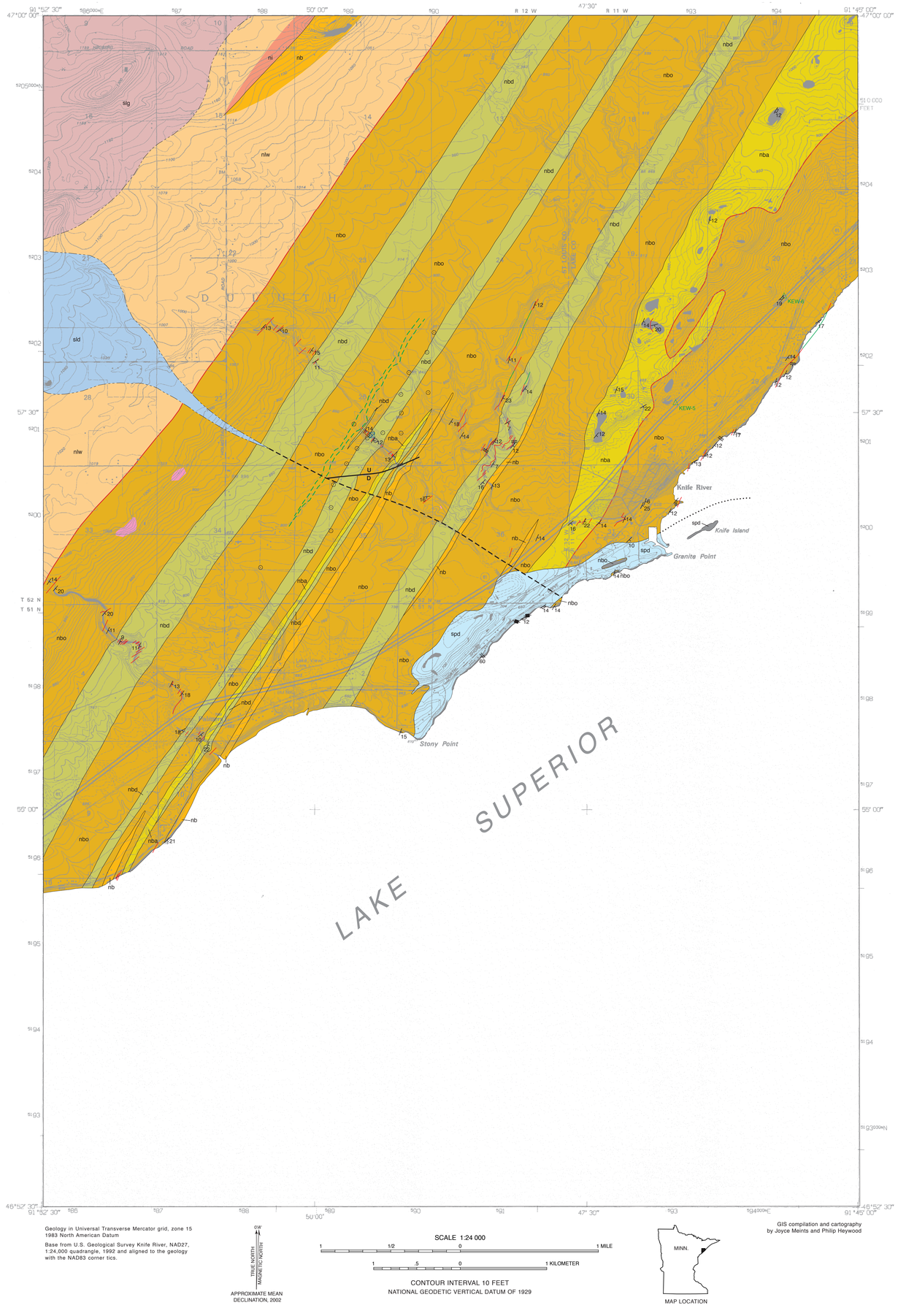
UNIVERSITY OF MINNESOTA
MINNESOTA GEOLOGICAL SURVEY
V.W. Chandler, Interim Director

Prepared and Published with the Support of
THE U.S. GEOLOGICAL SURVEY AS PART OF THE 2001 STATE GEOLOGIC MAPPING PROGRAM ELEMENT (STATEMAP)
OF THE NATIONAL GEOLOGIC MAPPING PROGRAM

MISCELLANEOUS MAP SERIES
MAP M-129
Bedrock Geology, Knife River Quadrangle



Geology in Universal Transverse Mercator grid, zone 15
1983 North American Datum

Base from U.S. Geological Survey Knife River, NAD27, 1:24,000 quadrangle, 1992 and aligned to the geology with the NAD83 corner tics.

APPROXIMATE MEAN DECLINATION, 2002

SCALE 1:24 000
1 1/2 0 1 MILE
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

MAP LOCATION

GIS compilation and cartography by Joyce Meints and Philip Heywood

The University of Minnesota is an equal opportunity educator and employer

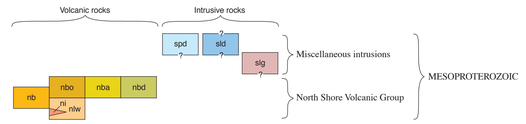
BEDROCK GEOLOGY OF THE KNIFE RIVER QUADRANGLE, ST. LOUIS AND LAKE COUNTIES, MINNESOTA

By

Terrence J. Boerboom, *Minnesota Geological Survey*
John C. Green, *University of Minnesota, Duluth*
Mark A. Jirsa, *Minnesota Geological Survey*

2002

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

MIDCONTINENT RIFT INTRUSIVE SUPERSUITE

MISCELLANEOUS INTRUSIONS—Subvolcanic sills that may be related in timing to the Beaver Bay Complex of the Midcontinent Rift Intrusive Supersuite (Miller and Green, 2002); emplaced into the North Shore Volcanic Group of the Keweenawan Supergroup. Terminology for the various rock groups and formations on this and the accompanying map (Boerboom and others, 2002) follows that of Miller and others (2002).

Stony Point diabase—Forms sheet-like intrusion that is discordant to volcanic stratigraphy of the Larsmont and Sucker River basalts (Fig. 1). Exposed portion of sill is calculated to be as thick as 100 meters (300 feet), but aeromagnetic data imply that the diabase thickens beneath Lake Superior. See Jerde (1991) for geochemical data.

spd — *Ophitic diabase*—Gray, medium-grained; massive olivine diabase with black augite oikocrysts that are typically 2–4 centimeters in diameter. Contains 60–65 percent plagioclase, 12–18 percent olivine, 12–18 percent clinopyroxene (augite), 0–5 percent hypersthene, and 2–4 percent opaque minerals. Locally exhibits weak modal banding; thin tabular segregations of pegmatitic gabbro and poikilitic olivine diabase are present locally within sill interior. Chilled margin at southwestern lakeshore exposure contains as much as 5 percent pyrrhotite and possible chalcopyrite. About 30 meters (100 ft) northeast of the contact the diabase contains xenolith of pale green anorthosite at least 1 by 3 by 3 meters in size.

Sawmill Lake intrusion—Poorly constrained unit defined by Miller and Green (2002) as Sawmill Lake gabbro; consists of various rock types, including olivine gabbro, olivine diabase, ferrodiorite, and granophyre.

sld — *Ophitic diabase*—Gray, medium-grained; generally altered, low in olivine; contains diktytaxitic chlorite. Poorly exposed; distribution inferred largely from inconsistent positive aeromagnetic anomaly.

slg — *Granophyric granodiorite*—Brownish to grayish pink, medium-grained, pyroxene-quartz monzodiorite to monzogabbro. In addition to plagioclase and K-feldspar, unit contains fresh intergranular to subophitic augite, altered olivine, and as much as 10 percent quartz, which typically exhibits bladed tridymite shapes in thin section.

KEWEENAWAN SUPERGROUP

NORTH SHORE VOLCANIC GROUP—The volcanic rocks are part of the upper sequence of the southwest limb of the North Shore Volcanic Group (Green, 2002). The sequence is further subdivided into informal formations (Fig. 1), as delineated by Green (2002). The formations are here subdivided into map units that consist of one or more flows of like compositional and physical attributes. Volcanic formations may not be defined by sharp compositional breaks; rather, they have boundaries distinguished on the basis of relative thicknesses and chemical compositions of the constituent flows, or they are separated by intervening diabase sills. Volcanic formations within the Knife River quadrangle include the Larsmont basalts, the Sucker River basalts, and the Lakewood lavas (Fig.1).

Total thickness of the Lakewood lavas is about 1070 meters (3500 ft); however, the portion of the Lakewood lavas within this quadrangle is only about 490 meters (1600 ft) thick, because part of the sequence has been cut out by the Sawmill Lake intrusions. Similar calculations indicate that the Sucker River basalts are about 1400 meters (4500 ft) thick, and the Larsmont basalts, within this quadrangle, are about 400 meters (1300 ft) in thickness.

This map uses both lithologic (rock type) and stratigraphic (formational) terminology for the North Shore Volcanic Group. The map units are delineated on the basis of lithologic features that can be discerned on the outcrop; the delineation is augmented by petrographic descriptions. Criteria include physical attributes, such as texture, amygdule composition, and flow morphology. Many of the units mapped are lithologically indistinguishable across formational boundaries. Thus, map unit nbo, for example, may be present in two or more formations. Where insufficient bedrock exposure exists, map units were amalgamated into a larger unit named with a general formational label, such as nlw.

Physical and petrographic attributes of units can be correlated in a general fashion using rock geochemistry. Brannon (1984) conducted a detailed geochemical study of the volcanic rocks, mainly from samples collected on the shoreline of Lake Superior and up the Knife River. Texture and flow morphology exhibit a general correlation to rock chemistry. However, the chemical composition of the ophitic basalts (nbo) and diabase-textured basalts (nbd) commonly overlap, which suggests that other factors, such as rate of extrusion and volatile content, may have played an important role in the textural genesis of the lava flows. All the Larsmont (ophitic) basalts in the Knife River quadrangle are of primitive olivine tholeiite composition, whereas the Sucker River ophitic basalts vary from iron-rich to intermediate olivine tholeiite. Other compositions within the Sucker River basalts include transitional basalt (unit nb) and basaltic andesite (unit nba). Further geochemical and petrographic information for two olivine tholeiite flows is available in Basaltic Volcanism Study Project (1981). In the chapter of that study entitled Pre-Tertiary Continental Flood Basalts (p. 30–74), the Keweenawan Reference Suite includes samples KEW-5 and KEW-6 from the Knife River quadrangle. Locations of these samples are shown on the map. Sample KEW-6 has the most primitive composition yet analyzed from the North Shore Volcanic Group.

Secondary minerals formed during hydrothermal burial metamorphism are abundant in the lavas, especially in the more permeable (fractured and amygdaloidal) upper zones of individual flows. The rocks are metamorphosed from prehnite-pumpellyite to upper zeolite facies (see Schmidt, 1990, 1993, for details).

Extensive exploration for copper mineralization was conducted in 1929 along the Little Knife River in sections 26, 34, and 35, T. 52 N., R. 12 W. (Schwartz, 1949). The exploration was part of a 20-hole diamond-drilling program; the holes were 98–455 feet in depth and included the sinking of a 110-foot deep shaft with 200 feet of lateral drift. The drilling intersected three mineralized horizons along flow-top horizons that contained subeconomic amounts of copper and minor silver (Listerud and Meineke, 1977). The locations of the drill holes and the shaft, as estimated from the original records, which were provided by the Mining Company of Canada, are shown on the map.

nbo — **Ophitic basalt**—Typically brown to gray, fine-grained, ophitic olivine basalt, having a mottled appearance due to oikocrystic augite. The Larsmont basalts exhibit a pronounced spotted ophite texture and commonly exhibit an irregular layering produced by alternating layers of large and small ophites. Included in the Larsmont basalts are local, fine-grained, hard, fresh, gray, non-ophitic basalts exposed along Minnesota Highway 61 near the eastern margin of the quadrangle and in the hills farther inland. They are apparently local non-ophitic layers or lenses within otherwise ophitic basalt. The olivine in the non-ophitic zones is mostly fresh, in contrast to the typically altered olivine in nearly every other volcanic rock type in which it is present. Flows locally contain pipe vesicles; they also commonly contain rows of small amygdules near the base and billowy to irregular rubbly flow tops. Upper parts of some flows contain contorted and detached flow-lobe fragments that have layered rows of laumontite amygdules. Rubbly a'a-type flow tops are typically infilled with zeolite-cemented silt and sand. Amygdules include laumontite, calcite, quartz, chlorite, and prehnite. Native copper was not seen in the Larsmont basalts, and it is rare in the Sucker River basalt flows. Traces of copper are present in sediment deposited in and above rubbly flow tops in the Sucker River basalts, where the sediment was cemented and variably replaced by prehnite

nba — **Basaltic andesite to andesite**—Maroonish gray to gray, fine-grained, and typically porphyritic. Several flows that are exposed immediately below Minnesota Highway 61 exhibit stretched, quartz-lined amygdules and rubbly flow tops. Knife River exposures project inland to a series of outcrops that mostly consist of thick, massive flows.

nbd — **Diabase-textured basalt**—Olivine basalt, typically dark green, fine- to medium-grained, altered and somewhat punky, variably ophitic. Characterized by felty plagioclase laths, scattered clot-like clinopyroxene oikocrysts, and abundant diktytaxitic chlorite. Dominant amygdule filling is laumontite; also calcite, prehnite, and chlorite-type minerals. Bottoms of individual flows typically contain pipe amygdules overlain by a massive 10–30-centimeter zone, which gives way upward to a zone containing 0.5–1 meter long vesicle cylinders oriented perpendicular to the flow base. In nearly every case, the vesicle cylinders are composed of a single bead-like string of amygdules. The uppermost portions of the flows are typified by alternating layers of basalt that contain abundant versus fewer amygdules.

nb — **Basalt**—Brownish gray to gray, fine-grained, dense, intergranular; rare small plagioclase phenocrysts. Commonly exhibits oxidation lamination (Green, 1989). Middle to upper portions of flows have vesicle cylinders containing quartz, chalcedony, minor chlorite, and zeolite.

ni — **Icelandite**—Maroonish brown, fine-grained, porphyritic; small amounts of plagioclase, augite, and magnetite phenocrysts. Exposed only in isolated outcrops at northeastern extension of Lakewood lavas.

nlw — **Basalt, basaltic andesite, icelandite, and rhyolite, undifferentiated**—Northeastern extension of the Lakewood lavas, which are well exposed to the southwest in French River and Lakewood quadrangles (Boerboom and others, 2002) but virtually unexposed in this quadrangle. Includes isolated outcrops of icelandite (ni) and massive basalt (nb) at north edge of quadrangle.

MAP SYMBOLS

- **Geologic contact**.
- **Geologic contact**—Concealed.
- **Geologic contact inferred from aeromagnetic mapping.**
- **Boundary between informal volcanic formations (see Fig. 1).**
- **Contact between individual lava flows**—Red where observed in outcrop; green where inferred; green dashes where projected from drill-hole data.
- **Fault inferred from aeromagnetic mapping.**
- **Fault showning minor displacement**—**D**, downthrown side; **U**, upthrown side.
- 12 **Strike and dip of inclined volcanic flow layering and sedimentary bedding**—Angle in degrees from horizontal; in volcanic rocks, includes flow parting and oxidation lamination.
- 12 **Strike and dip of flow- and sill-parallel sheet joints**—Approximates attitude of flow layering in volcanic rocks and orientation of sills in intrusive rocks; angle in degrees from horizontal.
- **Strike and dip of joints**—Only those having evidence for movement are shown.
- 60 **Strike and dip of minor fault plane.**
- **Copper exploration drill hole**—Information from company drill logs on file at the Minnesota Geological Survey
- **Copper exploration shaft.**
- KEW-5 **Reference sample number and location from Basaltic Volcanism Study Project (Basaltic Volcanism Study Project, 1981).**
- **Bedrock outcrop identified during fieldwork for this map.**
- **Bedrock outcrop identified by G.M. Schwartz (1949)**—Not verified by recent fieldwork.

REFERENCES

Basaltic Volcanism Study Project, 1981, Basaltic volcanism on the terrestrial planets: New York, Pergamon Press, 1286 p.

Boerboom, T.J., Green, J.C., and Jirsa, M.A., 2002, Bedrock geologic map of the French River and Lakewood quadrangles, St. Louis County, Minnesota: Minnesota Geological Survey Miscellaneous Map Series M-128, scale 1:24,000.

Brannon, J.C., 1984, Geochemistry of successive lava flows of the Keweenawan North Shore Volcanic Group: St. Louis, Mo., Washington University, Ph.D. dissertation, 312 p.

Green, J.C., 1989, Physical volcanology of mid-Proterozoic plateau lavas: The Keweenawan North Shore Volcanic Group, Minnesota: Geological Society of America Bulletin, v. 101, p. 486–500.

———2002, Volcanic and sedimentary rocks of the Keweenawan Supergroup in northeastern Minnesota, Chapter 5 *in* Geology and mineral potential of the Duluth Complex and related rocks of northeastern Minnesota: Minnesota Geological Survey Report of Investigations 58, p. 94–102.

Jerde, E.A., 1991, Geochemistry and petrology of hypabyssal rocks associated with the Midcontinent rift, northeastern Minnesota: Los Angeles, Calif., University of California, Ph.D. dissertation, 305 p.

Listerud, W.H., and Meineke, D.G., 1977, Mineral evaluation of the Lake Superior region of northeastern Minnesota—a progress report on field surveys: Minnesota Department of Natural Resources, Division of Minerals Report 132-I, 6 p.

Miller, J.D., Jr., and Green, J.C., 2002, Geology of the Beaver Bay Complex and related hypabyssal intrusions, *in* Geology and mineral potential of the Duluth Complex and related rocks of northeastern Minnesota: Minnesota Geological Survey Report of Investigations 58, p. 144–163.

Miller, J.D., Jr., Green, J.C., and Severson, M.J., 2002, Terminology, nomenclature, and classification of Keweenawan igneous rocks of northeastern Minnesota, *in* Geology and mineral potential of the Duluth Complex and related rocks of northeastern Minnesota: Minnesota Geological Survey Report of Investigations 58, p. 5–20.

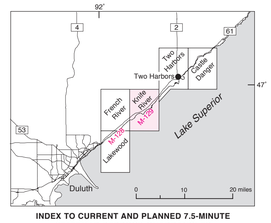
Schmidt, S.T, 1990, Alteration under conditions of burial metamorphism in the North Shore Volcanic Group, Minnesota—mineralogical and geochemical zonation: Heidelberger Geowissenschaftliche Abhandlungen, v. 41, 309 p.

———1993, Regional and local pattern of low-grade metamorphism in the North Shore Volcanic Group, Minnesota, USA: Journal of Metamorphic Geology, v. 11, p. 401–414.

Schwartz, G.M., 1949, The geology of the Duluth metropolitan area: Minnesota Geological Survey Bulletin 33, 136 p., 19 pls. in pocket.

Every reasonable effort has been made to ensure the accuracy of the factual data on which this map interpretation is based; however, the Minnesota Geological Survey does not warrant or guarantee that there are no errors. Users may wish to verify critical information; sources include both the references listed here and information on file at the offices of the Minnesota Geological Survey in St. Paul. In addition, effort has been made to ensure that the interpretation conforms to sound geologic and cartographic principles. No claim is made that the interpretation shown is rigorously correct, however, and it should not be used to guide engineering-scale decisions without site-specific verification.

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government. This map is submitted for publication with the understanding that the U.S. Government is authorized to reproduce and distribute reprints for governmental use. Supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under assistance Award No. 01HQAG0099.



INDEX TO CURRENT AND PLANNED 7.5-MINUTE STATEMAP BEDROCK QUADRANGLES ALONG THE NORTH SHORE OF LAKE SUPERIOR

Miscellaneous Map M-129 (this map) is highlighted. Miscellaneous Map M-128 (French River and Lakewood quadrangles) is also available. The Two Harbors and Castle Danger quadrangles will be completed in 2003.

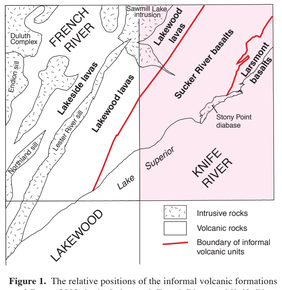


Figure 1. The relative positions of the informal volcanic formations of Green (2002) in the Lakewood, French River, and Knife River 7.5-minute quadrangles, St. Louis County. The area of this map is tinted pink. The French River and Lakewood quadrangles are published separately as Miscellaneous Map Series Map M-128 (Boerboom and others, 2002).