UNIVERSITY OF MINNESOTA
MINNESOTA GEOLOGICAL SURVEY
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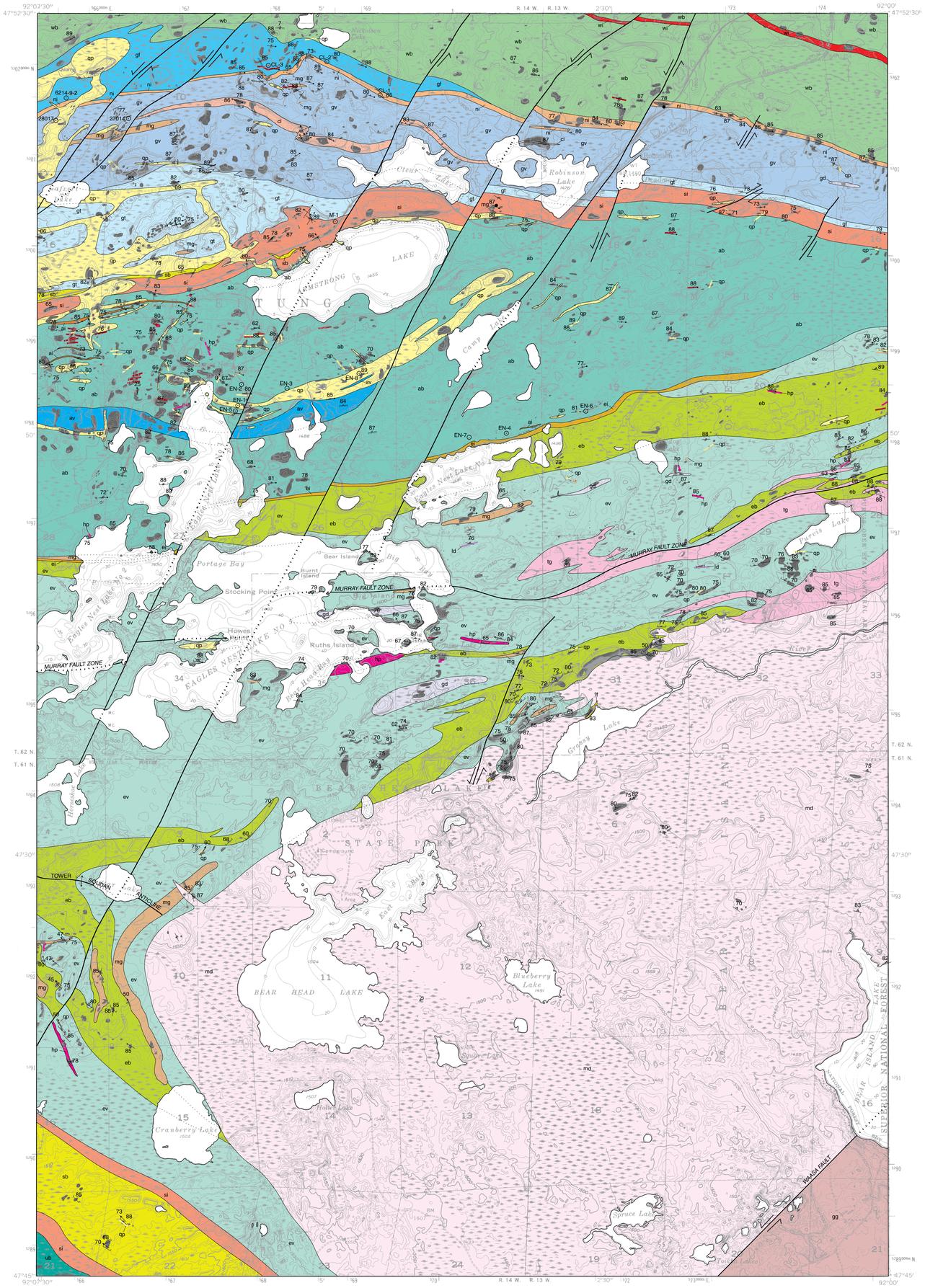
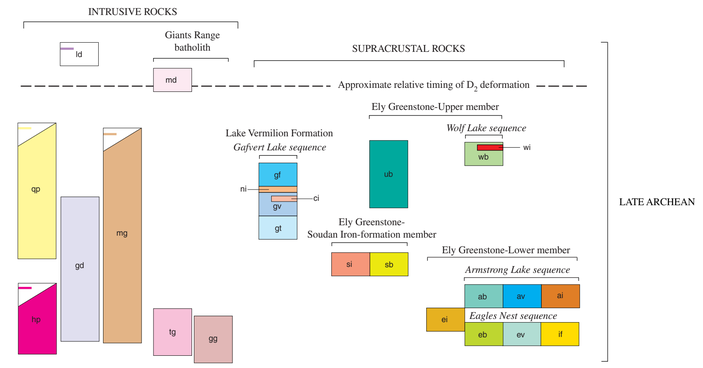
MISCELLANEOUS MAP SERIES
MAP M-114
Bedrock Geology, Eagles Nest Quadrangle



CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Intrusive rocks—Some intrusive dikes narrower than 10 meters are shown by a line symbol colored the same as units below; they show approximate strike length and trend.

ld **Lamprophyre dikes**—Gray to dark-green to nearly black, fine- to medium-grained rocks containing variable amounts of hornblende, biotite, and pyroxene phenocrysts in a feldspathic groundmass. Typically straight-walled dikes less than 1 meter thick.

md **Quartz-hornblende monzodiorite to monzonite**—Intrusions of the Giants Range batholith; pinkish-gray, medium- to coarse-grained, variably porphyritic, generally having a trachytoid fabric. Phenocrysts include microcline and hornblende. Typically contain cognate mafic enclaves of dark-green hornblende diorite. Borders of intrusions and smaller dikes emanating from them are weakly foliated, and locally contain xenoliths of iron-formation.

qp **Quartz-feldspar and feldspar porphyry intrusions**—Contain variable percentages of quartz and plagioclase phenocrysts, together with smaller shreds of chlorite after mica and hornblende, in a quartzofeldspathic groundmass. Vary from narrow and linear dikes to larger, irregularly shaped masses. Xenolithic blocks of supracrustal rocks are common in larger intrusions.

hp **Hornblende- and plagioclase-phyric dikes**—Granodioritic to dioritic intrusions containing phenocrysts of hornblende and plagioclase in finer groundmass of quartz, feldspar, hornblende, and rare biotite; variably foliated.

gd **Hornblende granodiorite to diorite**—Dikes and sill-like intrusions; typically aphyric, medium-grained, and foliated. Probably related magmatically to the tonalite unit (tg), but lacks the tonalite component.

tg **Tonalite**—Typically medium-grained, rarely porphyritic, variably magnetic; contains ragged, altered biotite and hornblende. Includes minor amounts of granodiorite, diorite, and gabbro as discrete layers and irregular, diffusely bounded masses. Intrusions locally show effects of D_2 deformation and are chemically similar to associated and stratigraphically overlying calc-alkalic volcanic rocks, implying that they may represent feeders for volcanism.

gg **Granitic, granodioritic, and dioritic to amphibolitic gneiss**—Inferred from outcrops to the east, and as depicted by Sims and Southwick (1985).

mg **Metagabbro and metadiorite**—Dark-greenish-gray, variably foliated, medium- to coarse-grained. Locally contains relict pyroxene phenocrysts altered to chlorite in rocks metamorphosed to greenschist facies, recrystallized to ragged amphibole in higher metamorphic grades within the contact zone of the Giants Range batholith. Typically occur in all volcanic sequences as sill-like, subvolcanic intrusions and local, cross-cutting dikes.

Supracrustal rocks—Supracrustal rocks are metamorphosed to greenschist facies, except in the south limb of the Tower–Soudan anticline and in that part of the north limb lying within about 1 kilometer of the contact with the Giants Range batholith, where minerals of amphibolite facies exist.

Ely Greenstone, Upper member

Wolf Lake sequence

wb **Basaltic lava flows**—Dark-green, massive to pillowed, and locally pyroxene-phyric. Geochemically are Mg-tholeiitic basalt (as classified from cation plots of Jensen, 1976). Flows typically lack vesicles, indicating deposition in relatively deep water. Individual flow units are thicker than 30 meters. Upper fragmental parts of flows are thin, and rarely have mild epidote alteration of pillow fragments.

wi **Iron-formation and iron-rich volcanic strata**—Includes pillowed basaltic lava flows and pillow-fragment breccia (flow-top breccia) that contain magnetite-rich matrix, and minor, discontinuous, interflow layers of thinly bedded, magnetite-chert iron-formation.

South limb of the Tower–Soudan anticline

ub **Basaltic lava flows**—Pillowed to massive, dark-green, tholeiitic basalt metamorphosed to the greenschist-amphibolite transition facies in the map area.

Lake Vermilion Formation

Gafvert Lake volcanic and volcaniclastic sequence

gf **Flows of calc-alkalic basalt**—Pillowed, massive, and fragmental, typically plagioclase-phyric, locally clinopyroxene-phyric. Color varies from medium-greenish-gray, to bluish-gray, to nearly white in upper, fragmental parts of flows that have been altered by silica and epidote.

ni **Nickolson Lake iron-formation**—Mostly straight-bedded layers of chert, magnetite, and minor jaspilite; microlaminations are common. Stratigraphically lower (southern) beds commonly consist of complexly interbedded magnetite, chert, and chloritic slate that contains abundant pyrite and rare chalcopyrite. Large folds in the western part of the unit appear unrelated to D_2 deformation and probably occurred prior to complete lithification because intrafolial, sedimentary breccia is associated. The westernmost part of the unit is a non-magnetic zone that drill core indicates is largely sulfidic slate and chert.

ci **Clear Lake iron-formation**—Lenticular unit of mostly folded chert and magnetite beds. The combination of lenticular distribution (strike length less than 5 kilometers), abrupt variations in thickness, and abundant internal disruption, including folds that predate D_2 deformation, imply deposition during or shortly before an intrafolial collapse event of Gafvert sequence volcanism.

gv **Volcanic breccia**—Composed of variably layered to poorly layered pillow-fragment breccia, tuff breccia, and lapilli tuff, together with irregular pillowed flows; all composed of gray to greenish-gray, plagioclase-phyric, calc-alkalic andesite and minor dacite. Fragments typically are silicified and epidote-altered, producing nearly white weathered surfaces.

gt **Tuffaceous graywacke and tuff**—Includes graywacke, resedimented feldspathic tuff, light-colored phyllite, and dark-gray slate. Generally of dacitic to andesitic composition. Thin and discontinuous beds of breccia and conglomerate at the base of the unit contain quartz grains, together with fragments of iron-formation, dacitic to andesitic lapilli, dacitic porphyry, and dark-gray, graphitic-looking slate. May represent doming related to early stages of Gafvert volcanism. This is overlain locally by beds of uniform feldspathic tuff. Much of the central and northern parts of the unit consist of tuffaceous graywacke that has normally graded turbiditic beds with channeled bed bases and fine-grained siltstone and slate drapes.

Ely Greenstone, Soudan Iron-formation member

si **Banded iron-formation**—Composed of alternating layers of magnetite-rich chert, magnetite, hematite, jaspilite, and white chert, interbedded with minor amounts of mafic volcanic material including flows and chloritic tuffaceous strata. Typically planar to wavy bedded, locally folded. Unit is transitional with basaltic lava flows (ab) in the north limb of the Tower–Soudan anticline. Defined in the south limb by aeromagnetic data and continuity with outcrops in adjacent quadrangles.

sb **Basaltic lava flows**—Interbedded with Soudan Iron-formation, dark-green, tholeiitic, pillowed to flow-layered, and typically non-vesicular.

Ely Greenstone, Lower member

Armstrong Lake volcanic sequence

ab **Basaltic lava flows**—Dark-green to dark-greenish-gray, and tholeiitic. Amygdules are rare. Sequence grades stratigraphically upward from comparatively thick, massive and pillowed flows on the south, to progressively thinner, laminated, and rarely pillowed flows to the north. As flow thickness decreases northward (up-stratigraphic section), the thickness and abundance of iron-formation interflow sedimentary rocks (ai) increases. The footwall of nearly every interflow layer contains volcanic fragments altered to epidote, quartz, and pyrite in a matrix composed of chlorite, magnetite, and minor pyrite. The orientation of small pieces of larger pillows can be used to estimate the direction of paleoslope: a general westward dip is indicated in several areas of this unit.

av **Volcanic flows of calc-alkalic basalt**—Weathers bluish-gray, typically massive with minor amounts of pillowed and fragmental strata. Largely aphyric, but locally contains scattered, small mafic phenocrysts.

ai **Iron-formation**—Typically thin, lenticular units of interbedded magnetite and chert within basaltic lava flows (ab). In general, units are thicker and become more laterally continuous stratigraphically up-section (northward) toward the Soudan Iron-formation. Units thinner than 10 meters are shown by a line symbol having trend that approximates strike.

Eagles Nest volcanic sequence—Metamorphosed to greenschist facies except in the southern part of the map, within about 1 kilometer of the Giants Range batholith (unit md), where metamorphism to amphibolite facies is evident. This progressive increase in metamorphic grade corresponds with the development of strong linear and planar fabrics, locally intense flattening, and abundant layer-parallel tonalitic to granodioritic intrusions. Protolith is typically recognizable despite recrystallization and deformation.

ei **Iron-formation**—Established largely from geophysical and drill hole data. Drill core contains beds of chert, magnetite-rich chert, carbonate-bearing rocks, siliceous tuff, chloritic tuff, and dark-colored, graphitic slate; all contain disseminated to semi-massive sulfide minerals including pyrite, chalcopyrite, and pyrrhotite. Unit is interbedded with mafic flows, tuffaceous rocks, and metagabbro, variably altered to epidote, quartz, iron carbonate and chlorite.

eb **Basaltic lava flows**—Dark-greenish-gray, tholeiitic where analyzed, massive to pillowed, contains plagioclase glomerophenocrysts in some places. Thin and discontinuous interflow beds of iron-formation occur locally.

ev **Calc-alkalic basalt and andesite**—Rock is medium-gray to bluish-gray; typically contains plagioclase and altered hornblende phenocrysts (now chlorite). Includes pillowed flows containing abundant hyaloclastite matrix and local thick sections of fragmental flows, such as along the east shore of Eagles Nest Lake No. 3.

if **Iron-formation**—Typically discontinuous layers of magnetite- and chert-rich beds. Xenolithic blocks are locally incorporated in the boundary zone of the Giants Range batholith (unit md).

MAP SYMBOLS

Structure symbols, including bedding, foliation, and lineations, are shown only on outcrops visited by the authors.

Geologic contact—Approximately located contact; inferred from geophysical maps, drill core, and topographic lineaments away from outcrops; dashed where inferred through lakes.

Minor iron-formation—Generally less than 10 meters thick; typically contains bedded chert and magnetite, though locally it is a stratabound zone of magnetite-rich material in the matrix of pillowed and brecciated flows.

Fault—Inferred, offset sense imprecisely known, located in part by geophysical maps, topographic lineaments, and extrapolation from outside of the map; dashed where inferred through lakes.

Strike-slip fault—Approximately located, relative offset sense as shown.

Fold (F_1)—Axial surface trace of first generation (F_1) Tower–Soudan anticline (modified from Sims and Southwick, 1985).

Fold (F_2)—Inferred axial trace of second generation (F_2) fold having associated axial-planar, metamorphic cleavage; anticline, syncline; showing plunge direction.

Asymmetrical fold (S)—Bearing and plunge of axis of minor asymmetrical fold; S-morphology.

Asymmetrical fold (M)—Bearing and plunge of axis of minor symmetrical fold; M-morphology.

Bedding—Inclined, vertical; stratigraphic younging direction not determined.

Bedding—Inclined, vertical; upward-stratigraphic younging.

Bedding—Overturned; northward-younging, southward-younging.

Bedding—Determined at rubbly flow unit contact; inclined.

Foliation—Defined by modal layering and trachytoid (magmatic) mineral fabric in intrusive rocks; inclined, vertical.

Cleavage, schistosity, and gneissic layering—All metamorphic in origin, associated with D_2 deformation; inclined, vertical.

Bearing and plunge of lineation—Bearing and plunge of elongate mineral grains, pillows, amygdules, and clasts lineated during D_2 deformation; may be combined with other symbols.

Outcrop—Outcrop or group of closely spaced, small outcrops.

Drill hole—Drilled largely at an angle; cores and records archived at Minnesota Department of Natural Resources, Division of Lands and Minerals, Hibbing, Minnesota.

Test pits—Varied surface dimensions, commonly 4 meters by 4 meters, and several meters deep.

Outcrop data were compiled from a variety of sources, including Sims and Southwick (1985), and those listed below. The letters correspond to the areas outlined on the figure. All areas were re-examined as part of this study.

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INTRODUCTION

Late Archean volcanic and related volcaniclastic and sedimentary rocks occupy both limbs of the Tower–Soudan anticline, a regional fold that extends westward from near Star Lake in the Eagles Nest quadrangle (for regional context, see Sims and Southwick 1985; Southwick, 1993; Peterson and Jirsa, 1999). This structure is inferred to have formed largely during D_1 deformation, and was modified by the main metamorphic and fabric-forming event of D_2 deformation. The steeply dipping, predominantly north-facing strata north of Star Lake are on the north limb of the anticline, and the steeply dipping, commonly overturned, south-facing strata south of Star Lake are on the south limb. The supracrustal and associated hypabyssal rocks are intruded by a variety of granitic rocks, the most voluminous of which are phases of the Giants Range batholith. A portion of the batholith occupies the southeastern third of the quadrangle.

Supracrustal rocks within this map sheet are part of the approximately 2,700 Ma Soudan belt, as defined by Jirsa and others (1992) and Southwick (1993). The age is based on a single U-Pb zircon date of 2,722 ± 0.9 Ma from a quartz-phyric, rhyolitic lava that lies stratigraphically beneath the Soudan Iron-formation member of the Ely Greenstone, and just west of the Eagles Nest quadrangle (Peterson and others, 2001). Rocks on the north limb of the Tower–Soudan anticline are well exposed, and therefore present a fairly complete stratigraphic section through various components of the Ely Greenstone and related rocks. The stratigraphic succession from the Lower to Upper members of the Ely Greenstone, to the Lake Vermilion Formation depicts an evolving submarine volcanic shield. Construction of this shield involved multiple cycles of volcanism, each followed by short-lived, intervolcanic periods during which iron-formation and other quiet-water sedimentation occurred. The stratigraphy is more complex within the south limb of the Tower–Soudan anticline. In general, stratigraphic units on the south limb are thinner, more lenticular, and have fewer exposures. Correlation of map units between the two limbs is speculative.

This map retains traditional stratigraphic nomenclature for the supracrustal rocks established by Morey and others (1970), and Sims (1976); however, it also uses new terminology to aid in the understanding of the particular stratigraphic section exposed in the quadrangle. This is accomplished by designation of informal stratigraphic sequences—each representing a single cycle of deposition, or multiple cycles that are inferred to be allied. An example is the informal designation of the Gafvert Lake sequence, which is applied to a cohesive assemblage of temporally and magmatically related units that were formerly considered parts of both the Lake Vermilion Formation and the Ely Greenstone. The boundaries between sequences are typically marked by iron-formation, representing volcanic inactivity of unknown duration between episodes of eruption that differed slightly in lava composition and environment of deposition.

The eastern axial zone of the Tower–Soudan anticline contains various intrusions of the Giants Range batholith, a composite body that extends several hundred kilometers to the west and many tens of kilometers to the east. Most of the supracrustal rocks were metamorphosed to the greenschist facies during D_2 deformation, with the exception of those near the batholith, which contain metamorphic minerals indicating lower to medial amphibolite facies conditions. This zone of higher metamorphic grade corresponds with increased development of both planar and linear rock fabrics. Lineations as great as 5:2:1 occur locally within the aureole of the batholith. The prefix "meta" could be applied to nearly all of the supracrustal and many of the intrusive rocks emplaced prior to and during D_2 deformation; however, it is generally omitted here and the nomenclature of rock protolith is used for clarity.

Structure

Most intrusions, folds, and faults are assigned a temporal setting based on their relationship to D_2 deformation, the main metamorphic and fabric-forming event. Based on geochronologic study of components of the Giants Range batholith southwest of this map sheet, D_2 can be bracketed between about 2,674 and 2,685 Ma (Boerboom and Zartman, 1993). Most of the intrusions of the Giants Range batholith contain weak metamorphic fabric, indicating emplacement synchronous with D_2. With the exception of the few, thin, lamprophyre dikes, most other intrusions were emplaced prior to D_2. In fact, many can be linked to extrusive equivalents, and are therefore considered integral to the volcanic stratigraphy. Folds are designated F_1 and F_2 in the explanation. F_2 folds predate metamorphism and are inferred to have formed while the rocks were not thoroughly lithified. The Tower–Soudan anticline is an example of this folding event known as D_1. The F_1 folds are typically marked by an axial planar metamorphic cleavage or schistosity. Though not shown specifically, F_1 folds are those that involve both bedding and metamorphic cleavage. Similarly, faults that are pre-, syn-, and post-D_2 were mapped. The east-trending Murray fault zone is probably a product of late-D_2 deformation. Some of the most obvious faults are relatively late, strike-slip structures that offset unit boundaries, metamorphic fabrics, and the Murray fault zone. Abundant linear topographic lows probably represent additional faults of this type, but are not shown as faults unless significant offset was observed across them in outcrop or geophysical data.

Alteration

Several local zones of moderate to intense alteration exist, but are not depicted specifically on this map. Two types of alteration are dominant: 1. Quartz + epidote + pyrite, with locally associated sericite and chlorite; and 2. Calcite, iron carbonate, and variable amounts of disseminated pyrite. The first type of alteration is confined largely to the fragmental upper parts of flows, particularly those capped by layered iron-formation. Quartz-epidote alteration is also common in the western, fragmental parts of the Gafvert Lake sequence. The apparent stratigraphic control of this alteration type indicates a volcanogenic origin. Carbonate-bearing alteration zones are associated with both major and minor faults, and with some of the volcaniclastic rocks of the Gafvert Lake sequence. A potentially significant alteration zone from the standpoint of mineral exploration is spacially associated with brittle structures related to the fault that extends southward through the western part of Armstrong Lake and Eagles Nest Lake No. 1. Sheared, carbonate- and pyrite-bearing rocks also lie along an anastomosing, easterly trending zone of shearing associated with the Murray fault that extends through Eagles Nest Lake No. 3.

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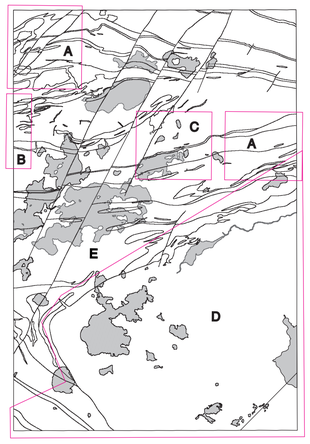

Base from U.S. Geological Survey Eagles Nest 1:24,000 quadrangle, 1956, photorevised 1986.

Universal Transverse Mercator Projection, grid zone 15
1983 North American Datum

SCALE 1:24 000
1 1/2 0 1 MILE
1 .5 0 1 KILOMETER
CONTOUR INTERVAL 10 FEET

0°10'
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 2001

MINN.
QUADRANGLE LOCATION

GIS compilation by M.A. Jirsa and T.E. Wahl
Edited by Lori Robinson

BEDROCK GEOLOGIC MAP OF THE EAGLES NEST QUADRANGLE, ST. LOUIS COUNTY, MINNESOTA

Compiled by

Mark A. Jirsa, Terrence J. Boerboom, and Dean M. Peterson

2001