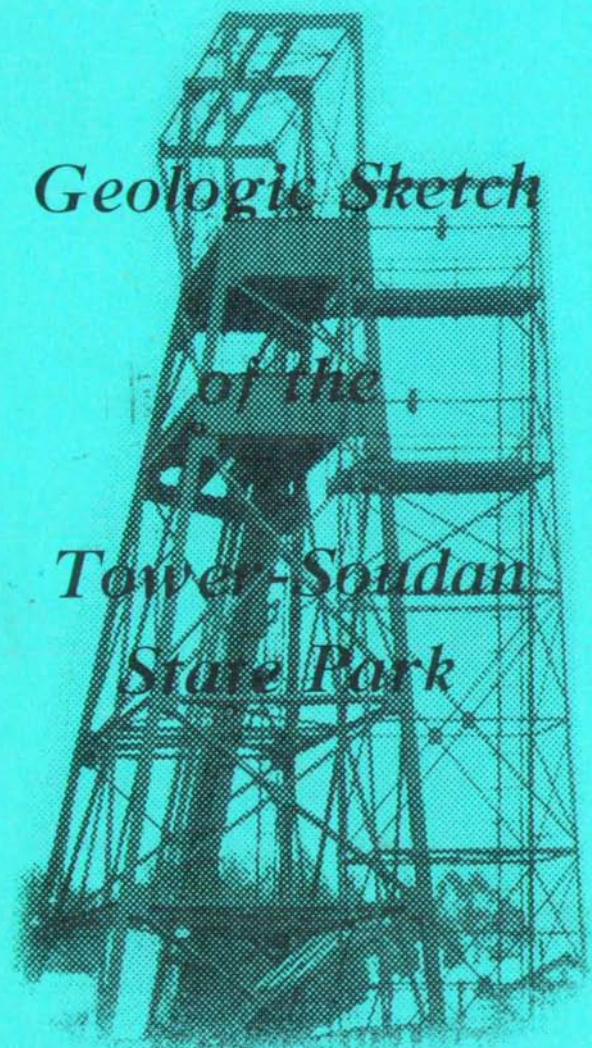


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Educational Series-3

*Geologic Sketch
of the
Tower-Soudan
State Park*



Minnesota Geological Survey

UNIVERSITY
OF
MINNESOTA



1966

Minnesota Geological Survey
Paul K. Sims, *Director*
Minneapolis, Minnesota 55455

*Geologic Sketch
of the
Tower-Soudan State Park*

P. K. Sims and G. B. Morey



Illustrations by Ann Cross



Soudan Mine, looking northeastward from State Highway 1. The head-frame visible in the distance is at No. 8 Shaft, which is used to take visitors underground.

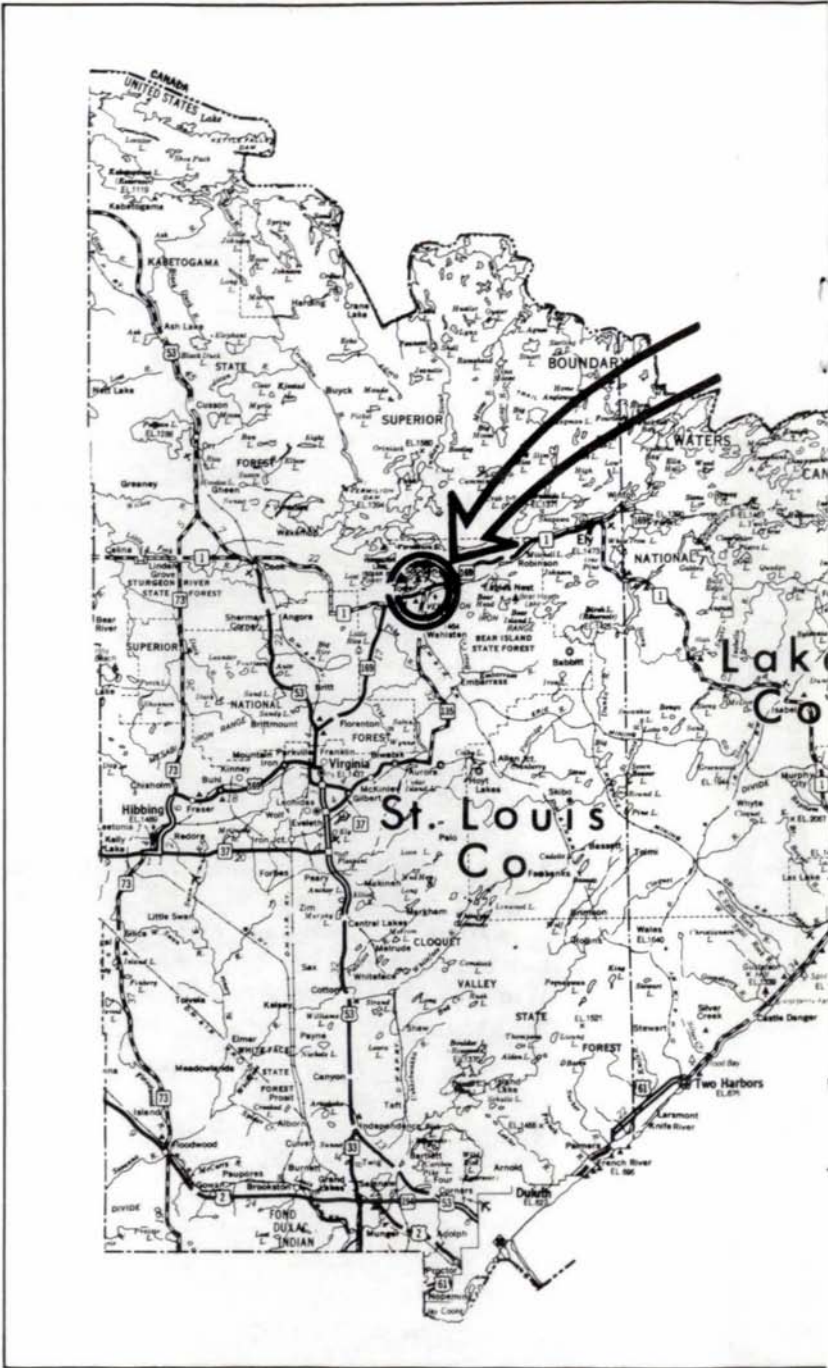
Of the many state parks in Minnesota none is more appropriate than the Tower-Soudan State Park. Situated in the wooded highlands of the Lake Vermilion area, the park is within one of the State's most scenic areas and at the same time is a symbol to Minnesota's heritage -- a monument to the vast iron ore resources that have been the backbone of the strength and wealth of the nation.

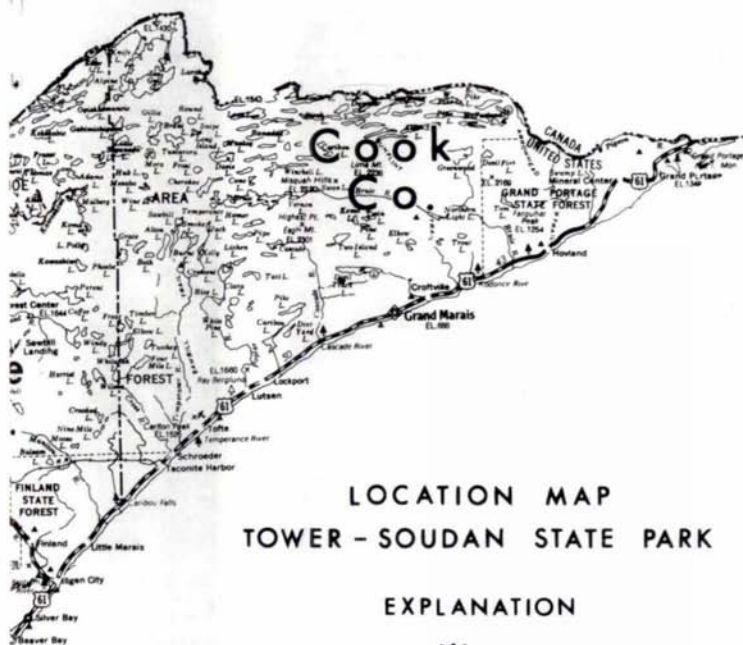
The central feature of the park is the Soudan Iron Mine. This, the first iron mine in the State of Minnesota, was operated nearly continuously from its discovery in 1882 until 1962, when it was closed ^{1/}. Through its active life, the mine yielded a high-grade iron ore that brought premium prices in the iron ore market and provided employment for thousands of miners.

Although the Soudan Mine was shut down because of the high cost of its operation and the reduced demand for its ore, in a sense its demise can be attributed to technological progress. Concurrently with the building of the large modern taconite plants, such as those on the Mesabi Range 20 miles to the south, the iron and steel industry has undergone revolutionary changes. The high-grade natural ores such as those from the Soudan Mine have been largely replaced by the marble-sized pellets of the taconite plants as the preferred feed for the steel furnaces. Steel men have found that through the use of pellets, production of the furnaces is greatly increased. As operation of the furnaces is the most costly of all the operations in steel making, it is little wonder that the demand today is for pellets rather than for the natural ores used in the past.

Visitors to the mine marvel at its awesome depth and at the underground chambers from which the ore was ex-

^{1/} Some historic facts about the Soudan Mine are listed in the appendix, page 24.

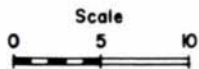




LOCATION MAP
TOWER - SOUDAN STATE PARK

EXPLANATION

- ▲ State parks
- ⬆ Roadside parks
- ⬢ U.S. route markers
- State highway route markers



1 inch to 8.75 miles

From Minn. Dept. of Highways



Picks and shovels were used in mining in the early days, when the Soudan was an open pit mine. Mine ore cars, drawn by mules, were used to haul the ore to the surface.

tracted. At the same time they have an innate curiosity about the rocks out of which the mine was carved. What are they, how do they differ among themselves, how did they form, and how old are they? By gaining knowledge of the rocks and of the geologic history, wonderment grows into a sense of deep enjoyment and the mine acquires new meaning and can be understood as an integrated whole.

THE SOUDAN MINE

The Soudan Mine began as a series of shallow open pits from which the iron ore was removed. As mining continued, shafts ^{2/} were sunk into the ground and the

^{2/} Definitions of mining terms are given in the appendix, page 25.

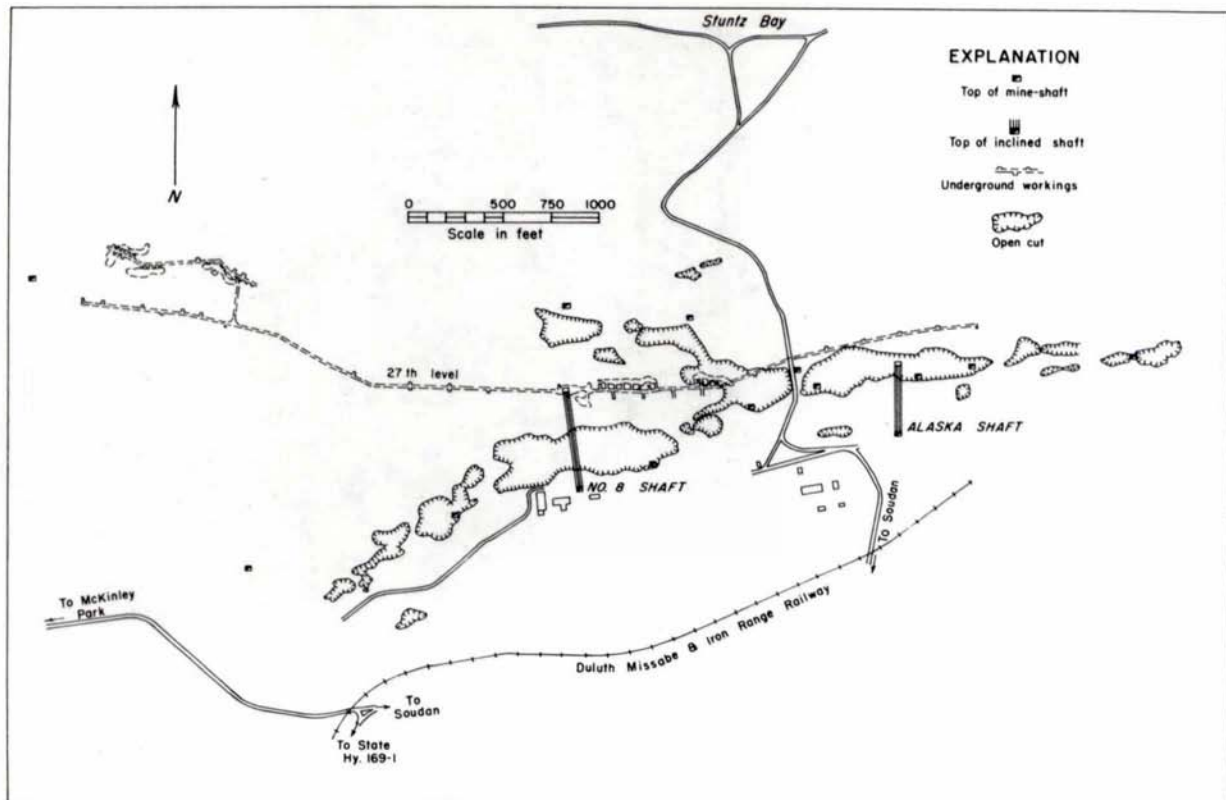
ore was extracted by underground methods. The shafts were spaced at intervals of a few hundred feet along the surface, each probing the depths of separate iron ore bodies. As the ore was mined out, some of the shafts were abandoned and eventually only two were operated. These were No. 8 Shaft, which is in use today, and the Alaska Shaft, which is located about 1,700 feet east of No. 8 Shaft (see map on page 6).

Underground mining of the ore was done from levels, which are spaced at vertical intervals of 100 to 200 feet



Open pit, as it appears today, looking northwestward from the top of headframe of No. 8 Shaft.

and connect to the shafts. At each level drifts were driven to reach the ore bodies. When a drift reached an ore body, raises were driven upward vertically into the ore to provide openings through which the ore was extracted. The raises also were a means of access for the



Map of Soudan Mine area showing locations of open pits, principal shafts, and main buildings. Visitors are taken underground to 27th Level of the mine, which is nearly half a mile below surface.

miners into the stopes.

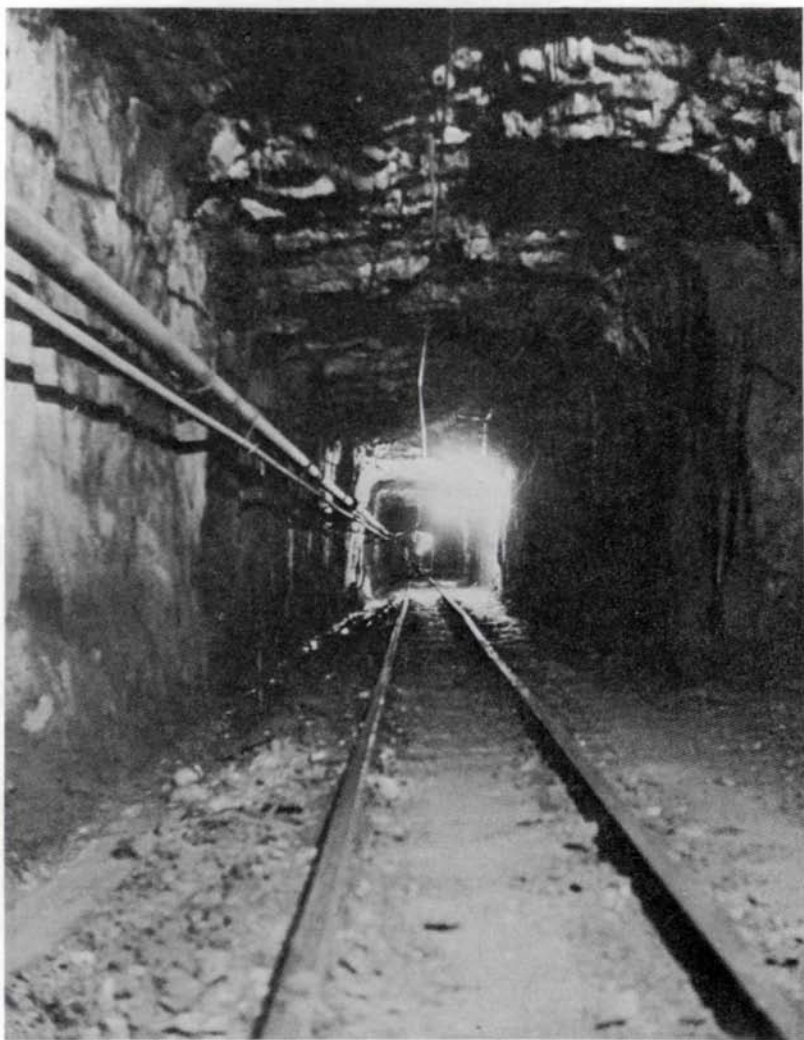
Access to the mine today is through No. 8 Shaft. The shaft is inclined to the north at an angle of 78 degrees (12 degrees from the vertical), and extends to the 27th Level, which lies at a depth of 2,400 feet below the surface. Visitors are taken down the shaft to the 27th Level, and are transported by an electric motor powered train to the workings of the Montana Ore Body in the northwestern part of the mine.

THE IRON ORE BODIES

The iron ore at the Soudan Mine occurs as local bodies within a rock known to geologists as iron-formation. In turn, the iron-formation is enclosed within a thick body of green rock of volcanic origin named Ely Greenstone.

Geologists define iron-formation as a chemical sediment, typically bedded and commonly laminated, that generally contains 15 or more percent iron and has layers of chert ^{3/}. Three types of iron-formation are recognizable in the Soudan Mine. These are (1) greenish-white chert, composed principally of quartz but containing minor amounts of chlorite and pyrite, (2) lean jasper, a rock composed of quartz and hematite, which has an iron content of less than 20 percent, and (3) jaspilite, a banded rock composed of quartz, jasper, and hematite, which contains somewhat more than 30 percent iron. Jaspilite is the dominant variety at the mine and is characterized by thin alternating red and white layers. The red layers consist mainly of hematite and quartz (jasper), whereas the white layers are dominantly white fine-grained quartz (chert). The layering (or banding) in the rock may be straight and uniform or may be folded back on itself many times to form complex zig-zag patterns. Straight-banded jaspilite can be seen underground on the 27th Level. Un-

^{3/} Definitions of geologic terms are given in the appendix, page 26.

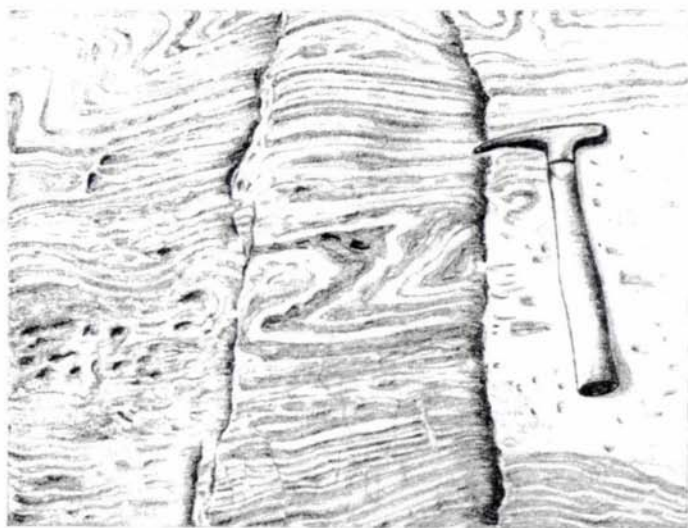


Typical underground drift in the Soudan Mine. These openings were used to haul the broken ore from the stopes to the shaft, where it was hoisted to the surface.

usually complicated zig-zag banded rock, such as that shown on the opposite page, can be seen at the surface just east of the road to Stuntz Bay, south of No. 4 Shaft. The jaspilite contains too little iron to be profitably mined.

The iron ore bodies that were mined at the Soudan

are local enrichments within the lean iron-formation. In contrast to the conspicuously red and white banded jaspilite the ore is red throughout and typically massive. A common variety of ore sought by the miners is very hard and distinctly bluish in color. Other varieties are made up of angular fragments of hematite in a hematite matrix. These are called brecciated ores. Individual hematite crystals in all the ore are extremely small and can be seen only with the aid of a microscope. Samples of each of the varieties of iron ore that were mined as well as of the lean iron-formation can be seen on the mine dump south of the parking lot.



Contorted jaspilite of Soudan Iron-formation. Light layers are composed mainly of white quartz; dark layers contain hematite and quartz.

The iron ores that were mined contained an average of about 65 percent but locally as much as 69 percent iron, which is nearly pure hematite (Fe_2O_3). The impurities in the ore are mainly silica and phosphorus. At a few places pyrite (FeS_2), chalcopyrite (CuFeS_2), and native copper (Cu) were found in the iron ore bodies. These minerals were avoided during mining because their deleterious effects.

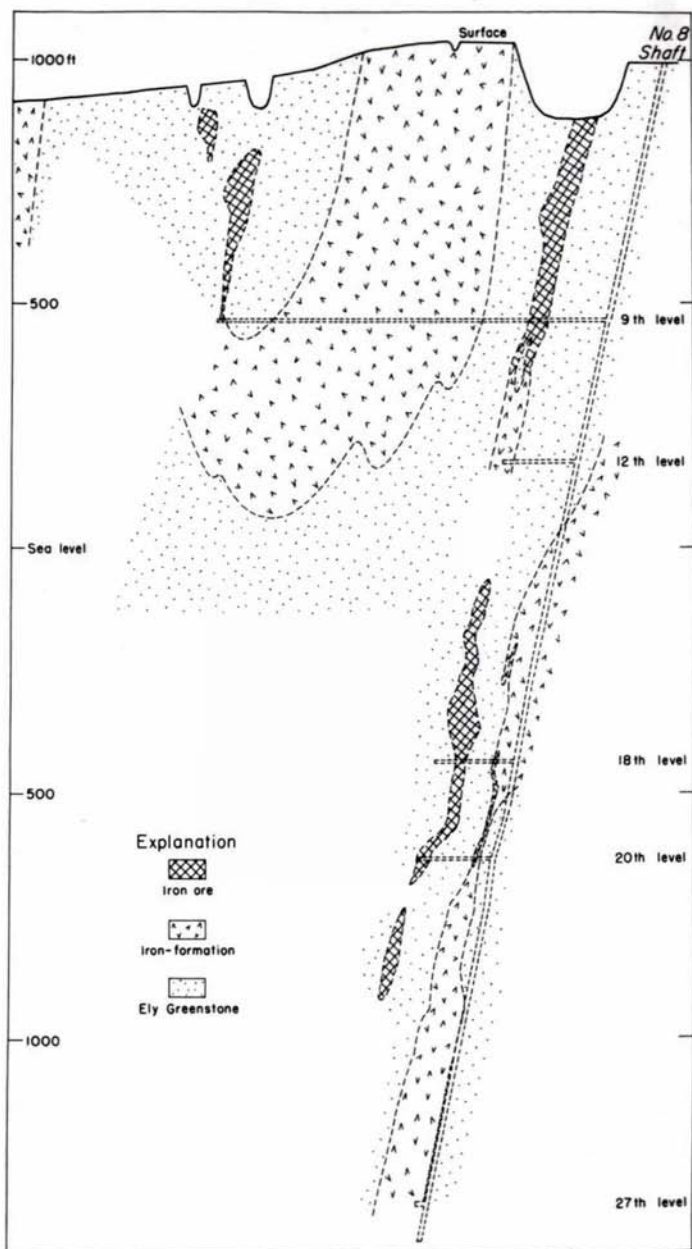
The iron ore bodies are generally long, narrow, somewhat sinuous, and extremely variable in size. Their long dimension in the horizontal plane (or strike) is about east-west. In the third dimension or dip direction, the bodies pinch and swell like beans in a pod. Because of the complexities in the structure of the ore, geologists and mining engineers were not able to accurately predict the shape and size of an ore body from one level to the next succeeding lower level. Accordingly, much expensive core drilling was required prior to the development of any particular level in the mine.

The general shape and structural attitude of the ore bodies and their relationship to the Soudan Iron-formation and to the Ely Greenstone are shown schematically in the diagram on page 11. The section represents a vertical north-south slice through the ground in the vicinity of No. 8 Shaft. The section is perpendicular to the strike of the ore bodies and the enclosing rocks. It is interesting to note that the Montana Ore Body -- to which visitors are taken on the 27th Level -- lies relatively near the surface in this section.

HOW THE IRON ORES AND ASSOCIATED ROCKS WERE FORMED

The geologic story of how the Soudan ores came into being is long and complex, spanning many hundreds of millions of years. Geologists since the time of the Winchell Survey in the late 1800's have studied the mine and surrounding area and have gradually assembled the facts concerning this segment of the earth's crust. Although some gaps in the geologic record remain, many pieces of the puzzle have fallen into place and can be recounted.

The first known geologic event in the area was the eruption of great lava flows onto the floor of a vast inland sea. Successive flows, piled one upon the other, built a sequence probably several thousands of feet thick. Because of their basic composition, the lava flows spread over



Generalized geologic section of Soudan Mine.

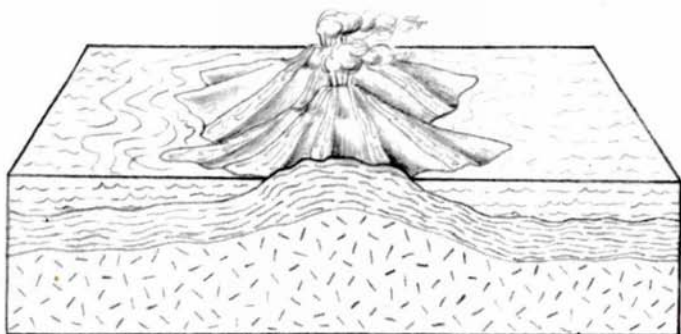


Lava flows that have ellipsoidal forms. The ellipsoidal forms are indicative of flows that are extruded under water.

large areas like molasses over a flat smooth surface. Their full extent is not known because they are covered at many places by younger rocks, but geologists have traced them from the vicinity of Tower-Soudan State Park eastward through Ely and the Boundary Waters Canoe Area into Canada. A characteristic of the lava flows is the presence of large ellipsoidal forms, called pillows, such as those pictured above. It is because of these that geologists know that the lava solidified under water, for such forms can be observed forming today offshore in the Aleutian Islands and in other areas of active volcanism. Flows having well-formed pillows are difficult to recognize underground in the Soudan Mine, but can be seen on the surface at Ely near the Zenith Iron Mine. Indeed, the rocks are named the Ely Greenstone from the excellent exposures at this locality.

In addition to lava, dust to boulder-sized fragments were periodically ejected from the volcanoes (see block diagram A, page 13). This material, called pyroclastics, was violently thrown into the air during eruptions. It solidified and fell back into the sea to be deposited in thin

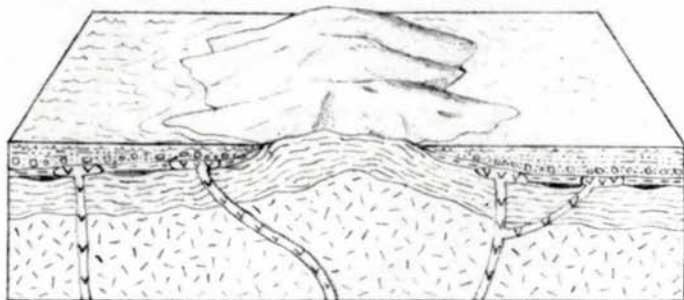
SKETCHES SHOWING
GEOLOGIC HISTORY OF TOWER-SOUDAN STATE PARK REGION



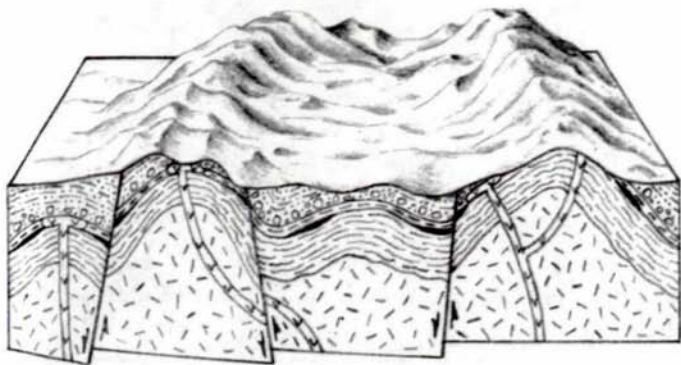
- A. During the earliest time recorded in the area, basic lava flows were extruded from local volcanic sources onto a surface of granitic basement rocks. Many of the flows were extruded under water.



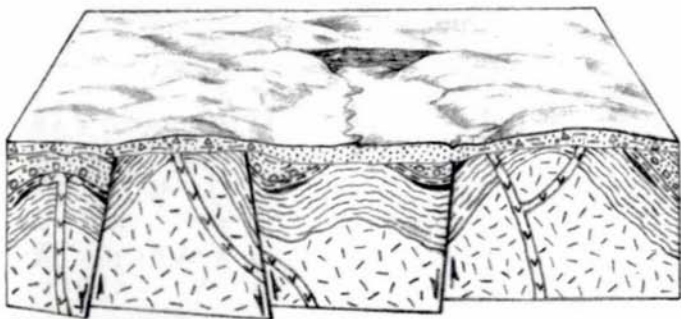
- B. Late in the period of the volcanic activity, silica and iron were deposited locally in depressions on the surface of the lava flows. The silica and iron accumulated rhythmically to form iron-formation (shown in black on diagram). Sporadic volcanic eruptions ejected pyroclastic material which was deposited on the iron-formation. Later, dikes and sills of quartz-feldspar porphyry were intruded locally into the older rocks.



- C. After cessation of the volcanic activity, the rocks that were exposed above sea level were weathered and eroded. Conglomerates and (graywacke) sandstones were deposited as a blanket-like cover in the sea on the surface of the older rocks.



- D. The layers of rocks were uplifted and crumpled into mountains. As a consequence, the rock strata were folded, upturned, and broken by fractures. The patterns of folds and faults that we observe today were formed during this episode of mountain-making.



- E. During many millions of years the mountains were worn down by erosion, and a moderately level surface remained. In relative recent geologic time, Ice-age glaciers moved over the region. When the ice retreated, it left unconsolidated deposits of clay, sand, and gravel, which largely obscured the solid rocks and left the landscape nearly as we see it today.

but widespread layers. The material in the pyroclastic layers is commonly graded as to size; that is, the larger, heavier particles are at the bottom of a layer and the smaller, lighter particles are near the top. This grading is additional evidence for original deposition of the volcanic rocks in water.

Late in the episode of volcanic activity, silica and iron oxide were deposited locally on the surface of the lava flows (see block diagram B, page 14). When solidified and compacted, this material became iron-formation such as that at the Soudan Mine. Probably the silica and iron oxides were accumulated in small basins or saucer-like depressions rather than as continuous blanket-like deposits. The source of the iron and silica is thought to be the same volcanoes that yielded the lava flows.

The next major geologic event was deposition of clastic sedimentary rocks (block diagram C, page 14). Conglomerates, such as those now exposed along the shores of Stuntz Bay, north of the Soudan Mine, and several types of sandstone called graywacke were the principal rocks to accumulate. Fragments of the lava flows and iron-formations and of quartz-feldspar porphyry that intruded these rocks are found in the conglomerates and graywackes, and provide evidence that these older rocks were exposed to erosion at the time the conglomerates and sandstones were deposited. Also volcanic activity persisted at this time, for fine-grained volcanic debris is locally inter-layered with the more abundant sedimentary rocks. Both the sedimentary and the volcanic rocks were deposited in bodies of water, for they are graded and contain other structures indicative of having formed in water. The succession of conglomerates, sandstones, and associated pyroclastic rocks is at least several thousand feet thick and has been named by geologists the Knife Lake Group, after excellent exposures of these rocks at Knife Lake east of Ely, Minnesota.

Following deposition and consolidation of the sediments of the Knife Lake Group, all the rocks were deformed by mountain-building forces into an east-west

trending range that probably extended into Canada. The original flat-lying rocks were compressed into folds, were upturned, and were broken by fractures. As a consequence of this upheaval, nearly all the strata we see today in this area dip steeply. Thus, as shown in block diagram D, page 15, the iron-formation and adjacent rocks extend into the ground at nearly right angles to the surface. This period of upheaval and deformation has been called the Algoman orogeny.

Probably contemporaneously with the upheaval, the primary minerals in the rocks were changed by warm fluids that pervasively penetrated the strata. The original minerals of the lava flows were converted largely to chlorite, epidote, and other green or greenish-gray secondary minerals. These minerals impart a green color to the rocks, which led early geologists to call them "greenstones".

At about the same time, parts of the iron-formation were changed to high-grade ores such as those in the Soudan Mine. The agent that transformed the lean iron-formation into ore was probably hot thermal waters, for such waters have a far greater capacity to produce the observed changes than do cooler ground waters. The enrichment involved the removal of silicon dioxide and the concentration of iron in the form of hematite. This modification and enrichment of the iron-formation took place only locally, for within the many miles of iron-formation known between Tower-Soudan and Ely, high-grade ore is known only at Soudan and at the Pioneer, Zenith, and Sibley mines in Ely.

Except for glaciation about 12,000 years ago, subsequent geologic events did not affect the Tower-Soudan area appreciably. Contemporaneously with the mountain-building of the Algoman orogeny, the Ely Greenstone and the Knife Lake rocks were intruded in nearby areas by large masses of molten igneous rocks. Today, these igneous rocks form two large batholiths, the Giants Range batholith, which lies 20 miles south of Tower along the north side of the Mesabi Iron Range, and the Vermilion batho-

lith, which can be seen at many places along the north shore of Lake Vermilion and along the scenic Echo Trail between the towns of Ely and Orr. Later, the iron-formation (or taconite) of the fabulous Mesabi Range was deposited in a vast inland sea that extended from the Giants Range eastward for many miles. Still later, basic lava flows were extruded in a long narrow basin that extended from the present site of Lake Superior southward through east-central Minnesota into Iowa, and these rocks were intruded at places by basic igneous rocks that geologists call the Duluth Gabbro Complex. The lava flows and gabbro form spectacular bluffs and cliffs at many places along the North Shore of Lake Superior.

Several glaciers invaded northeastern Minnesota during the Great Ice Age. The last ice sheet advanced over the area about 12,000 years ago and left a thin cover of bouldery drift over most of the solid bedrock (block diagram E, page 15). Typical drift can be seen in the upper part of the open pit opposite No. 8 Shaft at the mine.

GREAT ANTIQUITY OF THE ORES AND ROCKS

The rocks that are associated with the iron ores at the Soudan Mine do not contain fossils by which they can be dated, and accordingly other means are necessary to establish their age. As shown in the foregoing discussion, relative ages can be determined by noting the field relations that one rock bears to another. This information alone is not sufficient, however, to determine the position of the stratigraphic sequence with respect to a time scale, generally expressed in terms of millions of years ago.

Fortunately for geologists the age of certain rocks can be obtained by radiometric methods. These methods utilize the fact that radioactive parent isotopes such as uranium and thorium decay to daughter isotopes at a known rate. Thus, by measuring the amount of a daughter isotope present in a rock relative to the amount of the

Stratigraphic succession of the
Precambrian rocks of northeastern Minnesota

Era	Major Sequence		Formation			Age (millions of years)
Upper Precambrian	Keweenawan		Hinckley Sandstone			
			Fond du Lac Sandstone			
			Unconformity			
		North Shore Volcanic Group	Undivided			
			Puckwunge Sandstone			
Middle Precambrian		Penokean intrusive rocks			1,700	
		Animikie Group	Virginia Formation	Rove Formation	Thomson Formation	
			Biwabik Iron-formation	Gunflint Iron-formation		
		Pokegama Quartzite				
Lower Precambrian		Algoman intrusive rocks			2,600	
		Knife Lake Group	Undivided			
		Intrusive rocks			2,700	
		Keewatin Group	Soudan Iron-formation			
			Ely Greenstone			
	Gneiss and other crystalline rocks (presence inferred)					

parent isotope, geologists can calculate the number of years it took to form that amount of the daughter isotope. Minerals such as mica, hornblende, feldspar, and zircon contain small amounts of these radioactive isotopes, and are therefore useful in dating the rocks. Thus, it is possible to assign an age in terms of millions of years to many of the rocks at and near Tower-Soudan State Park.

The Ely Greenstone and the associated Soudan Iron-formation are the oldest rocks definitely known to be exposed in northeastern Minnesota (see table on page 19). They are overlain by rocks of the Knife Lake Group and are intruded by granites of the Vermilion and Giants Range batholiths. Neither the Ely Greenstone nor the Knife Lake rocks have as yet been successfully dated by radiometric methods because of their complex history. However, the granitic rocks of the Vermilion and Giants Range batholiths which intrude them have been determined to be about 2.6 billion years old. From field relations we can estimate that the age of the Ely Greenstone and Soudan Iron-formation approaches 3 billion years.

By comparison with rocks from other areas, the Ely Greenstone and Soudan Iron-formation rank among the oldest known on the North American continent.

EVIDENCE OF EARLY LIFE

Evidence of life as indicated by fossil remains is found abundantly in rocks younger than about 600 million years, but is sparse in older rocks of Precambrian age. In the search for records of primordial life in Precambrian rocks, scientists generally agree that simple forms that closely resemble specific living organisms are present in rocks at least as old as 2 billion years. These forms found in cherts of the Gunflint Iron-formation in Ontario, Canada -- the equivalent of the Biwabik Iron-formation of the Mesabi Range -- consist mainly of the so-called thread bacteria and the blue-green algae. A possibly valid record of still older life is found in the

Soudan Iron-formation in Tower-Soudan State Park. If valid, this occurrence would extend the geologic record of life back more than 2.7 billion years.



Microstructures from carbon-rich rocks of the Soudan Iron-formation. The microstructures may represent primitive life that lived more than 2,700 million years ago. Electron micrographs enlarged 13,600 times. (After Cloud and others, 1965.)

The forms that may represent primitive life in the Soudan Iron-formation occur within tiny pyrite (FeS_2) balls enclosed within carbon-rich rocks that have been found underground in the Soudan Mine and at the surface on the hill north of Tower. The carbon-rich rocks resemble impure graphitic coal. Analyses of them indicate that they contain hydrocarbons that are possibly, but not necessarily, of biologic origin. The forms within the pyrite balls in the carbon-rich rocks are seen at high magnification under the electron microscope to be extremely tiny blister-like objects that have a size and a degree of organization that is consistent with their interpretation as bacteria or microscopical blue-green algae. A typical form is shown above.

Continuing studies of primordial life not only will further our knowledge of the "beginning" but will improve our understanding of the geologic environment in which rocks such as the iron-formations at the Soudan Mine were formed. This, in turn, will aid geologists in discovering new ore bodies to enhance our economy.

APPENDIX

SUGGESTED READING

Additional information that pertains to the Soudan-Tower area and the adjacent region can be obtained in the following publications.

- Cloud, P. E., Jr. and others, 1965, Carbonaceous rocks of the Soudan Iron-formation (Early Precambrian): *Science*, v. 148, no. 3678, p. 1713-1716. (Describes carbon-rich rocks, nature of hydrocarbons, and character of microstructures of possible biologic origin)
- Goldich, S. S. and others, 1961, *The Precambrian geology and geochronology of Minnesota: Minnesota Geological Survey Bull. 41, University of Minnesota Press, 193 p.* (An up-to-date description of the Precambrian rocks of Minnesota and their geologic ages. Can be obtained from the University of Minnesota Press, Minneapolis, Minn., 55455, at a cost of \$4.00).
- Schwartz, G. M. and Thiel, G. A., 1963, revised edition *Minnesota's rocks and waters: Minnesota Geological Survey Bull. 37, University of Minnesota Press, 336 p.* (A summary of the geology of the State of Minnesota written in understandable language. Can be obtained from the University of Minnesota Press, Minneapolis, Minn., 55455, at a cost of \$4.00).

SOME HISTORIC FACTS ABOUT THE SOUDAN MINE

The first shipment of iron ore from the Soudan Mine was on July 31, 1884.

The last shipment of ore from the stockpile was on August 20, 1963.

The total amount of ore shipped from the mine was about 15.5 million tons, which would have a value at current prices in excess of \$150 million.

The principal bodies from which the ore was extracted are the Alaska, No. 8, South, and Montana ore bodies.

The iron ore was shipped by rail to Two Harbors and then by water to the blast furnaces.

The Soudan Mine was deeded to the State of Minnesota by the Oliver Mining Company of United States Steel Corporation.

DEFINITION OF MINING TERMS

Back -- The top or roof of an underground passageway.

Bottom -- The floor of an underground passage; also sometime referred to as the "sill" of a level.

Breast -- The end, in unmined rock, of an underground excavation or passage; sometimes called the "face".

Crosscut -- A horizontal underground passage driven so that it intersects, penetrates, or crosses geologic structure.

Drift -- A horizontal underground passage driven along or parallel to some geologic structure, such as a vein or another type of tabular body.

Glory Hole -- A large pit or hole from which ore has been extracted.

Raise -- A rectangular or less commonly a circular opening driven upward from a lower level to reach a level above. Raises driven on an ore body normally afford access to contiguous stopes.

Shaft -- An excavation of limited size, generally rectangular, compared with its depth. Made for finding or mining ore and for permitting access from the surface to underground workings.

Stope -- An underground excavation from which ore has been extracted, either above (overhand) or below (underhand) a level. Access to stopes is generally by way of adjacent raises.

Winze -- Similar to a raise except that it is driven downward from a level.

SELECTED GEOLOGIC TERMS

Bedding -- The arrangement of rocks in layers, strata, or beds.

Chemical sediments -- accumulations formed directly by precipitation from solution by means of chemical or biochemical processes.

Chlorite -- a general designation for a group of platy hydrous silicates of iron and magnesium with or without aluminum; it is closely related to micas.

Clastic rocks -- deposits composed principally of detritus from pre-existing rocks which is transported mechanically to the place of deposition.

Conglomerate -- a consolidated rock composed of rounded, water-worn fragments of rock, generally of pebble size, cemented by another mineral substance.

Deformation -- the processes whereby the original form or volume of rock masses are changed by tectonic or earth forces.

Erosion -- the wearing away and removal of materials of the earth's surface by natural means.

Fold -- a bend or flexure in a layer or layers of rock.

Fossil -- a trace or remains of an ancient animal or plant preserved within rocks or unconsolidated material at the earth's surface.

Fracture -- a crack in a rock resulting from folding or faulting.

Gabbro -- a medium or dark gray coarse-grained igneous rock composed mainly of the minerals calcium feldspar, pyroxene, and olivine.

Glacial drift -- the sediment or rock materials carried and later deposited by a glacier.

Glaciation -- alteration of the earth's solid surface by ice, including erosion and deposition and the resulting effects of these processes.

Granite -- a coarse-grained igneous rock consisting mainly of the minerals feldspar and quartz and containing minor amounts of mica, hornblende, and other minerals.

Graywacke -- a rock name used for poorly sorted sandstones composed of angular grains of quartz, feldspar and a variety of rock and mineral fragments embedded in a compact matrix having the composition of clay shale.

Ground-water -- that part of the subsurface water which is below the water table.

Hematite -- a common ore mineral of iron, having the chemical composition Fe_2O_3 .

Igneous rocks -- rocks formed by solidification from a molten magma. If crystallized above the earth's surface, it is called lava; if crystallized beneath the earth's surface, it is called an intrusive rock.

Isotope -- a chemical element that has the same atomic number, differing atomic weight and almost, but not quite the same physical properties.

Lamina -- a thin layer of stratified rock that commonly differs from another in either grain size or composition.

Lava flow -- igneous material that flows out upon the earth's surface and crystallizes or solidifies.

Massive -- a term applied to rocks that lack stratification, foliation, or similar features.

Porphyry -- an igneous rock that contains large crystals (phenocrysts) in a matrix of finer-grained minerals.

Primordial life -- original or elementary life.

Quartz -- a mineral of widely ranging color and form that has the composition SiO_2 ; it is the most common mineral.

Sedimentary rock -- a rock formed by the accumulation of sediments, either on land or in water.

Silicate minerals -- minerals having a lattice containing SiO_4 tetrahedra either isolated or in groups such as chains, sheets, and other three-dimensional structures. The silicate minerals feldspar, amphibole, pyroxene and olivine are among the most important rock-forming minerals.

Strata -- beds or layers of sedimentary, igneous, or metamorphic rocks.

Stratigraphic units -- divisions of the rocks of the earth's crust.

Volcanism -- a term used to include all natural processes resulting in the formation of volcanoes, volcanic rocks, and lava flows.

N O T E S

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