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MISCELLANEOUS MAP SERIES
MAP M-128
Bedrock Geology,
French River and Lakewood Quadrangles

BEDROCK GEOLOGY OF THE FRENCH RIVER AND LAKEWOOD QUADRANGLES, ST. LOUIS COUNTY, MINNESOTA

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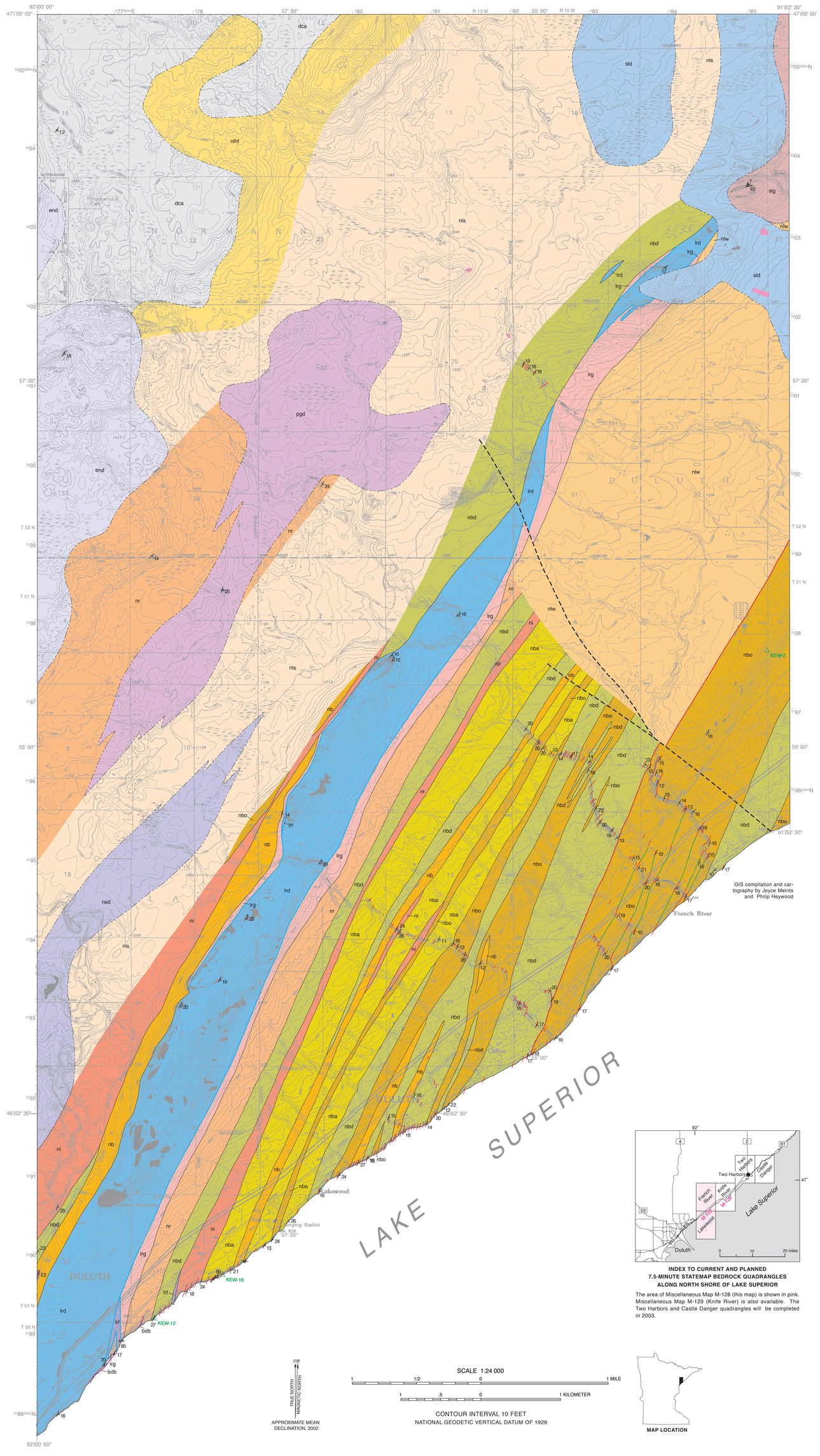
2002



Base from U.S. Geological Survey French River and Lakewood 1:24,000 quadrangles, 1992.

Universal Transverse Mercator grid, zone 15
1983 North American Datum

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 2002

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

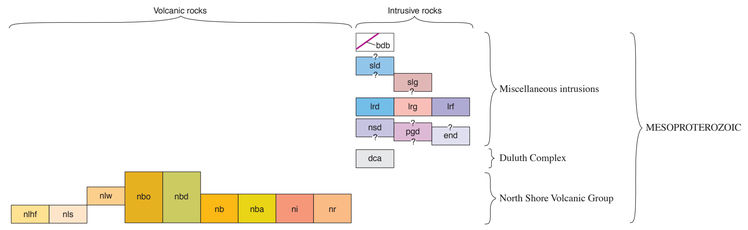
CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

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

The area of Miscellaneous Map M-128 (this map) is shown in pink. Miscellaneous Map M-129 (Knife River) is also available. The Two Harbors and Castle Danger quadrangles will be completed in 2003.

MAP LOCATION

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNIT

MIDCONTINENT RIFT INTRUSIVE SUPERSUITE

MISCELLANEOUS INTRUSIONS—Subvolcanic sills possibly related in timing to the Beaver Bay Complex of the Midcontinent Rift Intrusive Supersuite, emplaced into the North Shore Volcanic Group of the Keweenawan Supergroup. Within the map area the sills include, from lowest to highest in the volcanic pile, the Endion sill, an unnamed gabbroic intrusion, the Northland sill, and the Lester River sill. All intrude volcanic rocks of the North Shore Volcanic Group, and most are adjacent to felsic strata. The intrusions contain substantial felsic phases that are probably the product of partial melting and remobilization of the adjacent rocks. The Endion and Northland sills are exposed primarily west of the French River and Lakewood quadrangles, and they are poorly exposed within the map area. Terminology for various rock groups and formations on this and the accompanying map (Boerboom and others, 2002) follows that of Miller and others (2002).

bdb — **Olivine diabase**—Dark gray, fine-grained, subophitic, felty textured. Two separate dikes, one of which forms an anastomosing, 15-foot (4.6-m) wide dike that cuts the Lester River sill and adjacent volcanic rocks along the edge of the Lake Superior shoreline. See Green (1986) for geochemical analyses of the dikes.

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

sld — *Ophitic diabase*—Gray, medium-grained. Generally altered, low in olivine; diktytaxitic chlorite; distinguished from the Lester River sill on the basis of ophitic texture. Poorly exposed; distribution inferred largely from inconsistent positive aeromagnetic anomaly.

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

Lester River sill—Named for the diabase outcrops adjacent to the mouth of the Lester River (Schwartz and Sandberg, 1940). Forms prominent ridge (Moose Mountain) that extends about 6.5 miles (10.5 km) inland from Lake Superior; average dip to southeast is 19 degrees. Past estimates (for example, Schwartz and Sandberg, 1940) place thickness at about 950–1000 feet (290 m); this study estimates thickness of about 1300 feet (396 m) at lakeshore to 600 feet (152 m) at northeastern terminus. Sill is generally conformable with volcanic strata; emplaced more or less along contact of rhyolite flows above and basalt flows below. Topographic offsets along sill length imply faulting; however, detailed mapping indicates offset is probably product of slight variations in stratigraphic level at which sill was emplaced. Basalt flows underlying the sill are cut by intrusion midway along sill length. Upper sill margin contains abundant felsic micrographic granodiorite (red rock of Schwartz and Sandberg, 1940; Miller and others, 1993); whereas, bottom sill margin contains only thin and discontinuous pods of this hybrid rock. Jerde (1991) provides considerable geochemical, petrographic, and petrologic data on Lester River sill.

Upper portion of Lester River sill (UTM NAD 83, coordinate 577291, 5188887) locally contains nearly east-trending, clastic dikes that fill subvertical fractures. The dikes consist of dark greenish gray, well-sorted quartz arenite characterized by medium-grained, well-rounded, frosted quartz grains. The dikes are unlike any of the sedimentary rocks within the volcanic section and may represent the lowest reaches of a now-eroded younger sandstone, such as the Hinckley Sandstone.

lrg — *Granite, granodiorite, and monzodiorite*—Pink to grayish pink, fine- to medium-grained, massive, commonly porphyritic. Contains quartz, red-dusted K-feldspar, minor hornblende, and altered plagioclase, pyroxene, and olivine. Quartz typically exhibits bladed tridymite habit. Color index varies depending on degree of mixing between primary tholeiitic magma and secondary felsic melt generated from adjacent volcanic rocks.

lrf — *Ferrodiorite to granophyric gabbro*—Dark pinkish gray to gray, fine- to medium-grained, massive, variably porphyritic. Contains altered plagioclase, pyroxene, and olivine; anhedral-interstitial quartz-K-feldspar intergrowths. Composition gradational with units lrg and lrd; forms irregular pods in margins of Lester River sill.

lrd — *Intergranular to subophitic diabase*—Gray, medium- to coarse-grained, massive, locally weakly porphyritic, commonly granophyric in mesostasis. Contains 55–65 percent fresh, blocky, rectangular plagioclase, 8–15 percent intergranular to subophitic augite, 8–14 percent variably altered olivine, 0–4 percent orthopyroxene, 1–4 percent opaque oxides, 0–10 percent quartz and granophyre, 1–3 percent diktytaxitic chlorite, and trace amounts of apatite (no more than one percent), biotite, and hornblende. Quartz commonly contains wispy needles of rutile.

Northland sill—Exposed mainly to the west of map area; varies greatly in thickness from a narrow dike-like intrusion at the shore to a sill 300-meters thick (985 ft) farther inland (Schwartz and Sandberg, 1940; Miller and others, 1993). The sill intrudes mafic to felsic volcanic rocks of the North Shore Volcanic Group; consequently, it contains a substantial proportion of irregularly distributed intermediate to felsic granophyric phases that likely originated as partial melts of the volcanic wallrock. Within the map area, the Northland sill is represented by one isolated outcrop, and its general distribution is largely inferred from aeromagnetic maps.

nsd — *Intergranular diabase*—Brownish gray, medium-grained, felty-textured, weakly porphyritic. Dominant minerals include tabular plagioclase, prismatic to granular clinopyroxene rimmed by minor hornblende, bladed ilmenite, magnetite, and apatite; granophyric mesostasis.

pgd — **Unnamed porphyritic gabbro to diabase**—Outcrop in interior of body is gray, medium- to coarse-grained, altered, porphyritic, subophitic gabbro with about 30 percent tabular plagioclase phenocrysts in groundmass of partly altered plagioclase, altered olivine, subophitic augite, opaque Fe-Ti oxides, secondary chlorite, and minor quartz, hornblende, and apatite. Outcrop along southeast edge of body is gray, medium-grained, seriate-textured diabase composed dominantly of plagioclase and granular to prismatic augite, with lesser amounts of equant to tabular opaque oxides, chlorite, quartz, and hornblende. The diabase contains xenoliths of anorthositic rocks and is separated from the overlying rhyolite (unit nr) by a felsic hybrid zone too small to show on the map. The unit may correlate with the Northland sill to south (unit nsd). This poorly defined unit was mapped on the basis of three outcrops and aeromagnetic data. Correlation of rock types between the three outcrops is highly uncertain; the unit may consist of two or more separate intrusions.

Endion sill—Stratigraphically lowest hypabyssal intrusion into volcanic rocks above the Duluth Complex; approximately 1300-feet thick and intruded just beneath a rhyolite flow (Schwartz and Sandberg, 1940). Well-exposed portions of the sill west of the map area are composed of medium-grained, ophitic to intergranular olivine diabase; about 40 percent of the volume is composed of felsic phases (Miller and others, 1993; Miller and Green, 2002). Within the map area, a lone outcrop is inferred to be part of Endion sill on the basis of aeromagnetic mapping, but this connection is poorly constrained. Geochemical and petrologic data on the Endion sill are available in Ernst (1960) and Jerde (1991).

end — *Oxide gabbro*—Greenish gray, medium-grained, intergranular, magnetic; displays moderately well-developed textural foliation. Contains rare 1–3 centimeter euhedral plagioclase phenocrysts, fresh augite, and clots of mixed chlorite, actinolite, and sphene that constitute pseudomorphs of a primary mafic mineral. Contains local magnetite segregations.

DULUTH COMPLEX—Present at the far northwest corner of the French River quadrangle; represented by an isolated outcrop of anorthosite. Areal extent of anorthositic Duluth Complex rocks was inferred from a subdued, low-amplitude aeromagnetic anomaly and mapping northwest of map area (Miller and others, 1993).

dca — **Anorthosite**—Gray, coarse-grained; weak textural foliation. Contains one percent total interstitial clinopyroxene and secondary alteration minerals, including epidote, chlorite, hornblende, actinolite, zeolite-group minerals, and opaque grains.

KEWEENAWAN SUPERGROUP

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

Total thickness of the Lakeside lavas is estimated to be 1200 meters (4000 ft), the Lakewood lavas, 1100 meters (3500 ft), and the Sucker River basalts, 1400 meters (4500 ft).

Both lithologic (rock type) and stratigraphic (formational) terminology for the North Shore Volcanic Group is used on this map. 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. The 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 and given a general formational label, such as nlw.

Secondary minerals that 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).

Physical and petrographic attributes of units can be correlated in a general fashion with rock geochemistry. Brannon (1984) conducted a detailed geochemical study of the volcanic rocks from samples collected on the shoreline. The texture and flow morphology exhibit a general correlation to rock chemistry. In the map area, the lowermost Sucker River basalts (ophitic) are predominantly iron-rich olivine tholeiites, in contrast to the uppermost Sucker River basalts to the east (see Boerboom and others, 2002), which are generally of intermediate olivine tholeiite, transitional, or basaltic andesite composition. Within the Lakewood lavas, the ophitic basalts (unit nbo) are mostly iron-rich olivine tholeiites; the diabase-textured basalts (unit nbd) are mostly transitional basalts; and the andesitic rocks are entirely ferroandesite, in contrast to andesitic rocks within the Sucker River series to the east, which are basaltic andesite. In general, the Lakewood lavas show an inverse chemical evolution; the most silica-rich rocks (rhyolite, icelandite, and andesite) are at the base of the volcanic sequence (Brannon, 1984). Further geochemical and petrographic information for three flows in the map area is available in Basaltic Volcanism Study Project (1981; p. 30–74); the chapter on pre-Tertiary continental flood basalts (the Keweenawan reference suite) includes samples KEW-2 and KEW-12 (basalts), and KEW-18 (ferroandesite). Sample locations are shown on the map.

nbo — **Ophitic basalt**—Typically brown to gray, fine-grained, ophitic olivine basalt characterized by mottled appearance due to oikocrystic augite. The thick sequence of ophitic basalts at the base of the Sucker River formation exhibits a pronounced spotted ophite texture with 3–8-millimeter augite oikocrysts; characteric irregular layering is due to alternating bands of large and small ophites. Typically massive flows, with scattered large ovoid amygdules near the base and amygdaloidal flow tops range from smooth to lumpy and, less commonly, rubbly a'a-type, are infilled with silt and sand. Amygdule fillings include laumontite, calcite, quartz, chlorite, and prehnite. Native copper is rare within flows, but in the Sucker River basalts traces appear in sediments deposited in and above rubbly flow tops where it has been cemented and variably replaced by prehnite.

nbd — **Diabase-textured basalt**—Dark green to gray, fine- to medium-grained, altered and somewhat punky, variably ophitic olivine basalt. Characterized by felty plagioclase laths, scattered clinopyroxene oikocrysts, and abundant diktytaxitic chlorite. Dominant amygdule filling is laumontite; unit also contains amygdules of calcite, prehnite, and chlorite-type minerals. Native copper common in uppermost parts of flows that contain prehnite. Upper interiors of some flows (for example, those exposed along French River) are very coarse grained, with tabular plagioclase crystals as long as 10 millimeters surrounded by black augite oikocrysts as much as 30 centimeters in size. These coarse-grained zones may have formed through concentration of volatile constituents within a partially solidified flow. Overall, the flows exhibit textures typical of highly fluid pahoehoe type (for example, Green, 1989), with 5–20 centimeters long, Y-shaped pipe amygdules at the flow base overlain by a 10–30 centimeter massive zone that gives way upward to a zone of thin vesicle cylinders. The vesicle cylinders are typically 0.5–1 meter (1.5–3.25 ft) in length, oriented perpendicular to the flow base and in nearly every case are composed of a single bead-like string of amygdules. The uppermost portions of the flows are typified by alternating bands of basalt containing abundant versus fewer amygdules. Ropy textures and thin flow lobes are commonly visible on the surfaces of flows where appropriately exposed.

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. Some flows mapped as basalt may be gradational into andesite.

nba — **Andesite to basaltic andesite**—Maroonish to purplish gray, fine-grained, typically porphyritic. Pipe vesicles locally at flow bases; upper parts of flows contain abundant stretched amygdules of laumontite, as well as quartz, calcite, and chlorite. Flow tops have smooth to billowy lobes rimmed by scoria fragments grading to flow-top breccias. Thin interflow sandstone caps uppermost flow.

ni — **Icelandite**—Pink to grayish pink, fine-grained, slightly porphyritic. Typically contains centimeter-sized clots of gray, fine-grained, basaltic rock, as well as small, tabular plagioclase phenocrysts in a groundmass of plagioclase, K-feldspar, quartz, and minor fresh to altered prismatic clinopyroxene, opaque oxides, and apatite. Open vugs—tens of centimeters in diameter—are common and partially filled with calcite and lesser amounts of fluorite, barite, amethyst quartz, and laumontite. Upper parts of flows commonly exhibit well-developed, highly contorted and folded flow banding. Uppermost flow beneath andesite (along lakeshore) overlain by 12-foot (3.5-m) thick, fine-grained, interflow sandstone. Thick icelandite flow just northwest of (below) the Lester River sill has been informally named the Lester Park icelandite (Green, 1993). Geochemical and petrographic data on the flow are in Green and Fitz (1993) and Vervoort and Green (1997).

nr — **Rhyolite**—Pink, fine-grained, porphyritic. Typically contains poikilitic quartz, scattered small K-feldspar phenocrysts, local, sparse quartz phenocrysts, and clots of gray basaltic rock. Large cavities filled with calcite and lesser amounts of fluorite and barite are common; some open vugs lined with coarse barite blades are crusted with prehnite, calcite, and fluorite. Flow just southeast of (above) Lester River sill has been informally named the Lakewood rhyolite (Green and Fitz, 1993). For further data on this flow, see Green and Fitz (1993).

nlw — **Basalt, basaltic andesite, icelandite, and rhyolite, undifferentiated**—Lakewood lavas of Green (2002). Lack of outcrop precludes extension of mapped units from better exposed area to southwest.

nls — **Basalt, icelandite, and rhyolite, undifferentiated**—Lakeside lavas of Green (2002). Well exposed west of map area (for example, Miller and others, 1993).

nlhf — **Hornfels volcanic rocks**—Inferred from scattered outcrops mapped by Schwartz (1949) north of French River quadrangle. High-amplitude aeromagnetic anomalies, inferred as product of magnetic hornfels volcanic rocks, used as guide to infer distribution into map area. Considered part of Lakeside lava series.

MAP SYMBOLS

- **Geologic contact.**
- **Geologic contact inferred from aeromagnetic mapping.**
- **Boundary between intrusive phases.**
- **Boundary between informal volcanic units (see Fig. 1).**
- **Contact between individual lava flows**—Red line where observed in outcrop; green line where inferred.
- **Fault inferred from aeromagnetic mapping.**
- **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,
- **Strike and dip of inclined lamination and modal layering in igneous rocks**—Angle in degrees from horizontal.
- **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 minor fault plane.**
- KEW-12 — **Reference sample number and location from Basaltic Volcanism Study Project (Basaltic Volcanism Study Project, 1991).**
- **Bedrock outcrop identified by the authors of this map.**
- **Bedrock outcrop identified by George M. Schwartz (1949), not verified by recent fieldwork.**
- **Clastic dike.**

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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.

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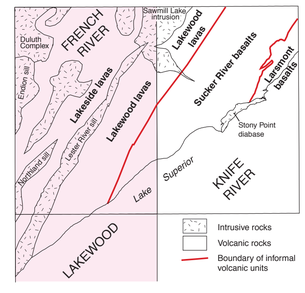

Figure 1. The relative positions of the informal volcanic formations of Green (2002) in the Lakewood, French River, and Knife Lake 7.5-minute quadrangles, St. Louis County. The area of this map is highlighted. The Knife Lake quadrangle is published separately as Miscellaneous Map Series Map M-129 (Boerboom and others, 2002).

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