COPY

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CONSULTING ENGINEER

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J. W. KINNEY, RESIDENT ENGINEER

MACKINAC STRAITS BRIDGE
FIELD OFFICE
P. O. BOX 422
ST. IGNACE, MICHIGAN
TELEPHONE: 276

ROEBLING BUILDING
117 LIBERTY STREET
NEW YORK 6, N. Y.

BARCLAY 7-2665
CABLE ADDRESS
"STEINMANCE", N. Y.

April 20, 1956

Dr. D. B. Steinman
D. B. Steinman
Consulting Engineer
117 Liberty Street
New York 6, New York

Dear Dr. Steinman:

I am pleased to forward herewith my final geological report, dated April 20, 1956. This report summarizes the geological history of the area known as the Straits of Mackinac and presents conclusions based upon exploration and study of bedrock conditions beneath the piers of the Mackinac Bridge and surrounding area.

The final boring logs with exploratory material and a complete set of 35 MM Kodachrome slides of the core recovered has been forwarded separately.

Very truly yours,

D. B. STEINMAN
Consulting Engineer

Per Jack C. Rosenau
Jack C. Rosenau
Resident Geologist

JCR:dg

D. B. STEINMAN, CONSULTING ENGINEER

MACKINAC BRIDGE

FINAL GEOLOGIC REPORT

Jack C. Rosenau
Resident Geologist

April 20, 1956

D. B. STEINMAN, CONSULTING ENGINEER

MACKINAC BRIDGE

FINAL GEOLOGICAL REPORT

Introduction

The Straits of Mackinac is a 70-mile connecting link between Lakes Michigan and Huron; its width at the site of the Mackinac Bridge is 4 miles and its depth is known to be at least 290 feet below lake level (578.5' USLS, MLWD). The greatest depth to rock is more than 350 feet and is located about mid-stream. A secondary rock valley, depth 237 feet, is located one-half mile from the south (Mackinaw City) shore. Both valleys were formed late in the glacial period and occupy the northern rim of a structural basin. They penetrate the Bois Blanc and St. Ignace formations and the main channel cuts into the Pointe Aux Chenes Formation. Eleven of the seventeen southern piers of the Mackinac Bridge are based on the cherts and cherty dolomites of the Bois Blanc. The remaining piers are based on the dolomitic limestones, shales, secondary or "stack" limestones and brecciated rocks of the St. Ignace Formation (Figure 1).

The origin of the Mackinac Breccia as presented by K. K. Landes is partially substantiated by the core borings, although the conditions of extreme chaos anticipated were not encountered. Geological exploration has established the solidarity of bedrock underlying the Straits of Mackinac and its adequacy to support the comparatively modest loads that will be imposed by the structure.

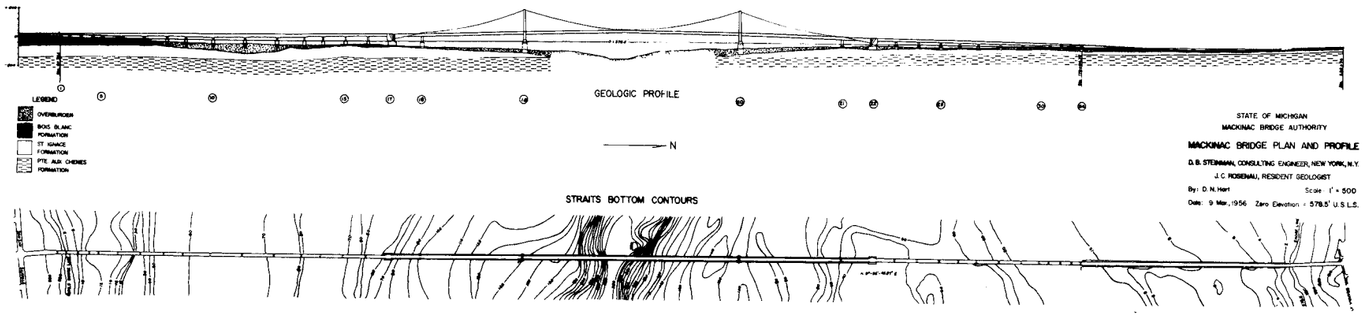
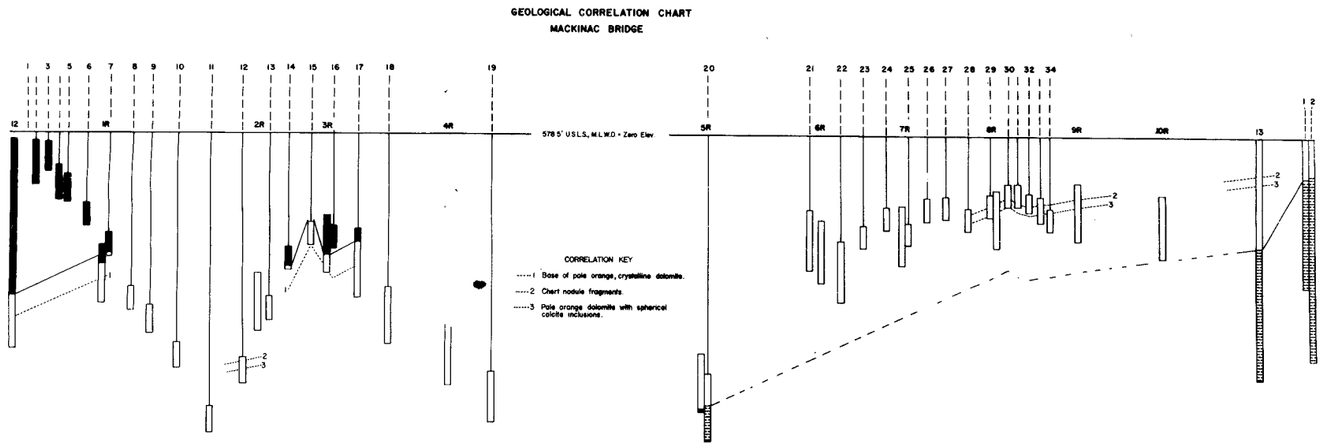


Figure 1



D. B. STEINMAN, CONSULTING ENGINEER
MACKINAC BRIDGE

GEOLOGICAL CORRELATION CHART DATA

Scale:
Horizontal: 1" = 500'
Vertical: 1" = 25'
Vertical Exaggeration - 20X

Legend:
Bois Blanc
St. Ignace
Pointe Aux Chenes

Top row of numbers, 1 through 34, are bridge piers at which one or more borings were made during 1954 and 1955.

Lower numbers, beginning with 12 at left and ending with 13 at the north shore, were borings made for the Michigan State Highway Department in 1939.

Borings marked 1 and 2, on the right side of the drawing, are Water Well Borings made by the American Bridge Division, U. S. Steel Corporation, 1955.

J. C. Rosenau, Resident Geologist
D. N. Hart - March 1956

MACKINAC BRIDGE AUTHORITY

608 Pruddon Bldg.
Lansing, Mich.

Box 326
St. Ignace, Mich.

Negative # _____

Photo by H. D. Allis

Geologic History

Some 300-400 million years ago in early to mid-Devonian time, the land mass in the area of the Straits emerged. This pseudo-uplift, due to the retreat of the Devonian sea, quickened ground water movement and thereby, leaching of the salt beds of the Salina Formation of the Silurian Period. As a result of the leaching, two important geological formations came into being: (1) the brine water worked its way into the Michigan Basin and deposited the upper salt beds of the Detroit River Formation, and (2) the solution of large quantities of rock salt left great voids or cavernous areas with an overlying rock mass of shales, limestones, dolomites, cherts, sandy shales and gypsum or anhydrite. These deposits are the Salina (Pointe Aux Chenes) and Bass Island (St. Ignace) Formations of the Silurian age and the Garden Island, Bois Blanc and Detroit River Formations of Devonian time. The void areas or caverns finally became so great that the overlying rock collapsed. The period of collapse was probably long and the rate of settling varied. A mass of broken angular rock was later recemented to form the so-called Mackinac Breccia. The size of the rock fragments making up the breccia varies from small fragments to large blocks, 30 feet or more in dimension. The uppermost undisturbed rock strata underlying the Pointe Aux Chenes shales are the Engadine limestone beds which crop out or are mantled by glacial drift in an arc beginning approximately 18 miles north of St. Ignace. The Engadine dips basinward (southerly) at a rate of between 50 and 65 feet per mile, so we may expect to find the Engadine approximately 1000 feet below the surface of the Straits.

During the long period of collapse, and for some time following, this portion of the Upper Peninsula was exposed to forces of erosion; while simultaneously, compaction, settling, and cementation of the broken rock of the collapsed zone began. It is probable that recrystallization occurred along fractures and in caverns below the then-existing lake level. A submergence of the land followed. Beginning about 300 million years ago, the deposition of younger rock materials began - the Dundee in the Straits area, followed by later Paleozoic sediments in the Michigan Basin. This episode was marked by numerous invasions of the Michigan Basin by the sea, followed by intervals of land uplift and receding waters. Compaction and cementation of the breccia zone and increased crystallization in void areas occurred during the high water intervals.

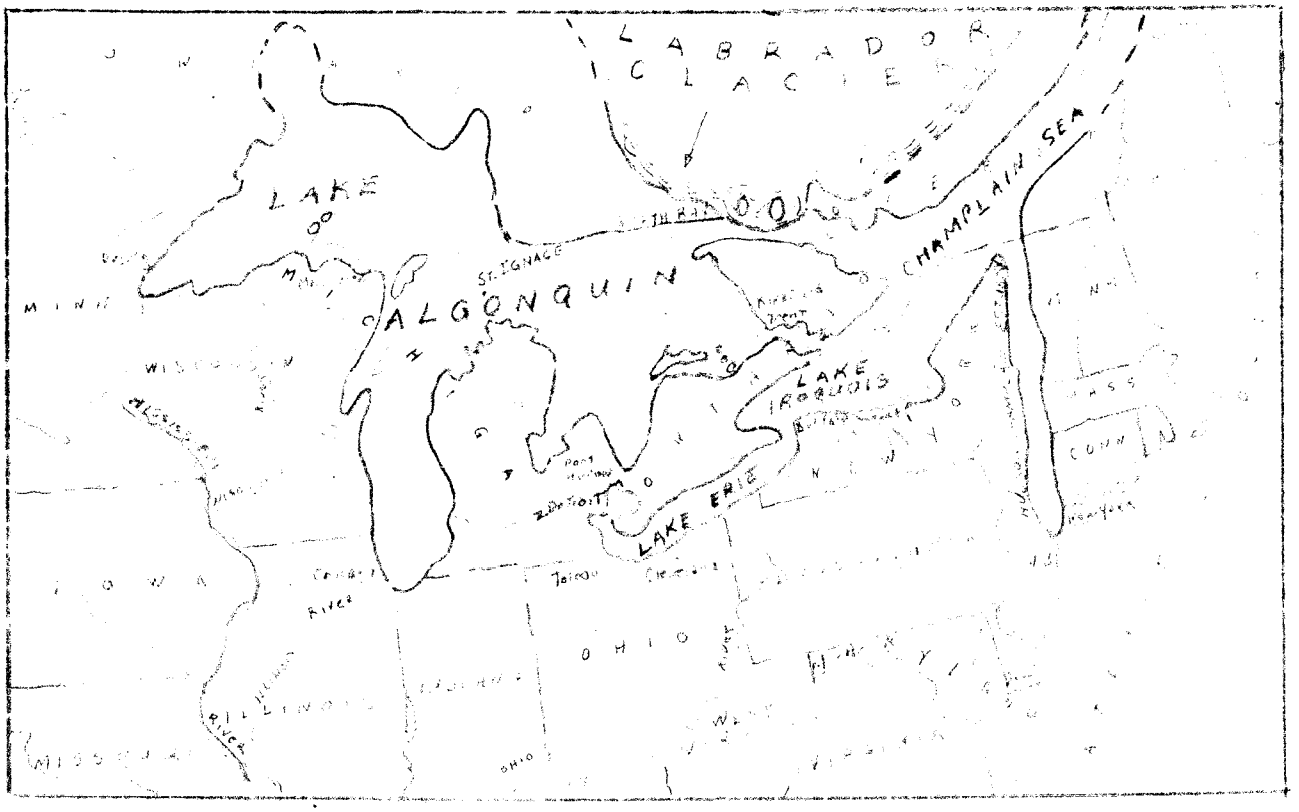
Establishment of the Mackinac River or Submerged Valley

The great ice age began about a million years ago and completely altered the face of Michigan. In order to amass such a quantity of ice, estimated to have been a mile or more thick over portions of Michigan, it was necessary for water levels throughout the world to be drastically lowered by evaporation and the moisture carried to growing ice field centers south of the Hudson Bay area by wind circulation and deposition. Thus, an episode of land emergence resulted with companion erosional forces leaching and dissolving -- weathering the rocks of exposed areas. The movement of glaciers into Michigan increased compaction of the brecciated area by pressures which may have exceeded 130 tons per square foot. Glaciers moved into Michigan

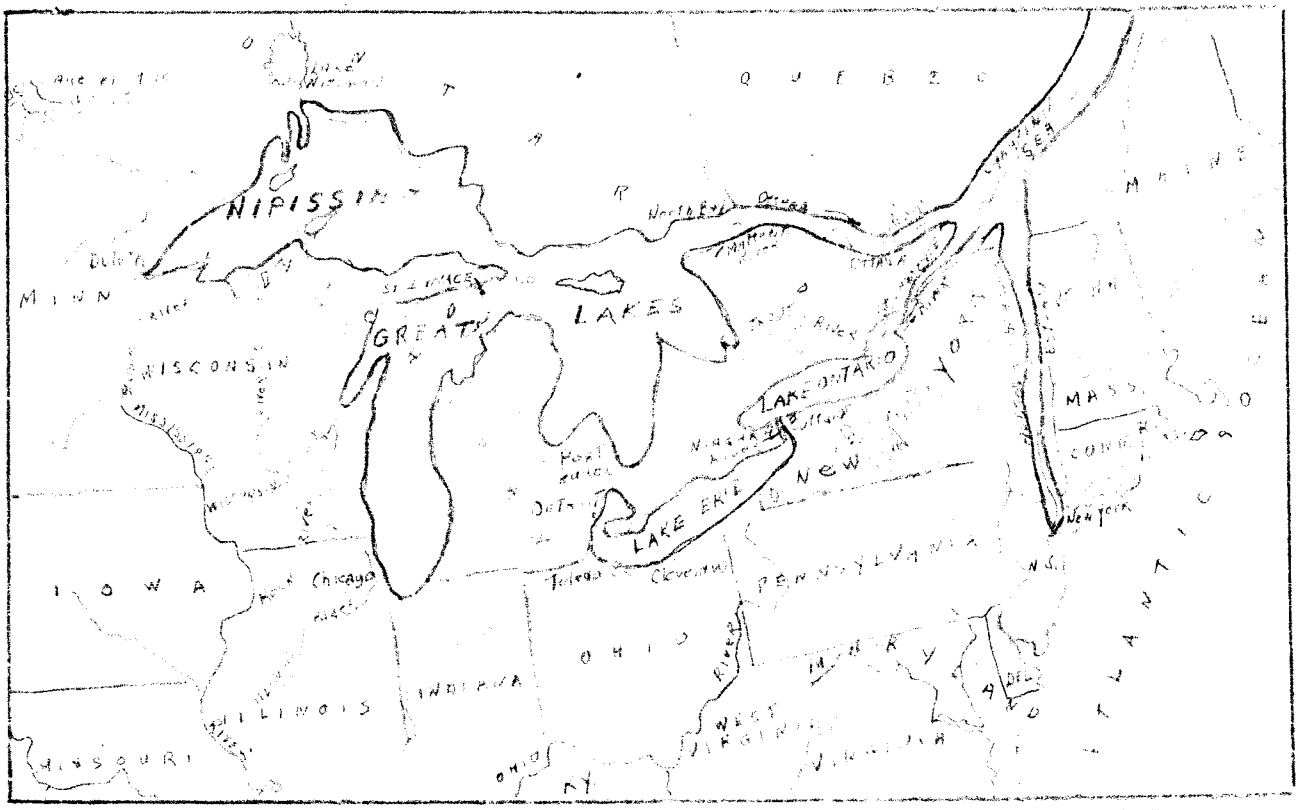
by way of established waterways; that is, moving southward via river valleys, now the Lake Michigan and Lake Huron basins. Some down-cutting of the valley through the Straits region may have preceded the onslaught of the glaciers.

The erratic pulsating retreat of the last glaciers from the Great Lakes area caused the development of numerous glacial lakes or lake systems. During a low water stage between Glacial Lake Algonquin (Figure 2) and Glacial Lake Nipissing (Figure 3) the Submerged Valley (G. M. Stanley, 1938) or Mackinac River (J. L. Hough, 1955) was completed while taking the waters of Lake Chippewa from the basin of present Lake Michigan to Lake Stanley in the Huron basin and thence to the Atlantic by way of North Bay, Ontario, and the Ottawa and St. Lawrence valleys. Numerous beaches, sea stacks, sea caves, terraces and cliffs testify to the activity of Glacial Lakes Algonquin and Nipissing in the Straits region. An upwarping of the northern lakes region began late in Algonquin time - the result of glacial abandonment of the Great Lakes area. With the uplift of the land mass and the North Bay outlet, water levels gradually rose to the Nipissing stage and then stabilized for some time before uplift again occurred and established the present system of Great Lakes. The long period of time during which the Straits area was above lake level and withstanding the forces of erosion was, therefore, followed by an age of submersion and recementation that existed during Pleistocene and Recent times.

The exploratory program across the Straits of Mackinac was



[illegible] 2. — [illegible]
The [illegible] transition [illegible] Algonquin: Outlets through Great River and Ottawa River to the Champlain Sea; [illegible] of the St. Lawrence Valley [illegible] Iroquois; independent Lake Erie. From Lantic After [illegible]

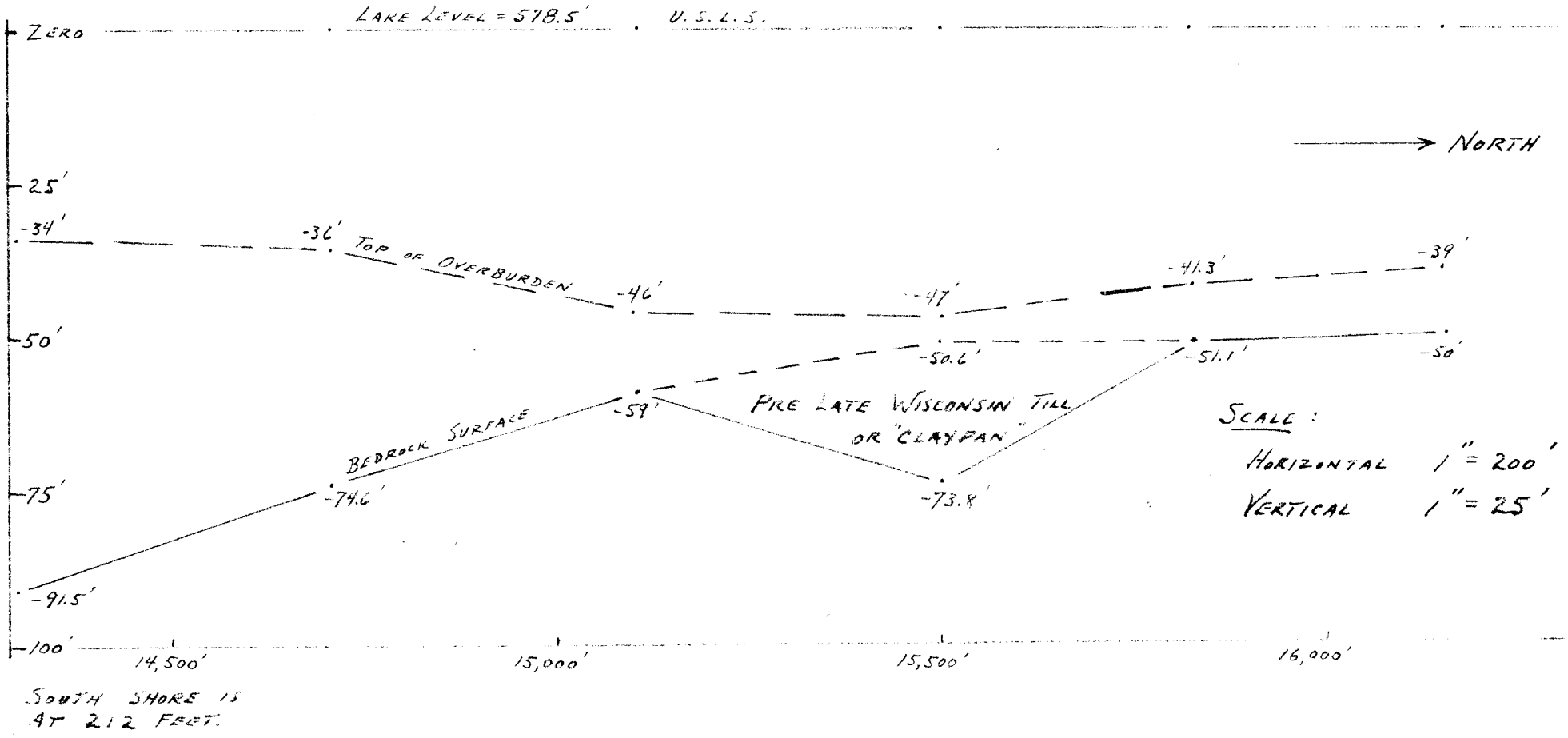


[illegible] 3. — [illegible]
The North Bay or Ottawa River outlet of the Nipissing Lakes; the St. Lawrence River outlet of Ontario [illegible] to the Champlain Sea. From Lantic After [illegible]

extensive and it seems fitting to here point out two discoveries that materially aid in the dating of the cutting of the Submerged Valley. First, evidence of pre-late Wisconsin till was found one mile from the north shore, when core drilling encountered 23 feet of glacial till or "claypan," a reddish-brown, very hard, pebbly material. This till bottomed at a depth of 74 feet on bedrock and was trapped between high bedrock to south and north (Figure 4). Secondly, preliminary rock probings at a point 1.8 miles south of the north shore (and south of the location of the North Tower Pier) revealed an extremely irregular surface. After making eighty-one probings to bedrock, it was established that a sea stack (Figure 5) was there buried under a hundred feet of mud, clay, sand and gravel. The base of the south face is at a depth of 226' below water level and the top of the "stack" is at 185', a near vertical drop of 41' in a horizontal distance of 7'. One hundred feet south of the "stack" the bedrock surface has decreased only 6', to a depth of 232'. This establishes a new low Algonquin (post-Payette) beach at present depth of 230' (60' below the Payette level or 250' below the highest Algonquin beach), or 430' before uplift, and extends the level of Glacial Lake Stanley considerably lower. Borings and probings established no other "stack-like" conditions.

The Bois Blanc Formation

This formation rests on the St. Ignace and dips basinward at an average rate of 55' per mile (40' to 70' measured). The formation was penetrated 142' by the exploratory drilling but no marker beds were located. The lithologic contrast, however, between the



D. B. STEINMAN, CONSULTING ENGINEER

MACKINAC BRIDGE - BEDROCK PROFILE

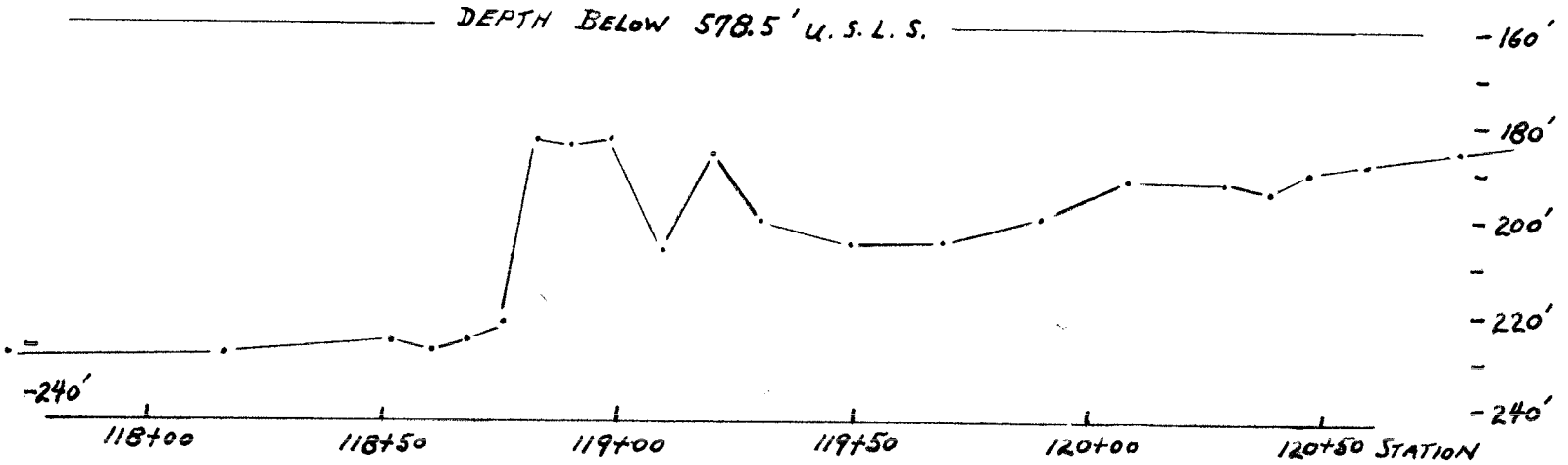
ALONG CENTERLINE.

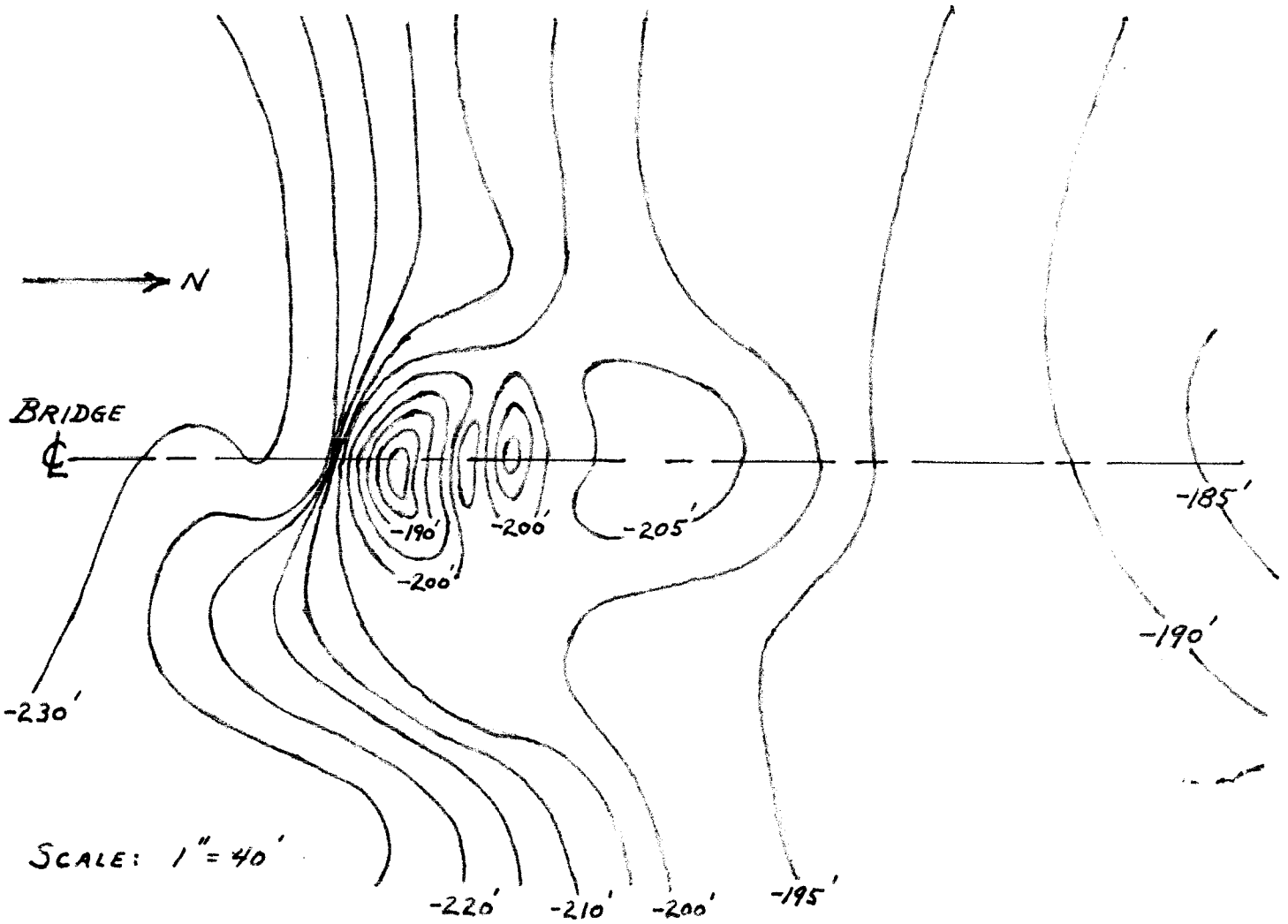
FIGURE 4

NOTE:
ELEVATIONS DETERMINED BY PROBINGS AND DIAMOND DRILL CORE BORINGS.

J. C. ROSENAU,
RESIDENT GEOLOGIST
MARCH, 1956

D. B. STEINMAN, CONSULTING ENGINEER
MACKINAC BRIDGE
BEDROCK PLAN AND PROFILE





NOTE: PLAN AND PROFILE BASED ON PROBINGS MADE IN JUNE, 1954.

Figure 5.

J. C. ROSENAU,
RESIDENT GEOLOGIST
MARCH, 1956

base of the Bois Blanc and the top of the St. Ignace is sharp and readily found (Figure 6). Although the cherty dolomitic limestones making up the Bois Blanc Formation showed definite signs of having been fractured, there is ample evidence of recementation and none of solution cavities. The drillers occasionally reported seams of clay which are believed to be the buff-argillaceous, soft material defined as clay-carbonate (a rottenstone or argillite) in the logs of the borings. Whether or not the Bois Blanc underwent an actual collapse, in the area under the Straits, is impossible to state from the core borings. No faults or areas of vertical displacement were located, and although the base of the formation is somewhat irregular, classification as a "disconformable contact" is not unreasonable. The Bois Blanc rocks are tough and resistant enough to have served as the caprock for the highland between the major and secondary valleys (Figure 1).

The St. Ignace Formation

This formation is 203' thick at the Mackinac Bridge and was the most extensively drilled formation, as it is the foundation rock for 68 per cent of the piers. It consists of dolomitic limestone, shale, shaly limestones, "stack" or secondary limestone and areas of breccia. The upper 75' is generally free of the brecciated "stack" condition and is topped by a 20-foot massive dolomitic limestone bed that is easily recovered by core drilling. A 4-foot zone of gray shale and shaly limestone with gray-black, banded, chert-nodule-fragments, was found 135' from the top of the formation. Immediately beneath it is a 10-foot area of thinly-bedded, pale-orange, dolomitic limestone that contains many

D. B. STEINMAN, CONSULTING ENGINEER
MACKINAC BRIDGE

GENERALIZED STRATIGRAPHIC COLUMN OF BEDROCK
PENETRATED CROSSING THE STRAITS OF MACKINAC

System	Group	Formation	Graphic Column	Footage	Bedrock Description	Comments
Devonian	Onesquethaw	Bois Blanc		142	142 ft. gray and yellowish-gray, very cherty dolomitic limestone, fossiliferous. Some thin seams of soft, argillaceous material. Many small fractures in limestone and chert filled with calcite.	Core recovery generally poor and badly broken. Very difficult drilling.
SILURIAN	Bass Island	St. Ignace			20 ft. pale-orange, massive crystalline dolomitic limestone, fossiliferous. Top 3 to 6 ft. of unit is oolitic.	Good to excellent core recovery.
					115 ft. yellowish-gray, fine-grained dolomitic limestones. Many acicular and rod-shaped calcite inclusions. Quartz oolites in irregular seams through top half of unit. Shaly seams in lower portion. Much secondary or "Stack" type limestone and limestone breccias present in lower half of unit.	Poor to fair core recovery.
					4 ft. gray shale and shaly limestone with included chert breccia. Chert fragments, gray and black banded with subvitreous luster, nodular.	Core recovery fair. This chert is unlike that found in the Bois Blanc formation.
					10 ft. pale-orange, fine-grained, thin-bedded, dolomitic limestone w/ small spherical calcite inclusions.	Good to excellent core recovery.
				203	54 ft. yellowish-gray to lt. brown, fine-grained dolomitic limestones with rod-shaped calcite inclusions, small spherical cavities and bituminous partings. Some "Stack" limestone and limestone breccia.	Poor to fair core recovery.
	Salina	Pointe Aux Chenes			50 ft. mottled green and red shale w/ thin Gypsum seams.	
				114	64 ft. interbedded lt. brown to brown dolomitic limestones and red and green shales. Thin Gypsum seams	Fair to good core recovery.

Figure 6.

March, 1956

small spherical calcite inclusions. These served as the St. Ignace Formation marker beds. They have an average southerly dip of 52' per mile. The accompanying exaggerated bedrock profile chart (Figure 1) shows the correlations made. From Pier 18 north to Pier 26 (inclusive) correlation of the St. Ignace was not attained. This may be due to poor core recovery, caused by the contrasting hardness and condition of the rock penetrated, or may be due to the amount of vertical displacement, or to brecciation, or most probably a combination of these. At the South Cable Bent Pier an ancient fault zone must separate two borings which show very dissimilar lithologies. The west side (represented by boring 18-B2, 114' west of 18-B1) appears to be the down-thrown side. Such obvious dissimilar conditions were not observed elsewhere.

Solution cavities thought to occur in the St. Ignace Formation and in the "stack" areas prevalent throughout the St. Ignace Formation were not found. Although the formation was once badly broken and contained much void space it has obviously been thoroughly cemented by secondary lime deposition. This fact was substantiated by pressure grouting and unconfined compression tests conducted on the rock (Figure 7) and by the study of surface outcrops and the core drillers' reports.

The Pointe Aux Chenes Formation

This formation has been penetrated at only 3 locations: (1) by borings made near the North Tower Pier, (2) at the north shore, and (3) while drilling two water wells located 700' north of the shore. No marker beds were identified but the first red shale

D. B. STEINMAN, CONSULTING ENGINEER
MACKINAC BRIDGE

February 6, 1956

UNCONFINED COMPRESSIVE STRENGTH TESTS

Pier	Boring Number	Core Sample Elev.	Core Size Dia. x Length	Sample Characteristics	Failure Lbs./sq.in.	Failure Tons/sq.ft.	Breaking Characteristics
4	4-B1	-35.0	2-1/8" x 4-1/4"	Dolomite and chert: bedded, fine-grained, hardness-5 to 7	11,938	860	Shattered, many splintery vertical fractures
9	9-B1	-153.0	2-1/8" x 4-1/4"	Dolomitic Limestone: finely crystalline, dense, hardness-4 to 5	9,410	678	Vertical fractures
17	17-B2	-93.0	2" x 4"	Dolomitic Limestone: saccharoidal, porous, vertical calcite seam, hardness -4	8,280	596	Vertical fractures, no failure on calcite seam
17	17-G2	-98.0	2" x 4"	Dolomitic Limestone: finely crystalline, slightly porous, calcite inclusions, hardness-4	7,006	504	Vertical fractures
19	19-B3	-218.0	2-1/8" x 4-1/4"	Dolomite: fine-grained, dense, hardness-4	11,235	809	Vertical fractures
20	20-B1	-232.6	2" x 4"	Limy-Shale: hardness-2	----	----	Parted along bedding while handling
21	21-B1	-69.0	2-1/8" x 4-1/4"	Limestone: finely crystalline, small solution cavities, hardness-4	5,477	394	Vertical and transverse fractures
22	22-B1	-135.5	2-1/8" x 4-1/4"	Shaly-Limestone: fine-grained, hardness -2½ to 3	4,494	324	Shattered, wedge-like
25	25-SB1	-66.0	2-1/8" x 4-1/4"	Clay-pan: calcareous, pebbly, hardness-2 to 3	2,387	172	Vertical fractures
28	28-B1	-67.5	2" x 4"	Shaly-Limestone: finegrained, hardness-2½ to 3	8,917	642	Shattered, with conical break
33	33-B1	-57.0	2-1/8" x 4-1/4"	Clay-carbonate Breccia: chalky, hardness-2 to 3	3,511	253	Shattered, with conical break
34	34-B1	-65.0	2-1/8" x 4-1/4"	Dolomitic Limestone: fine-grained, calcite inclusions, hardness-3 to 4	8,427	607	Vertical fractures

encountered (or red and blue-green mottled shale) was used for marking the top of the formation. Available information is not adequate for determination of regional dip, but it is sufficient to say that the deep valley or gorge separating Mackinaw City and St. Ignace was cut down into Pointe Aux Chenes rock.

None of the piers of the Mackinac Bridge is founded directly on the shales of this formation. The nearest approach to contact is under the North Tower Pier where a minimum of 28' of St. Ignace rock overlies the Pointe Aux Chenes, and it is interesting to note that the load distribution under the North Tower Pier places only a small fraction (approximately 6 tons/sq. ft.) of the total weight on the Pointe Aux Chenes shales -- shale capable of carrying up to 60 tons/sq. ft., as demonstrated by tests conducted by McLaughlin & Housel and reported in 1951.

General Data

Forty-three (43) exploratory diamond drill core borings, two inches or greater in diameter, were drilled, logged and analyzed during 1954 and 1955; they varied in length between twenty and fifty feet. These were supplemented by six (6) extra borings made beneath the anchorages in order to check the effects of pressure grouting; they were also logged and analyzed. The completed logs with pertinent data sheets are submitted separately.

The reports and logs of the ten (10) diamond drill core borings made in 1939 for the Michigan Highway Department, and described by O. F. Poindexter and L. Hale of the Michigan Geological Survey, were used; as was the information obtained from the

water well driller, W. A. Litzner of St. Ignace, who drilled two (2) deep holes at the site of the American Bridge field office on the north shore.

The data obtained through the probings of 1939 and 1954 were utilized as was much information obtained during actual construction. Inspections of numerous outcrops in the region of the Straits of Mackinac were also made.

Unconfined compressive strength tests were made on twelve (12) bedrock core samples in an effort to determine at least the relative strengths of the sedimentary rocks underlying the piers of the Mackinac Bridge. At least one sample of most of the rock variations encountered was tested and these included the recemented dolomitic-limestones, the breccias and the "stack" limestones with proportionately large void areas. The results of these tests are tabulated and shown as Figure 7. All material tested was air dry and at room temperature and the standard method for capping and testing of concrete cylinders was carefully followed.

Acknowledgments

Conferences with geologists and engineers materially aided the project. Most outstanding were the efforts of the late Professor S. G. Bergquist*, Glacialogist and Department Head, Michigan State University, East Lansing, Michigan; Professor W. S. Housel, Research Consultant, Michigan State Highway Department, Ann Arbor, Michigan; Robert F. Legget, Engineering Geologist and Director, National Research Council, Ottawa, Canada; Helen M. Martin, Research Geologist, Michigan Geological Survey, Lansing,

*Dec'd Mar. 31, 1956

Michigan; W. W. McLaughlin, Chief, Testing and Research Division, Michigan State Highway Department, Lansing, Michigan; and J. S. Steel, Mining Engineer, Oliver Iron Mining Division of U. S. Steel Corporation, Duluth, Minnesota.

Conclusion

In conclusion, it is clear that the data available -- including the 51 borings observed, the voluminous reports and the tests conducted -- leave no doubt as to the condition of the rock formations directly beneath the piers; that the bedrock areas explored are well cemented and formed into substantially one mass containing no significant voids and no caverns. The rock tested has much greater strength than needed to withstand the moderate pressures to be imposed by the structure, even under the most adverse climatic conditions.

Respectfully submitted,

Jack C. Rosenau
Resident Geologist

St. Ignace, Michigan
April 20, 1956

References

Publications and reports referred to during the period of drilling and research include the following:

Soil Samples on Range "A", Exhibit Q, submitted by: The Testing & Research Division, Michigan Highway Department, January 1939.

Report on Soil Boring Results, General Data and Rock Conditions, Mackinac Straits Bridge, Exhibit S, July 31, 1939.

Preliminary Report on Straits of Mackinac Drilling. Exhibit A; submitted by: Geological Survey Division, Department of Conservation, Lansing, Michigan, December 1939.

"Ne-Saw-Je-Won" by H. M. Martin, 1939.

Report on Test Borings for Mackinac Straits Bridge, Exhibit R; submitted by: The Michigan Highway Department, Testing Division, February 1940.

Report on Clay Overburden Borings on Line A for Mackinac Straits Bridge; submitted by: Testing Division, Michigan State Highway Department, April 1940.

Geology of the Mackinac Straits Region, Michigan Department of Conservation, Geological Survey Division, Publication 44, 1945, by K. K. Landes, G. M. Ehlers and G. M. Stanley.

Outline of Glacial Geology, 1946, by F. T. Thwaites, University of Wisconsin.

Sheet 12 Final Geological Report

Pleistocene and Early Paleozoic of the Eastern Part of the Northern Peninsula of Michigan, June 1948; publication of: The Annual Geological Excursion of the Michigan Academy of Arts, Sciences and Letters and the Michigan Geological Society.

Proposed Mackinac Straits Bridge, Preliminary Report. January 10, 1951.

Engineering Report on Mackinac Straits Bridge, Amended December 9, 1953, containing the reports of the Consulting Geologists, Berkey and Paige, and the Engineering Consultants, W. W. McLaughlin and W. S. Housel.

Report on Settlement of the Mackinac Straits Bridge Causeway, St. Ignace, Michigan; submitted by: Soil Mechanics Laboratory, Michigan State Highway Department, June 1954.

Lake Chippewa, a Low Stage of Lake Michigan, by J. L. Hough, University of Illinois; Geological Society of America, Bulletin Number 8, Volume 66, August 1955.