Art. XX.—*The Lopolith; an Igneous Form Exemplified by the Duluth Gabbro;* by Frank F. Grout.

Contents.

Introduction.—The several students of the Duluth gabbro as a formation have had several opinions as to its form and relations. Recent descriptions refer to it as a laccolith, though it differs from the typical laccoliths in some details. Several other large intrusions are of similar form, and it is here suggested that the form deserves a special name. The size and relations of the Duluth mass are summarized.

Possible forms of the Duluth gabbro, and early suggestions.[1]—In 1883, R. D. Irving referred to the gabbro as probably the reservoir from which the Keweenawan flows came. N. H. Winchell, in several papers from 1880 to 1910, refers to the "great basal flow" and later to bosses and intrusive masses. Bayley, as late as 1893, quotes Irving that it is "not intrusive in the ordinary sense," but says it might be a succession of thick flows or the reservoir from which the flows came. Grant, in 1900, and others more recently have described it as a laccolith.

The intrusive character of the gabbro is clearly shown at Duluth.[2] It has as definite a roof and floor as a laccolith or sill, and was intruded along a surface approximately corresponding to a previous structure,—the unconformity at the base of the Keweenawan. On the basis of its banded structure one may estimate the position of its floor. This eliminates the probability of anything funnel like or particularly irregular,—it is not like the "ethmolith" or "chonolith." Thus it comes about that by a process of elimination the gabbro is placed with

[1] Irving, R. D., Copper bearing rocks of Lake Superior: U. S. Geol. Surv., Mon, 5, pp. 144, etc.

Winchell, N. H., Minn. Geol. and Nat. Hist. Survey, Ann. Rept. 10, p. 114, 1881; Final Rept., vol. 4, and vol. 5.

Grant, U. S., Minn. Geol. and Nat. Hist. Survey Final Rept., vol. 4, p. 326; and Bull. Geol. Soc. America, vol. 11, p. 505, 1900.

[2] Grout, F. F., Paper at the December (1917) meeting of the Geological Society of America.

the laccoliths. It is best, however, to review the definitions and usage of the term laccolith.

The laccolith.—The laccolith as originally defined by Gilbert[3] is insinuated between strata (or along the plane of some previous structure) with a flat floor and an up-domed roof; its thickness ranges around one-seventh its width, and its ground plan is nearly circular. Several geologists, after wide experience with intrusive masses elsewhere, have found it convenient to slightly modify the definition to include clearly related masses.[4] Thus, the concordance with previous structure is not always perfect, but a general tendency is characteristic; the form also may be somewhat unsymmetrical. Laccoliths grade into sheets on one hand, and into "bysmaliths" with faulted uplifted roof, on the other. It seems to have been agreed that the magma was aggressive in uplifting its roof, stretching the overlying beds and separating its roof and floor; Harker even coined the name "Phacolith" for similar forms which might be attributed to other forces.[5]

Several large intrusions are known which differ from laccoliths in having a sunken rather than a domed roof; in fact, some are so thick that a roof could not have been held up, isostatically. The masses are now in the form of great saucers or basins. The process of intrusion was probably very different from that of a laccolith. In spite of the fact that each of the several examples has in recent years been described as a laccolith, it is difficult to formulate a definition to include both types. For example, Daly gives an excellent summary of current usage, and defines a laccolith as plano-convex or doubly convex.[6] Later he calls the larger concavo-convex masses laccoliths, frankly admitting that they are departures from the type.

This being the case, Professor Joseph Barrell has suggested that as igneous forms they deserve a distinct

[3] Gilbert, G. K., Report on the geology of the Henry Mountains, U. S. Geol. and Geog. Survey of the Rocky Mountain region, pp. 19, 53 and 55.

[4] Geikie, A., Structural and field Geology, p. 190.
Iddings, J. P., Igneous rocks, vol. 1, p. 314.
Harker, Alfred, Natural history of Igneous Rocks, p. 65.
Pirsson, L. V., and Schuchert, Charles, Text book of Geology, pt. 1, p. 297.

[5] C. R. Keyes, however, now argues for a different mechanism for the true laccolith, December (1917) meeting of the Geol. Soc. of America.

[6] Daly, R. A., Igneous Rocks and their Origin, p. 70.

name. Such a name is better based on the known facts of form or relations than on any theory of origin, and the name proposed by the writer is "lopolith" (from λοπάς, a basin, a flat earthen dish, and λίθος, a stone).*

The lopolith.—A lopolith may be defined as a large, lenticular, centrally sunken, generally concordant, intrusive mass, with its thickness approximately one-tenth to one-twentieth of its width or diameter. Most of the known lopoliths are in part of basic rocks, and probably because of their large size and slow cooling have differentiated notably. They may show the varying degrees of complexity described as "multiple," "composite," "divided," "interformational," as distinguished from "simple." The type departs from a laccolith, not only in form but in the probable mechanics of its intrusion.

The Duluth gabbro with its differentiates is one of the best illustrations of a lopolith. At Duluth the roof and floor dip east. The crescentic outcrop, concave toward Lake Superior (see fig. 1), dips in all parts toward the lake. The assumed eastern border of the lopolith is concealed under other rocks and under the lake, but the sheet of gabbro on the Gogebic range dips north even more steeply than the Minnesota mass dips south. It is thus somewhat unsymmetrical, but clearly sunken in the center. Its cross-section is also clearly lenticular. The overlying rocks are mostly Keweenawan flows, and though the horizon of the roof may vary some hundreds of feet, the discordance is unimportant when compared to a lateral extent of about 150 miles. The base of the gabbro rests on such a series of formations from Archean to Keweenawan, that the first impression is one of complete discordance with earlier structure. However, if the intrusion transgressed the earlier structure, it is a remarkable coincidence that the two ends, now outcropping 140 miles apart, and the southern outcrops almost as far to the south, all transgressed up to exactly the same horizon. This coincidence is not the only difficulty in the assumption of a transgressing intrusion. After the borders had transgressed to the Keweenawan, the central parts of the intrusion which must have been in the Archean, must have stoped their way up to exactly the horizon to which the border was first intruded; we now

* Pronunciation, *lō'polith.*

FIG. 1.

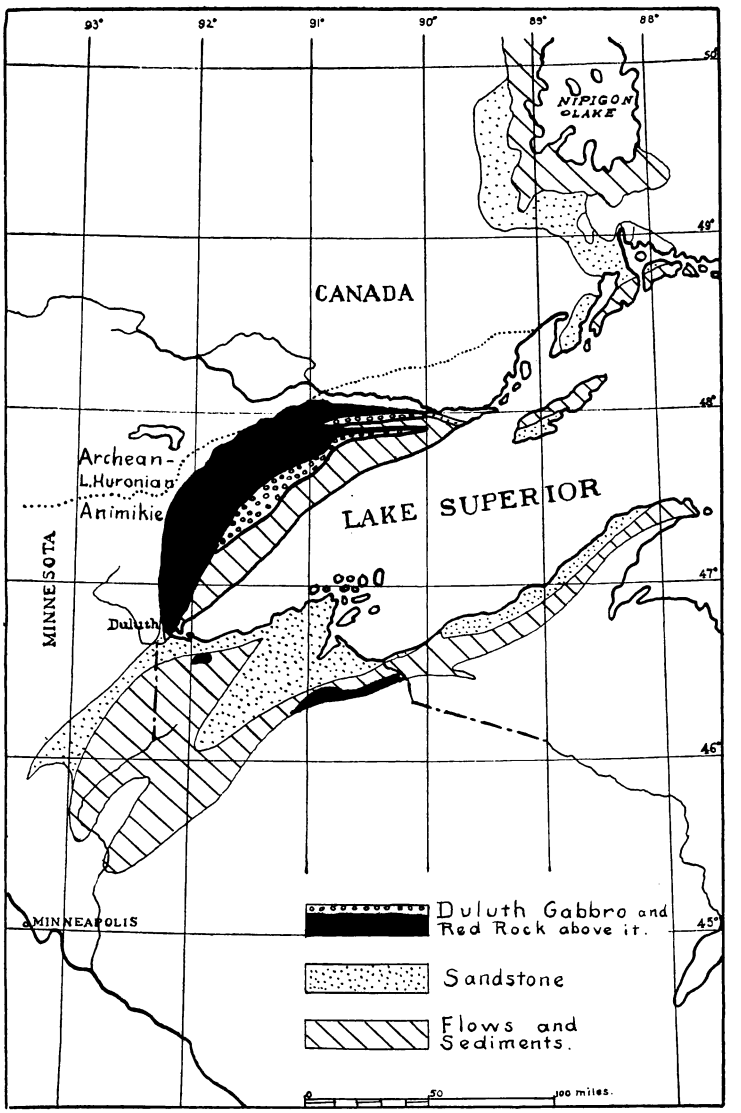

FIG. 1. Map of the west end of Lake Superior showing Keweenawan areas.

find the roof at a fairly constant horizon. The magma must have spread along an unconformity, or we are forced to the absurd conclusion that the magma knew when to cease its stoping. Another fatal objection to the idea of transgression and much stoping, is the volume of material missing. The Rove slate, where it dips under

FIG. 2.

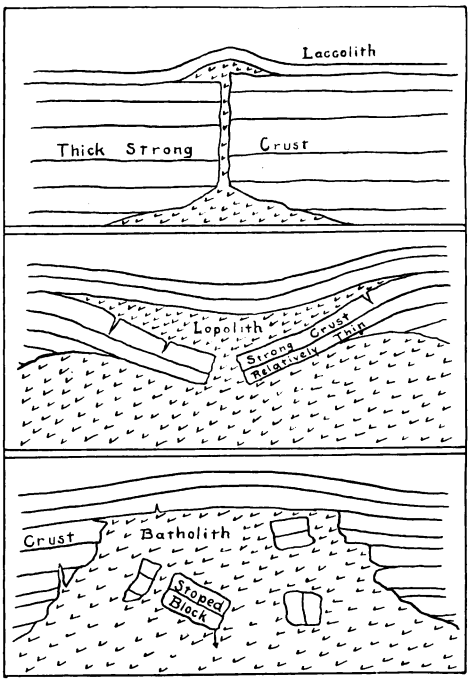

FIG. 2. Sketches to suggest the possible relation of a lopolith to the other forms of occurrence of igneous rocks.

the gabbro, is estimated to be 2600 feet thick,[7] and this is only one of several missing formations. Hall has estimated that the slates west of the gabbro are 20,000 feet thick, 5000 feet in sight.[8] The estimates are not based on accurate data, but are probably of the right order of magnitude. These formations could easily have been

[7] Van Hise, C. R., and Leith, C. K., Geology of the Lake Superior region; U. S. Geol. Survey, Mon. 52, p. 201.

[8] Hall, C. W., The Kewatin of eastern Minnesota: Bull. Geol. Soc. America, vol. 12, p. 374, 1901.

eroded in the long pre-Keweenawan interval,[9] but could hardly have been stoped into the gabbro, no matter what the horizon of intrusion. It seems certain, therefore, that the gabbro was intruded and spread approximately along the base of the Keweenawan.

Besides the Duluth mass as a type, one might classify as lopoliths the Sudbury and Bushveldt masses; and possibly the basin-like mass on the Isle of Skye and the banded rock of Julianahaab, Greenland.

As a piece of speculation it may be of interest to suggest a relation between laccoliths and the larger lopoliths; and note what would result from a continued increase in size. Figure 2 is self-explanatory.

General remarks on the Duluth gabbro.—If the form of the Duluth gabbro is as assumed, certain consequences may be stated. The form being roughly lenticular, it seems probable that the extent down the dip is nearly as great as the length of an eroded outcropping edge. Even if it is only half that extent, a glance at the map indicates that it is very probable, as Van Hise and Leith mention,[10] that the gabbro of the Gogebic range in Wisconsin is part of the same original lopolith.

If a roughly circular outline is drawn around all the known outcrops, it encloses over fifteen thousand square miles, the area once occupied by the lopolith; besides which it is evident that a part has been eroded, and probable that the subsidence which tilted the gabbro in Wisconsin to an angle of more than 75°, was accompanied by a good deal of crustal shortening. The present area of gabbro outcrops may be much less than the original.

Estimates of the thickness may be made on the assumption that the floor of the gabbro dips approximately with the adjacent internal structure.[11] The estimates are only approximate because of a scarcity of outcrops where the gabbro is widest, and because in the same region there are some thick sills which are distinguished with difficulty from the gabbro. The maximum thickness indicated in Minnesota is about 50,000 feet; at Duluth about 12,000 feet are exposed; at the northeastern outcrops in Minnesota the lopolith is less than 3000 feet thick. These estimates are conservative in the matter of dip,—former

[9] Van Hise, C. R., and Leith, C. K., op. cit., p. 208.
[10] Op. cit., p. 378.
[11] Grout, F. F., op. cit.

records of structure would indicate nearly twice as steep a dip as that here used.[12] In Wisconsin the thickness of the gabbro is probably less than 4,000 feet.[13] If the lopolith is thickest in the center like a lens, the real maximum thickness is concealed below the lake.

The volume of the lopolith may be estimated at over 50,000 cubic miles. It is evidently one of the largest known intrusive masses. Considered with some related intrusions,—the Logan sills, the sills at Beaver Bay, and other intrusions of the same age in more distant parts of the Lake Superior region—it indicates an immensity of intrusive action at this time, that has rarely been equalled.

Summary.—Certain large, centrally sunken intrusions are given a distinct name, *lopolith.* Lopoliths differ from laccoliths not only in these points of size and form, but probably also in the mechanics of their intrusion. The Duluth gabbro is a multiple, composite, divided lopolith which is furthermore interformational over most of its length. Conservative estimates of its size indicate an area of over 15,000 square miles, and a volume of over 50,000 cubic miles—one of the largest known floored intrusions. Other illustrations of lopoliths are suggested.

Acknowledgments are here gratefully given to the members of the geologic staff of the graduate faculty at Yale University, for very helpful suggestions.

[12] Irving, R. D., op. cit., p. 269.
[13] Van Hise, and Leith, op. cit., p. 377.