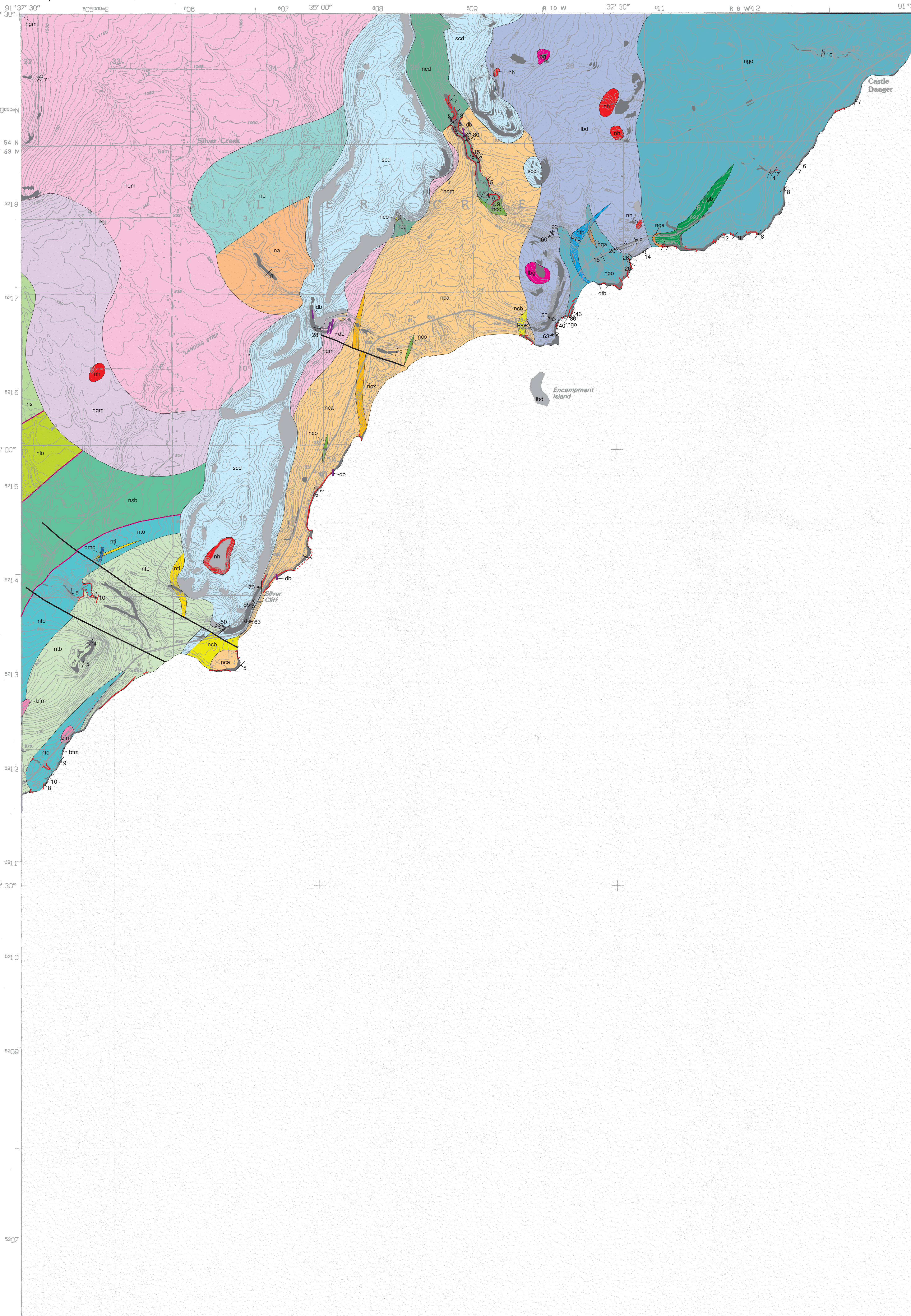


Base from U.S. Geological Survey Castle Danger 1:24,000 quadrangle, 1992.

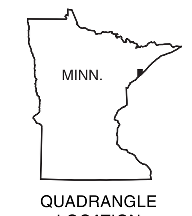
Universal Transverse Mercator grid, zone 15
1983 North American Datum

-0°17'
MAGNETIC NORTH
TRUE NORTH
APPROXIMATE MEAN DECLINATION, 2003

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

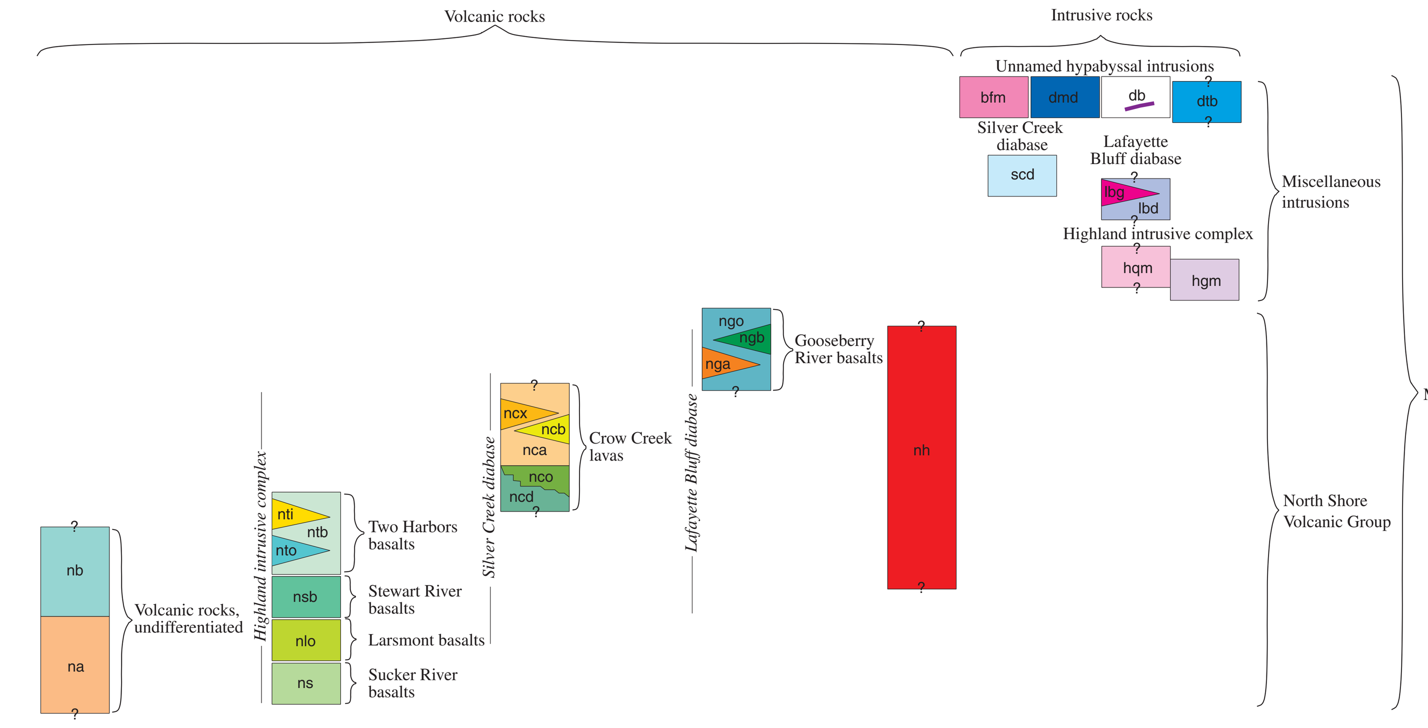
CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

GIS compilation and cartography by Joyce Meints and Philip Heywood
Edited by Lori Robinson



QUADRANGLE LOCATION

CORRELATION OF MAP UNITS



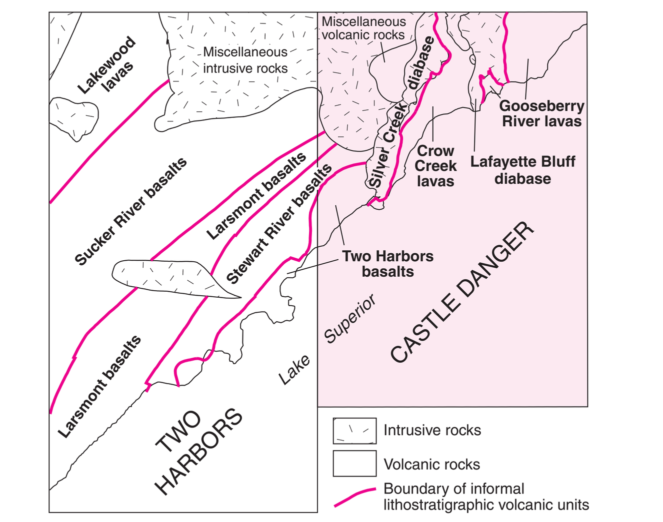


Figure 1. The relative positions of the informal lithostratigraphic volcanic units of Green (2002) and modified by this study of the Two Harbors and Castle Danger quadrangles. The area of this map is highlighted. The Two Harbors quadrangle is published separately as Miscellaneous Map M-139 (Boerboom and others, 2003).

DESCRIPTION OF MAP UNITS

MIDCONTINENT RIFT INTRUSIVE SUPERSUITE

Miscellaneous intrusions—Subvolcanic sheet-like intrusions possibly 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. The terminology for the various rock groups and formations on this and the Two Harbors quadrangle (Boerboom and others, 2003) follows that of Miller and others (2002). Pope (1976) mapped much of the Silver Creek and Lafayette Bluff diabase intrusions. The Lafayette Bluff diabase outcrops were remapped as part of this study, but most of the outcrops of the Silver Creek diabase shown on this map were taken from Pope's study.

Unnamed intrusions

db — ***Diabase***—Dark gray, fine- to medium-grained, ophitic. Contains small, round, chloritic amygdules near dike margins. The dike on the lakeshore in T. 53 N., R. 10 W., sec. 15 is 6.5 feet (2 meters) thick, weakly porphyritic, and has minor brittle faults present along its margins. The dike along the lakeshore in T. 53 N., R.10 W., sec. 14, is approximately 120 feet (37 meters) thick and cut by a second dike of fine-grained, weakly porphyritic, chilled ophitic diabase.

dmd — ***Prismatic monzodiorite***—Dark gray, fine-grained, felty prismatic-intergranular texture. Contains approximately 42 percent plagioclase, some of which forms radial clusters; 20 percent augite as small granular crystals and larger phenocrystic prismatic grains dotted with opaque oxides along grain margins; 18 percent opaque oxides; and 30 percent turbid brown material that may be either devitrified glass or altered orthoclase feldspar. Groundmass also contains fine dusty opaques, chlorite, leucoxene, and fine prismatic pyroxene. Occurs as a north–northeast-striking, 100 foot (30 meter) thick dike with prominent orthogonal jointing that cuts icelandite in the Stewart River area (T. 53 N., R. 10 W., sec. 16).

bfm — ***Porphyritic basalt to prismatic ferromonzodiorite***—Brownish-pink to dark gray, aphanitic to fine-grained. Exposed as a complex system of irregular subhorizontal intrusions emplaced into volcanic rocks. Exposed at the shoreline between the Stewart River and Silver Creek, along the boundary of T. 53 N., R. 10 W., secs. 21 and 28, as a lower intrusion 6.5 feet (2 meters) or more thick, and an upper intrusion that is greater than 23 feet (7 meters) thick. The lower intrusion contains variable amounts of microlitic skeletal plagioclase, prismatic pyroxene, and oxide granules in a glassy matrix, and the thin leading edge of it is composed entirely of brown, perlitic-fractured, possibly vitric glass of basaltic chemical composition. Round xenoliths of anorthositic rocks up to 1.6 feet (0.5 meter) in diameter are common within this lower intrusion. The upper sheet exposed at the lakeshore is coarser grained but probably petrogenetically related because it contains plagioclase laths and prismatic augite crystals lined by magnetite granules in a mesostasis of turbid brown material that may be K-feldspar or devitrified glass. The petrogenetic relationship between the two sills is uncertain but could be verified by geochemical data. Scattered inland outcrops of a rock type similar to the lower intrusion are exposed just to the west of the map area (Boerboom and others, 2003). Possibly related to unit dmd on the basis of similar texture and mineralogy.

dtb — ***Diatreme-like breccia***—Brown to yellowish-brown intrusive breccia characterized by angular clasts that range from 16 feet (5 meters) to less than 1 millimeter in size. Clast types include very fine-grained porphyritic basalt, amygdaloidal basalt, ophitic basalt, and minor interflow sedimentary rocks. Fine-grained, felty-textured, prismatic ferromonzodiorite associated with this intrusion occurs as clasts and possibly as the host intrusive phase, but this relationship is ambiguous. Diatreme is best exposed on a high lakeshore cliff east of Crow Creek (SE 1/4 sec. 1, T. 53 N., R. 10 W.), accessible only by boat, as a vertical east–west-striking 10 to 13 feet (3 to 4 meters) wide dike that cuts adjacent volcanic rocks. Poorly exposed on land, but outcrop distribution indicates a partial ring-like shape to the intrusion. Variably replaced by zeolite minerals, mainly laumontite, and locally mineralized by pyrite. Possibly related to the Lafayette Bluff diabase as an explosive discharge of volatile elements concentrated during the cooling history of that diabase.

Silver Creek diabase—Irregular subcordant to discordant subhorizontal intrusion of uniform ophitic olivine diabase that is at least 197 feet (60 meters) thick. Forms a prominent highland that projects north from Silver Cliff at Lake Superior to beyond this map area. Crow Creek has eroded through the sill and exposed the underlying volcanic strata, but soil and talus obscure the contact. A tunnel for State Highway 61, carved through the southern terminus of the diabase, has created good exposures of the contact between the diabase and the adjacent volcanic rocks. Within the Encampment River area, the diabase is in near vertical contact with the adjacent hornfels granite and volcanic rocks, possibly indicating the presence of an underlying feeder to the main sheet. With the exception of a roof pendant of metamorphosed mafic volcanic rocks and minor interflow sedimentary rocks near its southern terminus, the Silver Creek diabase is generally free of inclusions. Contact metamorphism of the rocks adjacent to the base of the diabase sheet is confined to a narrow zone that is not depicted on the map.

scd — ***Ophitic olivine diabase***—Gray, medium-grained, massive, with black augite oikocrysts typically 2 to 4 centimeters in diameter. Contains 60 to 65 percent plagioclase; 12 to 15 percent olivine; 15 to 18 percent augite; 0 to 3 percent pigeonite; and 2 to 4 percent opaque minerals. Locally exhibits a weak, discontinuous modal banding near the base of the sill. Exposures at the northeast end of the Silver Cliff tunnel show the presence of thin, dark grayish-black, fine-grained diabase dikes and pink, medium-grained, granitoid hybrid dikes that form small complex intrusions into the adjacent lava flows beneath the sill. Pope (1976) described thin, irregular, shallow dipping lenses of olivine-free, variably pegmatitic gabbro within the sill.

Lafayette Bluff diabase—Irregular, discordant, sheet- to dike-shaped body composed of soft, dark greenish-black, amygdaloidal and porphyritic diabase, with local differentiated pods of coarse-grained prismatic ferromonzodiorite. Typically deeply weathered to a brown crumbly grus bearing round corestones of fresh diabase. The Lafayette Bluff diabase forms prominent high hills near Lake Superior and low hills inland. The diabase locally contains abundant anorthosite xenoliths, such as outcrops on the lakeshore in the southwest corner T. 53 N., R. 9 W., sec. 6, as well as scattered xenoliths of metamorphosed basalt. State Highway 61 has been excavated through the Lafayette Bluff diabase near Lake Superior. Contact metamorphism of the wallrocks to the Lafayette Bluff diabase is restricted to a few meters in extent, and is not depicted on the map.

lbg — ***Prismatic pyroxene granodiorite to ferromonzodiorite***—Dark pinkish-gray, coarse-grained to locally pegmatitic, weakly porphyritic. Contains blocky, moderately altered, zoned euhedral plagioclase and moderately altered, subhedral, equant to prismatic clinopyroxene crystals that are altered to schiller structure. Mesostasis of pink intergrown graphic-myrmekitic quartz and orthoclase, irregular blocky to skeletal opaque oxides, brown clayey material, apatite, sphene, and small green clinopyroxene, possibly of aegirine-augite composition. Occurs as small differentiated bodies within the diabasic olivine gabbro unit (lbd).

lbd — ***Diabasic olivine gabbro***—Dark green, medium- to coarse-grained, typically ophitic, commonly porphyritic and amygdaloidal. Contains 55 to 80 percent generally fresh, fine- to coarse-grained plagioclase with characteristic zonally concentrated dusty inclusions of mafic material; 10 to 25 percent fresh, subpoikilitic to poikilitic augite; 5 to 12 percent variably altered olivine; 2 to 3 percent opaque oxides; trace amounts of pigeonite, inverted pigeonite, and orthopyroxene; and minor granophyric mesostasis. Amygdules and diktytaxitic cavities are filled with fibrous zeolite minerals. Readily recognized by its distinctive color, softness, variable amygdaloidal and porphyritic character, and weathered nature. Granophyre content is slightly elevated near unit lbg. Relatively abundant amygdules indicate that the magma may have been unusually enriched in volatiles, the concentration of which may have led to the formation of the diatreme-like breccia unit (dtb). Contains scattered xenoliths of coarse-grained anorthosite up to 10 feet (3 meters) in diameter and metamorphosed basalt.

Highland intrusion—Mixed gabbroic to felsic intrusive rocks exposed in scattered outcrops at the north edge of the map. Anorthosite xenoliths are common within the mafic phases. Geophysical data imply that these exposures are at the southern margin of a larger intrusive complex that continues northward into the Highland quadrangle.

hqm — ***Quartz monzodiorite to granite***—Dusky to brick red, medium- to coarse-grained, felty texture defined by randomly oriented laths of plagioclase and altered prismatic augite; somewhat quartz-miarolitic. Contains 25 to 35 percent euhedral, pink-altered plagioclase crystals and 2 to 5 percent prismatic, altered augite in a groundmass of mixed quartz (15 to 20 percent), and turbid pink K-feldspar (45 to 55 percent) that may include an indeterminate amount of altered plagioclase. Also contains apatite, diktytaxitic chlorite and zeolite, and abundant euhedral zircons. Grades into unit hgm (mixed gabbro). Outcrops of this unit in the Encampment River downstream from the Silver Creek diabase (scd) and locally on the hillslope southeast of the diabase show similar texture but contain altered prismatic olivine grains in addition to other minerals. These exposures show increasing effects of contact metamorphism in proximity to the Silver Creek diabase.

hgm — ***Gabbroic to monzogabbroic intrusive rocks, undivided***—Inferred from aeromagnetic data to form the eastern extension of the same unit shown on the Two Harbors quadrangle (Boerboom and others, 2003), where it is exposed in scattered outcrops. Includes foliated intergranular gabbro and intergranular to ophitic gabbro, monzogabbro and gabbronorite, and scattered xenoliths of anorthosite and hornfels basalt.

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 lithostratigraphic units (Fig. 1), as delineated by Green (2002) and modified by this study. These lithostratigraphic units are not defined by sharp compositional breaks, but rather have boundaries distinguished on the basis of relative thicknesses and chemical compositions of the constituent flows, or are separated by intervening diabase intrusions. Within the Castle Danger quadrangle, these lithostratigraphic units include flows assigned to the Sucker River basalts, the Larsmont basalts, the newly designated Stewart River basalts, the Two Harbors basalts, the newly designated Crow Creek lavas, and the Gooseberry River lavas (Fig. 1). The temporal correlation of the lithostratigraphic units that are separated by intrusions (as shown in the correlation of map units) is speculative.

The informal lithostratigraphic units are subdivided into map units that are delineated on the basis of features that can be discerned in outcrop and are augmented by petrographic descriptions. The field criteria include attributes such as grain size, texture, amygdule composition and abundance, flow thicknesses, and flow morphology. Many of the units shown in one formation are indistinguishable from similar units in other formations.

Brannon (1984) conducted a detailed geochemical study of volcanic rocks located to the southwest of this map area, along the Lake Superior shoreline, ending at the Two Harbors basalts, which are of quartz tholeiite composition. No significant geochemical analyses have been collected to date for the lava flows within this map area.

Secondary minerals formed during hydrothermal burial metamorphism are abundant in these lavas, especially in the more permeable (fractured and amygdaloidal) upper zones of individual flows. The rocks in this quadrangle are metamorphosed to the upper zeolite facies (Schmidt, 1990, 1993).

Gooseberry River Lavas—Mainly ophitic basalts well exposed on the shoreline northeast of T. 53 N., R. 9 W., sec. 6. Within the two prongs of the Lafayette Bluff diabase, these lavas show profound structural disturbance related to emplacement of the Lafayette Bluff diabase and the diatreme-like breccia unit (dtb). Includes thin flows of andesitic basalt and diabasic-textured basalt exposed on the shoreline northeast of the Lafayette Bluff diabase.

ngo — ***Ophitic basalt***—Brownish-gray, fine-grained, with oikocrysts less than 1 millimeter in thin flows to as large as 3 millimeters in thick flows, locally plagioclase-phyric. On the lakeshore, forms thick flows typically 33 feet (10 meters) or more thick and locally up to 164 feet (50 meters) thick. Flow tops contain variably thick amygdaloidal zones and commonly have aa-type tops with irregular interflow sediment layers as thick as 23 feet (7 meters), the thicker of which show prominent cross-bedded strata.

ngb — ***Diabasic-textured basalt***—Brownish-gray, fine-grained. Series of multiple 3 to 10 foot (1 to 3 meter) thick flows with pipe vesicles at the base and amygdule layers at the top, which overlie unit nga and associated sandstone in sharp contact.

nga — ***Andesite to icelandite***—Dark pink, very fine-grained, scoriaceous. Two flows are exposed; the top of the lower flow is scoria rubble; the base of the upper flow is scoriaceous, with large, open, 1 to 2 centimeter long stretched vesicles. There is a thin sandstone layer between flows. Overlain in sharp contact by unit ngb.

Crow Creek lavas—The "Crow Creek lavas" is a newly designated informal lithostratigraphic unit name for the flows that are located between the Silver Creek and Lafayette Bluff diabase intrusions. Most of the exposed portion of the Crow Creek lavas consists of andesite or basaltic andesite, exposed in a large area along the shoreline of Lake Superior and along some of the rivers inland. In addition, a long section of Crow Creek, which has eroded through the Silver Creek diabase, contains high cliff exposures of ophitic and diabasic-textured basalts that underlie the andesitic lavas. These basalts may correlate with the Stewart River or Larsmont basalts to the southwest, but here are considered part of the Crow Creek lavas because they are confined to the area between the intrusions. Beach exposures located on the point south of Silver Cliff show that the andesitic lava flows have flowed over basalts that have thinly-lobed flow tops that are truncated by erosional channels of 3 feet (1 meter) or more of relief. These channels are filled by the overlying andesitic flows.

nca — ***Basaltic andesite to andesite***—Brown, fine-grained, locally porphyritic lavas of mafic to intermediate composition. Lakeshore exposures near Silver Cliff and adjacent roadcuts on State Highway 61 contain abundant stretched, open, vuggy amygdules lined with small quartz crystals; metamorphosed adjacent to diabase. These flows show highly irregular flow surfaces, and shoreline exposures locally show cracks in the upper part of the flow filled in with sandstone. Inland exposures along Crow Creek and a lakeshore exposure farther northeast consist of brown, massive, fine-grained, variably porphyritic andesite or basaltic andesite. May include minor thin flows of icelandite composition.

ncx — ***Basaltic andesite to andesite, xenolith-bearing***—Similar to unit nca but less amygdaloidal, with scattered xenoliths of maroon-colored anorthosite. Exposed at the shoreline in SW 1/4 sec. 11, T. 53 N., R. 10 W., and in the Encampment River area north of State Highway 61.

ncb — ***Intergranular basalt***—Brownish-gray, fine-grained, intergranular-textured, possibly andesitic in composition. Metamorphosed adjacent to the Silver Creek diabase.

nco — ***Ophitic basalt***—Brownish-gray, fine-grained, contains small oikocrysts.

ncd — ***Diabasic-textured to ophitic basalt***—Brownish-gray, fine- to medium-grained, variably diktytaxitic. Typically occurs in multiple, thin, 3 to 10 foot (1 to 3 meter) thick flows with pipe vesicles at the base and amygdule layering at the top. High cliff exposures preclude mapping of the multiple individual flows exposed along Crow Creek.

Two Harbors basalts—Basal ophitic basalt with characteristic small oikocrysts, overlain by resistant, fine-grained, massive, intergranular basalt; ophitic flows also occur within this intergranular section. A minor volume of icelandite is included within the strata. Onland exposures of the Two Harbors basalts are approximately 656 feet (200 meters) thick, but an indeterminate thickness lies offshore beneath Lake Superior.

ntb — ***Intergranular basalt***—Gray to brownish-gray, fine-grained, oxidation-laminated, with amygdules of quartz, laumontite, calcite, and chlorite. Flow tops are commonly of aa type, and are highly irregular in morphology. Siltstone is common as thin lenses and crack fillings at tops of flows. These flows are very well exposed to the southwest, along the point south of Burlington Bay in Two Harbors (Boerboom and others, 2003).

nto — ***Ophitic basalt***—Gray to brownish-gray, fine-grained, fresh, with small oikocrysts up to 1 millimeter in diameter, and prominent straight to folded oxidation lamination. Stretched quartz amygdules are common in flow interiors, amygdules near tops of flows contain laumontite, chlorite, and calcite. Flow tops are typically irregular, rubbly aa-type, with fractures filled by variably prehnite-cement clastic dikes. Flows typically range from 10 to 33 feet (3 to 10 meters) thick.

nti — ***Icelandite***—Grayish-pink, fine-grained, weakly porphyritic. Outcrops on Silver Creek show a strong subhorizontal flaggy parting in low outcrops adjacent to the river, cut by unit dmd.

Stewart River basalts—Extrapolated from the west (Boerboom and others, 2003) where it is better exposed; not exposed on this map. Based on rudimentary calculations to the west, the Stewart River basalts are approximately 1,148 feet (350 meters) thick.

nsb — ***Diabasic-textured basalt***—Dark brownish- to purplish-green, fine- to medium-grained, altered, variably ophitic, based on outcrops to the west.

Larsmont basalts—Extrapolated from the west (Boerboom and others, 2003) where it is better exposed, not exposed on this map. Based on rudimentary calculations to the west, the Larsmont basalts have a maximum thickness of at least 1,083 feet (330 meters), but thin to the northeast.

nlo — ***Ophitic basalt***—Brown, fine-grained, typically with augite oikocrysts up to 1 centimeter in diameter, with lenses of intergranular textured basalt that contain fresh olivine, based on exposures to the west.

Sucker River basalts—Not exposed on this map; extrapolated from the Knife River quadrangle to the west (Boerboom and others, 2002).

ns — ***Basalt, undifferentiated***—Inferred from extrapolation with mapped unit to the southwest to consist primarily of basaltic lava flows.

Hornfels basalt xenoliths—Scattered inclusions within unit lbd, one xenolith in unit hgm inferred from water-well data.

nh — ***Mafic hornfels***—Gray on fresh surfaces, brown on weathered surfaces; fine-grained, and amygdaloidal. Contains granular to subophitic clinopyroxene, small granules of orthopyroxene that are both dispersed throughout rock and concentrated in metamorphosed amygdules, and abundant dusty oxide granules.

Volcanic rocks, undifferentiated—Inferred from outcrop and aeromagnetic data to form an outlying remnant of volcanic rocks surrounded by intrusions.

nb — ***Basalt, undifferentiated***—Inferred from aeromagnetic data.

na — ***Basaltic andesite to andesite***—Brown, fine-grained, weakly porphyritic, massive. Exposed in the Encampment River upstream from the Silver Creek diabase. The extent of this unit is inferred from aeromagnetic data.

MAP SYMBOLS

Geologic contact.

Geologic contact—Concealed below water.

Fault—Speculated on the basis of geophysical data.

Boundary between informal lithostratigraphic units—See Figure 1.

Contact between individual lava flows—Shown only where mappable at the scale of map. Lines are solid where observed in outcrop and dashed where projected between outcrops.

10 **Strike and dip of volcanic flow layering**—Horizontal, inclined. Angle in degrees from horizontal; includes flow parting and oxidation lamination.

14 **Strike and dip of flow- and intrusion-parallel joints**—Approximates attitude of flow layering in volcanic rocks and orientation of sill-like intrusive rocks; angle in degrees from horizontal.

60 **Strike and dip of igneous foliation, textural layering, and modal layering**—Angle in degrees from horizontal.

74 **Lineation and plunge of joint columns**—Angle in degrees from horizontal.

25 **Strike and dip of minor faults**—Angle in degrees from horizontal. Sense of movement unknown.

70 **Intrusive contact**—Angle in degrees from horizontal.

Bedrock outcrop—Identified during fieldwork for this map.

Bedrock outcrop—Identified by Pope (1976), not remapped as part of this study.

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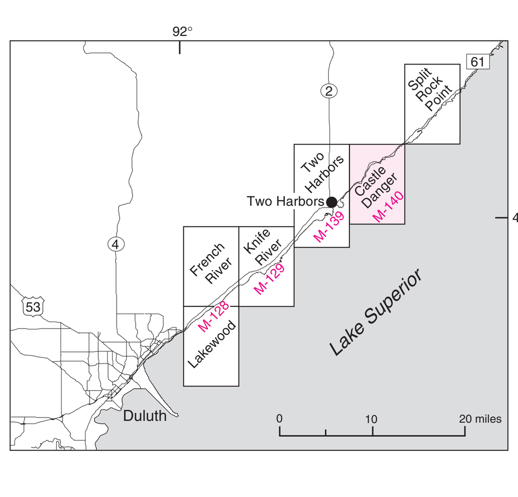

INDEX TO BEDROCK STATEMAP QUADRANGLES ALONG THE NORTH SHORE OF LAKE SUPERIOR IN THE MISCELLANEOUS MAP SERIES

Castle Danger (M-140)
French River–Lakewood (M-128)
Knife River (M-129)
Split Rock Point (to be completed in 2004)
Two Harbors (M-139)

BEDROCK GEOLOGY OF THE CASTLE DANGER QUADRANGLE, LAKE COUNTY, MINNESOTA

by

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2003

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