten magma, is uncertain. We have, however, examples of such differentiation in granite magmas in the case of pegmatite veins, which at their extremities frequently run out into veins of quartz associated with a little tourmaline. These schlieren, being evidently immiscible with the main mass of the magma, were analogous to globules, streaks, or sheets of oil in water, except that the magmas, being much less mobile than these fluids, the schlieren could not so readily run together into globules or rounded masses; or they might be compared with the globulites which separate from a solution which is about to crystallize and which, after appearing separately, aggregate themselves together into rows like strings of beads and eventually develop into va-

* Tvenne Nyupptäckta Svenska Klotgraniter. Geol. Fören. i. Stockholm Förh. 1894, p. 128.

† Helge Bäckström: Causes of magmatic differentiation. Journal of Geology, vol, I, 1893, p. 778.

rious incipient crystal forms, as shown by Vogelsang and others in their experiments on the crystallization of sulphur. Any very small isolated schlieren that were developed through the magma or detached from the larger schlieren by movements in the semifluid mass would, of course, without encountering much resistance, take upon themselves a globular form, while in the case of larger streaks and sheets more resistance would be offered by the stiffness of the magma and the tendency to assume a globular form would be less pronounced.

When the magma had cooled sufficiently and crystallization began to set in, the solidification in the case of the granite followed the usual course, while the schlieren and globules, having a marked difference in composition, gave rise to different mineral combinations, and at the same time, perhaps on account of their peculiar chemical composition or perhaps because they contained a greater proportion of mineralizers, they developed during crystallization a tendency to spherulitic arrangement. In the case of the separate nodules, the crystallization seems to have started from the center and to have proceeded outwards, and, toward the extremity of the schlieren, to have commenced at a series of points along the medial line. The medial line of the schlieren thus corresponds to and is identical in character with the central portions of the nodules.

The possibility of the nodules having been produced by the melting down of portions of some fibrolitic band in the wall rock is eliminated by the fact that not only are such bands not found in the wall rock, this being everywhere a basic gabro-like amphibolite entirely different from the nodules in composition and character, but also by the zonal arrangement often observed in the nodules and their passage into the indistinctly banded vein-like forms which, as before mentioned, in some cases divide and fork, and are thus clearly not portions of the wall rock.

Whether any of the quartz veins so commonly found associated with granitic gneisses of undoubted igneous origin in the Archean or the quartz veins and strings, often rich in sillimanite, found abundantly in the altered rocks surrounding certain great granite intrusions of later date have the same primary origin as these in the Pine Lake granite is a question worthy of investigation; but the study of this occurrence shows that "contemporaneous veins" of an acid character may be formed not only during the final stage of crystallization, as in the case of the hysterogenetic schlieren and the "kluftblätter" of Reyer, but that highly silicious portions are sometimes segregated or differentiated out of a granite magma before crystallization, and that the banded structure often seen in pegmatites and other allied bodies and sometimes cited as proof of their aqueous deposition in preexisting fissures is not necessarily so produced, but, as is now being generally recognized, may and usually does result from the primary crystallization of the cooling magma.