

A HISTORY OF GEOLOGIC MAPPING IN MINNESOTA

BY G. B. MOREY

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When I first came to Minnesota in 1986, I went to see a state senator about the prospects for the Minnesota Geological Survey budget. He said, “Well, Dr. Grew, when is the geological survey of Minnesota going to be finished? It was started in 1872; aren’t you people finished yet?” Since he said this with a faint smile, I decided it was okay to respond, “Geologic mapping will be finished about when the legislators finish passing the state laws.” He took it well, and we got our budget.

On a more serious note, there is still a good deal of misunderstanding about what a geologic map is, and why geologic maps of the same area look different when different geologists draw them and when time has passed between the making of different maps. The reasons for this apparent paradox are given in this publication. Professor G.B. Morey, Chief Geologist of the Minnesota Geological Survey, has been making geologic maps of Minnesota since 1958. He is an internationally recognized authority on Precambrian bedrock stratigraphy and sedimentology, and a member of the North American Commission on Stratigraphic Nomenclature. I asked Professor Morey to write this history of geologic mapping in Minnesota because he knows that history well and is one of the strongest advocates of geologic mapping I know.

In 1992 Congress passed, and President Bush signed, the National Geologic Mapping Act. Under this act, state geological surveys will be eligible to participate in cooperative agreements with the U.S. Geological Survey for expanded geologic mapping activities.

The Minnesota Geological Survey celebrated its 120th anniversary in 1992. With the new congressional interest in the importance of geologic mapping to the nation, the Minnesota Geological Survey joins other state surveys in the hope that a new era of geologic mapping, aided by the latest technology in computer graphics and geographical information systems, will enable us to improve our services to society through the production of geologic maps.

Priscilla C. Grew
Director
Minnesota Geological Survey

Geology is the study of the Earth. The first serious observers of geologic phenomena recognized that the rocks held a record of changing conditions on the Earth; they inferred a history of change from indications of relative age and time that they could observe directly. This historical aspect of geology distinguishes it fundamentally from the physical, chemical, and biological sciences.

The Earth as we know it today is the product of many kinds of processes. Many of those processes are rarely if ever observed, but their signatures are recorded in the rocks. It is the geologist's job not only to understand how those processes operated in the past, but also to place those processes in a chronologic framework so better to understand how they have changed over time. In their pursuit of the Earth's history, geologists reconstruct processes that happened on a vast scale and in the remote past, from a rock record that is only partly preserved and partly exposed. Because only a small portion of the rock record can be seen at any given time or place, geologists must use maps to position their observations relative to each other and bring them down to a manageable scale; they then integrate what they have seen with the whole, via their imagination. Geologists have a final task: to apply their knowledge of process and change to such social issues as land use, water supply, earthquake prediction, and mining. Thus geologists must be able to make sound observations, synthesize those observations in new and innovative ways, and make their conclusions intelligible to others.

There are many kinds of geologic maps. In fact, any map that portrays the Earth's surface can provide some information about the geologic history of that place. For example, topographic maps provide information about processes that shaped the landscape. Soil maps provide information about the parent materials from which the soil is formed. Air photographs can be used to delineate faults, folds, or other morphological features, and to determine the distribution of different kinds of rocks. Today, geophysical maps are a powerful aid to geologic mapping, especially in Minnesota. Computer-generated images of magnetic variation, or of variation in gravity, owe their form and pattern to the distribution and physical properties of rock types in the

Earth's crust. The images therefore can be used to infer the distribution and physical properties of rocks in places where the rocks themselves cannot be seen directly. A good geologist will consider and integrate observations from these and other sources of information when constructing a geologic map.

In most places in the world, the present geologic environment is composed of two classes of material. At and near the ground surface there is typically a complex layer of unconsolidated material, such as sand, clay, gravel, or soil, that overlies and partly obscures hard rock at greater depth. Because the physical properties and the factors affecting the distribution of the near-surface, unconsolidated materials are so different from those of the underlying bedrock, the surficial materials usually are studied and mapped separately from the bedrock. Thus, a surficial geologic map shows the form and distribution of unconsolidated materials in the surficial layer, and a bedrock geologic map shows the form and distribution of rock units that underlie the surficial materials. This distinction is especially important in Minnesota, where much of the bedrock is covered by thick surficial deposits, mainly of glacial origin. On a surficial geologic map the bedrock is shown only where it is actually exposed; a bedrock map, in contrast, not only shows what actually can be seen of the bedrock, but also interprets what the rocks are like where they are covered by younger materials. Thus a surficial map is largely observational, whereas a bedrock map can have a large interpretive component.

Today there is a widely held opinion, both in many major research universities and in agencies of federal and state government, that geologic mapping is a routine activity, which once finished is done forever. Many people fail to recognize the interpretive component and equate geologic mapping with topographic mapping. However, topographic maps for the most part use mechanical, instrumental, or other routine surveying methods to gather observational data. The construction of a modern topographic map involves little if any interpretation.

The appearance of many geologic maps also tends to obscure their interpretive component and adds to many people's confusion about what they portray. To many people, geologic maps, with their contrasting colors, structural symbols, and sharply drawn contacts between rock units, give the impression that they are

an objective presentation of clearly distinguishable classes of rocks. Yet a bedrock geologic map, especially in Minnesota, is first and foremost an interpretation of how different kinds of rocks are distributed at the bedrock surface.

Geologic maps also summarize what is known about the relative ages or the chronologic history of the rocks, generally as a geologic column that accompanies the map's explanatory materials. Though a geologic column may appear deceptively simple, it, like the map itself, contains both a factual and an interpretive component. The actual arrangement of rocks within a temporal framework (from oldest to youngest, for example) depends in large part on observational information. However, a geologic column also requires a suitable nomenclatural scheme that provides a reference frame in which to discuss geohistory. Generally, the construction of a suitable scheme includes the comparison of the rocks in question against a standard stratigraphic sequence that expresses ages either by name and subdivision of geologic time, or numerically in years. To the layperson, this process may seem like a minor interpretive step, but it can lead to controversies ranging from worldwide disputes to squabbles over boundaries between local rock units. Some disputes merely reflect personal biases, but others are sustained by differing geologic philosophies. It is because of the latter that nomenclatural disputes are not trivial. The geologists' nomenclature—their language—reflects how they think about chronologic relationships among rocks; and how they think about the rocks in turn governs their nomenclature. Thus a geologic column does not simply sort the rocks into separate entities and name the entities; it establishes an intellectual framework in which to place the rocks and evaluate their histories.

A geologic map and its column present an interpretation of many observations; the quality of that interpretation depends on the experience and skill of the geologist. Field geologists are presented with a wide variety of observational facts, often more than they can record or even comprehend at one time. They must select aspects of the observational data to assemble and reassemble in particular ways defined to serve their goals. Such interpretive steps are to a large extent based on theories and prejudices held by the geologic community at the time a map is made.

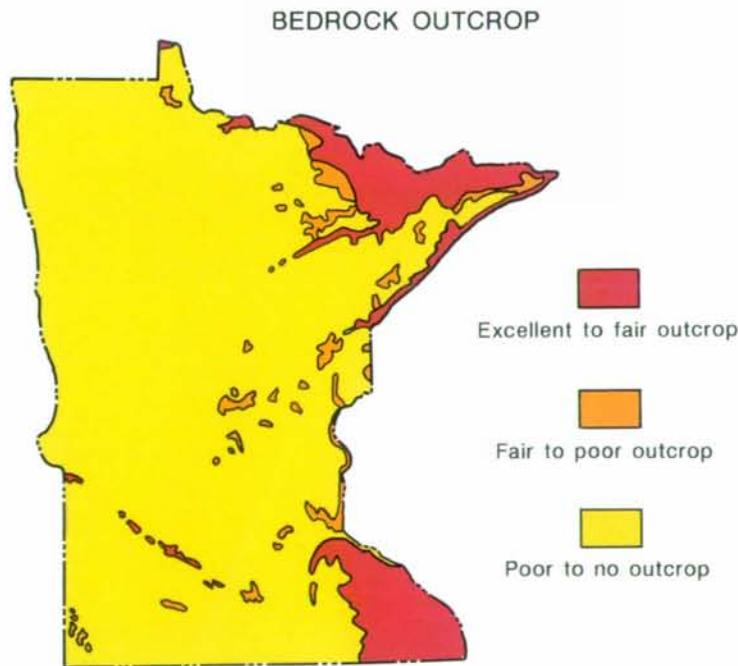
Although the collection of geologic data may resemble the collection of data for other kinds of maps, the meaningful assembly of the data requires a crucial interpretive step. That interpretive step creates or defines bodies of rocks that differ in some way from surrounding bodies of rock. Each body is separated from the next by some kind of bounding surface—e.g., contact, fault, unconformity—which appears as a line on a geologic map. For example, a geologic contact may separate two contrasting kinds of rock (e.g., sandstone and limestone) or it may separate a single kind of rock from a mixed unit (e.g., a sandstone or limestone from a unit consisting of both sandstone and limestone). In Minnesota, bounding surfaces are rarely exposed; geologists must use their knowledge of the relationships among geologic processes and their most likely geometric forms to infer where bounding surfaces most likely extend beneath the glacial cover.

Other factors being equal, geologists with more years of field mapping experience are better mappers than novices because they have seen more rocks. The eye can see only what it is taught to look for, and the more it has learned to look for, the more it can see. Experienced field geologists also are better able to judge the significance of their observations. This experience factor also sets apart geologic mappers from other map-makers. The makers of engineering or instrumental maps are much less dependent on their observational abilities and judgments than are geologic mappers, because the subject of their maps (topography, roads, power lines, sewers, and the like) are objects or entities of directly observable shape and established physical properties. To “map” them requires only that one establish their position in space, relative to some frame of reference. Although geologic observations also can be mapped spatially by mechanistic techniques, the result is a data compilation, not a geologic map in the true sense of the term. Except in rare cases, geologic data must be integrated by the mapper to become models or concepts consistent with accepted precepts of Earth history and geologic process. Because of this subtle distinction between compilations of geologic data and true geologic maps, there is an understandable tendency on the part of the public to confuse the two. Furthermore, data compilations generally can be made much faster than geologic maps, which makes them

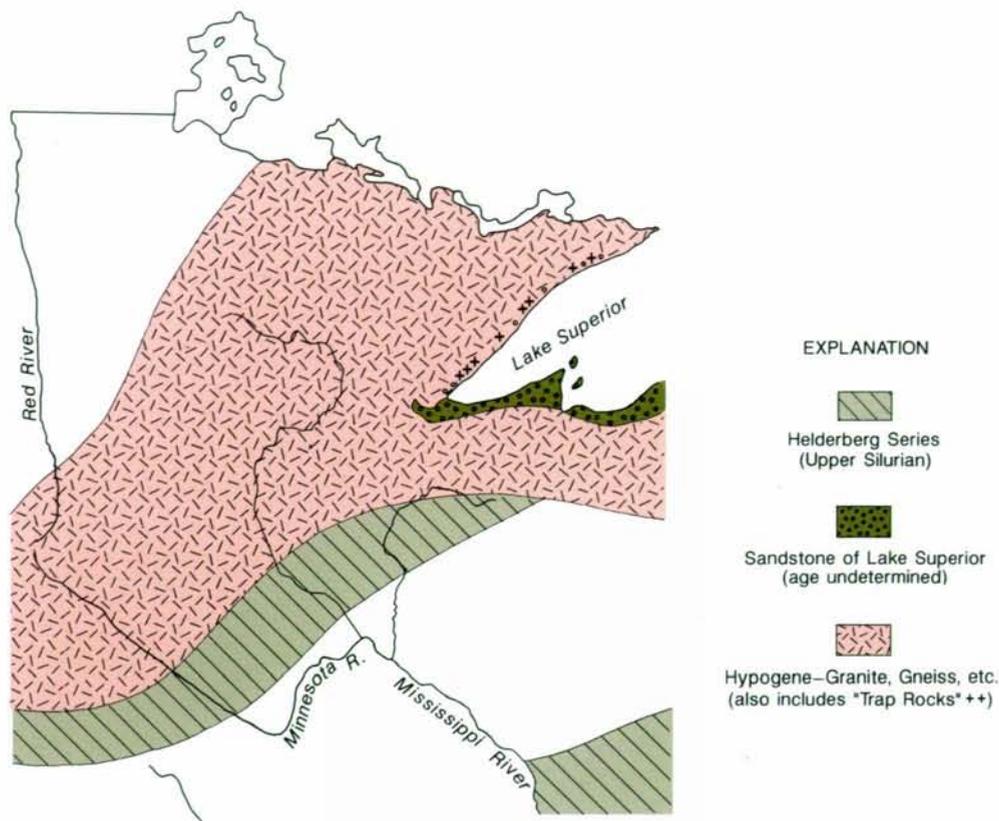
appealing to cost-conscious public officials who want "results" fast and at minimum expense. Such results often lack intellectual substance and are of limited value. The pressure for quick results partly explains why it is difficult to find people willing to invest the field time necessary to become competent geologic mappers. It also explains why geologic mapping programs are especially vulnerable to budgetary and political fluctuations. Experienced geologic mappers displaced by budgetary cuts often enter other geologic activities or leave the profession entirely, and it can be difficult or impossible to replace their mapping expertise when funding is restored. The retention of geologic mappers has become a major issue for

geological surveys around the world.

The history of geologic mapping in Minnesota, as recorded in a series of statewide bedrock geologic maps that began in 1845, illustrates the above mapping philosophy. Each map interprets observational data in terms of the theories and prejudices held by the geologic community at the time the map was prepared. More importantly, each map builds on the map before it. Together, the various maps record how geologic knowledge of Minnesota's part of the Earth has progressed over time. Geologists at the Minnesota Geological Survey continue to advance our geologic knowledge through a variety of mapping programs. ♦



The distribution of bedrock outcrop explains why geologists have concentrated their efforts on the northeast and southeast parts of Minnesota.



Reconstruction of Minnesota geology as portrayed by Lyell in *Travels in North America*, 1845

Organized geologic research began in Minnesota about 160 years ago. In the eighteenth and early nineteenth centuries, the interior of the North American continent was a great wilderness waiting to be explored. The part of North America that we now call Minnesota was first penetrated by French- or English-speaking fur-traders, missionaries, and adventurers who created a vast mercantile empire based on fur-trading with the Native American population. Travel through the area was mainly by canoe, either from the east along the Great Lakes and their tributaries, or from the south along the Mississippi and Minnesota rivers and

their tributaries. Many travelers published accounts of their adventures. Several of these contained useful descriptions of geologic phenomena in Minnesota; notable among them was Father Hennepin's 1790 description of the Falls of St. Anthony on the Mississippi River.

From 1770 to 1840, when modern geology was in its infancy, several naturalists in Great Britain, France, and Germany were beginning to record systematic observations about geologic phenomena. One of the fundamental relationships learned early on was the law of superposition—the placement of rocks in sequential order (it was only later realized that each layer was

older than the one above it). Geologists recognized that such an ordering, although developed in only limited geographic areas, could ultimately serve as a “type” for similar sequences elsewhere, and the network of sequence-ordering could gradually be extended across the globe on the basis of paleontologic and lithologic similarities. They also recognized that a map was the best way to illustrate the structural relationships of the fossiliferous rock bodies to one another. This intellectual breakthrough marked the beginning of modern geology.

Shortly after the American Revolution, the United States War Department organized and funded many geographic expeditions to Minnesota and areas to the west. The confluence of the Mississippi and Minnesota rivers was a frequent starting point. The explorations of Lieut. Z.M. Pike (1805), Major S.H. Long (1817), Lewis Cass (1820), H.R. Schoolcraft (1832), and Lieut. James Allison (1832) led to much knowledge of Minnesota geography. These military expeditions usually included one or more naturalists who described the natural phenomena along the way. However, because their primary task was to produce topographic maps and reports for military purposes, the expeditions travelled as quickly as possible, and the naturalists rarely had time for systematic or comprehensive study. Still, their reports were the beginning of organized scientific observation.

The naturalists’ studies, as well as observations by H.R. Schoolcraft (1820) on the south shore of Lake Superior and the St. Louis and Mississippi rivers, by J.J. Bigsby, M.D. (1824), along the north shore of Lake Superior and along the Pigeon and Rainy Rivers, and by H.W. Bayfield (1829) over all of Lake Superior were used by Sir Charles Lyell to produce the first geologic map of Minnesota in 1845. Lyell, one of the leading geologists in Great Britain, was the author of several standard textbooks that greatly influenced geologic practice in the nineteenth century. He also was one of a number of British geologists whose primary intellectual goal was the delineation of a sequence of distinctive major groups or strata that could be recognized throughout the world. Many of Lyell’s contemporaries believed that individual packages, or groups of rocks, were laid down worldwide simultaneously and possibly also instantaneously. In

that scheme, the composition of the rock itself served as the basis for both local and regional correlations. Fossils were generally thought of as funny marks on rocks that were of only local significance. However, Lyell believed that fossils “fingerprinted” various successions and therefore served to correlate one group of strata with another, regardless of their lithologic composition. Thus Lyell’s visit to North America involved, in part, testing the idea that groups of strata in North America could be equated with groups of strata in Western Europe because of similar fossil assemblages.

The Minnesota map was part of a larger map entitled “Geologic Map of the United States and Adjacent Parts of Canada,” which was compiled by Lyell in 1841 and 1842 and included as an appendix to his historical account, *Travels in North America*. This map illustrates how the theory worked in practice. Lyell noted that the sedimentary rocks exposed along the Mississippi and St. Croix rivers in southeastern Minnesota and adjoining parts of Wisconsin and Iowa contained fossils like those in rocks that crop out in New York State, which in turn have fossil assemblages like those found in so-called Upper Silurian rocks in Great Britain. Thus Lyell was completely comfortable in giving strata of the Upper Mississippi Valley place names from the eastern United States and in classifying the rocks as part of a Silurian System despite their distance from “type” Silurian strata in Great Britain.

Geologists of the 1840s also believed that the maximum thicknesses of successive systems were a roughly reliable guide to the relative duration of the successive periods of time in which the systems had accumulated. Therefore Lyell was comfortable in considering the Silurian Period the duration of geologic time in which the Silurian System had accumulated. It followed that rocks that lack fossil evidence as to their age could not be placed within the worldwide geologic column as it was understood in the 1840s. Thus Lyell was forced to use a local name, “the Red Sandstone of Lake Superior” to describe red, non-fossil-bearing, sedimentary rocks that crop out along the South Shore of Lake Superior. Lyell also recognized an undivided basement complex of old unfossiliferous rocks that he termed “Hypogene.” ♦

David Dale Owen's 1852 *Report of a Geological Survey of Wisconsin, Iowa, and Minnesota; and Incidentally of a Portion of Nebraska Territory*, in which the 1851 map appeared, was notable in two respects. First, the survey was sponsored by the Treasury Department rather than the War Department, and was undertaken for economic rather

than military objectives. Owen was to seek information that could be used to identify public lands with mineral potential. Secondly, Owen was given sufficient time to do scientifically sound work.

Owen's work established that extensive tracts of exposed bedrock occur only in northeastern Minnesota and within the valleys of the Mississippi and Minnesota

TABLE OF COLORS.

COLORS OF THE SUPERFICIAL SEDIMENTARY DEPOSITS.

		<i>Erratic Blocks & Fine and Coarse Drift.</i>	DRIFT PERIOD.
		<i>Red Clays and Marls, overlying the Red Sandstones of Lake Superior.</i>	

COLORS AND SUPERPOSITION OF THE FOSSILIFEROUS STRATA.

FORMATION OF THE PLATTE, CHICAGO & MISSOURI RIVERS & PEE HILLS, UPPER MISSOURI.	F.7		<i>Inoceramus, Ammonoite & Crucian Limestone.</i>	CRETACEOUS FORMATION.
	F.6		<i>Chiefly thick Beds of Sandstone & Conglomerate, Shale, Coal, Gypsum, Ironstone with carboniferous Beds of Limestone, Hydraulic Cement and Sphalerite.</i>	COAL MEASURES.
YORREDALE SERIES OF YORKSHIRE, LOWER SCAR LIMESTONE.	F.5		<i>Upper Series.</i>	CARBONIFEROUS LIMESTONE.
			<i>Lower Series.</i>	
HAMILTON GROUP ONONDAGA LIMESTONE.	F.4		<i>Upper Coralline Limestone.</i>	DEVONIAN PERIOD.
			<i>Middle Shell Beds.</i>	
			<i>Lower Coralline Beds.</i>	
CLINTON & NIAGARA GROUP ONONDAGA LIMESTONE IN PART HUDSON RIV. GROUP AND TRENTON LIMESTONE.	F.3		<i>Coralline and Pinnaculous Beds.</i>	UPPER SILURIAN PERIOD.
			<i>Level bearing Beds.</i>	LOWER SILURIAN PERIOD.
			<i>Shell Beds.</i>	
CALCIFEROUS SANDSTONE OF NEW YORK.	F.2		<i>Sandstone usually white and incoherent.</i>	LOWER SILURIAN PERIOD.
			<i>Magnesian Limestone with veins & aggregations of Chert and Quartz.</i>	
			<i>Magnesian Limestone with chert layers & green particles disseminated.</i>	
POTSDAM SANDSTONE OF NEW YORK.	F.1		<i>with interstratifications of Magnesian Limestone.</i>	LOWER SILURIAN PERIOD.
			<i>Soft fine Sandstones usually fine grained.</i>	
			<i>Upper Trilobite beds.</i>	
			<i>Fossiliferous layers and Green Earth.</i>	
			<i>Coarse Linguleta beds.</i>	
			<i>Lower Trilobite Beds, Linguleta & Obolus layers, Inferior pebbly Beds, Red Sandstones of T. Superior.</i>	

COLORS OF THE METAMORPHIC ROCKS.

	<i>Amphibolitic, Argillaceous and Siliceous Slates, alternating occasionally with bedded Traps.</i>
	<i>Alternations of Metamorphosed Schistes, Slates and Sandstones with Volcanic Gneiss and other bedded Traps and Porphyries.</i>
	<i>Metamorphic Schistes, Gneiss and Gneissoid Rocks.</i>

COLORS OF THE IGNEOUS ROCKS

	<i>Granite and Sienite.</i>
	<i>Gneiss.</i>
	<i>Trap Rocks.</i>

COLORS OF THE INTRUSIVE DIKES

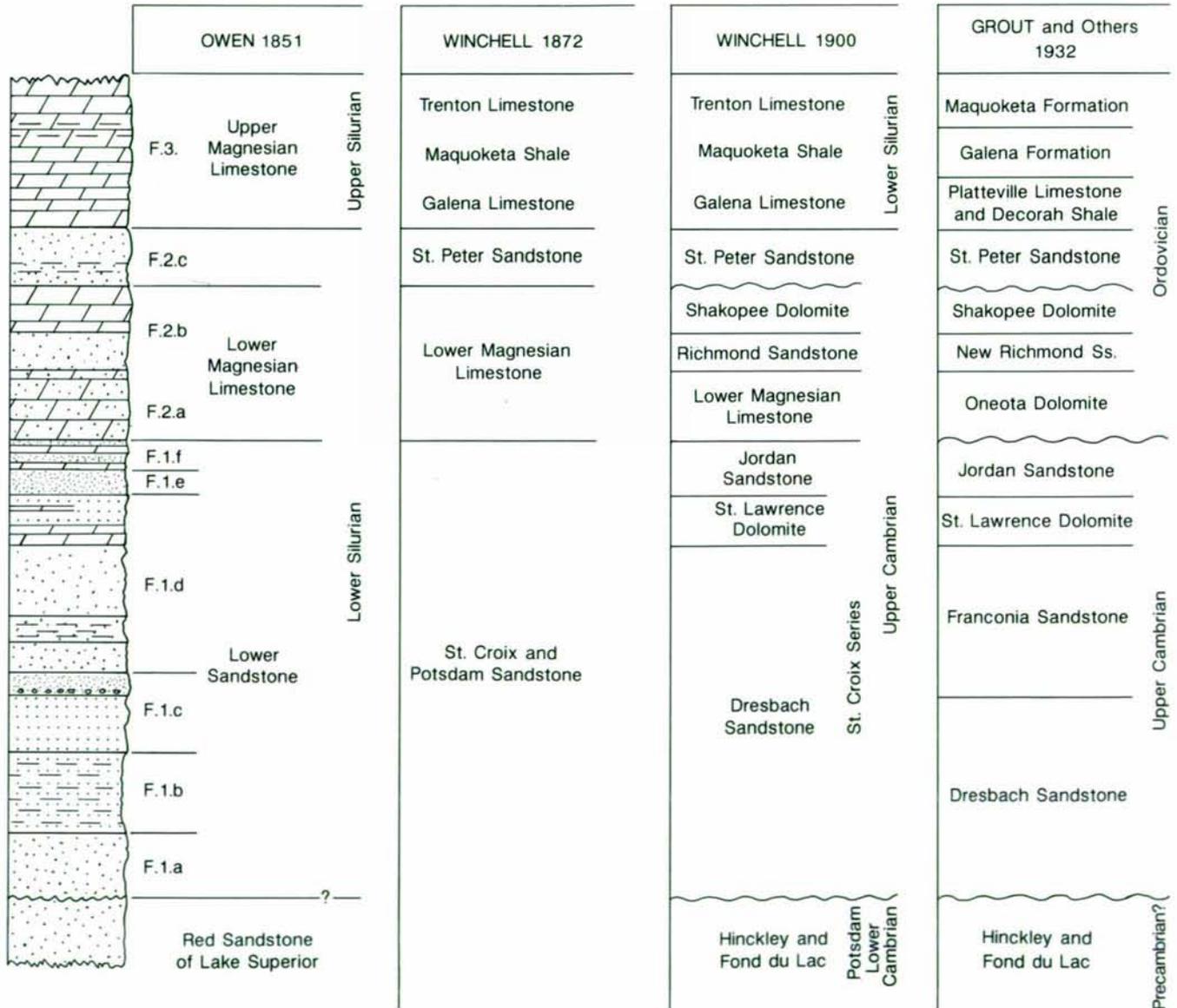
	<i>Gneiss and Basaltic Ridges and Dikes, traversing Granitic and Metamorphic Rocks.</i>
	<i>Granitic Gneiss and Intrusions in Metamorphic Rocks.</i>
	<i>Narrow Dikes of Basalt and Gneiss, traversing Metamorphic Rocks.</i>
	<i>Dikes of Feldspar in Metamorphic and Trap Rocks.</i>

rivers and their tributaries, a circumstance that continues to plague geologists today. His map reflects the development of geology from an observational science to an interpretive one.

Much of the information from the northeastern segment of the map was compiled by J.C. Norwood, M.D., who showed that the undivided "Hypogene" of Lyell's 1845 map could be divided into separate rock

units of diverse origin, some of which could be arranged sequentially on a local scale. Little more could be done in placing the rocks into a unified geologic column or a geologic time scale because they lacked fossils. However, in the southeastern part of the state, the fossiliferous rocks were a considerably different matter. By 1850 Lyell's and others' view of a geologic time scale based on the recognition in the

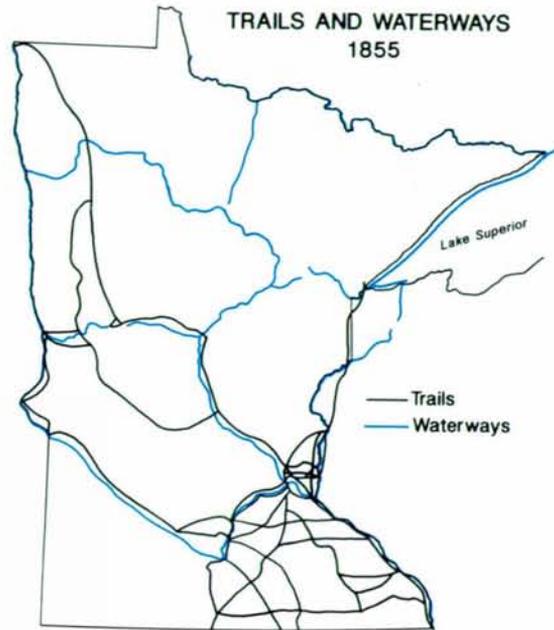
GEOLOGIC COLUMN AND CHANGES IN NOMENCLATURE, 1851 TO PRESENT, SOUTHEASTERN MINNESOTA



fossil record of widespread extinctions of animal species was well developed and generally accepted. Such extinctions seemed to occur worldwide, marking punctuations, or times of sudden biologic change, in an otherwise continuous evolutionary flow. Geologists found that many extinctions occurred at previously recognized systematic boundaries, supporting the view that unconformities were of considerable importance as a record of interrupted deposition. Thus Owen was

able to build on Lyell's original work and establish paleontologically that the rocks exposed in the Upper Mississippi Valley were deposited at about the same time as those in the lower part of the Silurian in Great Britain. Again on the basis of fossil evidence, Owen was able to establish that the rocks of the Upper Mississippi Valley could be divided into three lithologically distinct and widely distributed sequences. However, because sedimentation was no longer viewed as simultaneous and instantaneous over large parts of the world, Owen chose to give his sequences neutral names that did not imply lithologic continuity with better studied units in the eastern United States. ♦

FORMATIONS RECOGNIZED TODAY		
Maquoketa and Dubuque Formations		Upper
Galena Group		
Platteville Limestone and Decorah Shale		
St. Peter Sandstone		
Shakopee Dol.	Prairie du Chien Group	Lower Ordovician
New Richmond Ss.		
Oneota Dolomite		
Jordan Sandstone		
St. Lawrence Dolomite		
Franconia Sandstone		Upper Cambrian
Ironton Sandstone		
Galesville Sandstone		
Eau Claire Sandstone		
Mt. Simon Sandstone		
Hinckley and Fond du Lac		Precambrian



Adapted from John R. Borchert and Donald P. Yaeger, *Atlas of Minnesota Resources and Settlement*, 1968, and Theodore Christian Blegen, *Minnesota: A History of the State* (Minneapolis: University of Minnesota Press, 1963).

Travel through Minnesota in the late 1840s was still an arduous task, restricted principally to major waterways and military roads that connected forts and small trading settlements. Owen's introduction to the 1852 report gives a taste of what surveying was like then:

Our bowsman (as the voyageur who manages the bow paddle is called) having discharged his rifle at a deer, had reloaded it, and, in the excitement of the chase, had hastily laid it down beside another gun, on the forward thwart of the canoe, with the muzzle imprudently pointing, in a direct line, towards myself; I being seated, with Mr. B.C. Macy, in the centre of the canoe. A sudden jerk of the boat caused the discharge of the rifle. Had not the breech of the other gun chanced to lie slantingly across the muzzle of the discharged piece, this Report, in all probability, would have been completed by some one else than its present author. (p. xxiv)

We have frequently, notwithstanding the utmost prudence, exhausted the last pound of eatables, and travelled a day or more, without breaking our fasts. On one occasion, a single pigeon supplied a corps of men during three days...(p. xxiv)

Minnesota became the thirty-second state on May 11, 1858. The first effort by the state to institute a geological survey failed later that year. A second attempt, two years later, was rejected as too costly. An enabling act creating the Geological and Natural History Survey was signed into law on March 1, 1872, and N.H. Winchell was appointed director shortly thereafter. The Survey was to be administered through the Board of Regents of the University of Minnesota. The first report of the Geological and Natural History Survey was published in December 1872. In a section entitled "General Principles," Winchell wrote, "These two postulates stated—that time is long, and that the physical laws of the universe have been constant throughout time—and nothing more is needed for the foundation of the science."

The report included a geologic map that integrated the results of a brief reconnaissance survey in the southeastern part of the state by Winchell with the earlier conclusions of Owen, and with work underway by other geologists, mainly in Iowa and Wisconsin. The map was to show a complete section of fossil-containing strata that went from above the igneous and metamorphic basement, up to the top of a rock sequence assigned to a Devonian System. The Devonian System was a name applied to rocks once thought to be in the uppermost part of the Silurian System in Great Britain. Winchell had no firsthand knowledge about the unfossiliferous basement rocks and could do little with them. He therefore showed them as a composite unit. Previous geologic studies in southwestern Minnesota in the 1860s had shown that Devonian rocks were overlain by a yet younger sedimentary sequence that could be correlated with another European group of rocks assigned to a Cretaceous System. Winchell, however, decided not to show these strata on his map because (1) their distribution was poorly known beyond the limits of the Minnesota River Valley and tributaries, and (2) their presence on the map would obscure what he thought to be more fundamental stratigraphic relationships in the pre-Cretaceous strata.

By 1872, much of southeastern Minnesota was accessible by railroad and had a population density greater than five people per square mile. Winchell's field work was greatly aided both by the railroads and, more importantly, by the observations of local residents. These included Prof. W.H. Phelps of the Normal School at Winona, W.D. Hurburt of Rochester, and Frank Wilson of Mantorville, who all freely shared their large fossil collections with Winchell. Much of the complex cartography along the Lower Magnesian–St. Peter–Trenton boundary on the 1872 map is the product of Hurburt's efforts.

The 1872 map does show several new and unique features. For example, the map establishes the presence of a broad south-plunging syncline, or downfold—the southern Minnesota syncline—whose axis extends northward from Iowa through Freeborn County and to Minneapolis–St. Paul. Winchell also showed that the Devonian rocks—renamed for exposures once thought to be in the stratigraphically uppermost part of the Silurian System in Great Britain—extend from Iowa northward into southern Minnesota, along the axis of the southern Minnesota syncline.

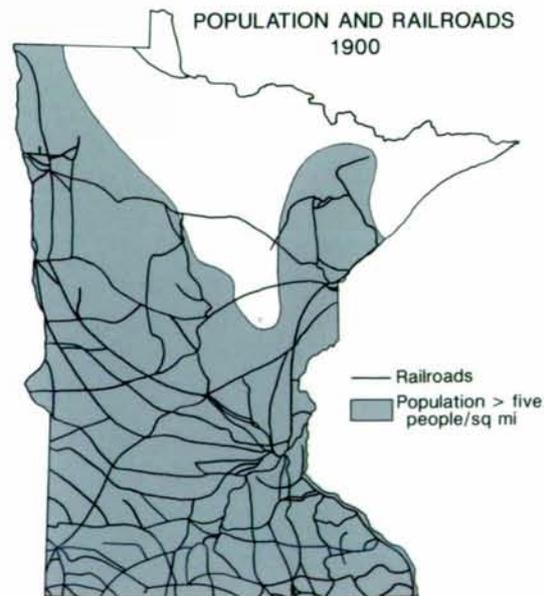
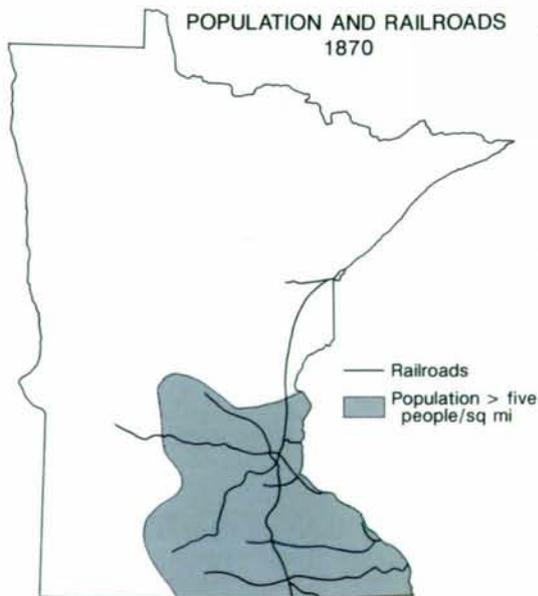
Nomenclatural changes between 1852 and 1872 reflect new stratigraphic procedures that identified rocks by a geographic type locally. Thus the 1872 map contains rock units first recognized near and then named for places in Iowa and Illinois. For example, in 1851 geologists with the Iowa Geological Survey renamed the upper part of Owen's Upper Magnesian limestone the Galena Limestone after exposures near Galena, Illinois. Twenty years later, in 1870, they established that the Galena was overlain by a thick shale unit first recognized around Maquoketa in northern Iowa. Winchell traced both units into southern Minnesota, using subsurface data obtained from domestic water wells, especially those drilled by the railroads.

The stratigraphic position of the Lower Magnesian limestone remained unchanged from Owen's map to the 1872 map. However, Winchell thought that Owen's term "Lower Sandstone sequence" was not definitive

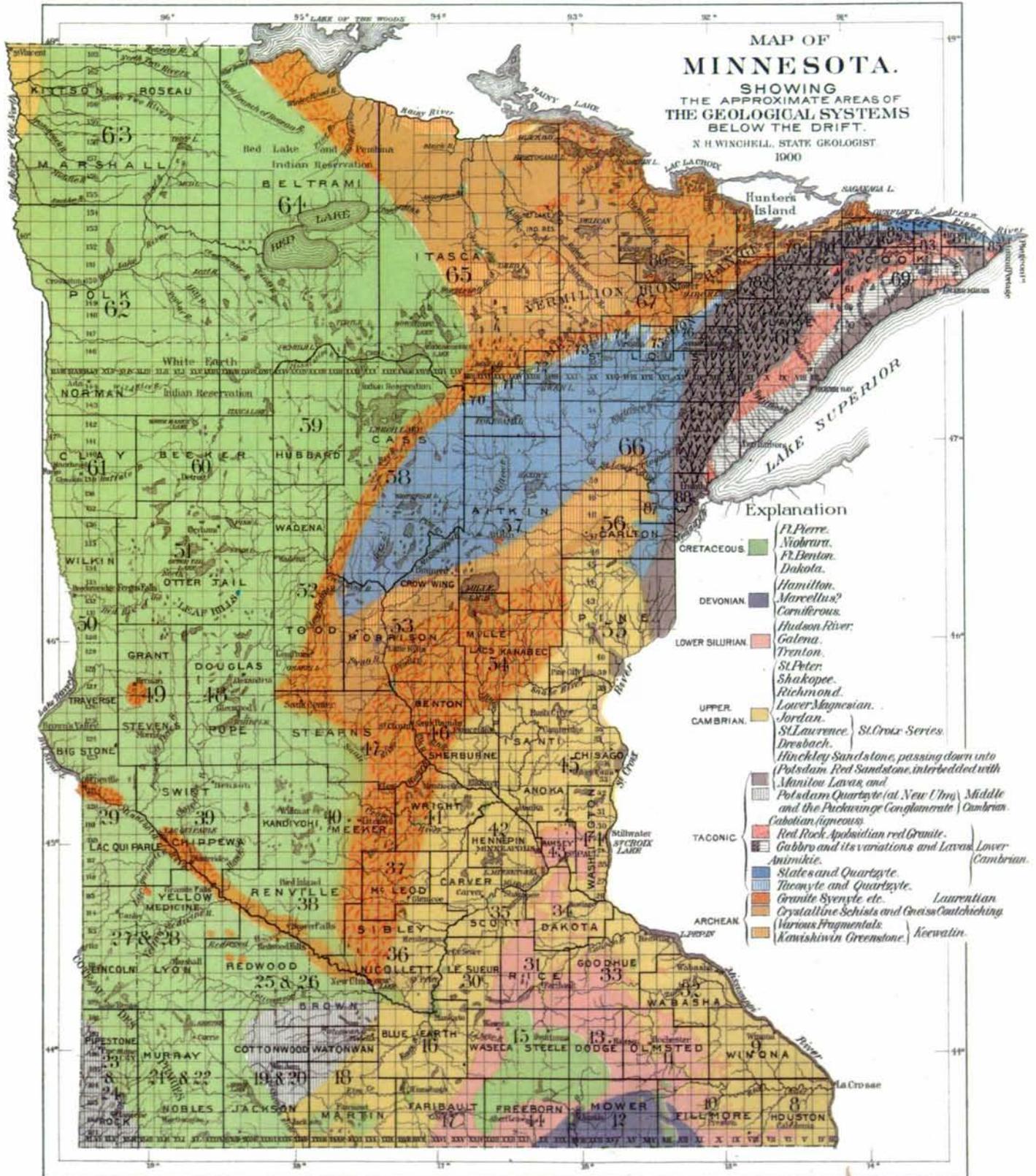
enough; he therefore renamed that package of rocks the St. Croix Sandstone from exposures along the valley of the St. Croix River. He gave the name Potsdam Sandstone, originally applied to outcrops of Lower-Middle Cambrian sandstone in New York State, to: (1) the Red Sandstone of Lake Superior, (2) outcrops of salmon-colored sandstone in Pine and Chisago counties, and (3) outcrops of red quartzite in Nicollet, Cottonwood, Rock, and Pipestone counties. Although these rocks lacked fossils, they—like the type Potsdam—were all underlain by igneous and metamorphic rocks and overlain by fossiliferous Upper Cambrian rocks; therefore, Winchell thought they could be stratigraphically correlated with one another. The term Cambrian itself had been coined for rocks

beneath and partly equivalent to the Silurian System in Great Britain.

The stratigraphy shown by Winchell in the northwestern part of the state was based on scant data from drill holes that presumably penetrated Lower Magnesian limestone in the northwestern corner of Pembina County (now Kittson County), and on outcrops of red quartzite near Pokegama Falls on the Mississippi River in Itasca County. Winchell correlated them with his Potsdam Sandstone. Thus it is apparent that in 1872 Winchell believed in the utility of fossils for purposes of correlation; but it is also apparent that he had not completely divested himself of the older ideas concerning lithologic type as a useful means of correlation. ♦



Adapted from John R. Borchert and Donald P. Yaeger, *Atlas of Minnesota Resources and Settlement*, 1968



In 1900, N.H. Winchell retired after twenty-eight years as director of the Geological and Natural History Survey. Much of the information acquired during his directorship was based on county-by-county mapping projects at a scale of about 2 miles to the inch. Mapping began in the southern part of the state in Houston County in 1884 and generally followed the northward and westward settlement of the state and the extension of the railroads into all but the northeastern part of the state. Mapping ended in 1899 with a special plate showing the geology of the city of Duluth. Other achievements included detailed maps and descriptions of the recently discovered Vermilion and Mesabi iron ranges in northern Minnesota.

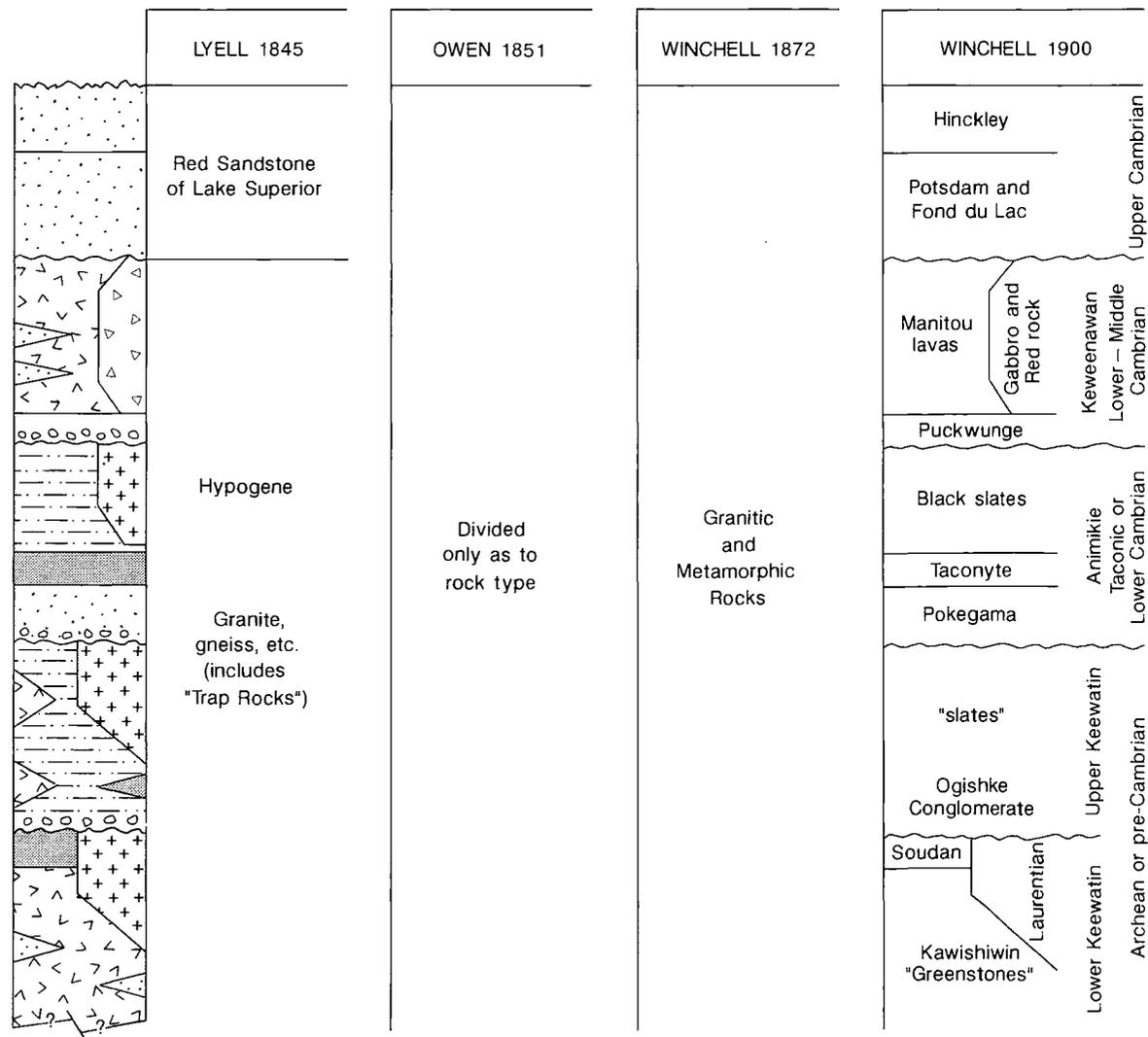
In 1900, Winchell summarized the mapping with a statewide geologic map. Despite extensive surficial deposits that obscure bedrock in much of the state, Winchell was able to infer geologic boundaries from his general knowledge of the structure of rock units. In some respects the map was a thoroughly modern rendition of the bedrock geology, particularly in its cartographic portrayal of the geographic limits of the larger rock units.

Much of the 1900 map of southeastern Minnesota reflects Winchell's continued use of stratigraphic concepts stated in 1872. The St. Croix Sandstone of 1872 was subdivided into five formations: the Hinckley Sandstone (1888), Dresbach Formation (1886), Franconia Formation (1897), St. Lawrence Formation (1874),

and Jordan Formation (1872), all named after type localities near small towns in east-central and southeastern Minnesota. Winchell continued to believe that the package of five formations was deposited in late Cambrian times, but he now used the term St. Croix Series for the interval of time during which Upper Cambrian rocks were deposited. Though the changing ideas about the geology of southeastern Minnesota, as reflected by the many nomenclatural changes, added considerable detail to the 1900 map, they did not substantially change the map's overall cartographic appearance.

The 1900 map was different from previous geologic maps of Minnesota in two important ways. First and of special significance, it summarized the classic mapping of Winchell and his son-in-law U.S. Grant in the (then-

GEOLOGIC COLUMN AND CHANGES IN NOMENCLATURE,



called) pre-Cambrian rocks of northeastern Minnesota, subdividing into ordered stratigraphic sequences a terrane that previously had been mapped as a single undecipherable entity. Secondly, the map was the first attempt to show how Cretaceous strata were widely distributed beneath glacial cover. Intentionally or not, this approach masked the problem that, due to the thick glacial cover in much of western Minnesota, Winchell lacked data on the distribution of the pre-Cambrian sequences. Many geologists since that time have been plagued by the problem—how to determine the distribution of pre-Cambrian rocks in much of western Minnesota, where the glacial cover is thick and outcrops are lacking.

The remarkable achievements of Winchell and Grant in the pre-Cambrian were based on many of

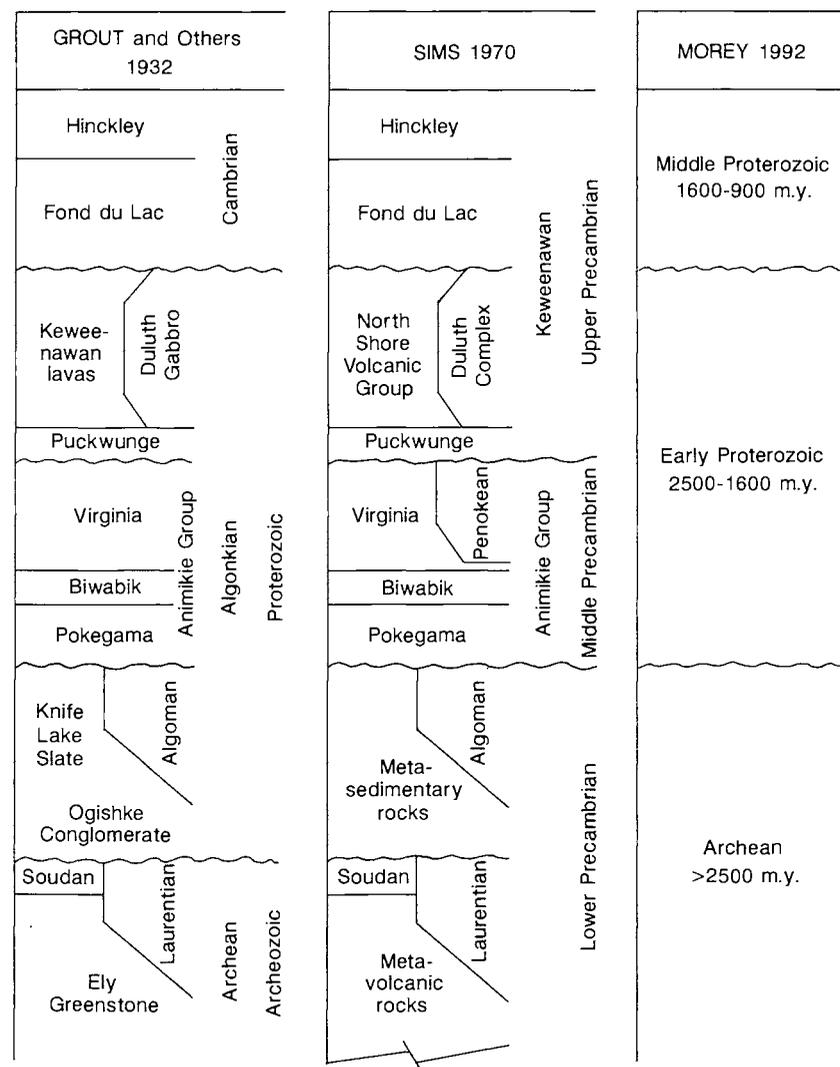
their own observations, but they also relied heavily on the ideas of the Geological Survey of Canada, which had people actively mapping the area in Ontario just across the International Boundary, and on the conclusions of several U.S. Geological Survey field parties who were working in Wisconsin and northern Michigan at about the same time. In the end, Lyell's Hypogene was divided into mappable units that were separated from each other by demonstrable unconformities of broad areal extent. They recognized an older sequence of strongly deformed rocks that included greenstone, iron-rich strata, and fragmental rocks, all cut by granites of at least two ages. Winchell called this package Archean and inferred a prominent unconformity to divide it into Lower and Upper Keewatin sequences. Names such as the "Archean"

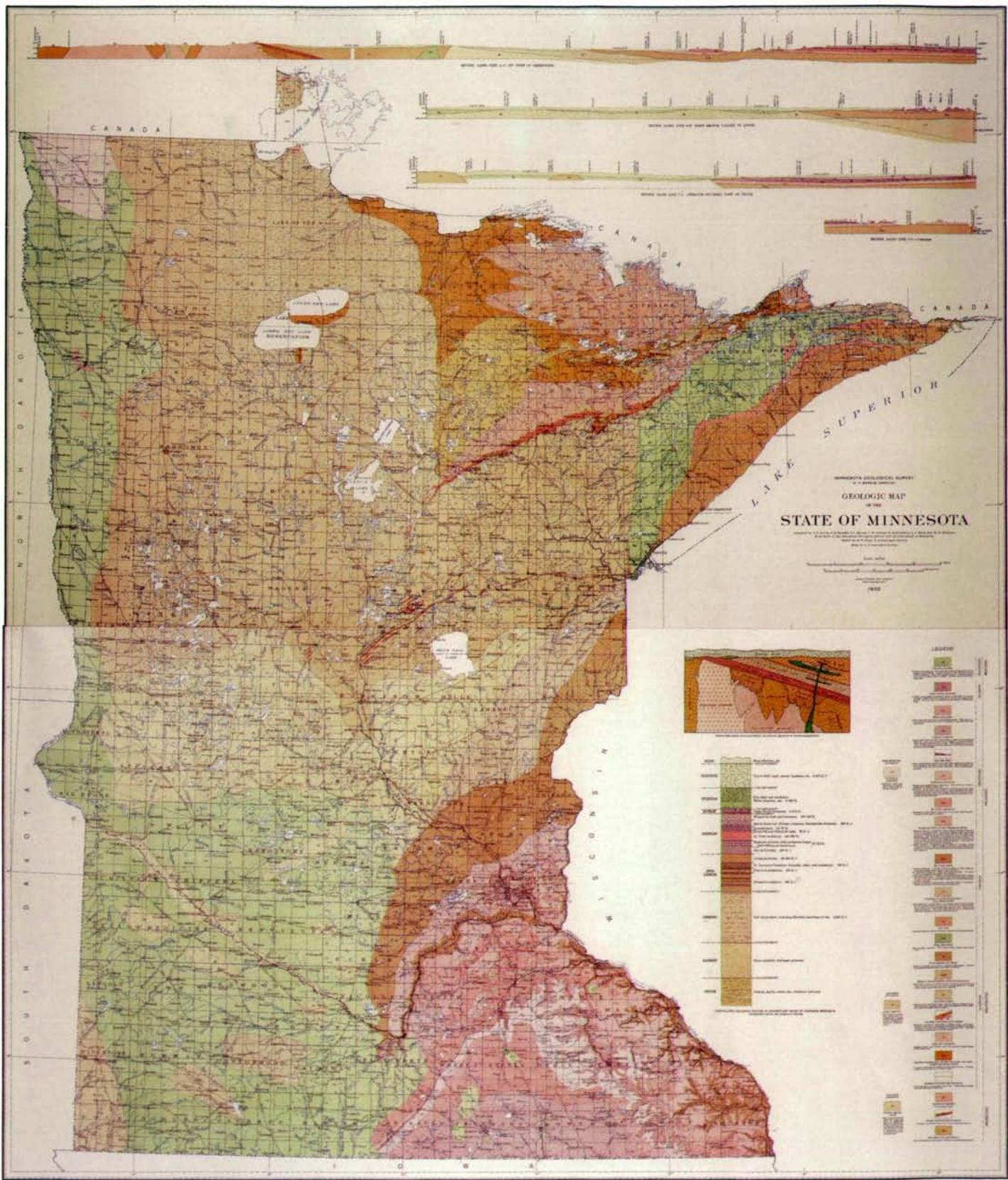
and the "Keewatin" were taken from geologic units first identified across the International Boundary in Canada. A second unconformity, atop the Archean, was overlain by a younger sequence that Winchell named the Taconic. The Taconic sequence included the iron-rich strata (taconyte) and associated rocks of the Mesabi Iron Range, called the Animikie from the Thunder Bay area of Canada; and the Duluth Gabbro and associated lava flows, called the Keweenaw from the Keweenaw Peninsula in Michigan. The term "Taconic" was taken from a sequence of rocks in New York that contained primitive fossils indicative of an Early or Middle Cambrian age. Within that scheme, the pre-Taconic or Archean rocks of northern Minnesota were simply pre-Cambrian in age.

Winchell continued to believe that the Red Sandstone of Lake Superior (he now called it the Fond du Lac Formation, from that town west of Duluth) and the red quartzite in southwestern Minnesota (now called the Sioux Quartzite, from Sioux Falls, South Dakota) were correlative with each other and with the Potsdam Sandstone of New York State. In New York, the Potsdam was thought to overlie the Taconic rocks of Early to Middle Cambrian age, making them late Cambrian or St. Croixian in age. Thus although these nomenclatural changes considerably changed the appearance of the 1900 map, they did not reflect any major change in geohistory from the 1872 map.

Regardless, by the end of the nineteenth century, geologic mapping in Minnesota had established the distribution of major rock units, especially in areas where the bedrock was exposed. Though the order of strata had been fairly well determined, the nomenclature describing that order was still confused. ♦

1845 TO PRESENT, NORTHERN MINNESOTA





pre-Cambrian to Precambrian underscored the recent recognition that the Earth's history before the beginning of Cambrian time was complicated.

Very little other geologic information was produced in Minnesota before World War I. After the war, cooperative projects with the U.S. Geological Survey focused on general problems of Pleistocene and groundwater geology, and on economically valuable materials such as iron ores, clay, peat, and building stones. These studies, though useful, had little impact on the bedrock geologic map. Much of the period from 1911 to the start of World War II was consumed by endless debate about how Precambrian rocks could be correlated from place to place. The debate centered largely on appropriate names for the larger unconformity-bound packages, and to a lesser extent on the value of unconformities in possible worldwide correlation schemes. In particular, considerable confusion existed as to the relationship between rock units and geologic time units.

In the 1890s the U.S. Geological Survey used the term Proterozoic as a synonym for pre-Cambrian. They also recognized an Algonkian System sandwiched between Archean rocks below and Cambrian rocks above. Thus Proterozoic (Precambrian) rocks could be divided into the Algonkian and Archean Systems; in Minnesota, the former included Keweenaw and Animikean rocks. In 1925, the term Proterozoic was redefined as the time interval during which Algonkian rocks were deposited, whereas the term Archaeozoic was used for the time interval during which Archean rocks were formed. Therefore Precambrian time was divided into Proterozoic and Archaeozoic Periods, during which the Algonkian and Archean Systems were deposited. Most geologists outside the U.S. Geological Survey found this too confusing and continued to use Precambrian for both rocks and time.

A good deal of stratigraphic paleontology was done in southeastern Minnesota prior to World War I. Much

of it involved redescribing the fossil assemblages from classical stratigraphic sections first identified by Winchell and his colleagues. Unfortunately, the later workers misidentified the place in the stratigraphic sequence of many fossil-bearing beds, in some cases by as much as 300 feet vertically. This had a profound effect on the 1932 map, where several geologic contacts were misplaced by 10 to 20 miles.

The 1932 map had its beginnings in the late 1920s, when the U.S. Geological Survey decided to publish a new small-scale geologic map of the United States, compiled from state geologic maps. Therefore, although the 1932 map was compiled at a scale of 1:500,000 by F.F. Grout, C.R. Staffer, I.S. Allison, J.W. Gruner, G.M. Schwartz, G.A. Thiel, and W.H. Emmons, all of the University of Minnesota, it was edited and published according to U.S. Geological Survey standards. Even though many of the names in the geologic column are different, cartographically the 1900 and 1932 maps are very similar. Differences include the geology of the Cuyuna Range and the distribution of Cretaceous strata in western Minnesota. Subsurface data acquired mainly from water wells showed that the Cretaceous strata were not as widely distributed as Winchell had thought in 1900. Grout and others chose a more conservative interpretation that "uncovered" an area of Precambrian bedrock about 180 to 200 miles wide from the International Boundary to the Minnesota River Valley. Although lacking Cretaceous cover, the Precambrian rocks of this area are obscured by a thick cover of Quaternary glacial deposits, and the compilers had to map them as undifferentiated. Though intellectually more honest, this vast, blank area of undifferentiated rock gave the map what geologists call an "artificial" look. Geologists ask of a map, "Does it talk to you?" The 1932 map did not talk, did not tell a story, did not reveal much of a history. ♦

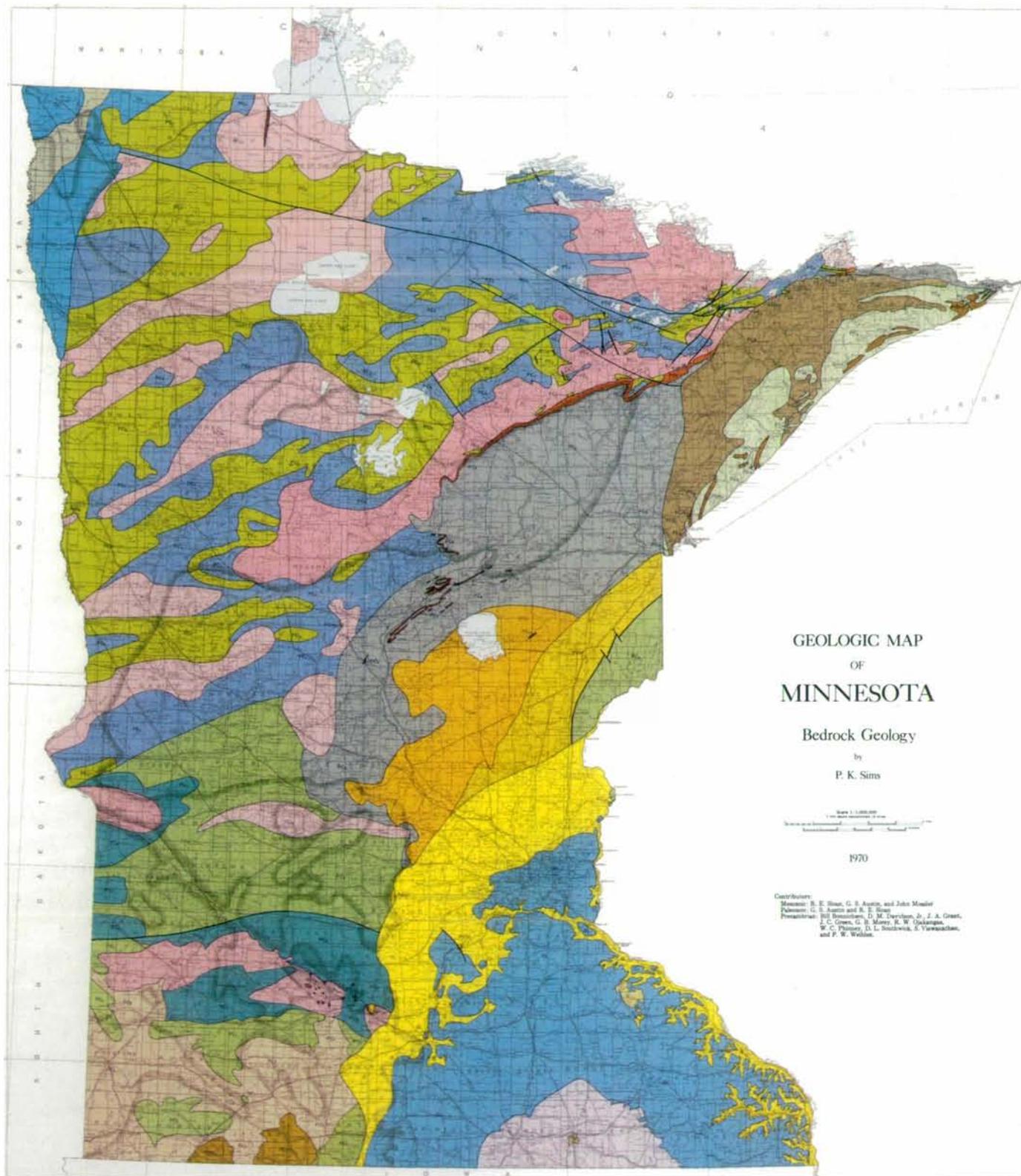
World War II changed how geologists thought about Minnesota geology. The iron-ore deposits had been all but depleted by the war effort. If Minnesota was to continue to produce iron ore, new resources would have to be found—and in those parts of the state where the glacial cover ruled out conventional mapping techniques. The undifferentiated Precambrian bedrock of Grout and others would have to be differentiated as to rock types. The U.S. and Minnesota Geological Surveys agreed in 1947 to produce jointly an aeromagnetic survey of the state (aeromagnetic methods distinguish magnetically contrasting rock types). The program, which continued to the late 1960s, led to the first statewide aeromagnetic map in the country.

Though the new data did not lead to any new iron-ore resources, it did result in new insights about the buried bedrock. P.K. Sims used those insights in 1970 to build on the earlier work of Winchell and Grant, and Van Hise and Leith to produce a new geologic map of the state at a 1:1,000,000 scale, the first since 1932. This map was one of the first regional attempts in the United States to use geophysical data systematically to interpret bedrock geologic attributes that could not be observed directly by field geologists. Sims showed that geophysical methods—and in particular, aeromagnetic methods—are a powerful aid to geologic mapping, especially in areas of poor outcrop.

Our understanding of chronologic relationships among different Precambrian map units was greatly aided in the 1960s by the development of reliable isotopic-dating techniques, especially those of S.S.

Goldich and A.O. Nier of the University of Minnesota. The work confirmed what every Precambrian geologist already thought—that Precambrian time was long, and that within that long interval was sufficient time for many events. In other words, rocks of similar appearance were not necessarily correlative. Consequently, the formal nomenclatural scheme devised by Winchell and Grant in 1900 and modified through the first half of the twentieth century had to be redefined. This effort continues today. Stratigraphic classification schemes now depend on isotopic evidence rather than the appearance of the rocks studied. For example, on the 1970 map, the terms Early, Middle, and Late Precambrian do not refer to the rocks themselves, but to the intervals of time in which the rocks formed.

The 1970 map included the work of Professor Robert Sloan and his students, who remapped much of the Paleozoic strata in southeastern Minnesota at a scale of 1:250,000 or approximately 1 inch = 3 miles. This work resolved many of the cartographic problems created by the 1932 map and formed the basis for all subsequent studies, until a county mapping program was begun in the mid-1980s. Sims believed that increasing demands on our national resources, as well as the need for new mineral sources, required accelerated research and mapping in areas of Precambrian strata with mineral potential. Thus he chose to portray the distribution of Cretaceous strata in outline form only, a technique designed to emphasize the distribution of underlying rocks that presumably are more important economically.



Miscellaneous Map Series, Map M-24

GEOLOGIC MAP OF MINNESOTA

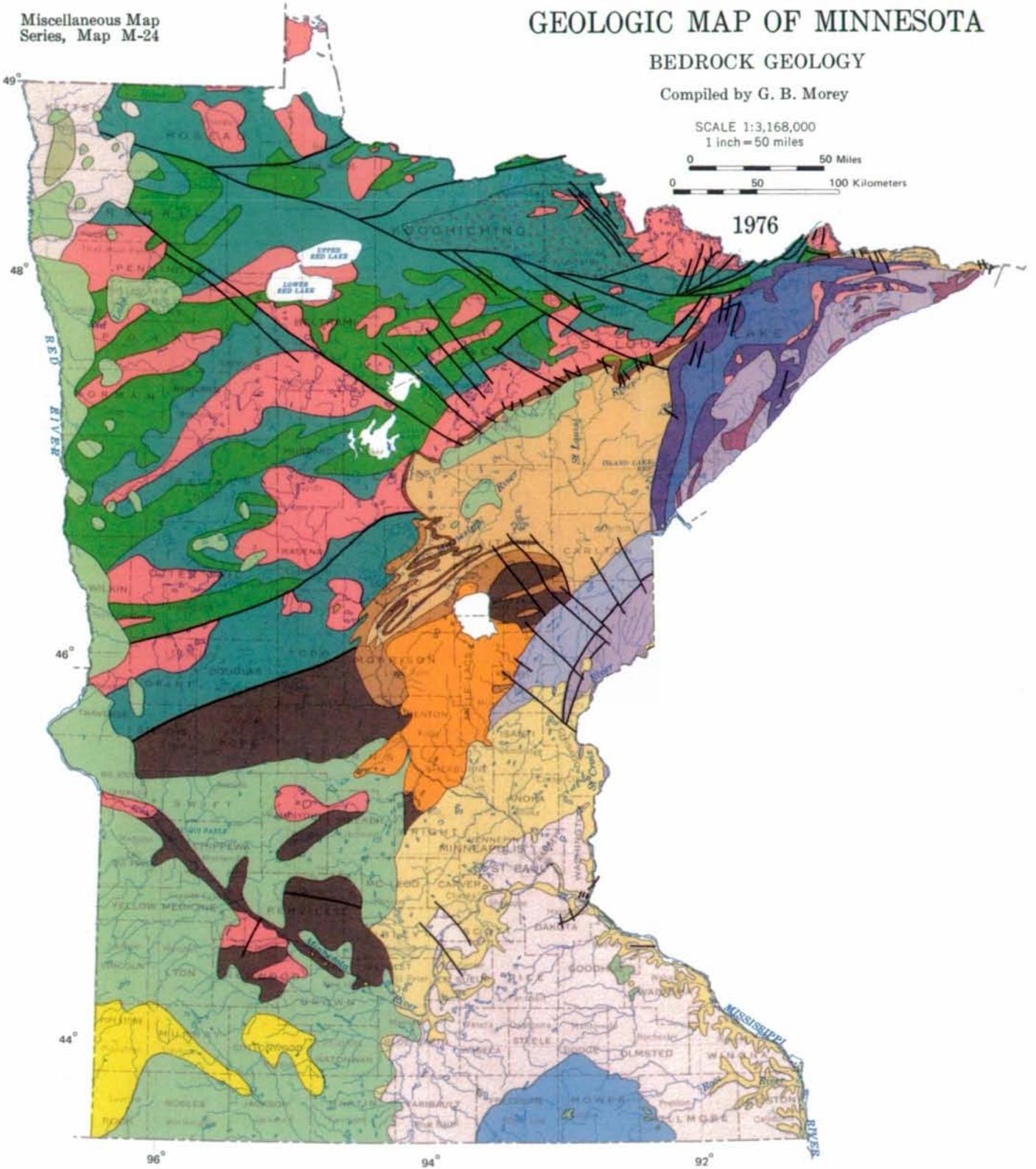
BEDROCK GEOLOGY

Compiled by G. B. Morey

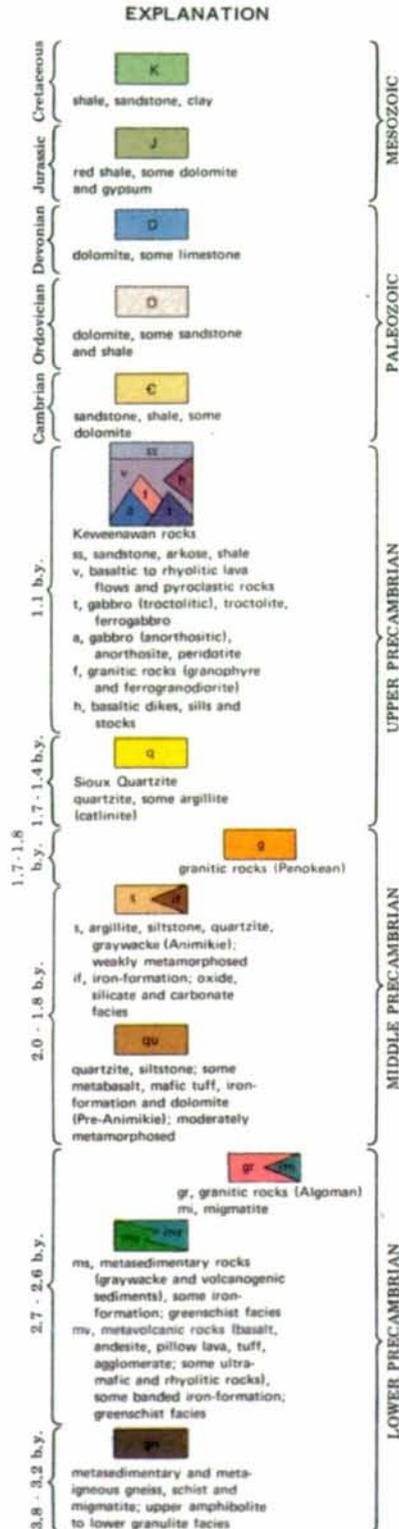
SCALE 1:3,168,000
1 inch = 50 miles



1976



The 1976 and 1982 Maps of G.B. Morey and Others



The 1976 bedrock geologic map was compiled by G.B. Morey at a scale of 1:3,168,000. Though much smaller in scale, it is essentially the 1970 map with two important modifications. First, the map identified two different Lower Precambrian terranes joined along an east-trending tectonic zone first recognized in 1973. Subsequent radiometric investigations by Goldich and colleagues found that the southern terrane consisted mainly of rocks with a long and complex history, with important events at 3,600, 3,000, 2,600, and 1,800 million years ago. In contrast, the terrane north of the tectonic zone, formed about 2,650 million years ago, was little affected by subsequent events. The two terranes were called the gneiss terrane and the greenstone-granite terrane. As defined, the greenstone-granite contains components typical of much of the Superior province of the Canadian Shield.

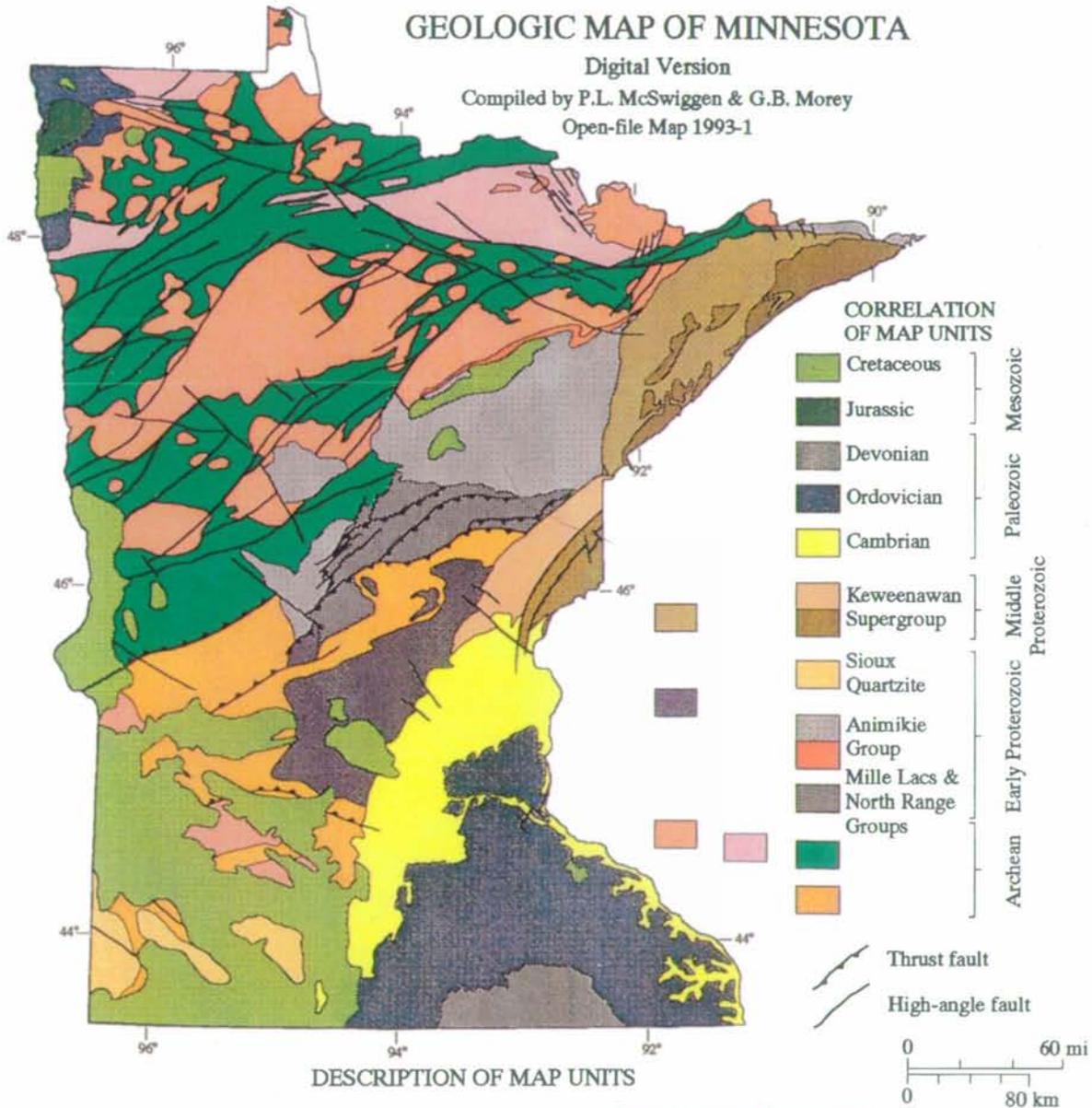
Secondly, the 1976 map reflects new mapping in east-central Minnesota, especially outside the immediate area of the Cuyuna Range, where subsurface data were made available to the general public by the iron-mining industry in the early 1970s.

A 1982 map of the Lake Superior region at a scale of 1:1,000,000 includes a compilation of the state by G.B. Morey and D.L. Southwick. That map, a revised version of the 1976 map, contains little new information. The explanatory materials, however, reflect the abandonment in the late 1970s of Goldich and Nier's Early, Middle, and Late Precambrian nomenclature for pre-Cambrian time, and its subdivision into the Archean and Proterozoic Eons. By international convention, the Archean-Proterozoic boundary is placed at 2,500 million years ago, the same time suggested by Goldich and Nier for their Early-Middle Precambrian boundary. ♦

GEOLOGIC MAP OF MINNESOTA

Digital Version

Compiled by P.L. McSwiggen & G.B. Morey
Open-file Map 1993-1



DESCRIPTION OF MAP UNITS

- | | |
|---|---|
|  Mudstone, siltstone, lesser sandstone. |  Intrusive rocks of dominantly granitic composition. |
|  Red shale. |  Graywacke, siltstone, shale. |
|  Limestone and dolostone. |  Iron-formation with a basal quartz arenite. |
|  Limestone, dolostone, lesser sandstone and shale. |  Quartz arenite, siltstone intercalated with mafic volcanic rocks, carbonaceous shale, and iron-formation. |
|  Sandstone, shale, lesser carbonate. |  Intrusive rocks of dominantly tonalitic to quartz monzonitic composition. |
|  Shale and arkosic sandstone overlain by quartz arenite. |  Schist- and granite-rich migmatite. |
|  Extrusive rocks of dominantly mafic composition. |  Extrusive rocks of mafic to felsic composition, associated volcanogenic rocks and derivative graywacke. |
|  Intrusive rocks of dominantly mafic composition. |  Quartzofeldspathic gneiss, amphibolite and other high-grade metamorphic rocks. |
|  Quartz arenite. | |



Aeromagnetic Shaded-Relief Image

limited results, mainly because water wells are only coincidentally sited at geologically critical locations. Therefore, he started a program of low-level, high-resolution aeromagnetic mapping to cover the entire state. The program, supported throughout its history by funding recommended by the Legislative Commission on Minnesota Resources, is complete. The data were acquired in digital form and have been issued by the National Geophysical Data Center on CD-ROM—the first aeromagnetic CD ever issued. More importantly, the digital nature of the database makes it possible to easily produce a variety of images such as the shaded relief image shown. Although the geophysical database is only a few years old, geologists using and thinking about the data already have come up with many new ideas and interpretations, as can be seen by comparing the 1976 and 1992 maps. The process of converting geophysical data into geologic maps will continue well into the twenty-first century.

The 1992 map illustrates another new trend in geologic mapping in Minnesota—the use of digital mapping techniques in cartographic design. This methodology will make it much easier to revise maps in the future, when new

The 1976 and 1982 maps took the drilling data and information from the geophysical maps of the 1960s as far as they could go. Therefore, the Minnesota Geological Survey, under Matt S. Walton, set out to collect from throughout the state water well and drilling records and, where possible, cutting samples from engineering test borings and mineral exploration holes. The program now has a database of more than 300,000 logs. Walton knew that this database could produce only

data and new ideas become available. The new methodologies also will make it much easier to integrate geologic and other kinds of map images using geographic information system (GIS) techniques. However, from the hand-colored maps of the nineteenth century to contemporary maps displayed on color computer monitors using GIS, the fundamental principle remains the same: It is the quality of the geologic interpretation that determines a map's value. ♦

A geologic map reflects the level of knowledge at the time of its production, and subsequent knowledge eventually leads to the obsolescence of any geologic map, no matter how good that map was originally. Yet even obsolete geologic maps are important as references. As such, they must be preserved because they are the means by which geologists of one generation communicate with those of another generation. Geologic maps also provide the basis for future research, in that they can be used to test new ideas. When a map fails a particular test, that failure sets the direction of new research.

The generation of new maps is dependent on the generation of new ideas and data. Generation of the former comes easily, but new data are particularly hard to come by in Minnesota, where thick glacial deposits and heavy vegetation cover the rocks. It is time-consuming to find the outcrops and collect the observations needed to read the story contained in the rocks. Thus it is not surprising that early interpretations tended to be simple and that later studies led to a more comprehensive history.

The practical value of a statewide geologic map is less tangible than its intellectual content, though the map can and should be an important tool for the resourceful user. For example, a geologic map can help identify areas where mineral deposits might be found. For the explorer, geologic maps give clues as to where to begin to search. Though a map will not pinpoint the location of the next mine or tell where to locate a dam, waste-disposal facility, or groundwater well field (for these one needs maps of much larger scale, designed for specific purposes), a statewide geologic map can be a useful planning document, especially when consulted along with maps showing other features such as topography, vegetation, climate, and land use. ♦

0P1993

Cover Illustration: Detail from Bedrock Geologic Map of
Northeastern Itasca County, Minnesota, 1990, by Mark A. Jirsa

