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OUR LAND AND MINERAL RESOURCES

a long-range plan for geologic research in Minnesota

MINNESOTA GEOLOGICAL SURVEY
UNIVERSITY OF MINNESOTA
Minneapolis, 1965

Copies of this report can be obtained upon
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SUMMARY

The geological research by the Minnesota Geological Survey has three major objectives:

(1) The discovery and appraisal of mineral resources within the State, to aid in maintaining the supply of raw materials for existing mineral industry and to encourage development of new or potential resources by new industry.

(2) To provide the geologic background needed for highway construction, urban development, and land-use planning.

(3) To develop the educational aspects of the geology of the State, for use in public education and recreation.

Increased effort toward these objectives is made urgent by a growing population and need for an expanded and diversified mineral industry.

To meet the challenges of the future, substantial increases are required in both budget and staff. In past years, support has been far below the minimum consonant with the State's needs. This is evident from one statistic alone--less than six ten-thousandths of one percent of the taxes levied on the iron ores of the State has been reinvested in geologic research.

Geologic mapping

Geologic mapping has lagged in Minnesota, and is needed to provide a basic foundation for geologic research on mineral and water resources and use of the land for countless purposes; information gained by geologic mapping assists in attracting new mineral industries. Currently about one percent of the State is adequately mapped and an area of equal size is in progress. The plan calls for a marked speed-up in geologic mapping. The goal is to complete, in 10 years, geologic map atlases of the bedrock and surficial materials in the State at a scale of 4 miles to the inch (1:250,000); and to begin detailed mapping of specific areas that are critical to evaluation of resource potential and to urban development, using the standard 7 1/2- or 15-minute quadrangle topographic maps as bases. The detailed mapping would be done in part on a 50-50 cost basis with the Geologic Division of the United States Geological Survey.

Geophysical studies

Minnesota is largely covered with glacial materials, and geophysical methods are useful in determining the geology of the bedrock and are an aid in searching for mineral deposits. About 85 percent of the State has been

flown with the airborne magnetometer. The goal is to complete aeromagnetic surveying of the State within two years. In addition, gravity and other geophysical methods will be used to a greater extent than previously to aid in the solution of geologic and economic problems.

Geochemical studies

Two types of geochemical research are planned: (1) geochemical prospecting, a technique known to be useful in locating concentrations of metals and (2) isotope studies, with emphasis on determining the ages of the State's rocks.

Mineral resources research

The need to expand the amount and kinds of mineral commodities produced in the State is given a high priority in the long-range plan. Plans call for continued geologic mapping and research on the iron deposits of the State and for increased attention, not only to possibilities of other metallic deposits in the State, but to nonmetallic resources in general. As a part of the studies, increased efforts will be given to the collection of basic data on the State's mineral resources for the use of government, industry, and private citizens alike. By this means, the Survey can serve as an effective clearing house in the State for information on our mineral resources.

Water resources research

The Survey plans to increase its studies on the geologic occurrence of underground water and to begin a modest program of research on hydrologic principles and the application of this knowledge to the solution of problems vital to ground-water supply and to policy making. The research will be coordinated with programs of the Minnesota Department of Conservation, Division of Waters, and the United States Geological Survey, Ground Water Division.

Engineering and urban geology

The plan calls for an acceleration of engineering geologic studies and compilation of data that are needed to provide information basic to land-use planning and highway and building construction in the major urban areas of the State. These studies require detailed geologic mapping of standard 7 1/2- and 15-minute quadrangles and collection of preliminary engineering data. Current studies in the Minneapolis-St. Paul metropolitan area will

be accelerated; future plans call for studies at Duluth and other cities.

Public education

The Geological Survey considers public education as a major responsibility. There is a need for interpreting the geology of the State in understandable terms for use in secondary schools, for recreational purposes, and for tourism. Plans call for the preparation of pamphlets and guidebooks on the geology and scenery of the State and for preparation of study materials for schools.

Publications

The Survey has increased the number and types of publications describing the results of its research, to better meet the necessity in the State for geologic and resource data. The number of reports and maps is expected to increase substantially during the next decade. Maps and publications are sold to the public at nominal prices, and proceeds are used to help defray costs.

Staff and budget needs

It is proposed that the increases needed in staff and budget to accomplish the goals outlined in this long-range plan be met in part from current sources of legislative funds and in part from funds made available through the Omnibus Natural Resources and Recreation Act of 1963. An annual budget of $150,000 in 1964 dollars is a minimum level for effective operation of the regular Survey program. Support of the proposed "catch-up" geologic mapping program is being requested mainly from funds provided under the Omnibus Natural Resources Act. About $130,000 annually for a 10-year period is requested in this program; a breakdown of the request is given herein and in recently issued Report No. 7 of the Minnesota Outdoor Recreation Resources Commission.

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INTRODUCTION

Minnesota's position as a leading state has been built on its natural resources. Through the fortunate combination of abundant water, productive soils, and vast mineral resources, the State has grown steadily in strength and wealth, and has contributed materially to the welfare of the Nation. The future presents new and greater challenges and opportunities. The rapid growth of population and industrialization will require ever increasing quantities of natural resources and more efficient use of the land.

Minnesota has taken the lead among the states in planning for the future. A major far-sighted step was the enactment of the Omnibus Natural Resources and Recreation Act of 1963. This together with other programs for natural resource studies will contribute to wise use of the State's natural resources for the future economic growth and social welfare of the people.

The Minnesota Geological Survey is one of the State organizations that has a basic responsibility in the development and utilization of our natural resources. Its chief role is to determine the distribution and quality of the State's mineral resources and to develop, by means of mapping and other studies, a comprehensive knowledge of the geology of the State. Knowledge of the surficial materials and of the rock strata beneath the surface are essential for evaluating our water resources and are an aid in the solution of the growing problems of urban development and industrial and highway construction.

In order to meet the tasks that lie ahead and to contribute toward the overall objectives of the State, the Minnesota Geological Survey plans to accelerate present studies and to initiate new ones. In part, increases are needed to fill the wide gaps in our knowledge caused by a lag in geologic research over past decades. The very fact that Minnesota has been richly endowed with a single major mineral resource--iron--has perhaps obscured the need for a broader program of geologic investigations. Now, more than ever before, new mineral products are needed to enhance the mineral economy and to broaden the tax base. New data are needed on the geologic occurrence of ground water to assure wise management of this essential resource. Accurate geologic and topographic maps are needed for the more efficient use of the land for a variety of purposes, such as agriculture, forestry, and recreation. Other applications of geology are as limitless as imagination or knowledge itself, so future uses will include many applications not yet even imagined.

MINNESOTA GEOLOGICAL SURVEY

HISTORY AND OBJECTIVES

The need for a geological survey in Minnesota was recognized in the mid-1800's, but it was not until 1872 that the Geological and Natural History Survey of Minnesota was formally established by an act of the Legislature. In 1911, the title was changed to Minnesota Geological Survey. Administration was placed under the Board of Regents of the University of Minnesota, where it still remains. */

Appropriately, the early work of the Geological Survey was concentrated on geologic studies of the iron deposits in the State. Maps were prepared of the main iron ranges and research was carried out that directly aided the mining companies in developing what was to become the backbone of this Nation's iron and steel industry. Studies of the iron ranges have since been carried on nearly continuously, with emphasis gradually changing from research on the natural ores to research on taconite. The important research by Survey geologists J. W. Gruner, F. F. Grout, and T. M. Broderick between World Wars I and II indicated the extent and nature of the taconite on the Mesabi range, and its potential as a future source of iron ore. Later research by David White, J. N. Gundersen, and G. M. Schwartz aided in problems related to the mining and concentration of taconite.

Geologic mapping and research on other aspects of the geology and mineral resources of the State have been carried on as staff and budget permitted. The work has contributed to knowledge of our mineral resources, to the development and conservation of our water resources and, through the application of geology to engineering problems, to the economical use of our land. Noteworthy among these studies are the reports published on the geology of Minneapolis-St. Paul and Duluth metropolitan areas, by G. M. Schwartz, and on the geology and underground waters of southern and northeastern Minnesota, by G. A. Thiel.

The growth in population and the need for an expanded mineral economy have emphasized the necessity for a broader and more intensive program of geologic research in the State. Greatly increased attention needs to be given to both metallic and nonmetallic mineral resources, to the geologic occurrence of our underground waters, and to problems related to urban growth

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*/ For a full account of the history, the reader is referred to a report by G. M. Schwartz, entitled History of the Minnesota Geological Survey, published as Special Report 1, 1964. Available upon request to the Minnesota Geological Survey.

and engineering works. Plans to accomplish these objectives are outlined in the pages that follow. In general, the plans outline a proposed course rather than a rigid plan of action. A few phases can be planned for orderly progress, but others are not susceptible to a definite schedule of action.

RESPONSIBILITY AND RELATIONS TO OTHER ORGANIZATIONS

The Minnesota Geological Survey has the responsibility for conducting investigations of the geology of Minnesota. It carries out this responsibility by geologic mapping and research on the occurrence, quality, and usefulness of our mineral resources; results of the research are published or are made available for examination in the Survey headquarters.

The Survey works closely with the Mines Experiment Station, the Limnological Research Center, and the Water Resources Research Center of the University of Minnesota. Current projects are being done cooperatively with both the Mines Experiment Station and the Limnological Research Center; a cooperative project is planned with the Water Resources Research Center.

The research of the Geological Survey is planned and conducted to provide State agencies with basic data needed to administer programs in water and mineral resources. For example, in planning geologic mapping consideration is given to the needs of the Conservation Department's Division of Waters for maps in areas of potentially critical water supply; also, resource data obtained by the Survey are utilized by the Conservation Department's Division of Lands and Minerals in administering State lands.

GEOLOGIC MAPPING

Geologic maps are the basic element in development of natural resources. They are required for the efficient use of the land, and are needed in the State to fully evaluate the mineral and water resource potential, to sustain intelligent mineral exploration, to attract new industries, to provide data necessary for engineering purposes, and to assist in long-range planning for our recreational resources.

Currently, the Geological Survey's program of geologic mapping consists mainly of detailed mapping at scales of one mile per inch or larger, but includes some regional mapping and map compilation at a scale of 4 miles per inch. Plans call for an accelerated program of detailed mapping and for the completion by the year 1975 of State geologic map atlases both

of the bedrock surface and of the overlying surficial deposits.

The program of geologic mapping outlined below is timely because of the availability of modern standard 7 1/2-minute and 15-minute topographic maps for about 50 percent of the State (fig. 1). Systematic topographic mapping has progressed satisfactorily in Minnesota since 1949, when cooperative topographic mapping programs were initiated with the United States Geological Survey, but must be continued.

A substantial part of the proposed program of geologic mapping that follows is described in Report Number 7 of the Minnesota Outdoor Recreation Resources Commission, issued in December, 1964. The same report also contains the long-range program of topographic mapping recommended by the Commission.

Types and Scales

A geologic map depicts, commonly by means of colors or patterns and symbols, the distribution and attitudes of different kinds of rocks within a specific area. Lines on the map are used to delineate separate rock units.

The common geologic map shows the character and distribution of the solid rock within the area of the map. This type of map is a bedrock geologic map. In Minnesota, as well as in other glaciated areas, a second type of map also is useful--a surficial geologic map; this type indicates the distribution of the various unconsolidated materials that overlie the solid rocks.

A geologic map does not encompass by itself all that is known, or all that needs to be known, about the geology of an area. Geologic sections that provide a three-dimensional picture of the rock strata below the earth's surface--needed for the solution of many economic and scientific problems--can be constructed from geologic maps and from observations made during mapping. Also, knowledge of the physical and chemical properties of the rocks themselves is gained through the field observations and laboratory studies.

Geologic maps may be prepared at different scales, depending on the one hand on the complexity of the geology, accessibility, and number of rock exposures, and on the other hand on the specific needs for geologic data. In this country the principal scales of geologic mapping are 1 mile per inch (1:62,500) or 2,000 feet per inch (1:24,000). These are at the

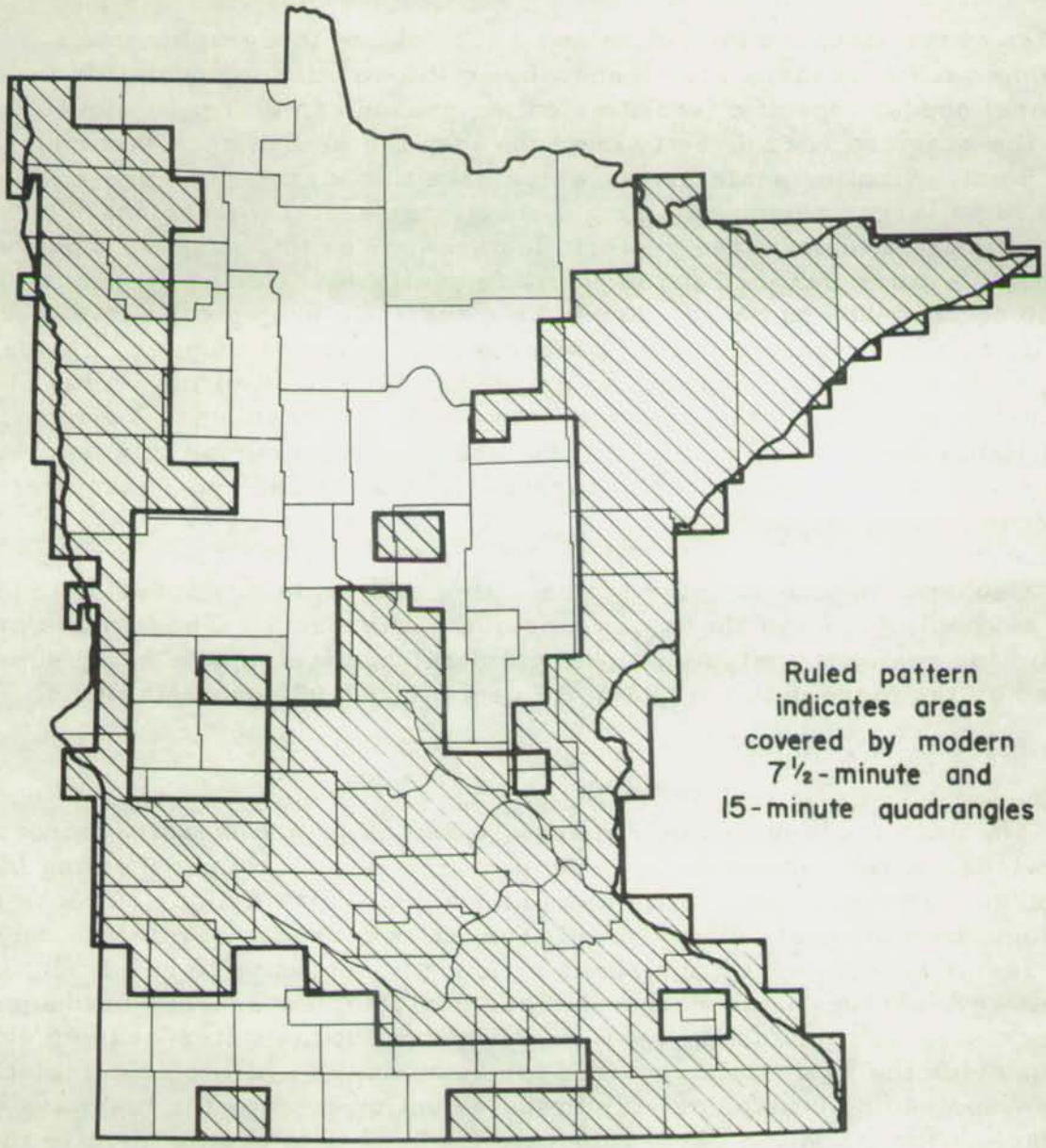

FIGURE 1. Status of topographic mapping

scales of the standard 15-minute and 7 1/2-minute topographic maps. Geologic maps at these scales show basic information adequate for most general needs. Specific localities on the ground can be readily located, and the user can read directly from the map the kind of rock that underlies any point. Smaller scale maps, which have the advantage of presenting data for a larger region on a single sheet, are useful for regional planning and interpretation of large geologic features. For this purpose topographic maps at 4 miles per inch (1:250,000) are available. Geologic mapping at a scale of 1:250,000 has been adopted by many state geological surveys and the U. S. Geological Survey as a standard for regional mapping. Maps at this scale have been compiled for more than 12 percent of the United States exclusive of Alaska. The states of New York, Pennsylvania, Vermont, New Hampshire, New Jersey, and Indiana have been completely mapped at this scale, and the states of California, Nevada, Utah, and Texas are currently being mapped.

Geologic maps that cover entire states at a scale of 1:500,000 or larger are available for 40 of the states, including Minnesota. These maps are useful for regional analysis of geologic data, but are rapidly being superseded by the more detailed and more useful 1:250,000 geologic maps.

Uses

The uses made of geologic maps are extensive and steadily increasing. Knowledge of the geology of any specific area is basic to prospecting for mineral resources. It is little use to know that certain kinds of rocks or geologic environments are favorable for the occurrence of mineral deposits unless one knows where such rocks or environments are to be found. In the same way, geology is needed to find and evaluate new sources of underground water. Geologic and geophysical mapping can outline water-bearing strata and provide the basic data required for quantitative hydrologic calculations. Likewise, geologic mapping aids in the selection of sites for highways, bridges, dams, and the like. Adequate geologic data can materially reduce the cost of foundation testing needed prior to the final design and construction of virtually any heavy engineering structure. Within the agricultural areas of the State, geologic maps aid in preparing soils maps. Detailed data on the geologic parent materials, which can be obtained from geologic maps, is basic to soils mapping.

Status

Geologic mapping has lagged in Minnesota since the turn of the century, and most existing maps are inadequate for modern day needs.

OUR LAND AND MINERAL RESOURCES

Detailed geologic maps, prepared at scales of 1 mile per inch or larger, are available for only about one percent of the State (see fig. 2). Geologic mapping by the Minnesota Geological Survey now is in progress in an area of approximately equal size. Maps prepared prior to World War II are inadequate for modern needs, either because they were not plotted on accurate topographic base maps or because of new knowledge and techniques.

By comparison with other states, Minnesota ranks near the bottom with respect to geologic map coverage. A recent compilation of maps in the Public Realm of the United States, published in the April 1963 issue of The State Geologists Journal, indicates that 9 states in the Union are more than 60 percent mapped and an additional 9 states are more than 30 percent mapped at a scale of one inch to the mile or larger. The geology of one state, West Virginia, is completely mapped. The state of Kentucky recently undertook the tremendous job of mapping the entire state geologically in a 10-year period; this is being done in cooperation with the United States Geological Survey.

The current state geologic map of Minnesota (scale: 1,500,000, or about 8 miles per inch) was published in 1932 and is out of date. Much new geologic information has been accumulated since its compilation, particularly in conjunction with the airborne magnetometer surveys completed in the State since 1947. Other areas for which adequate data are lacking will require geologic reconnaissance surveys.

Current Program

The Geological Survey's program of geologic mapping consists mainly of detailed mapping at scales of one mile per inch or larger. Five detailed quadrangle mapping projects are currently underway in the State (fig. 2); the total effort is at a rate of about 12 man-months annually.

The regional mapping program at a scale of 4 miles per inch is the first step toward completing state-wide map coverage at this scale. The St. Paul and Mason City sheets, in southeastern Minnesota, have been completed, and reconnaissance has started in the Stillwater and Hibbing sheets (see figure 3). The current rate of mapping is about 3 man-months per year.

The mapping is accompanied by paleontological research in a few areas; this is essential to determining the age and correlating fossiliferous strata.

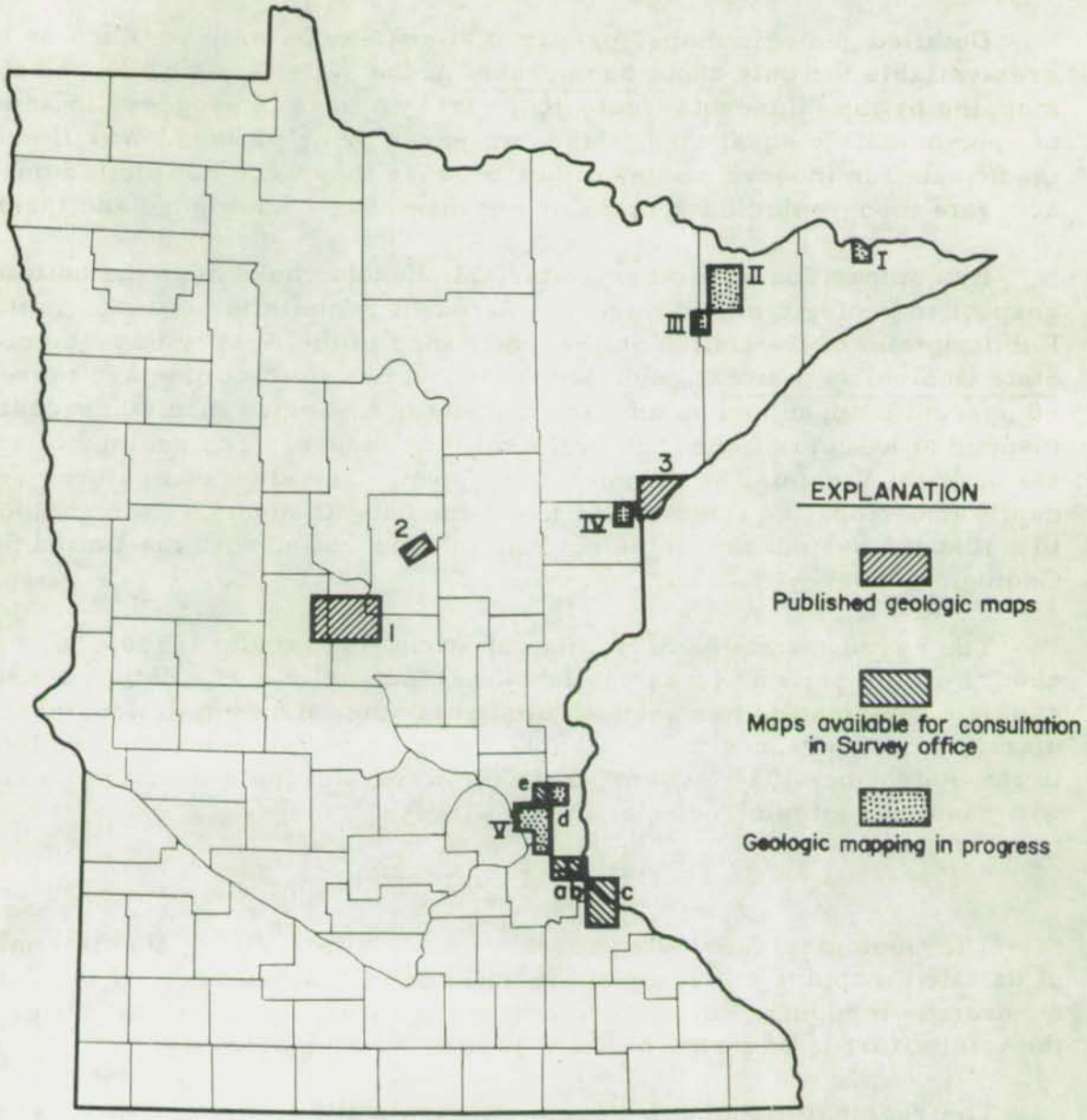

FIGURE 2. Status of geologic quadrangle mapping

OUR LAND AND MINERAL RESOURCES

(KEY TO FIGURE 2)

Published Maps

1. Cushing and Belle Prairie 15-minute quadrangles--surficial geology (MGS Bull. 40)
2. Cuyuna North Range--bedrock geology (USGS Prof. Paper 407)
3. Duluth and adjacent quadrangles--bedrock geology (MGS Bull. 44)

Open-File Maps

a. St. Paul Park quadrangle (bedrock geology)

b. Prescott quadrangle (bedrock geology)

c. Red Wing quadrangle (bedrock geology)

d. Minneapolis-St. Paul and vicinity (bedrock geology)

e. New Brighton quadrangle (surficial geology)

Mapping in Progress

I. South Lake quadrangle (bedrock geology)

II. Gabbro Lake quadrangle (bedrock geology)

III. NE Babbitt quadrangle (bedrock geology)

IV. Cloquet quadrangle (bedrock and surficial geology)

V. White Bear Lake West, Hugo, Centerville, and St. Paul East quadrangles (surficial geology)

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Proposed Program

The Geological Survey plans to increase its efforts severalfold in both detailed geologic mapping (at scales of one mile per inch or larger) and in regional geologic mapping (at a scale of four miles per inch).

It is recognized that detailed mapping of the bedrock at the scale of the standard quadrangle topographic maps is not necessary in all parts of Minnesota. Because of the thick mantle of glacial deposits in many parts, a large part of the western half and a few areas in the eastern half can be adequately mapped for present needs at the scale of four miles to the inch. Certain areas in the State--where the bedrock is at or near the surface--particularly in the northeastern and southeastern parts, however, should be mapped in detail. This mapping will be programmed by target areas; each target area is selected for a particular economic or scientific goal.

Regional Geologic Mapping

Regional geologic mapping at a scale of four miles to the inch is urgently needed to provide the geologic framework necessary for State-wide planning and an inventory of its mineral resources. Maps are needed for both the bedrock geology and the surficial (glacial) deposits. It is planned to combine these maps into atlases to replace the present out-of-date state geologic maps.

The plan for regional mapping is shown in figure 3. Atlases for both the bedrock geology and the surficial deposits will consist of 13 separate sheets, which conform essentially to the published Army Map Service 1:250,000 topographic maps. Individual sheets will be published separately as mapping is completed; they will be bound into atlases when the program is finished.

Detailed Mapping

Geologic mapping of 15-minute (scale: one inch to one mile) and 7 1/2-minute (scale: one inch per 2000 feet) quadrangles is needed in the northeastern and southeastern parts of the State for many purposes.

Northeastern Minnesota

The northeastern part of the State contains our most valuable known mineral deposits, and is a potential source of additional raw materials for

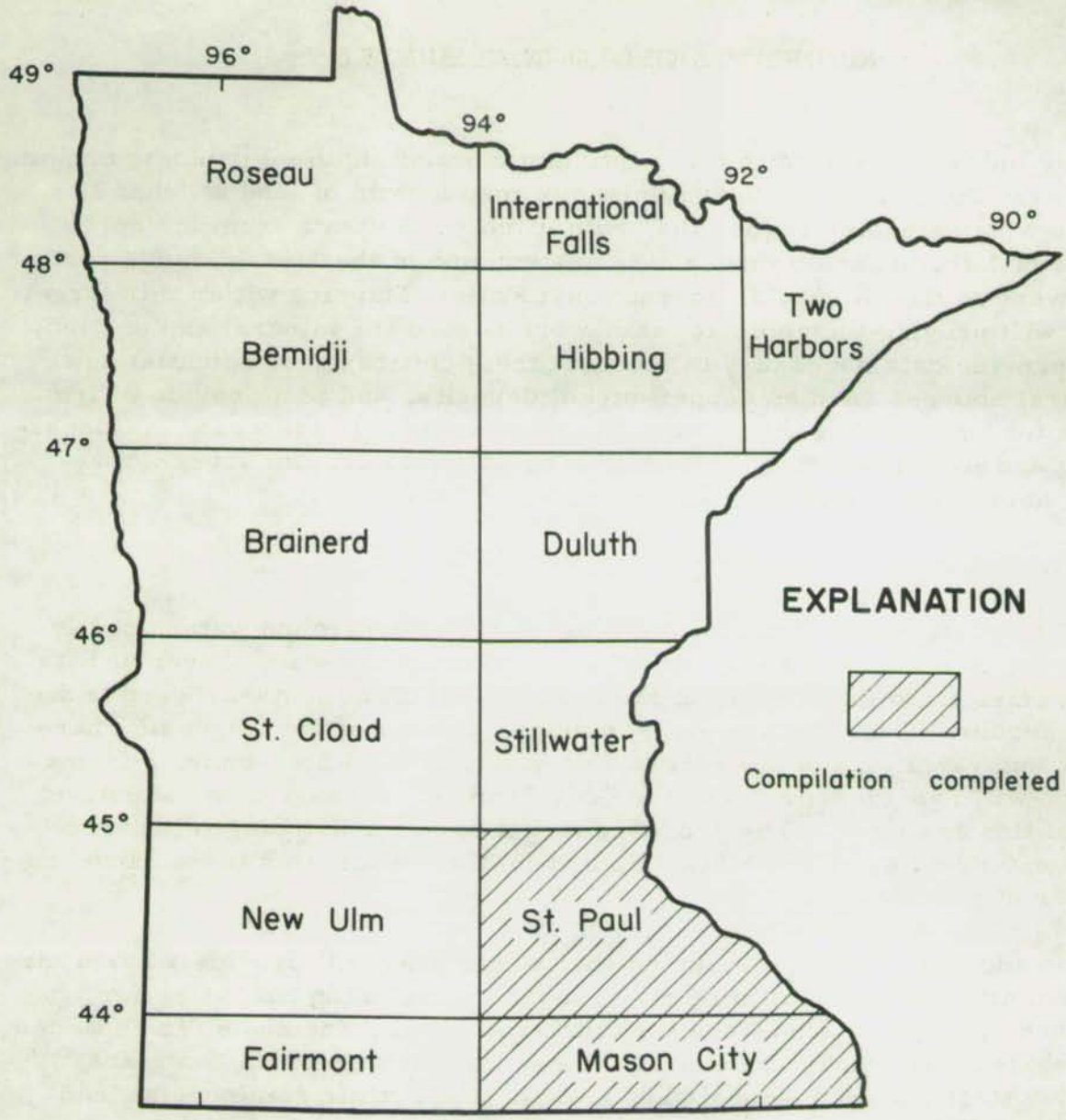

FIGURE 3. Plan for proposed geologic mapping at a scale of 1 : 250,000

use by industry. In addition to continuing current detailed geologic mapping projects, the Geological Survey plans to map a strip of land at least 20 miles wide extending across the grain of the rock strata from the north shore of Lake Superior through the eastern end of the Mesabi range northwestward to the vicinity of International Falls. Mapping within this target area will provide the geologic framework needed for mineral exploration, will provide data necessary to evaluate the significance of potential new mineral sources such as copper-nickel deposits, and will provide a firm basis for interpreting the geology in covered areas to the west, in Koochiching and Itasca counties. The region is known to contain several magnetic anomalies of potential economic significance.

Southeastern Minnesota

Paleozoic rocks, which yield most of the underground water used in the area, are exposed along and adjacent to the Mississippi River and its tributaries from the vicinity of Minneapolis-St. Paul southeastward to the Iowa border. Geologic mapping, including studies of the lithologic character and variations of the rocks--especially of the water-bearing formations--will provide data needed for development, management, and wise use of this resource. The proposed target area for mapping is a narrow strip extending along the Mississippi from the Twin Cities to the southern border of the State.

In addition, geologic mapping within this area will provide a basis for determining the potential mineral resources, including limestone for crushed aggregate, sandstone for industrial silica, and shale for expanded aggregate. The rocks exposed in the southeastern tip of the State are similar to strata in Wisconsin and Illinois that contain commercial lead-zinc deposits.

Minneapolis-St. Paul metropolitan area

Geologic information is essential for long-range planning and economic and efficient use of the land within urban areas. On the one hand, geologic maps provide data on the characteristics of rock and unconsolidated materials that bear on construction engineering, and on the other, they provide information on water resources and sources of construction materials. The Geological Survey plans to accelerate the current program of detailed geologic mapping on 7 1/2-minute quadrangles within the greater metropolitan area. Further details of the program are given in the section on engineering and urban geology.

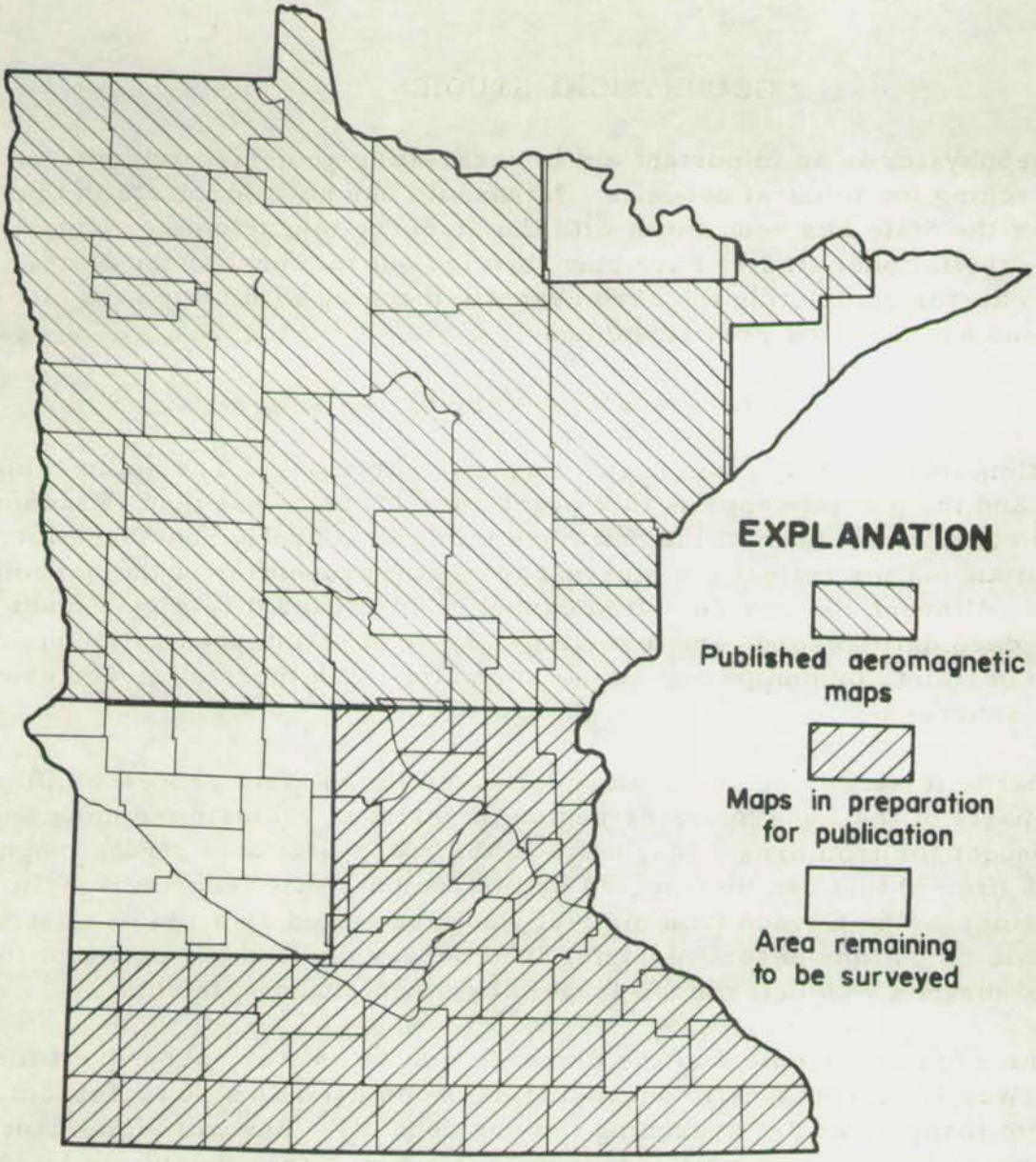

FIGURE 4. Status of aeromagnetic surveying

MINNESOTA GEOLOGICAL SURVEY

GEOPHYSICAL STUDIES

Geophysics is an important aid in unravelling geologic problems and in searching for mineral deposits. Minnesota has been fortunate in that most of the State has been flown with the airborne magnetometer (fig. 4); also, gravitational studies have been carried out in a part of the State. Plans call for completing the aeromagnetic mapping within the next biennium and accelerating gravity studies.

Aeromagnetic Mapping

Minnesota is ideally suited for magnetic surveying. The sedimentary rocks and the glacial deposits that overlie the ancient basement (Precambrian) rocks in so much of the State are thin and virtually nonmagnetic, and the anomalies reflect the inherent magnetic properties of the basement rocks. Although the sources often cannot be identified directly--except where deep drill records are available--they can be inferred with considerable certainty by comparing actual anomalies with those observed above known sources.

Magnetic surveying has been widely used in the State as well as in other parts of the Lake Superior region to assist in geologic mapping and to prospect for iron ores. Magnetite in the rocks produces strong magnetic effects (fig. 5) that can be detected by instruments that record magnetic deflections. The Cuyuna iron district was discovered as a result of strong magnetic variations observed during land surveying, and the extent of the Mesabi district was determined largely by magnetic instruments.

Since the development of the airborne magnetometer, about the time of World War II, aeromagnetic surveying has been used as a powerful tool in geologic mapping and in searching for ore deposits. Several significant ore discoveries have been made by aeromagnetic surveying, notably in Missouri and Pennsylvania.

In Minnesota, aeromagnetic surveying has located several buried magnetic iron-formations; a few of these have been explored by private mining companies. The aeromagnetic surveying in Minnesota has been done by the U. S. Geological Survey, in cooperation with the State of Minnesota, largely as a part of research projects. The published maps are based on traverses spaced at one-mile intervals; the flying altitude has been at either 500 or 1,000 feet above ground level.

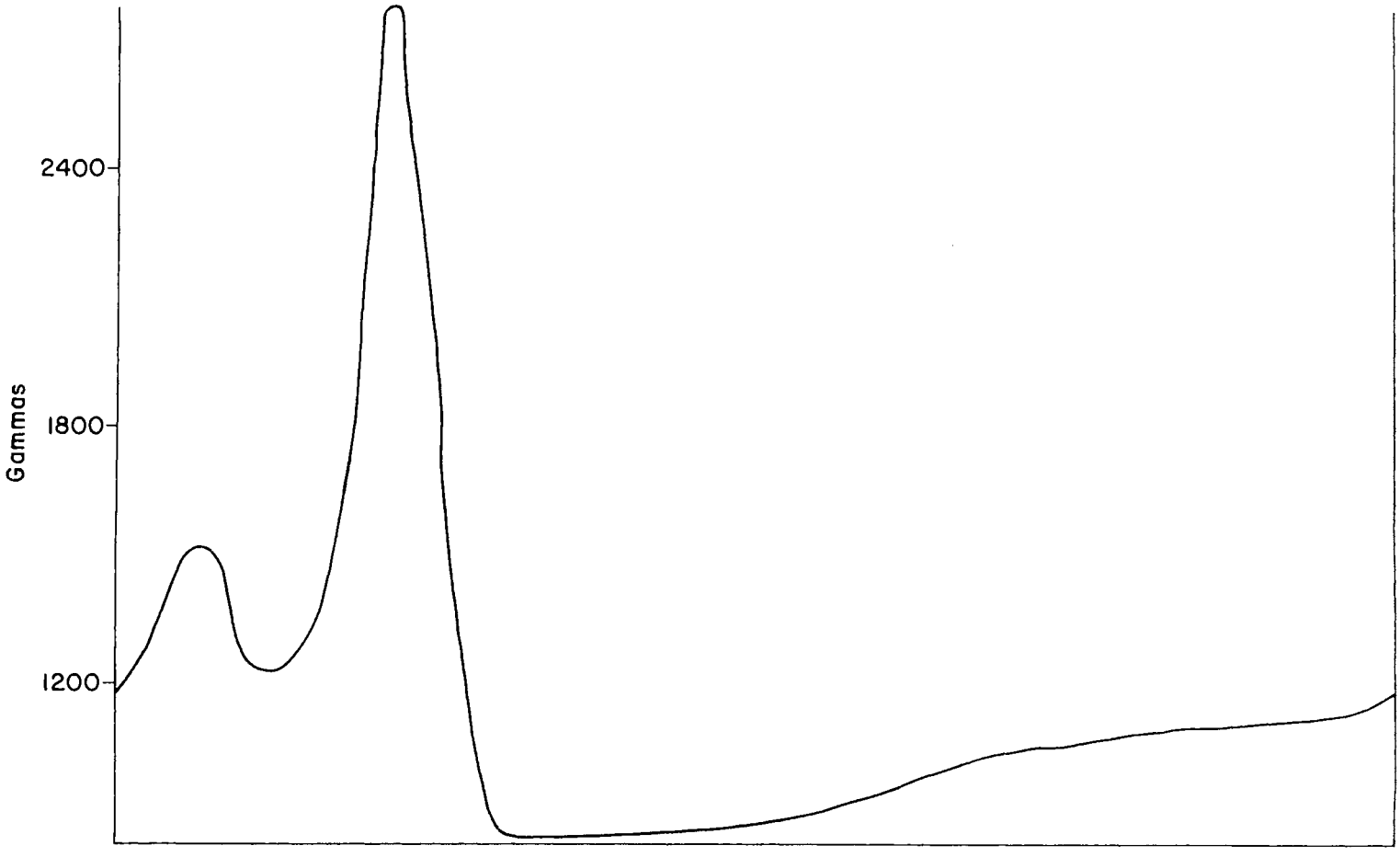

Figure 5—Geologic interpretation of airmagnetic profile.

MINNESOTA GEOLOGICAL SURVEY

About 72,000 square miles, or 85 percent of the State, has been flown with the airborne magnetometer (fig. 4). A substantial proportion of this--about 47,000 square miles, lying north of latitude 46°N.--was surveyed from 1947 to 1955. In 1961, an additional 10,000 square miles in east-central Minnesota was flown; and in 1963, following renewal of the cooperative agreement with the U. S. Geological Survey for aeromagnetic surveying, the area south of latitude 44°30'N., aggregating 17,500 square miles, was flown. Funds for the latter were authorized as a part of the Omnibus Natural Resources and Recreation Act of 1963.

Approximately 12,500 square miles in the State remain to be flown with the airborne magnetometer.

Gravity Studies

Gravity measurements spaced at intervals of 6 to 8 miles have been made in the State by Federal agencies and University personnel. In addition, the eastern part of the State, dominated by the "midcontinent gravity high," and selected areas in central and northeastern Minnesota have been covered by a closely spaced network of stations.

Currently, the Minnesota Geological Survey in cooperation with the Department of Geology and Geophysics is assembling all available gravity measurements as the first stage in compiling a gravity map of Minnesota; also, specific studies are continuing of the "midcontinent gravity high."

Future plans call for increases in the scope and extent of gravity studies. Gravity data in conjunction with magnetic data will be useful in preparing the regional geologic maps and will aid in evaluating potential economic mineral targets.

GEOCHEMICAL STUDIES

Geochemistry ranks with geophysics as an important adjunct to geologic mapping and resource studies. As the more obvious mineral deposits exposed at the surface are discovered and depleted, search must be directed to finding those that are lower in grade or buried beneath surficial materials. In a manner similar to geophysics, geochemistry is a valuable tool in narrowing the target areas. The principal geochemical

studies to date have been geochronology*/ and field geochemistry and petrology. These studies will be continued, and in addition studies are planned in geochemical prospecting, a powerful aid in searching for hidden ore deposits.

Studies of the geochronology of the Precambrian rocks of Minnesota have been carried out during the past decade by S. S. Goldich and, more recently, by P. W. Gast and students of the Department of Geology and Geophysics. The work has been financed largely by grants from the National Science Foundation. The major results of the studies are published in the Survey Bulletin 41, issued in 1961. Current studies employing the use of "atomic clocks" include determining the geochronology of (1) the Precambrian rocks in the Minnesota River valley and (2) the Precambrian igneous rocks in the Giants Range batholith. Continuing efforts in radioactive dating are necessary to meet the steadily increasing demand for additional and more precise rock ages.

A major study of the geochemistry and petrology of the Duluth Gabbro Complex, intended to determine the differentiation history and origin of the silicate rocks and minerals and the ores of the complex, has been underway by W. C. Phinney and graduate students in the Department of Geology and Geophysics since 1961. This research, financed in part by the National Science Foundation, will be accelerated as funds and staff permit. Other significant studies include research on the metamorphism of the taconite in the Biwabik Iron-formation adjacent to the Duluth Gabbro Complex; this research has aided in the solution of problems related to beneficiation of the taconite.

Geochemical prospecting has been used since World War II as a tool in the search for mineral deposits, but the technique has not been widely applied in Minnesota. Often metallic elements are distributed as halos around ore bodies, and determination of the elements in the soil, water, and plants at the surface can lead to the discovery of buried mineral deposits. Such studies are planned in conjunction with geologic mapping and resource investigations in areas believed to contain potential ore deposits.

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*/ Geochronology, a relative new field of earth science, is concerned with the application of the ages of rocks--as determined by measuring the decay of certain radioactive elements--to the interpretation of the geology and geologic processes of an area.

MINNESOTA GEOLOGICAL SURVEY

MINERAL RESOURCES RESEARCH

A state geological survey has a dual responsibility toward a state's mineral resources: (1) mapping and research on the geology and occurrence of the raw materials, to aid in discovery and development, and (2) collection and analysis of resource data, to provide reliable information essential to state planning and policy. The Survey plans to increase efforts in both activities.

Status of Minnesota as a Mineral-Producing State

Minnesota is one of the leading mineral-producing states in the Nation; it has an average annual production of about $500 million (fig. 6). Until recently it ranked consistently among the top 10 states in mineral production, and in 1962 it ranked thirteenth, directly behind Michigan. If the mineral fuels--petroleum, natural gas, and coal--are excluded, Minnesota's output exceeds all other states.

Minnesota owes its position as a leading mineral producer to iron ore. It is the principal iron-ore producing state in the United States, and has shipped more than 2 1/2 billion tons, which would have a present day value in excess of $25 billion dollars. Other mineral raw materials produced in the State are nonmetals, which are becoming increasingly important to the economy annually, and in 1963 accounted for 9 percent of the total mineral value (fig. 7).

Currently, the iron-ore industry of the State is in a transitional period from the mining of the "natural ores," which have been the backbone of the industry, to the mining of taconite, the hard "mother rock" from which the high-grade ores were derived (fig. 8). The reserves of high-grade ores are rapidly being depleted, and the taconite deposits of the Mesabi range are becoming increasingly more important to the State as a raw material for iron and steel making.

Production of nonmetallics comes from a limited number of raw materials known as industrial minerals and rocks. Of these, sand and gravel, dimension stone, and crushed stone are the principal nonmetallic products; clays, industrial silica, abrasive stones, and peat are lesser but significant raw materials. Production of nonmetallics has doubled in the State in the past decade, matching the rate of increase at the national level.

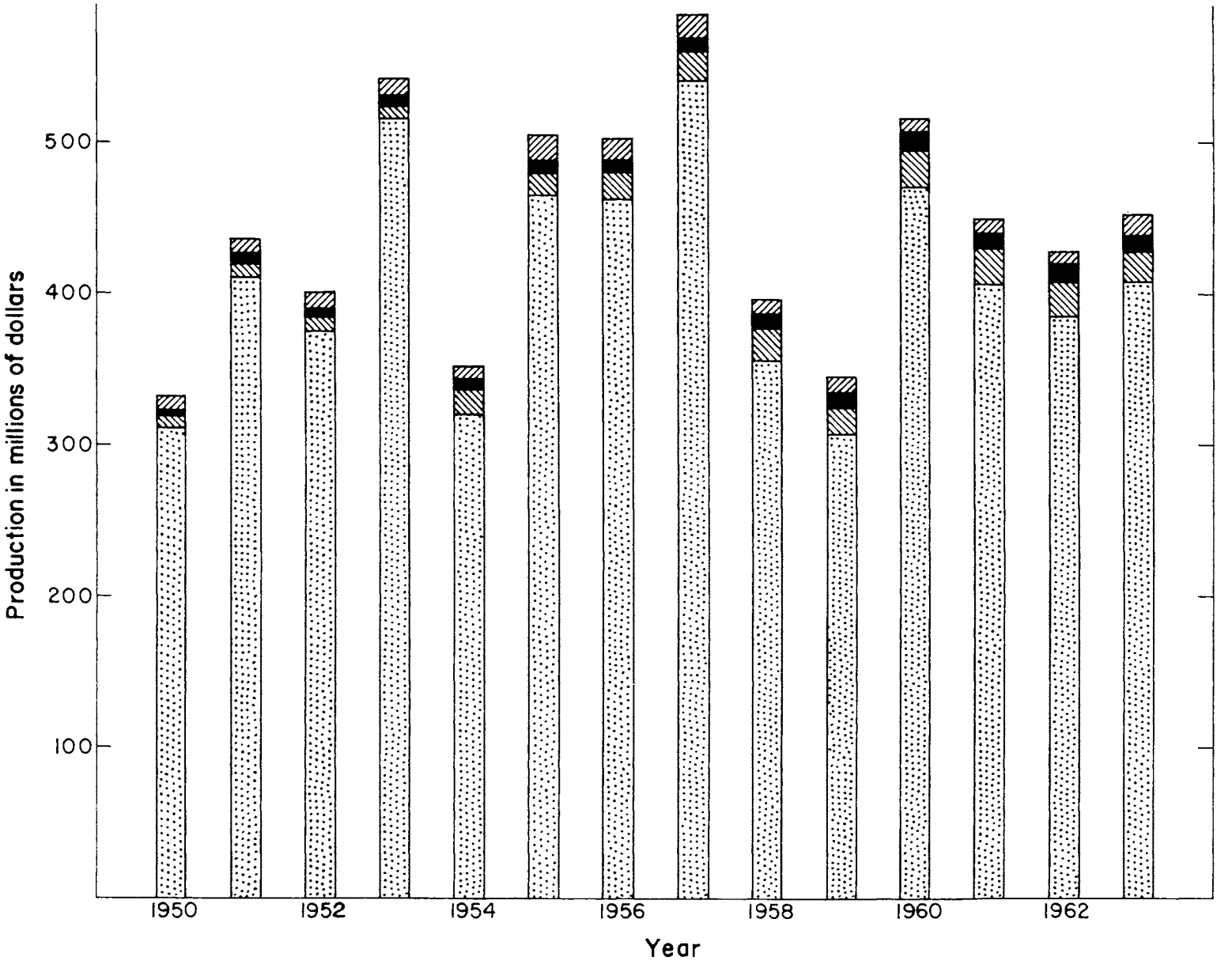

Figure 6 — Value of mineral production in Minnesota, 1950-1963

Iron ore, exclusive of manganiferous ores

Stone, including limestone and granite

Undistributed clay, peat, marl, abrasives, cement, fire clay, gemstones

Sand and gravel

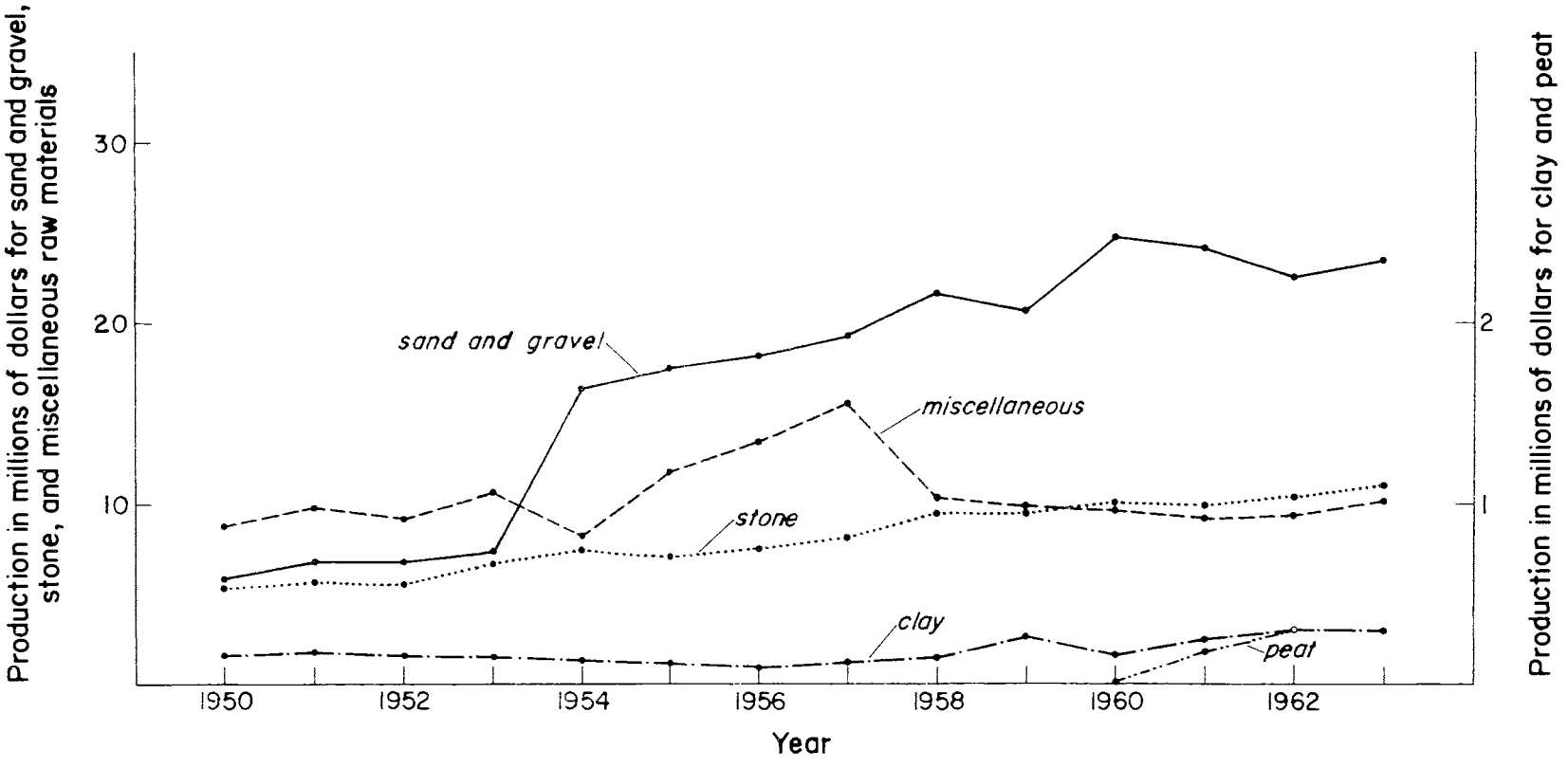

Figure 7—Value of nonmetallic (industrial) mineral production in Minnesota, 1950-1963

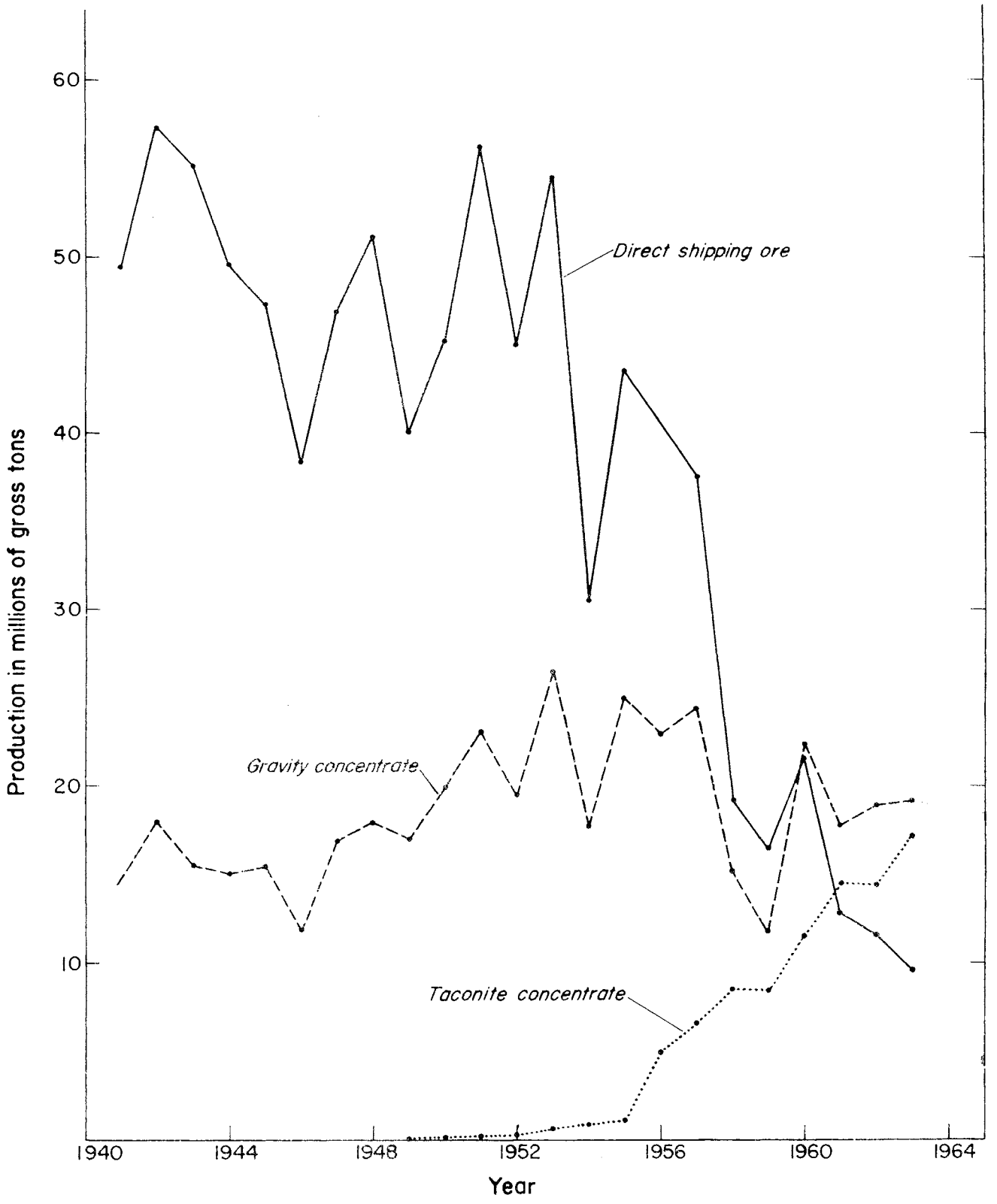

Figure 8—Iron ore shipments, in gross tons, from Minnesota, 1941-1963

The sand and gravel, crushed stone, and clay resources of Minnesota, as in other states, are generally restricted to small geologic areas, and thus the volume to a considerable extent is dependent upon the demand of local markets. However, Minnesota's dimension stone materials for architectural purposes are shipped throughout the World. Other products such as special industrial silica sands and abrasive stones also are competitive in a large market area.

Minnesota lacks deposits of the fuels, coal and oil and gas, and there is little likelihood that they will be found in commercial quantities.

Future Needs

The current unprecedented growth in population, in industrialization, and in economic wealth have led many economists and governmental agencies to forecast that the demands for mineral raw materials at the National level will double over a 10- to 20-year period. Man's demands for ever larger amounts of minerals are continuing on both an absolute basis, and--what is more significant, in view of rising populations--on a per capita basis (figs. 9 and 10).

At the State level, demands for mineral raw materials can be expected to increase in the same way. State population is increasing, urban areas are expanding at the expense of rural areas, and new industries are being developed annually. The demand for industrial minerals and rocks, in particular, for new construction, highways, and other engineering purposes can be expected to accelerate sharply as population and industrialization increases.

It can be expected that the future demands for raw materials will include some now considered worthless. Research continuously develops new uses for previously valueless materials and creates new ways of mining and refining mineral resources that once could not be extracted or treated profitably. An example of the first is uranium. Prior to the discovery of fission and the consequent demand for the element as a source of energy, uranium was in small demand; it was used primarily for the manufacture of radium. From World War II until recently it was the most sought-after metal in the World. Similarly, in this State, taconite was converted from a worthless rock to a valuable ore material by research; it is rapidly becoming the principal ore of iron in this State and in many parts of the World.

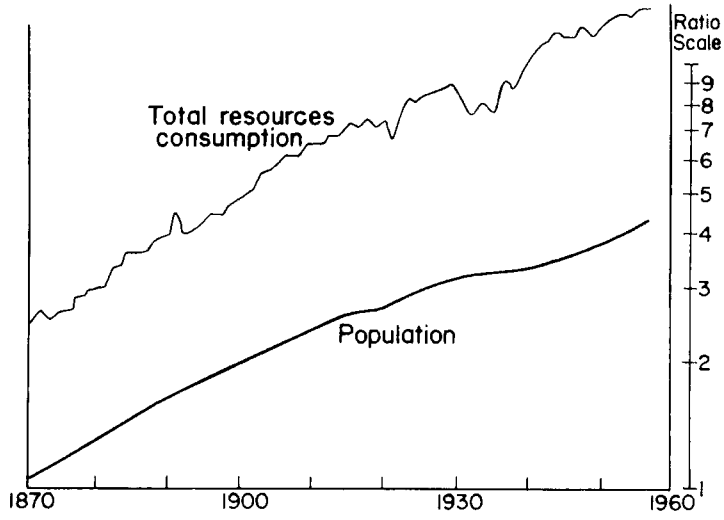

Figure 9—Growth in use of resource materials in the United States.
The growth in use of extractive resource materials has exceeded growth in population in the United States.

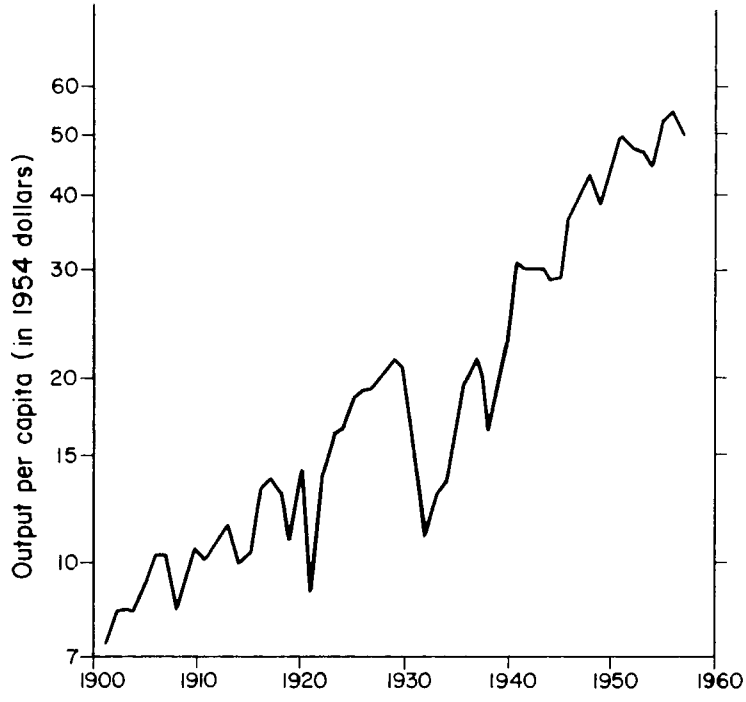

Figure 10—Output of clay per capita in the United States.
Clay is one of the fastest growing extractive industries. For the period 1900–1960, output grew considerably more than population--about twice as fast as the average of all nonmetals.

MINNESOTA GEOLOGICAL SURVEY

Proposed Program

The following general studies are planned in Minnesota to help obtain the minerals needed for future economic growth:

(1) Delineation of areas favorable for the occurrence of additional mineral deposits, through geologic mapping, geophysical and geochemical surveys, and related research.

(2) Field and laboratory research on known deposits, to gain the knowledge essential for efficient mining and the discovery of possible extensions.

(3) Investigation of deposits now considered marginal or submarginal, to gain information on their extent and origin that will aid in future development.

(4) Compilation and analysis of data on minable and potential mineral resources, to provide basic information on the location, extent, quality, and availability of all minerals found in the State.

(5) Acquisition of data on previously little-used minerals and elements that may be needed by future technology.

Metallic Minerals

The geology of Minnesota is favorable for the occurrence of additional metallic mineral deposits other than iron ores. Concentrations of copper- and nickel-bearing minerals are known in northeastern Minnesota, and geologic environments of the type known elsewhere to contain base-metal deposits, especially lead, zinc, and copper, occur locally both in the northeastern and southeastern parts of the State.

Iron Deposits

(a) Because of the major economic importance of the iron deposits of the Mesabi district, studies in the district will be continued at least at the same level as in the past. Emphasis will be given to geologic mapping and research on the taconite deposits.

(b) Geologic mapping in the Vermilion district is needed to determine the gross setting of the iron ores and to assist in unravelling the complex structural and stratigraphic relations in this and adjacent areas.

(c) Geologic and geophysical studies of other known iron deposits and magnetic anomalies are needed to obtain more precise information on the location and quality of potential new sources of iron ores.

(d) The titanium-bearing magnetite deposits within the Duluth Gabbro Complex, Lake and Cook counties, warrant further studies as a potential

long-range source of titanium and iron. They will be studied in conjunction with other metals in the gabbro body.

Other Potential Metallic Mineral Deposits

(a) The concentrations of copper-nickel minerals in the Duluth Gabbro Complex, in Lake and adjacent parts of St. Louis and Cook counties, are a major potential new source of metals. Geologic mapping and studies to determine the geologic setting of the deposits are in progress; future plans call for detailed studies of the mineral deposits, to determine their size, extent, localization, and origin and to assist in evaluating their commercial possibilities.

(b) The occurrences of copper minerals in the Keweenawan lava flows in Pine County are being investigated as a part of regional geologic and geophysical studies of the Keweenawan basin of Minnesota and adjacent states.

Favorable Geological Environments

A major objective of the geologic quadrangle mapping program, outlined in the previous section, is to gain knowledge of the distribution and structure of strata favorable for the occurrence of mineral deposits. A broad area in the vicinity of Lake Vermilion and Soudan is underlain by rocks favorable for the occurrence of base-metal sulfide deposits, and the southeasternmost part of the State contains the same rocks that have lead-zinc deposits in nearby areas of Wisconsin and Illinois.

Nonmetallic (Industrial) Minerals

Minnesota does not have a large number of industrial minerals as compared with some states, but it has ample supplies of many of those essential to construction and the building industries and for soil conditioning. The State can never be self-sufficient with regard to all needed mineral raw materials, but output of known nonmetals can be increased and others not now being used commercially in Minnesota can be developed for future technology. A summary of present information on the nonmetallic mineral deposits of the State and of specific plans for study are listed below.

Sand and Gravel

Sand and gravel essential to highway construction, building, and many

other engineering projects is plentiful in the State, but knowledge is lacking of the locations, quality, and quantity of material available in many specific localities. The regional geologic maps of the State's surficial deposits, discussed in a previous section, will provide information of a general nature on the availability of deposits. More detailed studies are needed in certain areas. The purpose of studies now in progress in the Minneapolis-St. Paul metropolitan area are to determine new potential sources of sand and gravel and to provide information useful for metropolitan planning and zoning. Subsequent studies will be planned to meet local urgent needs within the State for aggregate.

Industrial Silica

Sands for special purposes such as for manufacturing glass, grinding and polishing, sandblasting, oilfield fracturing, engine use, filler, and foundry purposes are obtained from the Paleozoic Jordan and St. Peter formations. Studies of these formations are being carried out on a small scale as a part of the geologic mapping program.

Stone

Dimension and crushed stone are produced from a wide range of rock units within the geologic column. Granites quarried from Precambrian rocks in central Minnesota, near St. Cloud, and in the upper Minnesota River valley, are among the most beautiful dimension stones in the United States and are in demand in a wide variety of sizes, forms, and finishes by architects and builders throughout the World. Studies are planned to attempt to extend the known areal limits of the granites by geologic mapping and photographic and geophysical techniques, and to gather data on the structural relationships, geochemistry, and rock mechanics of the rock bodies.

Dolomite and limestone for dimension and crushed stone and for agricultural liming is quarried from lower Paleozoic rocks in 16 counties in south-central and southeastern Minnesota. Studies are needed, especially by the dimension stone industry, of the structure, stratigraphy, and geochemistry of the carbonate rocks.

Clay and Shale

Minnesota's clay and shale deposits have sustained a small clay-products industry in the State for many decades, but have not been developed

to their maximum extent. Growth in the industry has lagged far behind the national average, as can be seen by comparing figures 7 and 10. A long-range research program is in progress to locate deposits suitable for various products, including brick, tile, pottery, lightweight aggregate, and paper fillers and coatings, with the objective of stimulating new industry. Investigations of this type in some states have aided materially in increasing the output of clays and clay products. In Kansas, as an example, the dollar value of clay and clay products increased six fold in the decade 1950-1959 over the previous decade, concurrently with an accelerated research program on clays by the Kansas Geological Survey.

Limestone for Cement

Most Minnesota carbonate rocks are too high in magnesium for the manufacture of Portland cement, but the Prosser Member of the Galena Formation in southeastern Minnesota is suitable. Investigations are planned to determine the facies, stratigraphy, and geochemistry of the Prosser Member.

Marl

Fresh water marl, a mixture of calcium carbonate, water, and variable amounts of clay, silt, and sand suitable for liming of soils is abundant in many bogs and lakes in central Minnesota. Studies are needed to determine the geochemistry and origin of marl.

Peat

Minnesota is estimated to have some five billion tons (dry basis) of peat, which is about half the United States supply. General knowledge of the location and extent of the deposits is known, but specific information on commercial-grade peats is limited because of the lack of available data on the physical, chemical, hydrological, and botanical characteristics of the peat and on the factors controlling their formation, preservation, and useful properties. The slow rate of growth of the industry has had adverse effects on research efforts. Geologic studies and research are planned to supplement the current investigations in progress by the Iron Range Resources and Rehabilitation Commission and by the University of Minnesota, under Rouse S. Farnham of the Soil Science Department.

Data-Collecting Function

There is an urgent need in the State for reliable data on the State's

mineral resources other than iron. The Geological Survey has much information in its files concerning the mineral resources, but the records are incomplete and inadequate for detailed inventorying and for planning at the State level. Information collected during the course of the geologic mapping and resource studies outlined herein will be compiled and analyzed, and made available to industry, government, and private citizens alike. A primary goal of data-collection will be to publish summary reports on specific mineral commodities or groups of commodities.

The Survey has a small well sample and core library. Selected water well samples have been collected intermittently during past years, but coverage is neither widespread nor completely representative of the State's rock strata. Selected cores, particularly from the iron ranges, have been assembled as a part of special geologic studies. Adequate facilities and staff are needed to increase the collections and to make them available to the people of the State. The facilities would complement those now available at the Fort Snelling headquarters of the United States Bureau of Mines.

WATER RESOURCES RESEARCH

The Geological Survey has taken an active part in the past in investigations of the State's water resources, largely through studies of the geologic occurrence of ground water. Plans call for increases in these studies and for the start of research on hydrologic principles and the application of this knowledge to the solution of problems vital to groundwater supply and to policy making.

Future Water Needs

The ultimate growth of population and industry in the State will depend upon the amount and quality of the available water. Perhaps more than any other factor, the adequacy of a water supply limits growth and expansion of a region.

The demand for water in the future can be expected to increase in all areas of the State, and especially in the Minneapolis-St. Paul metropolitan area. Estimates of water use in the Twin Cities area, made recently by the Minnesota Conservation Department, Division of Waters, indicate that by the year 2000 the daily needs will more than double present-day consumption (fig. 11). This estimate may be conservative, for it is based on a projected population for the metropolitan area of 2.8 million, whereas

more recent estimates[1] are for a population of about 4 million.

It can be expected that the demand for water also will increase sharply for the taconite plants on the Mesabi range. A recent estimate of the potential for taconite plants in Minnesota[2] calls for 12 plants on the range having an annual production capacity of about 90 million tons of pellets. If constructed, the needs for water would be at least 6 times present consumption in taconite processing.

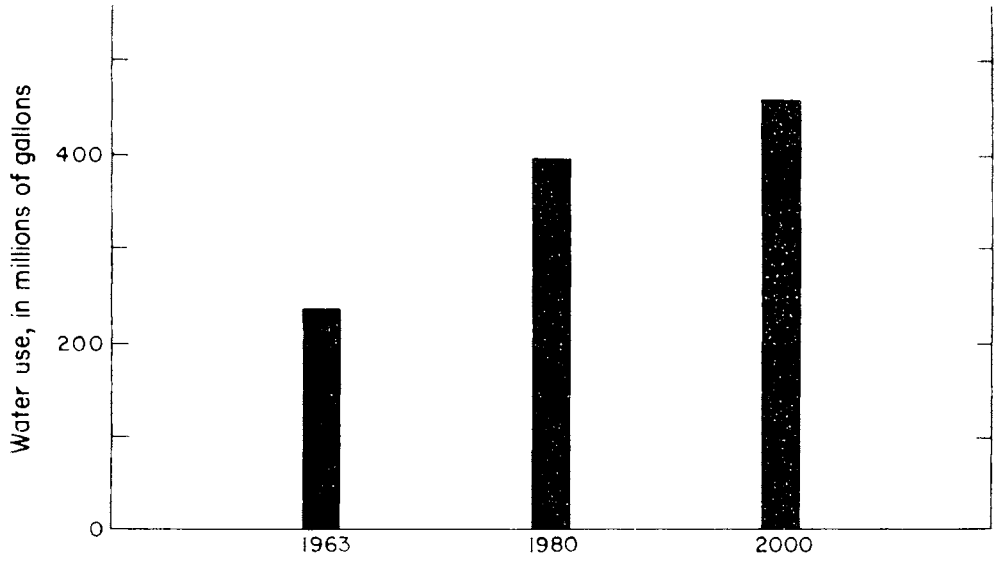

Figure 11 – Present and estimated future daily water needs, Minneapolis-St. Paul metropolitan area.
Source: Bulletin 11, Minnesota Department of Conservation, Division of Waters, August, 1961.

The adequacy of a supply of water to meet the estimated future growth in the Twin Cities metropolitan area is not fully known. A recent study by the Division of Waters of the Minnesota Department of Conservation indicates that the available supplies of ground water and surface water may not

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[1] Anonymous, 1963, New population projection for 1980 and 2000, The Joint Program, an inter-agency land use transportation planning program for the Twin Cities Metropolitan Area

[2] Pfleider, E. P., 1964, Minnesota's taconite potential: Skillings Mining Review, v. 53, no. 39

be adequate for the estimated needs by the year 2000. Much more quantitative data are needed, particularly to determine the ultimate safe yield of ground water. These data can be obtained by quantitative hydrologic studies of the subsurface water-bearing strata.

On the Mesabi range, studies have been underway for several years by the U. S. Geological Survey in cooperation with the State Division of Waters; these studies should be continued if the expected demands for water in this area are to be met.

Proposed Program

The following studies are planned to assist water users and water-policy-makers alike in the State:

(1) Broaden the knowledge of ground-water occurrence through geologic mapping and related research.

(2) Investigate the hydrology of basins and important aquifers in the State, to further understanding of physical and chemical processes pertinent to water problems and to provide data for management decisions in water-resources development.

A major objective of the geologic mapping program, outlined above, is to gain information on the distribution, structure, and potential significance of water-bearing strata throughout the State. These data are essential to both regional and local water studies and provide background information basic to quantitative hydrologic research. Information gained in mapping is particularly useful in locating potential new sources of water supply.

Because of the definite need for reliable data to solve water problems in the Minneapolis-St. Paul area, hydrologic studies in this area are given a high priority. Research is needed on the movement of water in the ground-water systems and on aquifer-recharge. Analog computer models will be utilized in the research. In these studies, the Survey will work closely with the Water Resources Research Center of the University of Minnesota.

ENGINEERING AND URBAN GEOLOGY

A significant part of the Survey's investigations is concerned with the application of geology to land-use and engineering problems, which can be termed environmental research. Increases are planned in the scope and extent of this research, mainly in urban areas where the needs are most urgent.

OUR LAND AND MINERAL RESOURCES

The application of geology in land-use, construction and other engineering activities, and recreational planning is growing steadily as human use of the land is intensified. Knowledge of the rock materials and particularly of their behavior when disturbed is basic to all earth and rock excavations and to many heavy construction projects; in the same way knowledge of potential sources of construction materials is essential to building projects.

The current environmental studies of the Survey are designed to provide information for land-use planning, zoning, and highway and building construction in the greater Twin Cities area. An area of about 1,200 square miles, approximately equivalent to the outline of the metropolitan area designated by the Metropolitan Planning Commission, is being mapped geologically. Plans call for preparation of geologic maps of each of the 24 7 1/2-minute quadrangles of the area, with emphasis on the gathering of preliminary engineering data on each of the geologic units. Currently, about two man-years are devoted to this project annually.

Future plans call for an acceleration of the investigations, in an attempt to complete the studies in a ten-year period. At least two additional personnel are required to complete the investigation within this time limit.

As personnel and funds permit, environmental studies will be extended to other urban areas; high priority will be given to the city of Duluth, and then to the larger cities in southern and western Minnesota.

LABORATORY FACILITIES

The State Survey has standard petrographic laboratory equipment and a sedimentation laboratory. In addition, through association with the Department of Geology and Geophysics, the Survey has access to X-ray powder cameras and diffractometers, chemical laboratories, an X-ray fluorescence analyzer, an electron microscope, an electron microprobe, and various geophysical equipment. A mass spectrometer for low-level isotopic studies on both strontium and lead and oxygen isotope equipment are available in the Department of Geology for special studies. The University's computer is available for various calculations.

The laboratory facilities available to the Survey provide its personnel with modern equipment and instruments required to carry out quantitative and analytical research.

MINNESOTA GEOLOGICAL SURVEY

PUBLIC EDUCATION

It is appropriate that a geological survey consider public education as a major responsibility. This contribution can take many forms such as providing geologic study materials for elementary and high schools; geological field trips; geologic exhibits in museums and fairs; and pamphlets and guidebooks on various aspects of state geology. In addition, there is a need for interpreting the geology of the State in understandable terms for use by tourists, "rock hounds", fossil collectors, and sportsmen.

The wide interest in geology within the State is indicated by the sale of Minnesota's rocks and waters, issued as Survey Bulletin 37 in 1954 and revised in 1963. More than 10,000 copies have been sold, to place the book high on the bestseller list. Also, several short articles on the geology of various State Parks have been written for publication in the Conservation Volunteer.

Another indication of the interest in and necessity for reliable information on the geology and resources of the State is the large number of personal requests received from the citizens, industries, and governmental agencies of the State and from tourists from other states. Requests are increasing substantially each year, and will grow still more rapidly as our fund of knowledge increases.

The Survey plans to increase both the scope and extent of its efforts in public education. Pamphlets are being prepared on the State's rocks and minerals and on the fossils, and others will be prepared in the future. Also, a guidebook on the geology and scenery of the North Shore and on the Tower-Soudan State Park are planned for the near future.

PUBLICATIONS

The results of research by the Geological Survey are made available to the public through various series of book reports and maps. The formal reports are listed below:

Issued by University of Minnesota Press

- Bulletin series
- Geologic Map series

Issued by Minnesota Geological Survey

- Report of Investigations series

Special Publication series
Information Circular series
Summary Report series
Miscellaneous maps and reports

The bulletin series, which was started in 1889, has in the past been the primary publication media for Survey reports. The Geologic Map series was initiated recently as a means of releasing colored geologic maps, which are mainly on standard topographic base maps. The reports issued directly by the Survey provide means to release shorter reports and data of immediate geologic and economic interest.

Reports issued by the University Press and the Geological Survey are furnished to college and university libraries in the State. A complete list of the publications is available upon request from the Survey. The maps and publications are sold to the public at nominal prices, and proceeds are used to defray costs.

ORGANIZATION OF THE GEOLOGICAL SURVEY

The Geological Survey is a research department in the School of Earth Sciences, Institute of Technology. The operations of the Survey are planned and conducted by the Director and his staff. Office and laboratory facilities are in Pillsbury Hall and in Temporary South of Folwell, on the Minneapolis campus.

In its investigations, the Survey has the advantage of association with the faculty and graduate students of the Department of Geology and Geophysics, the Limnological Research Center, and the Water Resources Research Center, University of Minnesota.

Finances

The Survey is supported by monies from the General University Fund and, since 1961, also by direct appropriations by the State Legislature. Prior to 1961, the annual budget was less than $25,000; in 1961 the budget was increased to about $65,000 annually and in 1963 it was further increased to about $85,000 per year. Through fiscal year 1963-64, the total funds available to the Survey since 1872 totaled $794,197.

The level of support has been far below that consistent with the State's needs. It is a wise policy to reinvest some of the returns from an extrac-

tive industry such as mining in geologic mapping and research, yet Minnesota has provided less than six ten-thousandths of one percent of the taxes gained from iron mining to support the work of the Geological Survey.

Staff

The permanent staff of the Geological Survey now consists of a director and three full-time geologists. In addition, two or more part-time staff members and four faculty members and 10 or more graduate students of the Department of Geology and Geophysics are employed during the summer.

The senior staff members have advanced degrees in geology; they are appointed to academic positions and are selected in cooperation with the Dean of the Institute of Technology. The supporting staff members and clerical personnel are Civil Service appointees selected by the Director.

COMPARISON WITH OTHER STATE GEOLOGICAL SURVEYS

The Minnesota Geological Survey is small by comparison to most state surveys. If total appropriations are used as a basis for comparison, in 1963 Minnesota ranked last among midwestern states (figs. 12 and 13) and 41st in the nation as a whole. Although the scope and functions of state surveys differ somewhat depending on the needs of the particular state, it is evident that Minnesota ranks far below the average.

STAFF AND BUDGET NEEDS

The long-range plan for expanded programs of geologic studies within the State outlined above calls for increases in both appropriations and staff. It is proposed that the needs be met from two sources: (1) by increasing the regular legislative appropriation to the Survey, and (2) by providing funds available through the Omnibus Natural Resources and Recreation Act of 1963.

(1) Increases in the direct appropriations to the Survey should be orderly, to assure steady growth and the build-up of a competent, well-trained staff to a level consonant with the State's needs. An annual budget of $150,000 in 1964 dollars is a minimum level for effective operation of the Survey at this time In all probability that will have to be increased as its usefulness and obligations grow.

(2) Funds to supplement the regular budget are being requested of the

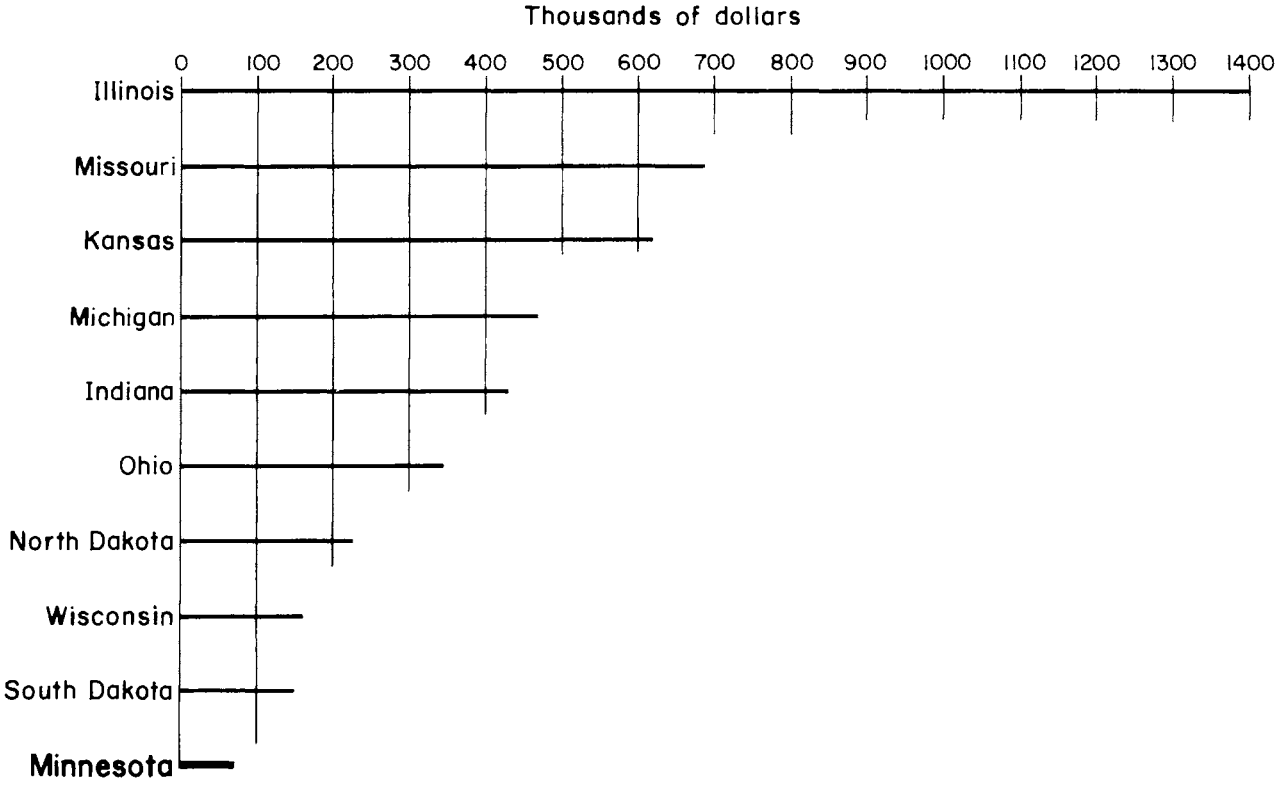

Figure 12—Appropriations of midwestern state geological surveys, 1963.

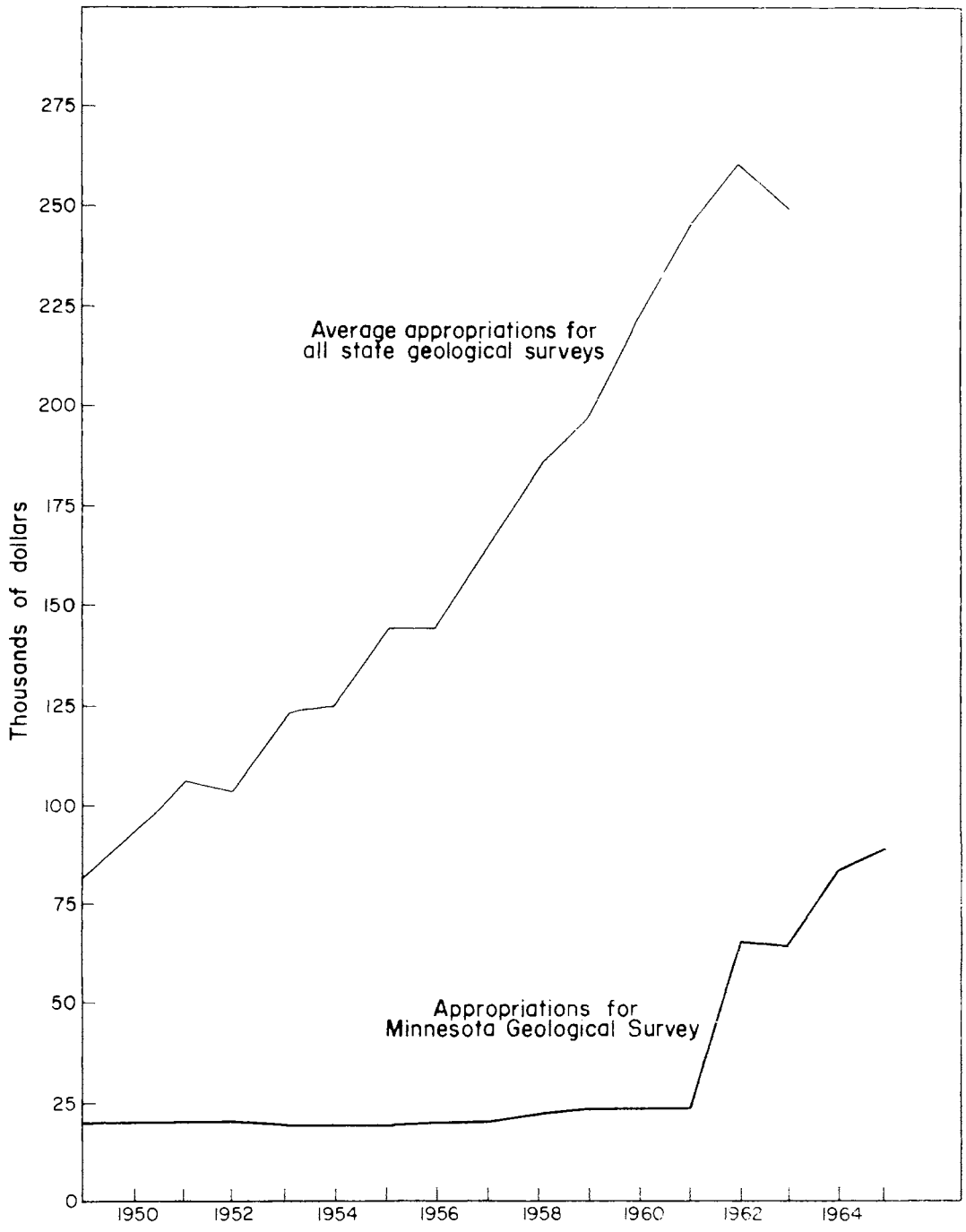

Figure 13 — Minnesota Geologic Survey growth has accelerated since 1961, but appropriations remain far below the average of all state surveys.

1965 State Legislature, primarily to accelerate geologic mapping and fill the gap in knowledge caused by a lag in past work. The proposed program is outlined in Report Number 7 of the Minnesota Outdoor Recreation Resources Commission, a commission established by the Omnibus Natural Resources and Recreation Act of 1963. About $130,000 each year for a 10-year period is being requested in this program. An additional $50,000 annually is being requested for geologic mapping to be done by the U. S. Geological Survey in cooperation with the State Survey; this would be matched on a 50-50 cost basis by the Federal government.

A budget of $150,000 annually for the Geological Survey would provide funds for a maximum of 8 full-time staff members with advanced degrees in geology and 4 full-time supporting staff members. In addition, a few members of the teaching staffs of the geology departments at the University's Minneapolis and Duluth campuses could be employed on a part-time basis during summers.

The staffing plans for the geologic mapping program proposed to the Outdoor Recreation Resources Commission is outlined in Report No. 7 of the Commission.

Additional laboratory and office space will be required if the Survey is expanded to the level needed in the State. The necessity for new building space is being coordinated with that of other departments in the School of Earth Sciences--the Department of Geology and Geophysics and the Limnological Research Center.

Key to geologic map of Minnesota:

p€u	-	Precambrian undifferentiated, iron-formation, metamorphic rocks and igneous rocks.
Paleo	-	Paleozoic sedimentary rocks.
K	-	Cretaceous sedimentary rocks.

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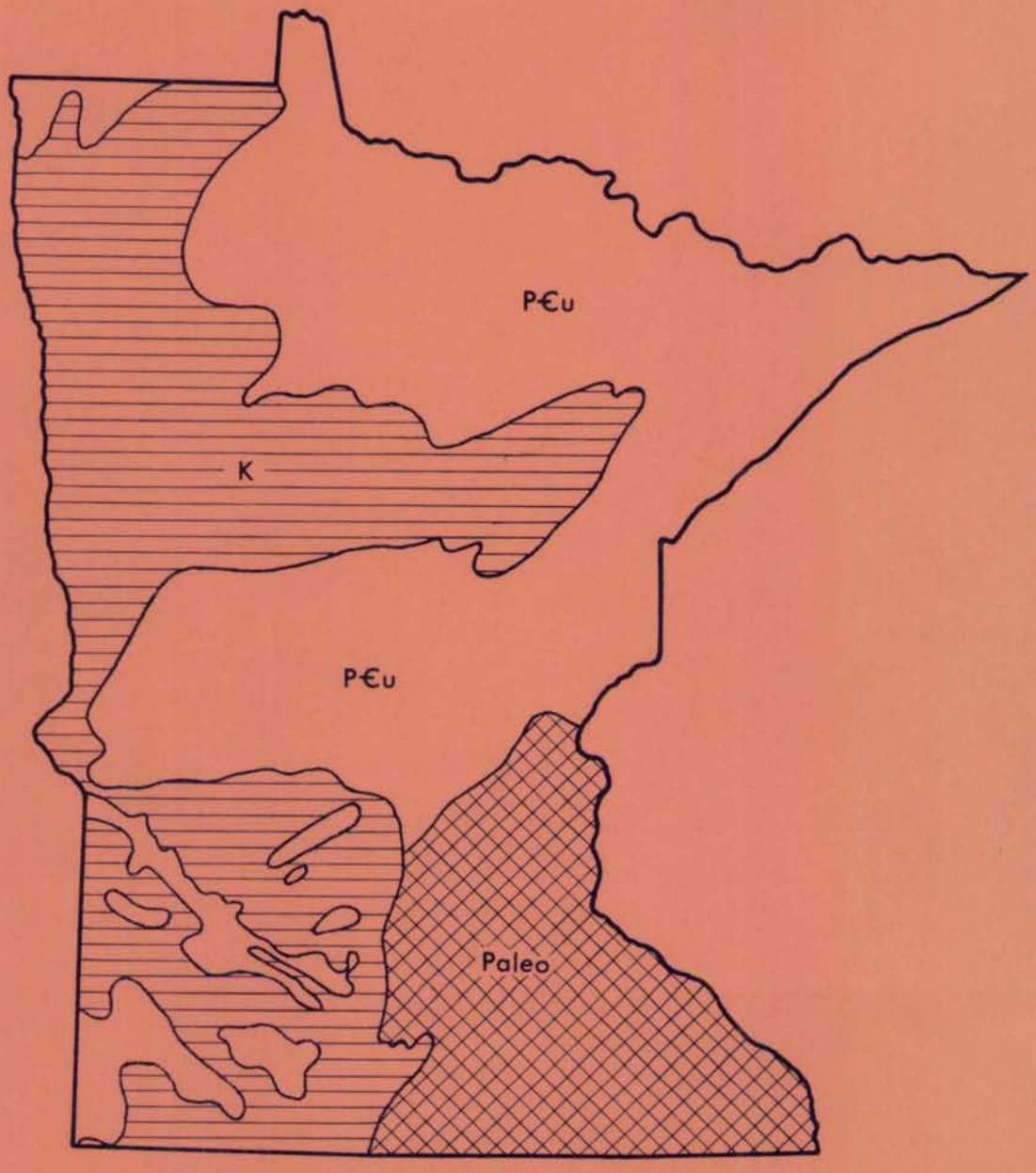

Geologic map of Minnesota