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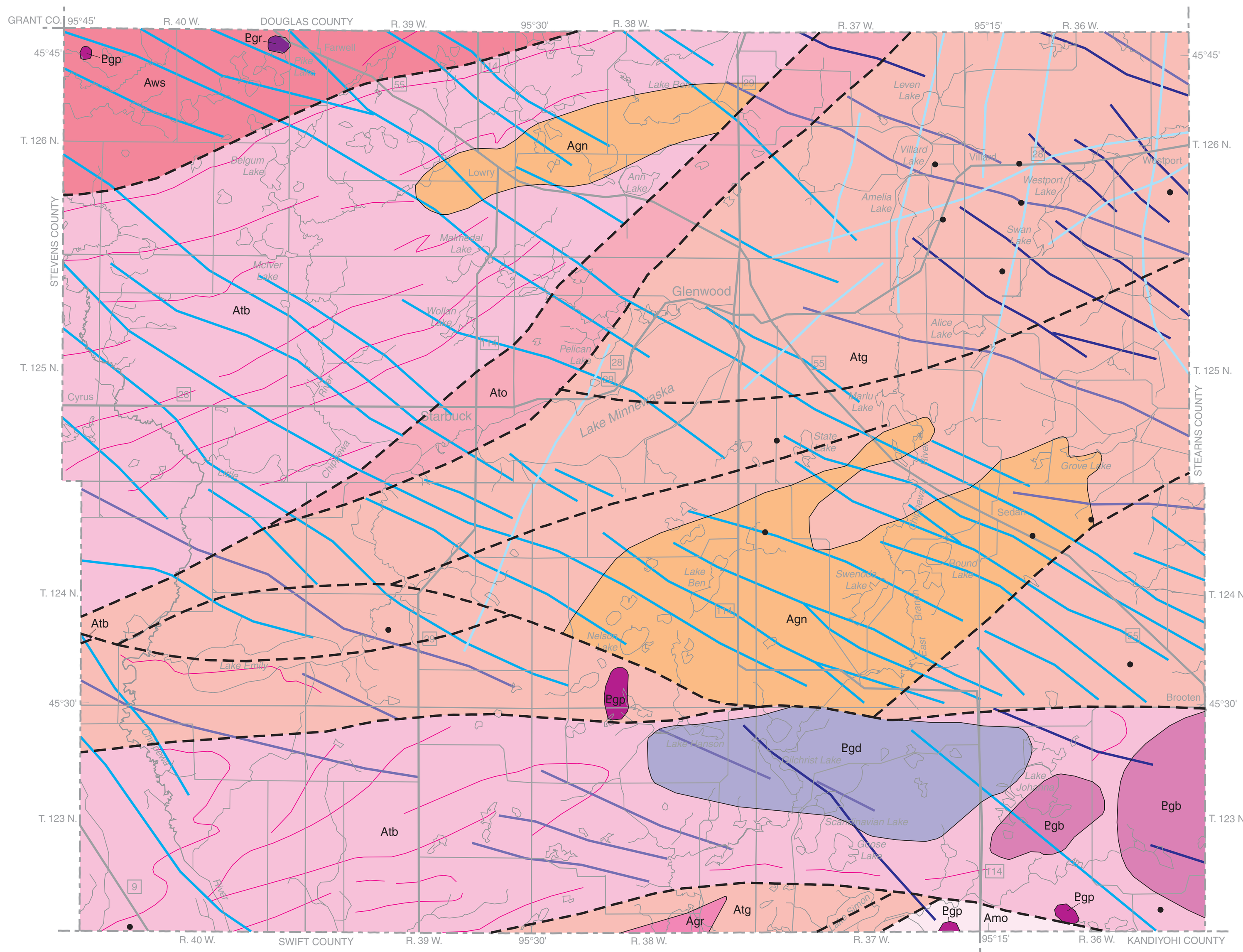
COUNTY ATLAS SERIES
ATLAS C-15, PART A
Plate 2—Bedrock Geology, Bedrock Topography, *and* Depth to Bedrock

BEDROCK GEOLOGY

By
Terrence J. Boerboom and Val W. Chandler
2003



Digital base modified from the Minnesota Department of Transportation BaseMap data; digital base annotation by the Minnesota Geological Survey.

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

SCALE 1:200 000
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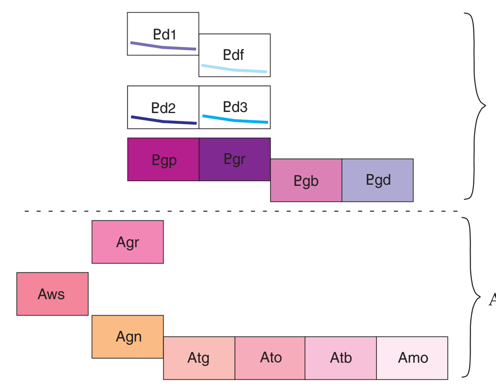
CORRELATION OF MAP UNITS



MAP SYMBOLS

Geologic contact—Approximately located; inferred from geophysical data.

Inferred fault—Sense of displacement is unknown; based on aeromagnetic derivative maps.

Structural form lines—Derived from first vertical derivative aeromagnetic images showing the general trend of gneissic layering. Shown only where anomalies have sufficient amplitude and contrast to trace.

Sample location—Location of an exploration borehole, scientific borehole, or water well from which core or cuttings samples of Precambrian bedrock were recovered.

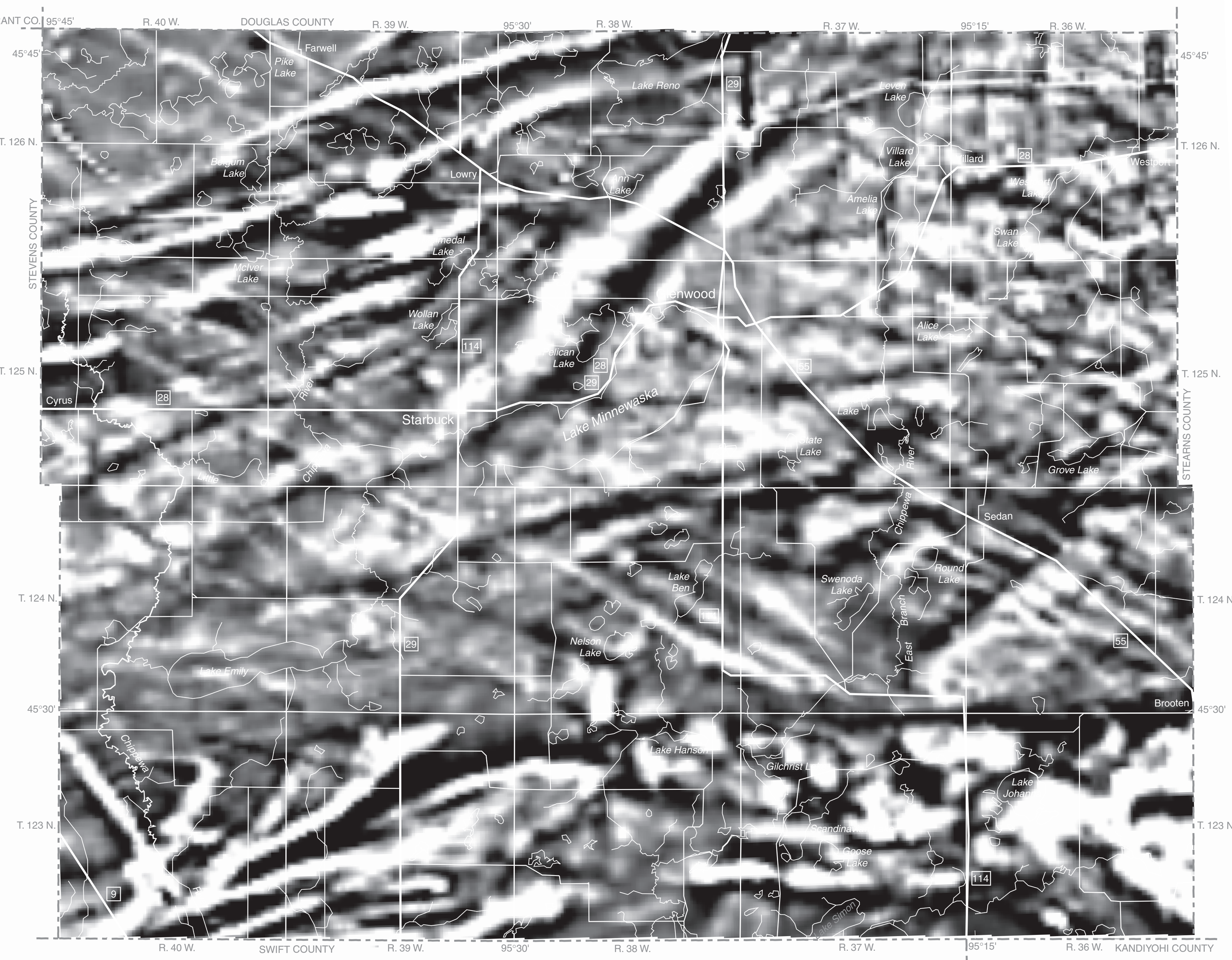


Figure 1. First vertical derivative, reduced-to-pole aeromagnetic anomaly map of Pope County.

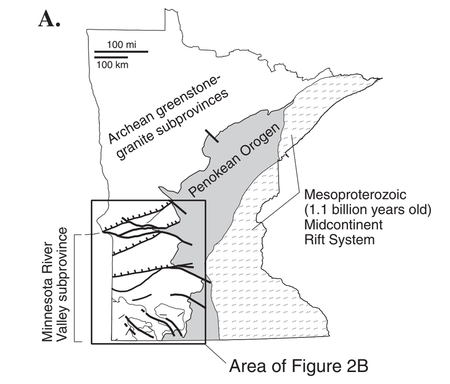
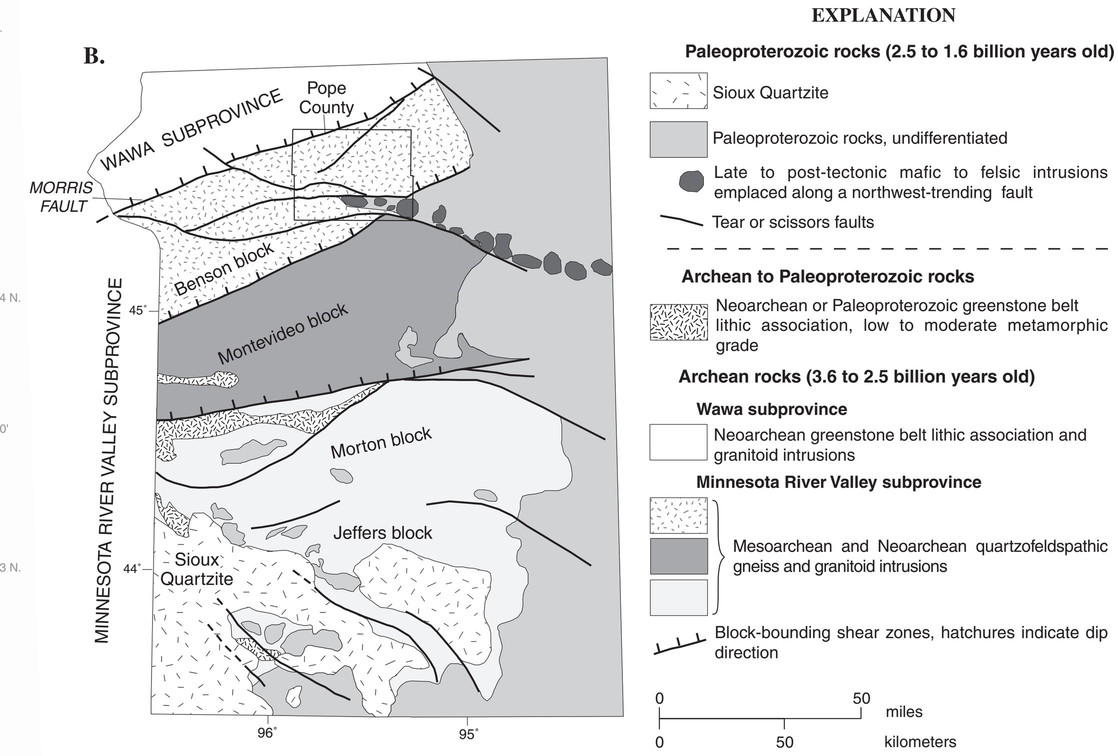


Figure 2. Bedrock geologic setting of Pope County; modified from Southwick and Chandler (1996), and Southwick (2002).
A. Index map of Minnesota showing major geologic terranes; box outlines the area enlarged in Figure 2B.
B. Simplified geologic map of the southwest corner of Minnesota showing major northeast-oriented, crustal-scale shear zones within the Minnesota River Valley subprovince and the locations of selected Paleoproterozoic intrusions.



INTRODUCTION

The bedrock geologic map of Pope County is largely a geophysical interpretation because the bedrock in the county is buried by at least 100 feet (30 meters), and in places as much as 650 feet (198 meters) of glacial deposits. Interpretation of the bedrock units was derived from magnetic and gravity derivative geophysical maps, coupled with sparse drill cores and cuttings samples that are located mainly along the southern and eastern portions of the county. Accordingly, the rock unit descriptions are very generalized and incorporate the geophysical characteristics of each unit. Where no rock sample data were available, the rock types were inferred by correlation with drill cores and outcrops located outside of the county, using geophysical data as a guide. Figure 1 shows a first vertical derivative, reduced-to-pole, gray-scale aeromagnetic anomaly map of Pope County. The lighter areas represent positive magnetic anomalies, and the darker areas reflect negative magnetic anomalies.

With the exception of the Paleoproterozoic diabase dikes and mafic to intermediate intrusions, all of the bedrock in Pope County consists of Archean gneisses that have been subjected to amphibolite- or higher-grade metamorphic conditions. Prominent geophysical breaks and lineaments, that are likely the product of oxidation of magnetite in the rocks along fault and shear zones, were used to interpret the gross structural aspects of the bedrock geology. The approximate positions of diabase dikes were inferred from the numerous linear magnetic anomalies, and the locations of Paleoproterozoic mafic intrusions were inferred from round to irregularly shaped high-amplitude magnetic anomalies.

Pope County lies at the northern margin of the Minnesota River Valley subprovince (Fig. 2), which forms the southernmost subprovince of the Superior Province at the edge of the Canadian Shield. The Minnesota River Valley subprovince has been divided into four crustal blocks on the basis of lithologic and geophysical attributes (Southwick and Chandler, 1996). As shown on Figure 2, Pope County is located atop the Benson block, the northernmost of these four crustal blocks. The Benson block is dominated by moderately deformed and recrystallized tonalite, diorite, and granodiorite, which are intruded by coarse-grained pink granite that is variably deformed and recrystallized.

The northwest corner of Pope County overlies the Morris fault segment of the Great Lakes Tectonic Zone—a major east–northeast-trending, craton-wide, Archean shear zone that extends east from eastern South Dakota to Michigan. The Morris fault segment is a north-dipping shear zone (Gibbs and others, 1984) marked by a regionally prominent and straight geophysical break that crosses the northwest corner of Figure 1. Drill cores recovered from this fault zone outside of Pope County show that rocks in the Morris fault zone are mylonitic, which indicates that they have been sheared and deformed within the now inactive fault zone. The bedrock geology north of the Morris fault is poorly constrained, but drill samples indicate that it is probably part of the Wawa subprovince. The Wawa subprovince is a typical Archean greenstone–granite terrane that is well known from numerous rock exposures in northeastern Minnesota and adjacent Ontario.

Paleoproterozoic rocks are present in minor proportions in the form of mafic- to intermediate-composition intrusions. Although these intrusions are not exposed at the surface, their generally mafic composition produces coincident positive gravity and magnetic anomalies that are readily visible on geophysical images. The largest of these mafic intrusions, located just south of Brooten in southeastern Pope County, forms a prominent magnetic anomaly (Fig. 1) that coincides with a pronounced gravity high. Gravity measurements reflect the density of a rock body. In general, light-colored rock types such as granite form gravity lows, whereas iron- and magnesium-rich, dark-colored mafic rock types such as gabbro tend to form positive gravity anomalies. These iron-rich rocks also tend to form positive magnetic anomalies; thus, a coincident magnetic and gravity anomaly indicates the presence of a mafic rock body. Other smaller geophysical anomalies in northwestern Pope County are probably similar to intrusions in east-central Minnesota that have been shown by drilling to consist of ultramafic peridotitic rocks.

DESCRIPTION OF MAP UNITS

PALEOPROTEROZOIC ROCKS

Diabase dikes—Four groups of diabase dikes are recognized on the basis of orientation and positive versus negative linear aeromagnetic anomalies.

Ꞓd1 *Reversely polarized, northwest trend (azimuth 110-120)*—Fine-grained ophitic diabase. Magnetic anomaly maps indicate these cut the normally polarized, northwest-trend dike swarm (Ꞓd3). A drill hole from northeastern Pope County (T. 126 N., R. 36 W., sec. 29), which has apparently intersected one of these dikes, contains fine-grained, red-dusted ophitic diabase with fresh ophites of clinopyroxene up to 1.5 millimeters in diameter as the dominant rock type.

Ꞓdf *Reversely polarized, north–northeast and northeast trend (azimuth 5-10, 50-70)*—Negative magnetic anomaly lineaments that define a fracture pattern in the host gneissic rocks; interpreted as fractures occupied by reversely-polarized diabase dikes, but possibly the product of large oxidized fracture zones within the host gneiss.

Ꞓd2 *Reversely polarized, northwest trend (azimuth 105-130)*—Aeromagnetic lows interpreted as dikes that are continuous with the normally polarized dike trends of unit Ꞓd3.

Ꞓd3 *Normally polarized, northwest trend (azimuth 120)*—Linear, positive magnetic anomalies interpreted as dikes assigned to the Kenora–Kabetogama swarm of northern Minnesota and southern Canada that have yielded an age of 2076 ± 5 Ma (Wirth and others, 1995; Buchan and others, 1996).

Ꞓgp **Peridotite, pyroxenite, and gabbro**—Plug-shaped intrusions that produce small, sharp, positive aeromagnetic anomalies, inferred to be similar to intrusions throughout central and southern Minnesota that have been sampled by drilling and mapped in outcrop.

Ꞓgr **Reversely polarized ultramafic to mafic intrusions**—Similar to the peridotite, pyroxenite, and gabbro unit (Ꞓgp) but with reversed magnetic polarity.

Ꞓgb **Gabbroic rocks, undivided**—Characterized by coincident positive gravity and aeromagnetic anomalies. A drill core obtained from the southeast corner of Pope County (T. 123 N., R. 36 W., sec. 35, NE 1/4), adjacent to one of these intrusions, contains several intervals of weakly metamorphosed fine- to medium-grained, variably porphyritic diabase, and medium- to coarse-grained, quartz-bearing gabbro and gabbronorite. These mafic intervals are inferred to be dikes that emanate from the intrusion and crosscut the host quartzofeldspathic gneiss. These mafic intrusions are at the western end of a 30- to 40-mile-long (48 to 64 kilometers) string of mafic to felsic intrusions that were emplaced along parts of a prominent northwest-trending crustal feature that separates Archean rocks on the southwest from Paleoproterozoic rocks on the northeast (Fig. 2B). Aeromagnetic data indicate that the large round intrusion south of Brooten is compositionally zoned, with a thin rim of more magnetic rock types.

Ꞓgd **Granodioritic to gabbroic rocks, undivided**—Geophysical characteristics indicate a slightly more felsic composition to this intrusion compared to unit Ꞓgb.

MESOARCHEAN TO NEOARCHEAN ROCKS

Agr **Late- to post-tectonic granitic intrusion**—Characterized by a flat, uniform aeromagnetic anomaly; inferred from the correlation of geophysical characteristics with mapped granite bodies southwest of Pope County.

Aws **Supracrustal and intrusive rocks typical of granite–greenstone terranes of the Wawa subprovince**—Inferred from sparse drill-core data outside the county to be comprised of metasedimentary rocks typical of the Superior Province in northern Minnesota and Canada. Characterized by a flat aeromagnetic anomaly pattern.

Agn **Granitic gneiss**—Inferred from aeromagnetic data to be similar to the tonalitic to granitic gneiss unit (Atg), but slightly less magnetic and possibly more granitic in composition.

Atg **Tonalitic to granitic gneiss**—Compositionally diverse rock types, probably derived from an intrusive protolith. Sparse drilling data show rocks to be composed of dark- to light-gray tonalite and trondhjemite to diorite, and pinkish-gray granodiorite to granite, all cut by thin dikes and sills of deformed granite pegmatite. All rock types contain biotite and varied amounts of hornblende. Sillimanite was noted in cuttings samples from drill hole USGS-21 (T. 126 N., R. 37 W., sec. 25). Granulite conditions of metamorphism are indicated by the prograde mineral assemblage of orthopyroxene–clinopyroxene–biotite–hornblende in a granite-derived hornblende granulite gneiss (drill hole BPL-88-2, T. 125 N., R. 37 W., sec. 29). Geophysically characterized by a moderately high and uniform magnetic anomaly pattern.

Ato **Tonalitic to granitic gneiss**—Geophysically characterized by a moderately positive magnetic signature. Not intersected by drilling, but inferred from geophysical anomaly patterns to be a slightly more magnetic variation of unit Atg, possibly due to proximity to shear zones.

Atb **Hornblende-biotite tonalite to biotite monzodiorite gneiss**—Compositionally similar to unit Atg, but the presence of sharp linear magnetic anomalies implies that rafts of amphibolite-grade supracrustal volcanic rocks may form a significant component of this unit. Cut by deformed granite pegmatite.

Amo **Montevideo Gneiss**—High-grade quartzofeldspathic gneiss that is part of the Montevideo block of Southwick and Chandler (1996), and Southwick (2002).

REFERENCES

Buchan, K.L., Halls, H.C., and Mortenson, J.K., 1996, Paleomagnetism, U-Pb geochronology, and geochemistry of Marathon dykes, Superior Province, and comparison with the Fort Frances swarm: Canadian Journal of Earth Sciences, v. 33, no. 12, p. 1583-1595.

Gibbs, A.K., Payne, B., Setzer, T., Brown, L.D., Oliver, J.E., and Kaufman, S., 1984, Seismic-reflection study of the Precambrian crust of central Minnesota: Geological Society of America Bulletin, v. 95, no. 3, p. 280-294.

Southwick, D.L., 2002, Geologic map of pre-Cretaceous bedrock in southwest Minnesota: Minnesota Geological Survey Miscellaneous Map M-121, scale 1:250,000.

Southwick, D.L., and Chandler, V.W., 1996, Block and shear-zone architecture of the Minnesota River Valley subprovince: Implications for late Archean accretionary tectonics: Canadian Journal of Earth Sciences, v. 33, no. 6, p. 831-847.

Wirth, K.R., Vervoort, J.D., and Heaman, L.M., 1995, Nd isotopic constraints on mantle and crustal contributions to 2.08 Ga diabase dykes of the southern Superior Province: Proceedings of the 3rd International Dyke Conference, Jerusalem, Program and Abstracts, p. 84.

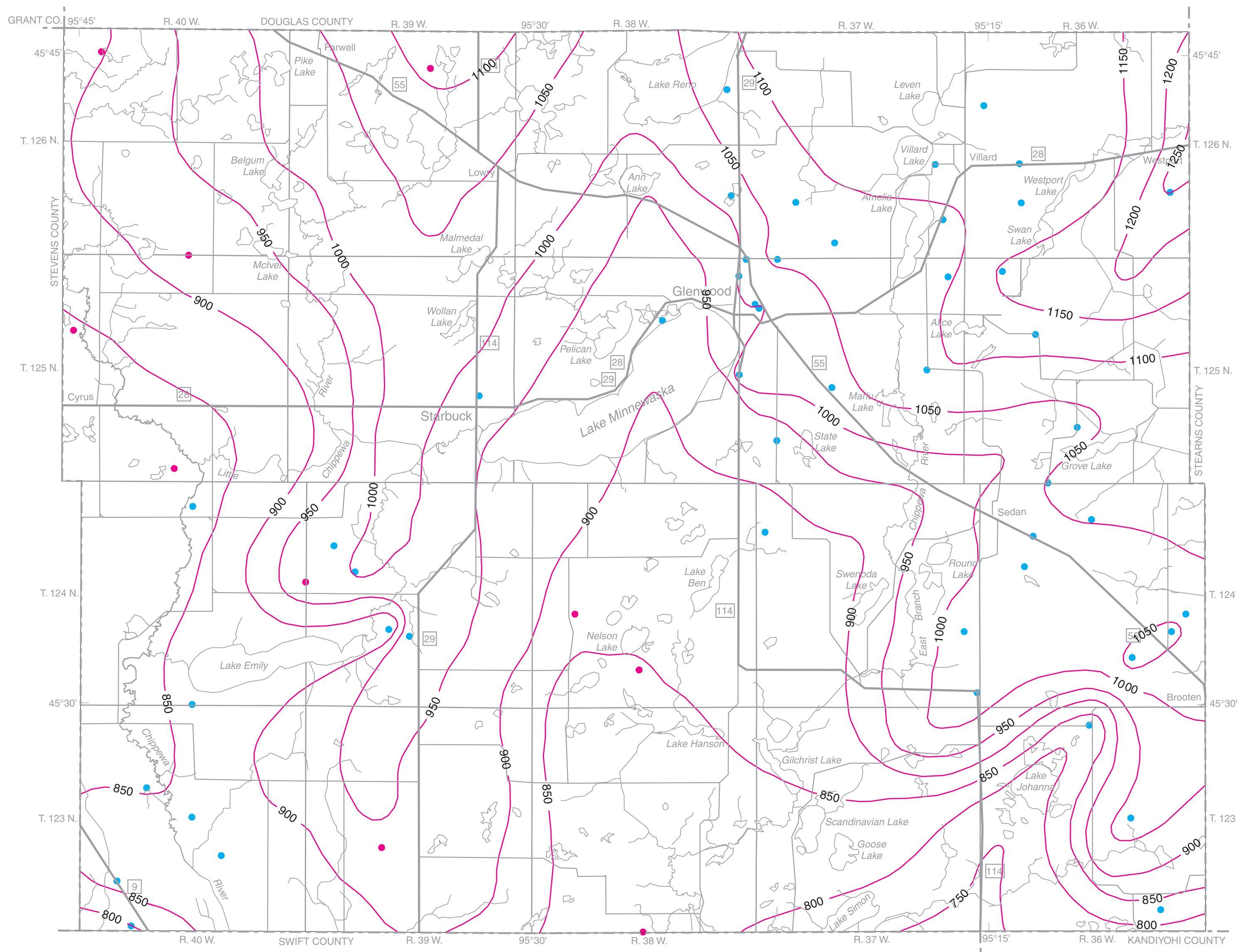
BEDROCK TOPOGRAPHY

By
Dale R. Setterholm
2003

Bedrock elevation data from drill holes

Seismic line location

850 Line of equal elevation of the bedrock surface in feet above mean sea level



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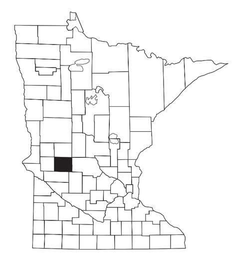
GIS compilation and cartography by Joyce Meints and Philip Heywood
Edited by Lori Robinson

INTRODUCTION TO THE BEDROCK TOPOGRAPHY AND DEPTH-TO-BEDROCK MAPS

The elevation and shape of the bedrock surface in Pope County are represented by contours (lines of equal elevation) on the Bedrock Topography map. The position of those contours was determined from records of water-well, mineral-exploration, and scientific drilling, and from geophysical investigations. Drilling records that include bedrock intersections are sparse, and some townships do not have any such bedrock elevation data. Seismic-refraction surveying was used to supplement the drilling records in these areas. The elevation of the bedrock surface varies from more than 1,250 feet (381 meters) above sea level in northeast Pope County, to less than 750 feet (229 meters) above sea level near the southeast corner of the county. The total relief is greater than 500 feet (152 meters), which is approximately 100 feet (30 meters) greater than the relief of the land surface. The shape of the bedrock surface is the result of displacement (faulting and warping), weathering, and erosion. The composition of the bedrock may also affect bedrock topography because rock that is more resistant to erosion tends to create higher parts of the topography, whereas less resistant rock tends to be located in lower areas. The correlation between bedrock geology and bedrock topography is not strong in the current geologic and topographic maps, most likely due to the overall homogeneity of the bedrock composition, and the lack of topographic detail resulting from few control points.

The bedrock in Pope County is mostly granitic (see Bedrock Geology, this plate), and it is completely covered by glacial sediment that varies in thickness from a few tens of feet to almost 700 feet (213 meters). The thickness of the glacial sediment (Depth-to-Bedrock map) is the depth from the land surface to the bedrock surface. To calculate that thickness at any given place in Pope County, the elevation of the bedrock surface (Bedrock Topography map) was subtracted from the elevation of the land surface. To accomplish this task over the entire county, a grid of bedrock-surface elevations (90-meter cell size) was subtracted from a similar grid of land-surface elevations. This calculation produced a third grid of derived glacial-sediment thicknesses. That grid was supplemented with measured glacial-sediment thicknesses taken from drilling records. Finally, the values of that grid were contoured digitally to produce the Depth-to-Bedrock map. In places, the thickness of the glacial sediment varies greatly over short distances, and mapping at this scale (1:200,000) is not able to display that detail. For that reason, it is best to consult site-specific data wherever they are available.

The thickest glacial sediment in Pope County is in the southeastern and south-central portions of the county, where the bedrock surface is quite low. The thinnest glacial cover is found in the northeastern part of the county, just east of Westport, and in the area 2 to 5 miles (3 to 8 kilometers) southwest of Starbuck. These thin glacial sediments occur over areas where the bedrock surface is relatively high. Most of the details of the depth-to-bedrock map are related to landforms because the model of the land-surface topography is of higher resolution and based on more data than the bedrock surface model.



LOCATION DIAGRAM

DEPTH TO BEDROCK

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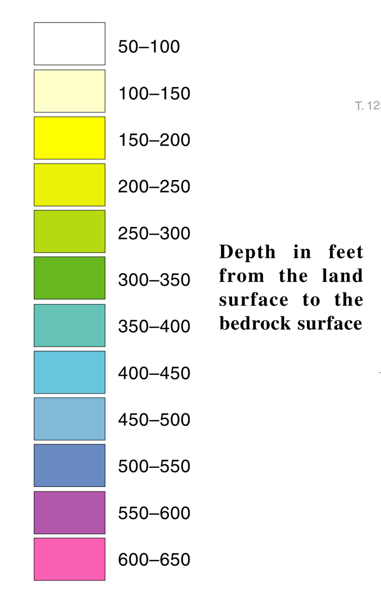

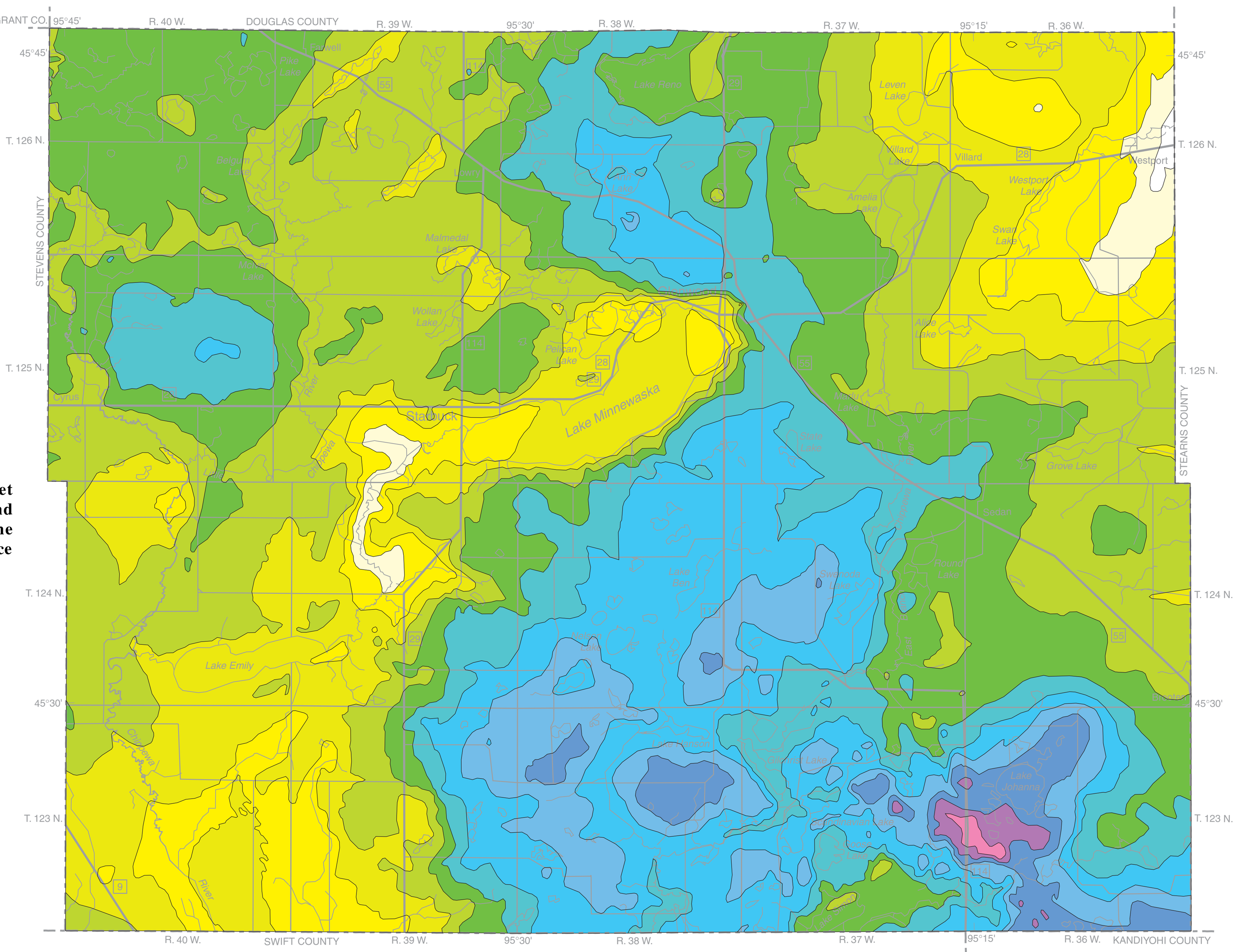

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GEOLOGIC ATLAS OF POPE COUNTY, MINNESOTA