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Bedrock Geology of Duluth and Vicinity

ST. LOUIS COUNTY, MINNESOTA

BY RICHARD B. TAYLOR

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Abstract

Duluth, Minnesota, is on the northwest limb of the Lake Superior syncline, a northeast-trending structure of Precambrian age. The northwest limb of the syncline dips 10–20 ° S.E. toward Lake Superior and is dominated by the Duluth Gabbro Complex, a huge sill-like mass with crescentic outcrop that extends almost 150 miles from Duluth to near Hovland. At Duluth the gabbro complex lies on the Thomson Formation, and apparently was intruded along the surface of unconformity below the Keweenawan rocks. The gabbro complex was formed by multiple intrusion, and consists of an older anorthositic gabbro and a younger layered gabbro and related intrusions. Keweenawan flows above the gabbro mass are cut by diabase sills.

The basalt flows at one locality currently are being quarried as a source of crushed rock for concrete aggregate.

Contents

Bedrock Geology of Duluth and Vicinity

INTRODUCTION AND GEOLOGIC SETTING

Duluth, Minnesota, is on the northwest limb of the Lake Superior syncline. From the city northward along the shore of Lake Superior, Keweenawan flows of the North Shore Volcanic Group dip at low angles toward the lake. Most of the flows are basalt, but some are of intermediate or rhyolitic composition. The geology is dominated by the Duluth Gabbro Complex, a gigantic sill-like mass that stretches about 150 miles from Duluth northeastward to a point near Hovland. The gabbro was intruded below the volcanic rocks and above older igneous and metamorphic rocks, and apparently mainly followed the surface of unconformity on which the Keweenawan volcanic rocks were extruded. The gabbroic mass was formed by a number of separate intrusions of basic magma. At Duluth, two main periods of intrusion are recognized: the first is represented by anorthositic gabbro, and the second by a layered series gabbro and related intrusive bodies of ferrogranodiorite and granophyre. West of Duluth, the Thomson Formation, consisting of interbedded graywacke and slate layers, lies with angular unconformity below the Keweenawan flows, or was intruded by the gabbro.

Geologic studies in the Duluth area probably began with the observations by Kloos (1871) on the petrographic character of some of the gabbroic rocks. Van Hise and Leith (1911) give a complete list of references on the geology of the Precambrian of Minnesota through 1910. Classic studies at Duluth by Grout (1918a,b,c,d) contributed concepts fundamental to the study of stratiform intrusive masses. A later report by Schwartz (1949) formed an important base for the present work. The support of the Minnesota Geological Survey and the assistance of G. M. Schwartz and S. S. Goldich in these investigations is gratefully acknowledged. A subsequent paper, to be published as Bulletin 44 of the Minnesota Geological Survey, will report in greater detail on the petrology of the Duluth Gabbro Complex.

GENERAL GEOLOGY

Brief descriptions of the formations in the Duluth area are given here. Further information on the regional setting can be found in summary papers by Grout and others (1951) and Goldich and others (1961); a detailed description of the geology of the Duluth area is furnished by Schwartz (1949). The generalized succession of formations and absolute age data are given in the accompanying table.

STRATIGRAPHIC SUCCESSION OF THE PRECAMBRIAN ROCKS OF NORTHEASTERN MINNESOTA
(modified from Goldich and others, 1961; italicized units crop out in the Duluth area)

Era	Period-System	Major Sequence	Formation	Intrusive Rocks
			.....unconformity.....	
(0.6 b.y.)			Hinckley Sandstone	
			Fond du Lac Sandstone	
			.....unconformity.....	
(1.1 b.y.) Late Precambrian	Keweenawan	*North Shore Volcanic Group*	(undivided)	*Duluth Gabbro Complex, sills at Duluth* Beaver Bay Complex, Logan intrusives
			Puckwunge Formation	
			.....unconformity.....	
			.....unconformity.....	
(1.7 b.y.)			Virginia Argillite = Rove = *Thomson*	
		Animikie Group	Biwabik Iron-Formation = Gunflint	
Middle Precambrian	Huronian		Pokegama Quartzite	
			.....unconformity.....	Algoman granitic rocks
(2.5 b.y.)	Timiskamian	Knife Lake Group	(undivided)	
(? b.y.)			.....unconformity.....	Laurentian granitic rocks
			Soudan Iron-Formation	
Early Precambrian	Ontarian	Keewatin Group	Ely Greenstone	
		Coutchiching (?)	(undivided)	

Pleistocene glacial deposits cover the greater part of the Duluth area and bury most of the bedrock. These deposits, discussed by Schwartz (1949), include clay, sand, and gravel from glacial Lake Duluth, and till from the Superior lobe; they are not discussed in this report.

Thomson Formation

The Thomson Formation, composed of interbedded graywacke and slate, crops out in the western part of the area. The graywacke is gray to black, fine- to coarse-grained, and contains angular grains of quartz, feldspar, and rock fragments in a matrix of quartz, chlorite, and sericite. The black slate has a well-developed flow cleavage and is composed largely of sericite and quartz, with lesser amounts of chlorite, carbonate, feldspar, and magnetite. Gradations between graywacke and slate form intermediate types. The chlorite and sericite in the matrix of the rock indicate low grade regional metamorphism of the greenschist metamorphic facies. In the Duluth area the Thomson Formation strikes roughly east-west, at about a 45 degree angle to the trend of the structure in the Keweenawan rocks. In the southern part of the area, flows of the North Shore Volcanic Group or sedimentary rocks of the Puckwunge Formation rest unconformably on the truncated beds of the Thomson Formation; in the northern part, gabbro intrusion apparently followed the surface of unconformity. Recent investigations (Goldich and others, 1961) have suggested the correlation of the Thomson Formation with the Virginia Argillite and the Rove Formation.

Puckwunge Formation

The Puckwunge Formation, composed of quartzite and conglomerate, crops out in the western part of the area just north of Eldes Corner. The quartzite is buff to gray, well indurated, somewhat less than 100 feet thick, and baked by the overlying basalt flow. These outcrops show that the formation unconformably overlies the Thomson Formation. In other localities stratigraphic relations between the quartzite and the Keweenawan flows may be complex, but this cannot be shown by surface exposures in the Duluth area. A description by Winchell (1899) of the rocks encountered in the drilling of a deep well in Short Line Park (southwest part of Bardon Peak) shows 217 feet of flows, 48 feet of pyritiferous quartzite and quartz conglomerate, and 91 feet of flows above the Thomson Slate. This well log casts some doubt on the suggested basal position of the Puckwunge Formation below the Keweenawan extrusives and on its assignment to the Lower Keweenawan (Schwartz, 1949, p. 36).

North Shore Volcanic Group

The North Shore Volcanic Group (Goldich and others, 1961) is a thick sequence of lava flows, tuffs, and interflow sediments. It crops out below the Duluth Gabbro Complex in the vicinity of Elys Peak and above the

gabbroic rocks in the eastern part of the city of Duluth. A maximum thickness of 2500 feet of flows beneath the gabbro is indicated by Sandberg (1938); a more recent estimate by Grout and others (1951, p. 1054) indicates a total thickness of 30,000 feet for the flows on the north shore of Lake Superior. Sandberg (1938) has described in detail the stratigraphic succession of units along the shore of Lake Superior. The present choice of map units follows Sandberg's nomenclature and divides the rocks into basaltic, rhyolitic, and sedimentary units. It is now recognized that flows of a composition intermediate between basalt and rhyolite are present in significant amounts; most of these are included within the rhyolite unit in the geologic map. In particular, the rhyolitic unit mapped near Cascade Park in downtown Duluth is an adamellite in composition. The thick rhyolite at the east edge of the map is a true rhyolite.

The interflow sandstones are chiefly buff, gray, or pink medium-grained rocks composed of the disintegration products of volcanic rocks. Generally thinly laminated, most are crossbedded. The thickest unit, about 115 feet thick, is exposed along the shore of Lake Superior at Leif Ericson Park; most of the sandstone units, however, are less than 10 feet thick. The rough amygdaloidal tops of some of the flows acted as traps for sediments that were washed over them, and are now complex mixtures of clastic particles and flow material.

Duluth Gabbro Complex

The sequence of rocks which make up the Duluth Gabbro Complex resulted as the culmination of the period of igneous activity that formed the North Shore Volcanic Group. Enormous volumes of basaltic magma moved up and intruded the flows. Because this sequence of rocks was formed by differentiation of basaltic magma, the intimate structural relations observed between different units can only be explained as the result of multiple intrusion. Two major gabbroic units are present at Duluth. The older is anorthositic gabbro, a coarse-grained feldspathic rock. The younger is a layered series gabbro, a finer-grained olivine gabbro characterized by banding. Intrusive bodies of ferrogranodiorite and granophyre are closely related to the layered series. Age determinations (Goldich and others, 1961) on a series of samples of gabbro and related rocks and on older rocks metamorphosed by the gabbro yielded numbers from 1.06 to 1.2 billion years; 1.1 billion years is considered a probable age for the Duluth Gabbro Complex.

Anorthositic Gabbro. The rock unit formed during the first major period of intrusion is mapped as anorthositic gabbro; it was recognized by Grout (1918a) and called the feldspathic gabbro. The anorthositic gabbro crops out in a band about three miles wide that extends northward from West Duluth beyond the limits of the mapped area. The upper contact can be seen behind Villa Scholastica and near the WFTV towers. At Villa Scholastica coarse feldspathic gabbro intrudes the basalt flows and shows little evidence of chilling; even narrow dike-like apoph-

yses are coarsely crystalline. Near the WFTV towers the gabbro is more mafic, slightly finer-grained, and probably was chilled. The basalt flows were recrystallized to a granoblastic hornfels and are veined by dark minerals, chiefly amphibole, that seem related to the contact action of the magma. Numerous blocks of basalt hornfels, torn from the flows, form xenoliths in the gabbro near the contact. The nature of the original basal contact of the anorthositic gabbro is unknown because the unit is cut off to the west by gabbro of the younger period of intrusion.

The anorthositic gabbro is coarse- to very coarse-grained, generally contains more than 75 per cent of calcic plagioclase, and is characterized by abundant cognate inclusions composed of many varieties of coarsely crystalline gabbro. Most of the rocks are spotted, with poikilitic crystals of titanaugite and magnetite-ilmenite enclosing tabular plagioclase crystals. Single titanaugite crystals up to six inches across enclosing hundreds of feldspar crystals can be distinguished by cleavage and schiller structure. Many rocks have a well-developed fluxion structure produced by parallel orientation of tabular feldspar crystals. These structures wrap around inclusions and are so influenced by local flow conditions as to obscure any large regional structure. The plagioclase content ranges from about 50 to almost 100 per cent. True anorthosite with 95 per cent or more of plagioclase is found only in discrete inclusions, generally rounded, and with grain size varying from pegmatite-like crystals as much as 14 inches long to fine-grained cataclastic rocks resembling chert.

Gabbroic pegmatite occurs as segregations with indefinite boundaries. Titanaugite and labradorite are the most common minerals, and ilmenite, magnetite, biotite, and apatite are ubiquitous accessory minerals. Late-stage alteration locally uralitized the augite, sericitized the edges of plagioclase crystals, and formed small pink crystals of perthitic orthoclase.

The composition of the pyroxene and plagioclase in the anorthositic gabbro suggests that the anorthositic gabbro is a crystal accumulate derived from basaltic magma. The absence of banded structures, which would show bottom accumulation of fractionated crystals, and the feldspathic composition show that the processes of differentiation were very different from those that produced the later gabbros. Expected basic complementary rocks may have been cut out by the intrusion of the three-mile-thick body of layered series gabbro, but no evidence of their existence is available. The anorthositic gabbro was intruded into its present position as a crystal mush, and the inclusions probably represent early phases that solidified, then were broken up, and finally were moved to their present location by a succession of pushes of magma.

Layered Series Gabbro. The layered series makes up about two thirds of the gabbro complex at Duluth. It crops out in a broad band about five miles wide that extends northward from Bardon Peak beyond the limits of the mapped area. The upper contact of the layered series with the anorthositic gabbro can be traced accurately only in the southern part

of the area. The contact is sharp, irregular in trend, and follows widely spaced joints in the anorthositic gabbro. Large blocks of anorthositic gabbro are found as inclusions more than a mile from the contact; a few are sufficiently large to be mapped, as near Bayview. Northeast of Keene Creek the contact dips steeply and strikes about N.20°W.; a mile and a half northwest of Skyline Drive the trend changes to N.20°E. The gabbro of the layered series is chilled against the contact, and narrow dikes extending into the anorthositic gabbro were chilled to a fine-grained basalt. One complex apophysis was mapped above the rock quarry at 57th Avenue West. The contact of the layered series with the ferrogranodiorite near Miller Creek was not seen, though its position can be located accurately between closely spaced outcrops. The contact between the anorthositic gabbro and the layered series is not exposed north of Highway 53, but the trend is northerly, and the location is probably accurate within a mile. The western, basal contact of the layered series trends north-south and dips to the east. It transgresses about 2500 feet of basalt flows from the southernmost exposures on Elys Peak in a distance of eight miles to the north, and from this point, near Hermantown Road, intrudes the Thomson Formation north to the map boundary. Outcrops at Elys Peak suggest that the basal contact strikes N.10°W. and dips about 45°E.; banded structures in the gabbro some distance above the contact have a similar strike but a lower dip. The basalt flows beneath the gabbro have been recrystallized to a hornfels.

Banded structures with relatively consistent regional trend justify the name of layered series for this unit. Rhythmic layering with local gravitational stratification is developed in many parts of the mass. At Bardon Peak the troctolite is strikingly banded by alternating olivine-rich and feldspar-rich layers from a fraction of an inch to several inches thick. The upward transition from feldspathic layers to olivine-rich layers is abrupt; the transition from olivine-rich layers to feldspathic layers is gradational. This feature, called gravitational stratification, strongly resembles graded bedding in sedimentary rocks and is convincing evidence that the banding formed on a floor of crystal accumulation, with the crystals forming from magma that moved cyclically above it. Rhythmic layering near Rest Point is broken by later intrusions of gabbro of slightly different composition and texture. Similar evidence in many other places leads to the hypothesis that the stable conditions of bottom crystal accumulation were interrupted many times by renewed intrusion. A large-scale banding with lenticular units tens of feet thick is encountered in the central part of the layered series. The size and shape of these units were probably controlled by movements in the magma during crystallization.

North of Adolph the position of the basal contact is based on magnetometer traverses by Schwartz (1944).

Generalizations on the composition of the layered series gabbro are necessarily crude because of the diversity of rock types and irregularities

in distribution, but a few statements seem warranted. The gabbroic rocks in the lower (western) part are characteristically rich in olivine, and most are banded or have well-developed fluxion structure. In the central part the rocks have highly variable proportions of plagioclase, olivine, augite, and magnetite-ilmenite; layers of a single composition and texture are from a few inches to many feet thick, and intimate structural relations suggest that part of the variation is due to bottom crystal accumulation and part is due to multiple intrusions which broke up solid or semi-solid material. The rocks of the uppermost part contain less olivine, some having small amounts of quartz and potassium feldspar formed as late-stage minerals; there is abundant evidence of multiple intrusion in these rocks.

One of the intrusive bodies could be mapped separately, and has been informally called the intrusion at Bardon Peak. The body is tabular, more than 200 feet thick, and has been traced for about a mile and a half. Coarse-grained olivine gabbro with large poikilitic titanaugite crystals is the main rock type, but a local related peridotite as much as 50 feet thick forms the upper part of the body on the tracks of the Duluth, Winnipeg and Pacific Railway. The contacts are sharp against the banded troctolite of the layered series and there is no sign of chilling; apophyses of peridotite cut the troctolite, and inclusions of troctolite were found in the coarse gabbro. This is probably but one of many individual intrusive bodies within the layered series.

Cryptic layering has been defined by Wager and Deer (1939) as the change in composition of minerals with height in a stratiform intrusive body. This compositional change is controlled by the changes in magma composition determined by crystallization-differentiation. Only slight variations were found in the composition of the mineral phases in the layered series of the Duluth Gabbro Complex, and these were not a regular function of height in the intrusion.

On Bardon Peak numerous gabbroic pegmatites crosscut the banded troctolite near the base of the layered series. The pegmatites are tabular to irregular in shape and many are zoned. Olivine, basic plagioclase, and titanaugite form the margin; the titanaugite crystals are rudely oriented perpendicular to the walls. An intermediate zone of altered feldspar, uralite, biotite, quartz, and K-feldspar grades to a central core of quartz-K-feldspar granophyre. Dikes of basic pegmatite are found in other parts of the gabbro, but nowhere else is there a concentration of bodies like that at Bardon Peak.

Ferrogranodiorite. Medium-grained dark-colored granodiorite, adamellite, and syenodiorite form three major bodies and several narrow dikes. These show iron enrichment akin to the ferrogabbro of the Skaergaard mass (Wager and Deer, 1939) and here are called ferrogranodiorite.

The largest body crops out along Miller and Coffee creeks. Exposures along the eastern side of the mass are of a fine-grained syenodiorite border facies that has an irregular, steeply dipping contact with the anor-

thositic gabbro. The contact with the layered series to the west is not exposed. Blocks of fine-grained basaltic rock are included within the granodiorite and probably were derived from the chilled margin of the layered series gabbro. The main rock type is ferrogranodiorite; it is massive with a few pegmatitic concentrations of quartz and feldspar, generally medium-grained, and a medium to dark greenish gray color. Andesine, hornblende, ferroaugite, and magnetite are the major minerals; orthoclase, albite, and quartz are present in lesser amounts.

Half a mile east of Coffee Creek, a tabular intrusive body of ferrogranodiorite cuts the anorthositic gabbro. It is about a third of a mile long, 100 feet thick, strikes N.70°W., and dips northeast. The rock is slightly more felsic than that at Miller Creek.

The lower part of an irregular-shaped intrusive mass northeast of Enger Tower is ferrogranodiorite. The rock is dark gray and equigranular; flow banding is well developed locally. The ferrogranodiorite appears to grade upward (eastward) to granophyre, but exposures are lacking and relations between these rocks are not defined.

Granophyre. Intrusive bodies composed of brick-red granophyre ("red rock" of the older literature) cut all the other rock types in the Duluth Gabbro Complex. Found at almost all stratigraphic levels in the layered series, the masses are concentrated near the contact with the anorthositic gabbro; they are widely distributed in the anorthositic gabbro and the overlying flows. Although contacts with the gabbroic rocks are locally sharp, corrosion and alteration of the basic rock, introduction of quartz and red-dusted feldspar into it, and assimilation that forms dark mafic varieties of granophyre are more characteristic. The granophyre is composed chiefly of quartz and feldspar, intergrown in granophyric texture. The feldspar is a mixture of orthoclase and sodic plagioclase formed by exsolution, and both perthitic orthoclase and antiperthitic albite commonly occur in each rock. The feldspars are clouded by a heavy dusting of hematite and are partly altered to clay minerals. The rock has a fine, even-grained appearance except for local pegmatitic spots and miarolitic cavities.

Narrow dikes of granophyre cut the basalt flows beneath the gabbro on Elys Peak and the lower rocks of the layered series in the vicinity of Bardon Peak. Some of these are biotite-rich and have coarse intergrowths of quartz and feldspar. Near Rest Point numerous dikes cut the gabbro, stratigraphically in the central part of the layered series. At the upper contact of the layered series with the anorthositic gabbro near Lincoln Park, several small bodies of granophyre exhibit many different relations to gabbroic wall rock. On Miller Creek, dikes with sharp contacts intrude the anorthositic gabbro and locally contain little-altered fragments of finer-grained gabbro derived from the chilled margin of the layered series. At 27th Avenue West and 12th Street, effects of corrosion, replacement, and assimilation are evident. On Skyline Drive, at the contact of the anorthositic gabbro with the layered series, an uncommon

granophyre rich in silica and soda and poor in potash has developed by replacement and metasomatism of the fine-grained chilled margin of the layered series.

East of Enger Tower, granophyre occurs as the upper (eastern) part of a compound intrusive mass. The anorthositic gabbro near this body has significant amounts of introduced quartz and K-feldspar related to the granophyre. Contaminated granophyre is exposed in the quarry at 13th Avenue West and Third Street; inclusions with vague boundaries are common, but a few have sharp outlines.

The largest bodies of granophyre crop out in the northern part of the area along Amity Creek, Jean Duluth Road, and Woodland Avenue. These granophyre bodies clearly intrude the anorthositic gabbro, but in turn are cut by microgabbro from the Endion sill. The granophyre is fine-grained and has a detailed implication texture, locally with radiating fan-like structures of intergrown quartz and red-dusted feldspar.

Petrology. The various rocks of the layered series probably were derived from a tholeiitic basaltic magma by processes of fractional crystallization. Although the variation in rock composition cannot be traced within any single unit, there is a rock and mineral series as indicated in the accompanying tabulation.

	gabbro	syenogabbro	ferrogranodiorite	granophyre
Composition of plagioclase	An_{65}	An_{55}	An_{45}	$An_{5\text{-}15}$
Composition of pyroxene	clinopyroxene-titanaugite		ferroaugite	

Conditions of bottom crystal accumulation of gabbroic rocks were interrupted from time to time by surges of magma which also modified the composition of the magmatic liquids in the chamber. The transgressive ferrogranodiorite and granophyre bodies indicate progressive enrichment of residual liquids in iron, silica, and alkalies, and subsequent movement of these residual magmas from their place of origin to the final site of crystallization. Small amounts of granophyre probably were formed by replacement, but granophyre-forming fluids also were derived during the process of differentiation.

Microgabbro Dikes and Sills

Dikes and sills composed for the most part of microgabbro were formed in the final igneous episode that can be recognized in the Duluth region. Border rocks were chilled to fine-grained or aphanitic basalts. Most of each mass is a fine-grained diabasic gabbro chiefly composed of

plagioclase, pyroxene, and olivine. In the Endion sill, near Congdon Park, part of the material is granodiorite and granophyre.

A swarm of basalt dikes is concentrated in the NE¼NW¼ Sec. 28, T.50N., R.14W., near Hilltop Park. Most of these dikes intrude the anorthositic gabbro, a few cut the ferrogranodiorite, and one, just east of Twin Lakes, intrudes granophyre. The largest dike of this group is about 80 feet thick and has been traced for about a mile. The dike strikes N.50°W. and dips 20°N.E. It may extend to the east and be continuous with the sill noted by Schwartz (1949, p. 56) in the Duluth sewer tunnel at Second Avenue West.

Microgabbro dikes cropping out in the bluffs above Smithville and Merritt Park intrude, respectively, the layered series and the anorthositic gabbro. They are similar in lithology and trend to the group near Enger Tower.

The largest intrusive mass grouped with the late microgabbro dikes is the Endion sill, a mass about 1500 feet thick. Although roughly concordant to the lava flows which it cuts at the shore of Lake Superior, it becomes sharply discordant two miles to the north. The composition and petrology of this sill near the lake is discussed by Ernst (1960); he concludes that the granodiorite and granophyre found in the upper part of the mass formed by fractional crystallization. Farther inland the differentiated phases seem to be absent.

PRECAMBRIAN HISTORY

The rocks of the Thomson Formation contain the first record of geologic history in the Duluth area. The sedimentary materials that formed the formation were an interlayered succession of impure sandstone, mudstone, and shale. Regional metamorphism and folding, dated about 1.7 billion years ago, formed easterly trending folds and recrystallized the minerals to the greenschist metamorphic facies. Beveling and truncation of these rocks by a pre-Keweenawan erosion surface preceded the extrusion of the thick succession of lava flows and deposition of the intercalated sediments that constitute the North Shore Volcanic Group. The culmination of the period of igneous activity was reached with the intrusion of the Duluth Gabbro Complex about 1.1 billion years ago. An initial anorthositic gabbro phase was intruded as a crystal mush containing abundant cognate xenoliths. The later gabbro of the layered series chilled against the anorthositic gabbro and was formed by many intrusions, probably closely spaced in time, that are generally indistinguishable except where crosscutting relations can be seen. Closely related intrusive bodies of ferrogranodiorite and granophyre represent differentiated magmas moved from the chamber of differentiation to their present position. Late microgabbro dikes constitute the final igneous event.

ECONOMIC GEOLOGY

The basement rocks of the Duluth region have been exploited as a valuable source of crushed crystalline rock and prospected in a limited way for copper and titaniferous magnetite.

The only active rock quarry is on the west slope of Elys Peak. It produces crushed trap rock from the basalt flows that lie stratigraphically below the Duluth Gabbro Complex. The rock makes an excellent concrete aggregate, and the supply is virtually unlimited. Many small excavations in basalt flows above the gabbro have supplied small amounts of rock for local uses. These quarries are within developed areas of the city and probably cannot be expanded appreciably. Gabbroic rocks have been obtained in the past from quarries located near 57th Avenue and Franklin Street, and in Central Park southeast of Enger Tower. The rock has been used for breakwater facings; it cannot compete with the basaltic rock for aggregate because the more massive gabbro is much more difficult to crush than the trap rock. At present most sand and gravel for aggregate and fill are obtained from numerous small pits in Pleistocene glacial deposits.

The famous native copper deposits of the Keweenawan Peninsula of Michigan occur in rocks similar to the flows of the North Shore Volcanic Group, and have prompted prospecting of the flows on the west side of Lake Superior. Prospects have been found north of the Duluth area, but not within it. Shallow pits dug during copper prospecting at the junction of Mesabi Avenue and Superior Street were covered by construction of a filling station. Veinlets of prehnite were found in the outcrop of anorthositic gabbro behind the station, but no copper-bearing minerals were seen.

Titaniferous magnetite segregations, discovered by N. H. Winchell (Winchell, N. H., and Winchell, H. V., 1891), are located just north of Hermantown Road, west of Haines Road. Old test pits may still be seen west of the church but little magnetite remains. Pits in the NW¼SW¼ Sec. 7, T.50N., R.14W., discussed by Schwartz (1949, p. 130), are now covered with rubbish, but the dump from the pits indicates that magnetite-ilmenite veins up to two inches wide cut coarse-grained gabbro. There is no reason to believe that these deposits have appreciable potential value, for the much larger and higher grade deposits in the northern part of the gabbro complex (Grout, 1949–1950) are not being exploited at the present time.

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