A Geochemical Reconnaissance for Gold in the Sedimentary Rocks of the Great Lakes Region, Minnesota to New York

GEOLOGICAL SURVEY BULLETIN 1305

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By DAVID A. SEELAND

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Atomic-absorption analyses indicate an absence of fossil placers and relatively abundant but noneconomic amounts of gold of syngenetic chemical(?) origin in marble and glauconitic sandstone

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CONTENTS

ILLUSTRATIONS

TABLES

A GEOCHEMICAL RECONNAISSANCE FOR GOLD IN THE SEDIMENTARY ROCKS OF THE GREAT LAKES REGION, MINNESOTA TO NEW YORK

By David A. Seeland

ABSTRACT

Fossil placers were sought in the Precambrian and Paleozoic sedimentary rocks of the Great Lakes region of the North Central United States. The gold-mining area of the Canadian Shield north of the Great Lakes was postulated to be a primary source of particulate gold that should have been carried down the southward-dipping paleoslope into the Great Lakes region by fluvial and marine currents. However, of 777 10-gram samples analyzed by cold extraction–atomic absorption (lower limit of detection, 0.020 part per million gold) and 22 10-gram samples analyzed by fire assay (lower limit of detection, 0.025 part per million), only 36 (4.8 percent) had detectable gold; and in the 36 samples the modal gold content was only 0.020 part per million. An overall arithmetic mean of 0.0087 part per million gold for the 799 analyzed samples was calculated by use of a statistical technique applicable to data in which there is a large proportion of samples in the "not-detected" class. Inasmuch as 95-percent censoring extends the technique to its limits, the mean should be accepted with reservations.

The arithmetic mean of 0.0087 part per million gold is so small that the presence or absence of a single minute flake of gold in a sample gives results that are, respectively, too high or zero. Because of this problem, meaningful gold analyses or gradients were not obtained. A possible, but impracticable, solution to the problem would be the collection of samples weighing 120 kilograms and the separation and analysis of the heavy-mineral fraction.

The relative amounts of gold in each of the sampled rock types can be estimated by comparing the percentage of samples that contain detectable gold for each rock type. The percentage of gold found in the sampled rock types that contained gold follows: nonglauconitic sandstone, 1.0; shale, 3.1; limestone and dolomite, 3.3; conglomerate and conglomeratic sandstone, 6.7; glauconitic sandstone, 16.7; and marble, 24. Glauconitic sandstone samples are from the Franconia Sandstone in Wisconsin, and the marble samples are from the Grenville Series in the Adirondack Mountains in New York. Gold was also detected in gypsum and halite samples, but the sample size was too small for the percentage to be significant.

The frequency with which gold was detected in the chemical rocks of the region suggests the possibility that certain undetermined syngenetic chemical processes have concentrated anomalous amounts of gold in rocks of chemical origin. These chemical processes may be more effective concentrators of gold than the expected placer-forming physical processes, even in a region relatively close to a source of clastic gold. Possibly, also, the general lack of gold and the small grain size of the gold that was found (less than 5 percent of the hydraulic equivalent size in the nonglauconitic sandstone-quartzite category) are results of postdepositional leaching.

The apparent abundance of chemically or biochemically precipitated gold and the relative lack of clastic gold in a region close to a major gold source could also be explained by the presence of an east-west late Precambrian–early Palezoic continental divide just north of the Great Lakes separating a known south- and southeast-trending paleocurrent system from a

probable north-trending system. Most Canadian Shield gold deposits would lie north of this divide, and the logical place to look for fossil placers would then be in the basal Paleozoic clastic rocks near James Bay.

INTRODUCTION

The project was initiated in hopes of finding fossil gold placers in the clastic rocks of the Great Lakes region. The postulated source for the fossil placers is the rich Canadian Shield Precambrian gold area north of the Great Lakes. Canada at one time supplied about 13 percent of the world's annual gold production (Bateman, 1950, p. 437), and about 80 percent of this production was from just north of the Great Lakes in western Quebec and Ontario.

Prior to Mississippian time the Canadian Shield was the chief source of clastics for the area from Minnesota to northern New York; during and after the Mississippian, the northern Appalachian Mountains were a major source of clastics for the Illinois and Michigan basins and adjacent areas, and the Canadian Shield was a minor source area (Potter and Pryor, 1961, p. 1226). Paleocurrents inferred from crossbed orientations determined during the study confirm the general southerly transport direction in the Great Lakes region during the early Paleozoic. Divergences from this general trend are present. In northern New York on the northwestern margin of the Adirondack Mountains, crossbed orientations indicate an easterly, or Adirondack Mountains, source for the Cambrian Potsdam Sandstone. In contrast, on the northeastern and eastern margins of the Adirondack Mountains, crossbedding indicates a northerly to northwesterly source area for the Potsdam.

Late Precambrian–Cambrian paleocurrents of the United States and western Canada were perpendicular to the continental margins, and they transported sand radially from the interior toward the ocean basins (Seeland, 1969, p. 271). Then, by analogy, there were northerly currents along the north edge of the continent which were separated from the generally southerly currents of the Great Lakes region by a continental divide. If this divide was north of the major gold deposits of the Canadian Shield, fossil placers could exist in the sedimentary rocks of the Great Lakes region. If the postulated divide was south of the major gold deposits, fossil placers very likely could not exist on the southern margin of the Canadian Shield.

An initial reconnaissance sampling of the clastic sedimentary rocks of the region determined the feasibility of establishing gradients of gold abundance in one or more of the formations sampled. Because gold was detected in only 9 of the 204 original samples, gradients clearly could not be obtained from unconcentrated samples of these clastic rocks. As analytical results on additional rock types were obtained, it slowly became evident that quartzose clastic rocks contained less gold than chemical and biogenic rocks, such as marble, limestone, and glauconitic sandstone.

Samples were collected in Minnesota, Wisconsin, Michigan, Iowa, Illinois, Missouri, Kentucky, Ohio, Pennsylvania, Virginia, and New York (fig. 1). Chip samples were collected at most outcrops. Channel samples were taken in poorly cemented rocks. The field samples were reduced, if too large, to several hundred grams; these were ground to pass through a No. 100 U.S. Standard sieve mesh (less than 0.149 mm), and a 10-g (gram) split was analyzed for gold. The lower limit of detection was 0.020 ppm gold for the 777 10-g samples analyzed by solvent extraction–atomic absorption techniques (Lakin and Nakagawa, 1965) and 0.025 ppm gold for the 22 samples analyzed by fire-assay methods.

The locality, stratigraphic unit, lithology, and gold analyses for all samples collected during the field investigations have been tabulated previously (Seeland, 1973).

A problem related to that of analytical sensitivity is the problem of analyzing for low concentrations of particulate gold where the analytical results depend on the presence or absence of a gold particle rather than on the actual gold content of the rock unit from which the sample was collected. This problem has been termed the particle-sparsity effect by Clifton, Hubert, and Phillips (1967, p. 2); papers by Clifton, Hunter, Swanson, and Phillips (1969) and Tourtelot (1968) provide a basis for evaluating its effect on this study. Because nearly half the samples collected were sandstone, the particle-sparsity effect is applied to the analytical results for sandstone.

Jones (1969, p. 22) reported neutron-activation analyses of 24 sandstone samples from 9 different areas in which the gold content averaged 0.0075 ppm and ranged from 0.0006 to 0.041 ppm. DeGrazia and Haskin (1964, p. 562) analyzed five sandstone and quartzite samples for gold by a neutron-activation technique and arrived at a "characteristic" gold content of 0.006 ppm after discarding a sandstone sample (0.041 ppm) from the Kettleman Hills, "a placer deposit."

The minimum sample size necessary to obtain statistically reliable results is based on the number of gold grains which in turn is based on the weight of the grains and the gold content of the rock.

The diameter of a gold sphere hydraulically equivalent to medium sand (0.37 mm) is 0.075 mm (Tourtelot, 1968, fig. 1). If it is assumed that a gold flake with a 5:1 ratio of diameter to thickness represents the actual shape of the gold grain, it can then be determined that the hydraulic equivalent of the the 0.075-mm gold sphere is a flake 0.13 mm in diameter and 0.026 mm thick (Tourtelot, 1968, fig. 3) which weighs about 6×10^{-6} g.

To determine background values of gold as low as 0.001 ppm in sandstone containing gold particles weighing about 6×10^{-6} g, a 120-kg sample containing 20 gold grains is required for 95-percent certainty that the true gold content varies no more than 50 percent from the analytical results obtained (Clifton and others, 1969, fig. 3). This is clearly impractical for a reconnaissance effort, inasmuch as 799 samples that each weigh 120 kg (264 lb) weigh 95,700 kg (211,000 lb) in aggregate, and the rock would have to be ground and the gold separated prior to analysis.

Although the samples may be too small for reliable results, limits can be put on the gold content and gold-particle size of the sampled nonglauconitic sandstone and quartzite units. Assuming that the gold flakes are the 6×10^{-6}-g hydraulic equivalents of medium sand and that the sampled units contain the 0.006 ppm gold thought by DeGrazia and Haskin (1964, p. 562) to be characteristic of sandstone, then in 100 samples of 10 g each, 1 sample will contain an entire flake of gold; this is quite close to the 1 in 104 nonglauconitic sandstone samples that actually do contain detectable gold. However, a 6×10^{-6}-g gold flake in a 10-g sample amounts to 0.6 ppm gold, whereas a 10-g sample with 0.031 ppm gold (the mean for three positive analyses from 312 nonglauconitic sandstone and quartzite samples) contains a gold particle that is only 5 percent as large as the hydraulic equivalent size if it is assumed (1) that each positive analysis is due to a single flake of gold (probably true in many cases), and (2) that all flakes are large enough to have been detected at the lower limit of detection (possible but not probable). As a result of the second assumption, the calculated mean particle size is likely to be too large. This combination of assumptions and analytical results also permits calculation of a minimum mean gold concentration of 0.0003 ppm in the sampled nonglauconitic sandstone and quartzite units. In summary, the mean gold content of the nonglauconitic sandstone and quartzite units sampled is greater than 0.0003 ppm but less than 0.031 ppm, and individual gold particles weigh less than 3×10^{-7} g, or less than 5 percent of the hydraulic equivalent size.

The validity of the difference between the apparent and the calculated hydraulic equivalent gold-particle size might be questioned because the samples are ground to minus 100 mesh before analysis, but experimental evidence of John C. Antweiler of the U.S. Geological Survey (oral commun., 1971) shows that grinding, with the techniques used for these samples, is unlikely to have appreciably reduced the gold particle size.

The positive analytical results from sand-size or coarser clastic samples should therefore be viewed as a maximum values or perhaps only as qualitative indicators that a rock unit does contain gold. Conversely, negative analytical results can mean either that the rock unit represented by the sample has no gold or that the analytical split did not contain a detectable gold particle. Also, analyses of small samples containing clastic gold may not be comparable to analyses of small samples containing chemically precipitated gold, because chemically deposited gold particles probably are much finer and, therefore, are more likely to occur in a given analytical sample.

Another possible approach to the estimation of gold abundance is statistical. Miesch (1967) described a method combining techniques of

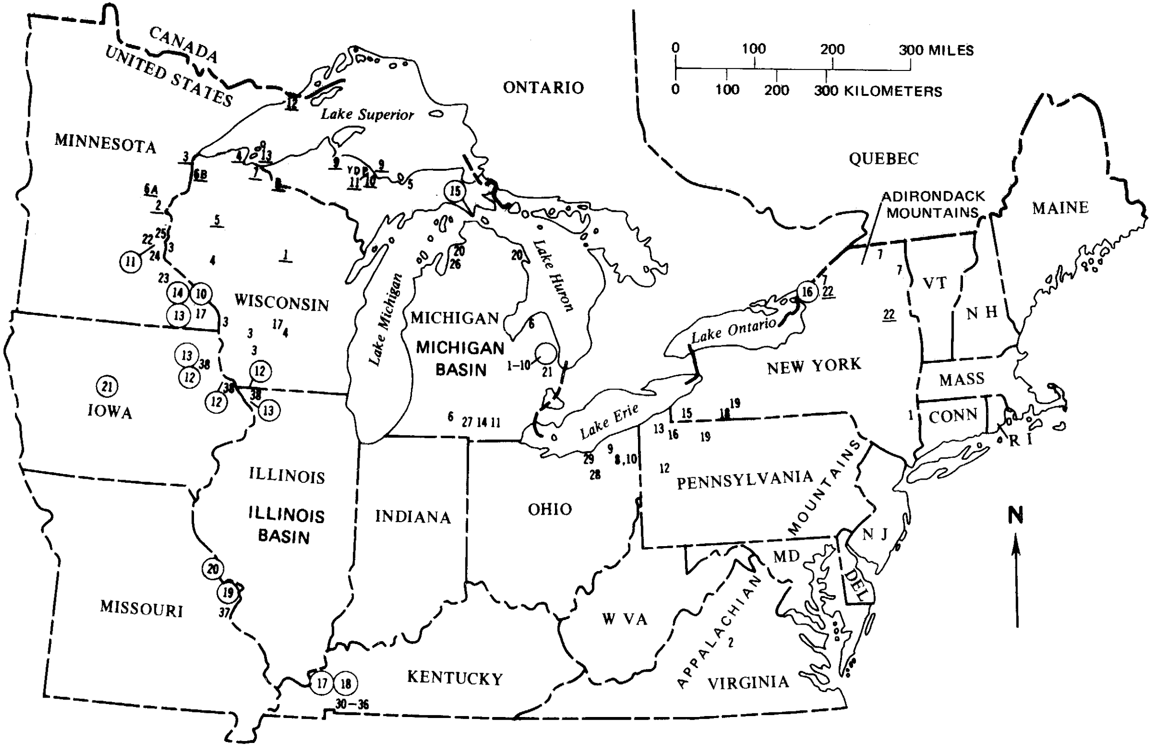

FIGURE 1. — Map of Northeastern United States, showing sampling areas. Number only, Paleozoic clastic rocks; circled number, Paleozoic and Precambrian chemical rocks; underscored number, Precambrian clastic rocks; YDP, Yellow Dog Plains. Locality numbers are referred to in tables 1 and 2.

Sichel (1952) and Cohen (1959, 1961) by which the mean can be efficiently estimated even when a large fraction of the data is in the not-detected class. The 36 analytical values obtained by the analysis of 799 samples plot as a straight line on probability paper, indicating that the data are log normal. The data are strongly left censored because the gold content of 95 percent of the samples was below the limit of detection. Cohen (1961, p. 538) tabulated the factor λ as a function of the degree of censoring (h) and of another calculated quantity; however, h is tabulated between 0.01 and 0.90, and since $h=0.954$ for the data of this report, λ was obtained by graphical nonlinear extrapolation. Because the degree of censoring is outside the range tabulated by Cohen, some doubt is cast on the calculated overall arithmetic mean gold concentration of 0.0087 ppm for the 799 samples. In addition to certain computational difficulties, the overall arithmetic mean gold concentration was biased by collection of additional samples from units found to contain relatively more gold.

ACKNOWLEDGMENTS

The project was conceived by Walter S. White, who together with Robert H. Muench and the author, planned and executed the initial sampling in 1966. Willard P. Puffett led us to some outcrops of Precambrian clastic rocks in Michigan. Wallace DeWitt spent 2 weeks during 1967 sampling the Olean Conglomerate Member of the Pottsville Formation in Pennsylvania and New York. C. E. Brown provided locations of basal Maquoketa Shale outcrops in Iowa. The Michigan Geological Survey provided cuttings and a stratigraphic log of the dry James Spencer 1 oil test well.

CLASTIC ROCKS

PRECAMBRIAN CLASTIC ROCKS

The sampled Precambrian clastic rocks are listed in table 1, which also gives the number of samples, the approximate sampling locality, and the results of all positive gold analyses. The sampling areas are also indicated in figure 1.

Analysis of a sample of slate from the Precambrian Thomson Slate in Carlton, about 10 miles southwest of Duluth, Minn., showed 3.0 ppm gold, the highest gold concentration found in any of the samples from the Great Lakes region. However, three other splits of the same sample had less than 0.02 ppm gold. Negative analytical results (less than 0.02 ppm) for 17 additional samples of the Thomson in the vicinity of Carlton suggest that the 3.0-ppm value may have been a single flake of gold, either natural or a "ring scrape" (the outcrop is nearly vertical, next to a street, and only about 100 yards from the Carlton High School).

Of the 10 samples of the Marshall Hill Conglomerate collected along the Wisconsin River west of Brokaw, Wis., one had detectable gold (0.3 ppm). Gold was detected in only one (0.03 ppm gold) of the three samples of the

TABLE 1. — *Gold content of clastic rocks of the Great Lakes region*

Sampling area	Locality (fig. 1)[1]	Formation	Number of samples analyzed	Gold content (ppm) of individual samples[2]
		Precambrian clastic rocks		
Wisconsin:				
Central northern	1	Marshall Hill conglomerate of Weidman (1917) (volcanic fragments in sericitic matrix).	10	[3]0.3
Northern	7	Keeweenawan Series (sandstone and conglomerate).	8	---
	4	Bayfield Group (sandstone).	14	---
Northwestern	5	Barron Quartzite	12	---
Wisconsin and Minnesota:				
Near west end of Lake Superior.	6	Fond du Lac Sandstone of Winchell (1899) (sandstone, conglomerate, and pyritic conglomerate).	19	.03 .05
Minnesota:				
East central	2	Hinckley Sandstone	12	---
	3	Thomson Slate of Spurr (1894).	18	3.0(?)
Northeastern	12	Puckwunge Formation of Winchell (1897) (conglomerate).	11	---
Michigan:				
Northern	8	Palms Quartzite (conglomerate).	7	---
	9	Jacobsville Sandstone[4]	16	---
	10	Goodrich Quartzite	4	---
	11	Ajibik Quartzite	2	---
	11	Enchantment Lake	1	---
	13	Copper Harbor Conglomerate.	6	---
		Paleozoic clastic rocks		
Minnesota:				
Southeastern	22	Glenwood Shale	9	---
	23	St. Peter Sandstone	5	---
	24	Decorah Shale	3	---
	25	Jordan Sandstone	2	---
Wisconsin:				
Southwestern	3	Franconia Sandstone ("greensand" and very glauconitic sandstone).	30	0.027, 0.03, 0.02, 0.04, 0.04
	3	Franconia Sandstone (slightly glauconitic sandstone).	16	---
	4	Dresbach Group	14	.1
Illinois-Iowa-Wisconsin.	38	Maquoketa Shale (shale).	25	---
Wisconsin and Minnesota.	17	St. Lawrence Formation (dolomite).	1	---
Michigan:				
Upper peninsula	5	Munising Sandstone	14	.027
Lower peninsula	20	Antrim Shale (black shale).	2	---
	26	Ellsworth Shale	2	---
	6	Marshall Formation (sandstone).	7	---
	11	Napolean Sandstone Member of Marshall Formation.	3	---
	14	Parma Sandstone	1	---
	21	Clinton Formation (shale).	1	---
Ohio:				
Northern	28	Chagrin Shale	1	---
	29	Ohio Shale (black shale).	4	.02
Northeastern	8	Sunbury Shale (black shale).	1	---
	9	Sharon Member of Pottsville Formation (conglomerate).	3	---
	10	Berea Sandstone	9	---

TABLE 1 — *Gold content of clastic rocks of the Great Lakes region* — Continued

Sampling area	Locality (fig. 1)[1]	Formation	Number of samples analyzed	Gold content (ppm) of individual samples[2]
		Paleozoic clastic rocks — Continued		
Pennsylvania:				
Northwestern	12	Shenango Formation (sandstone).	3	---
	13	Le Boeuf Conglomerate Member of Tesmer (1958) of Cattaraugus Formation.	4	---
	16	Amity Shale of Chadwick (1925).	1	---
Pennsylvania and New York.	19	Olean Conglomerate Member of Pottsville Formation.	109	0.2, 0.2, 0.06
New York:				
Southwestern	15	Panama Conglomerate Lentil of Cattaraugus Formation.	1	---
	18	Corry Sandstone	3	---
Southeastern	1	Poughquag Quartzite	1	---
Northern	7	Potsdam Sandstone	111	0.04, 0.02, 0.02, 0.04
Virginia:				
Northern	2	Weverton Quartzite	2	---
Kentucky:				
Western	30	Chattanooga Shale (black shale).	3	---
	31	Caseyville Formation (conglomerate).	6	---
	32	Palestine Sandstone	1	---
	33	Tar Springs Sandstone	1	---
	34	Hardinsburg Sandstone	1	---
	35	Cypress Sandstone	1	---
	36	Bethel Sandstone	1	---
Missouri:				
Central eastern	37	Bushberg Sandstone Member of Sulphur Springs Formation.	1	---

[1]Single locality numbers usually refer to areas, not a specific site; multiple numbers outline larger sampling areas.
[2]Individual positive analytical results in excess of lower limit of detection: 0.02 ppm for the 97 percent of samples analyzed by solvent extraction—atomic absorption method and 0.025 ppm for the 3 percent of samples analyzed by fire assay—atomic absorption bead method. Dashes indicate lack of detectable gold.
[3]Of the 10 samples analyzed, 1 had 0.3 ppm Au, 9 had less than 0.02 ppm Au.
[4]Since preparation of this report Jacobsville is considered to be of Cambrian and (or) Precambrian age.

Precambrian Z Fond du Lac Sandstone collected on the Snake River near Woodland, Minn., and in one (0.05 ppm gold) of the eight samples from the basal Fond du Lac in Jay Cooke State Park (Morey, 1967, p. 2) near Duluth, Minn.

PALEOZOIC CLASTIC ROCKS

From the Paleozoic clastic rocks 403 samples were collected from 37 formations in Minnesota, Wisconsin, Michigan, Pennsylvania, New York, Iowa, Illinois, Missouri, Virginia, and Kentucky. Rock types sampled were sandstone, glauconitic sandstone, shale, conglomeratic sandstone, siltstone, and pyritic shale. Of the 403 samples, 15 contained detectable gold. The formations sampled, the sampling areas, number of samples analyzed for gold, and the analytical results are presented in table 1. Figure 1 shows sampling areas for each unit.

Of the 111 Potsdam Sandstone samples analyzed, 4 samples (2 conglomeratic and 2 nonconglomeratic) had at least 0.02 ppm gold. Only 8.5 percent of the analyzed Potsdam samples were conglomeratic, so the conglomeratic portions appear to be relatively more favorable.

Of the 14 samples analyzed from the Mount Simon Sandstone of the Dresbach Group in Wisconsin, 3 were conglomeratic sandstone, and only 1 of these had detectable gold. A possible correlative of the Mount Simon is the Chapel Rock Member (Hamblin, 1958) of the Munising Formation in northern Michigan (Hamblin, 1958, p. 114). From the Chapel Rock, 4 conglomerate samples and 10 sandstone samples were analyzed; 1 conglomerate sample had 0.027 ppm gold.

In summary, 141 basal Cambrian samples were analyzed, and of these 6 contained 0.02 ppm or more gold. Conglomeratic samples accounted for 4 of the 6 positive results.

Glauconitic sandstone from the Franconia Sandstone of Late Cambrian age in southwestern Wisconsin had more than 0.020 ppm gold in 5 of 30 samples analyzed. A much higher proportion of samples from the Franconia contained detectable gold than samples from other nonconglomeratic Cambrian sandstones.

Gold was detected in four other Paleozoic clastic samples; three were from the Pennsylvanian Olean Conglomerate Member of the Pottsville Formation in New York and Pennsylvania (0.060, 0.20, 0.20 ppm gold), and one was from a 1.5-inch pyrite bed in the Devonian Ohio Shale in Cleveland, Ohio (0.02 ppm gold). However, only 2.7 percent of the Olean samples and 5.5 percent of the black shale samples had detectable gold.

Neutron-activation analyses, reported by Bradbury, Hester, and Ruch (1970), of 38 black shale and 3 sandstone samples from Illinois were all negative; however, the lower limit of detection was very high, averaging 0.184 ppm for the black shale samples and 0.063 ppm for the sandstone samples.

PLEISTOCENE CLASTIC SEDIMENTS

The sands of the Yellow Dog Plains, a kame terrace near Marquette, Mich. (Segerstrom, 1964, p. C126), are locally reputed to contain appreciable gold. However, panned heavy-mineral concentrates from 32 sand and pebbly sand samples all contained less than 0.020 ppm gold. No gold colors were seen in the pan concentrates.

Bradbury, Hester, and Ruch (1970, p. 13) reported that gold was not positively detected in 27 heavy-mineral concentrates from glacial sand and gravel deposits and associated river alluvium in Illinois. Although the actual presence of gold could not be confirmed, they stated that the highest possible concentration on the basis of their analyses would be 0.04 ppm.

CHEMICAL ROCKS

PRECAMBRIAN CARBONATE ROCKS

The Precambrian carbonate rocks consist entirely of marble and calc-silicate rocks of the Grenville Series which crop out in the Adirondack Mountains of northern New York. The Grenville Series consists of coarsely crystalline marble, local dolomitic beds, quartzites, gneisses, amphibolitic

TABLE 2. — *Gold content of chemical rocks of the Great Lakes region*

Sampling area	Locality (fig. 1)[1]	Formation	Number of samples analyzed	Gold content (ppm) of individual samples[2]
Minnesota:				
Southeastern	10	Trempealeau Formation (limestone).	1	---
	11	Platteville Limestone	12	---
	14	Prairie du Chien Group (dolomite).	8	---
Iowa:				
Central	21	Fort Dodge Gypsum of McGee (1884).	2	---
Missouri:				
East-central	19	Kimmswick Limestone	2	---
	20	Callaway Limestone	1	---
Illinois-Iowa-Wisconsin.	12	Maquoketa Shale (basal phosphatic and carbonaceous rock).	32	0.02
Illinois-Iowa-Minnesota.	13	Galena Dolomite (limestone).	15	---
Michigan:				
Eastern[3]	1	Traverse Group (limestone and shale).	5	---
		Dundee Limestone	2	.03
		Detroit River Group (anhydrite and dolomite).	13	.02
		Bois Blanc Formation (dolomitic limestone).	1	---
		Bass Islands Dolomite	1	---
		Salina and Niagara Groups (dolomite, halite, and shale).	22	0.06, 0.03
		Cataract Formation (limestone and shale).	2	---
		Cincinnatian Series (limestone and shale).	2	---
		Trenton Limestone and Black River Group (limestone).	7	---
		Trempealeau Formation (limestone).	1	---
Upper Peninsula	15	Mackinac Breccia of Douglas (1839) (limestone and dolomite).	1	---
New York:				
Northern	16	Theresa Dolomite	1	---
	22	Grenville Series (marble).	46	0.02, 0.02, 0.02 0.20, 0.10, 0.02 0.08, 0.04, 0.04 0.02, 0.02
Kentucky:				
Western	17	Fredonia Oolite Member of Ste. Genevieve Limestone.	2	.02
	18	Fort Payne Formation (chert).	1	---

[1]Single locality numbers usually refer to areas, not a specific site; multiple numbers outline larger sampling areas.
[2]Individual positive analytical results in excess of lower limit of detection: 0.02 ppm for the 97 percent of samples analyzed by solvent extraction—atomic absorption method and 0.025 ppm for the 3 percent of samples analyzed by fire assay—atomic absorption bead method. Dashes indicate lack of detectable gold.
[3]From dry James Spencer 1 oil test well, Sanilac County.

layers, migmatites, and granulites (Buddington, 1939, p. 11). Outcrops were selected that were dominantly marble, and samples were collected from the most carbonate-rich part of each outcrop. Of the 50 samples analyzed, 46 were marble and 4 were more siliceous metamorphic rocks. Of the 46 marble samples analyzed, 11 contained detectable gold, in amounts that ranged from 0.020 to 0.20 ppm and averaged 0.052 ppm (table 2). Gold was found in a greater proportion of the samples from the Grenville marble than from any other sample group. Grenville marble samples can be separated by area into northwestern Adirondack and eastern Adirondack groups (fig. 1). The northwestern group had a higher proportion of samples containing detectable gold than did the eastern group (1 of 3.7 compared to 1 of 5.3). Jones (1969, p. 22) found that marble has the lowest and highest gold values (0.0009 and 0.022 ppm) of metamorphic rocks analyzed by neutron-activation analysis.

PALEOZOIC CHEMICAL ROCKS

The Paleozoic chemical rocks sampled and analyzed are listed in table 2 and located in figure 1. Some are outcrop samples; the remainder are cuttings, provided by the Michigan Geological Survey, of formations penetrated by the dry James Spencer 1 oil test well (loc. 1−10), Sanilac County, southern Michigan.

Only chemical rocks from the James Spencer 1 had detectable gold. Gold concentrations in excess of 0.20 ppm were found in one sample of each of these units: Dundee Limestone, 0.03 ppm (finely crystalline limestone with shale lenses; lithologic descriptions from Michigan Geological Survey records); Detroit River Group, 0.02 ppm (anhydrite); Niagara and Salina Groups, 0.06 ppm (halite) and 0.03 ppm (limestone, brown to dark-brown, finely crystalline, streaks of carbonaceous material).

A sample of the Fredonia Oolite Member of the Ste. Genevieve Limestone from Caldwell County (loc. 17), western Kentucky, had 0.02 ppm gold.

Hershey (1899) reported gold in the phosphatic, locally pyritic and (or) carbonaceous, "depauperate zone" at the base of the Upper Ordovician Maquoketa Shale near Pearl City and Eleroy in northwestern Illinois. Near Pearl City a shaft mentioned by Hershey is caved, and there is no depauperate-zone float on the surface in the vicinity of the shaft. Near Eleroy the basal Maquoketa was mined for paint pigment in the late 1800's and again in the 1930's. Carbonaceous basal Maquoketa float, probably from the mine, had less than 0.020 ppm gold in the 2 samples analyzed. In the present investigation an additional 30 samples of the basal Maquoketa were collected in Iowa and Illinois. Of these, 1 phosphatic sample from the Cooney quarry, 4 miles east of Elgin, Iowa, contained 0.020 ppm gold; no other samples contained detectable gold.

SUMMARY AND CONCLUSIONS

The sedimentary rocks of the Great Lakes region contain very little gold in spite of their proximity to the gold-rich Precambrian shield rocks of Canada. The analytical results must be evaluated qualitatively, for the most part, because they are strongly influenced by the particle-sparsity effect (Clifton and others, 1967). Analytical results based on small samples of clastic rocks containing near-background amounts of particulate gold are not representative of the gold values that might be expected in large bulk samples. If the analytical sample happens to have only one gold particle, the results may be too high; if the sample has no gold particles, a likely occurrence, obviously no gold will be detected, and the results may be too low. The particle-sparsity effect could have been circumvented only by collection of large samples (about 120 kg), followed by separation and analysis of the heavy-mineral fraction. This procedure was quite impractical for a reconnaissance effort, and therefore the analytical results must be interpreted with much caution.

Because of the particle-sparsity effect, a particular analytical result from one of the unconcentrated 10-g samples of this study, such as 0.050 ppm gold in a sandstone, does not mean that the unit from which this sample was collected has 0.050 ppm gold, but it does indicate that the unit represented by the sample contains some gold. The proportion of gold-containing samples from a particular geologic unit may indicate the relative amount of gold in that unit, especially if compared to units represented by samples with similar gold values.

Though outcrops and units having detectable gold were resampled, more than 95 percent of the rock samples had less gold than the limit of detection, which was 0.025 ppm for 22 samples analyzed by fire assay and 0.020 ppm for 777 samples analyzed by solvent extraction—atomic absorption techniques. The distribution of gold values is strongly left censored (fig. 2) and log normal. The mean gold content is thus obviously less than the lower limit of detection. A statistical technique for estimating the mean of censored distributions (Miesch, 1967) such as presented by the data of this report was used to calculate an overall arithmetic mean gold concentration of 0.0087 ppm for the sampled rocks.

Marble from the Grenville Series and sandstone from the Franconia, Mount Simon, and Fond du Lac Sandstones had significantly greater proportions of samples with detectable gold than the other formations sampled. Table 3 lists the rock types found to contain detectable amounts of gold together with the number of samples analyzed and the number and percentage with detectable gold. Obviously if only a few samples of a rock type are analyzed, as was true of the gypsum-anhydrite and halite

TABLE 3. — *Number, percentage, and mean gold content of analyzed samples with detectable gold by rock type*

	Number of samples	Number of samples with detectable gold	Percentage of samples with detectable gold	Mean gold content (ppm) of samples with detectable gold
Nonglauconitic sandstone	314	3	0.96	0.031
Shale	64	2	3.1	.020
Limestone-dolomite	92	3	3.3	.027
Conglomerate and conglomeratic sandstone	137	9	6.7	.111
Halite	8	1	12.5	.061
Gypsum-anhydrite	8	1	12.5	.020
Glauconitic sandstone	30	5	16.7	.031
Marble	46	11	24.0	.053

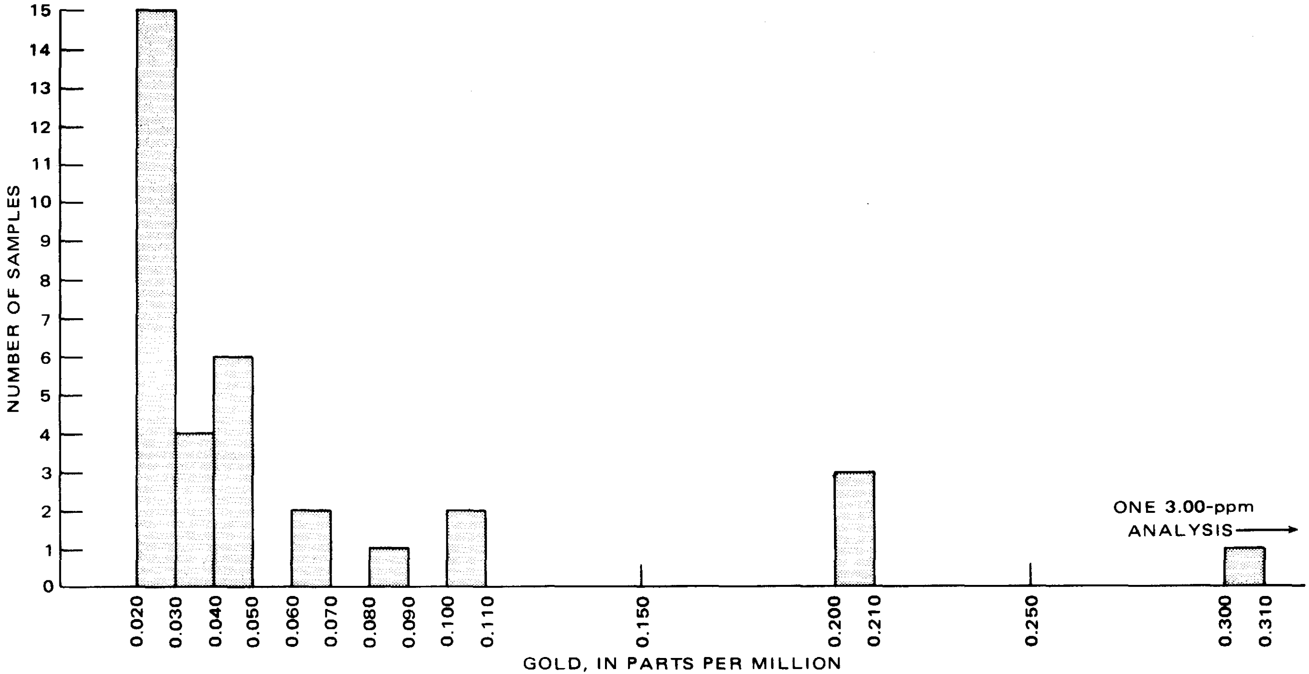

FIGURE 2. — Frequency distribution of gold in analyzed sedimentary rocks from the Great Lakes region.

categories, a high percentage of samples with detectable gold is not particularly significant. Interestingly, however, Jones (1969, p. 22) believed that analyses for gold in gypsum and rock salt reported in 1897 and 1911 are suspiciously high (gypsum: 0.083, 0.083 ppm; rock salt: 0.097, 0.100, 0.1, <0.003, 0.12 ppm). Table 3 suggests that the gold in marble is finer grained than gold in conglomerate and conglomeratic sandstone because a greater percentage of the marble samples contained detectable gold but their mean gold content was lower.

Positive gold analyses were obtained from a larger proportion of conglomerate and conglomeratic sandstone samples (6.7 percent) than from nonglauconitic sandstone samples (0.96 percent); moreover, of the samples with detectable gold, conglomerate and conglomeratic sandstone samples had a mean gold content of 0.111 ppm, whereas nonglauconitic sandstone samples had a mean content of only 0.031 ppm. These differences are probably partly of hydrodynamic origin; the currents that deposited the conglomerates were more competent and could carry larger flakes of gold than the currents that deposited the sandstone. Another factor of possible significance is that conglomerates are more likely to be single-cycle sediments than sandstones and, therefore, to have an igneous rather than a sedimentary source. Finally, many basal Cambrian conglomerate samples that were collected overlie "basement" rocks that could be gold sources, whereas the sandstones are stratigraphically higher, and possible primary gold sources to the north likely were covered at the time of sandstone deposition.

There were 30 glauconitic Franconia Sandstone samples, of which 5, or 16.7 percent, contained detectable gold, whereas there were 283 nonglauconitic sandstone samples, of which 3, or 1.1 percent, contained detectable gold. It is very likely that nondetrital — that is, chemical — deposition of gold somehow related to the glauconite content of the Franconia accounts for this striking difference. Syngenetic chemical deposition in the limestone-dolomite, halite, and gypsum-anhydrite categories is also postulated to be important, although the number of positive values in each of these categories is very small.

·Also, that the gold in some of the clastic rocks possibly is of chemical origin is suggested by the fact that the gold in the nonglauconitic sandstone category is less than 5 percent as large as the hydraulic equivalent size. However, presence of substantially more gold in the conglomerate and conglomeratic sandstone (table 3) argues against this hypothesis. It is possible to explain both the lack of gold and the apparently small particle size of gold that is present by postulating that gold, once in appreciable amounts in most of the rocks, was partially leached from those that did not have a protective chemical or physical environment.

Less clear is the origin of the gold in the Grenville marble, which could be syngenetic chemical or even detrital. The gold could also be secondary and related to the post-Grenville granitic igneous rocks of the Adirondack region.

If an east-west late Precambrian–early Paleozoic continental divide was located south of most of the Canadian Shield gold deposits, then the meagerness of gold in the sedimentary rocks of the Great Lakes region most likely is the result of paleogeographic factors, and if fossil placers derived from Canadian Shield gold deposits are to be found, they would be in the basal Paleozoic rocks of the James Bay region. However, if the divide was north of these gold deposits — the assumption made at the start of the search for fossil placers — then one must conclude that syngenetic processes of undetermined nature have concentrated anomalous amounts of gold in rocks of chemical or biochemical origin, and that even in a region relatively close to a gold source, these chemical processes are more effective concentrators of gold than the physical processes that are expected to form fossil placers.

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