SEDIMENTARY ANALYSIS OF
THE MIDDLE DEVONIAN SYLVANIA SANDSTONE
IN THE MICHIGAN BASIN

by

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of the requirements for the degree of
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ABSTRACT

The tectonics, facies, and paleogeography of Devonian rocks in the Michigan basin are not well known. This study of the Sylvania sandstone affords a good opportunity to evaluate older concepts relative to the additional information presented.

Previous work on the Sylvania sandstone in Michigan and Ohio is briefly reviewed, and some of the concepts of other workers appear in the text.

The analysis of the Sylvania sandstone was partially chemical and partially mechanical. The results of the analysis are presented as contour maps which show the distribution of the constituents in lower Michigan.

The data from the analysis and the known stratigraphy and paleogeography were used to modify the geological history as conceived by other writers.

The study showed the Sylvania sandstone to be marine in origin. The principle source area supplying the sand was southeast of Michigan.

It was difficult to name the agent responsible for carrying the Sylvania sand into the Sylvania sea; but, nevertheless, once the sand was deposited in the marine sea, waves and currents were most important in distributing, reworking, and sorting the sand.

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INTRODUCTION

Purpose of Study

This study was conducted in an attempt to determine the origin of the Sylvania sandstone of the Michigan Basin. The problems to be answered by an analysis of the Sylvania sandstone are: 1) the depositional environment of the sandstone, 2) the type and location of the area supplying the sediment, and 3) the geological history as it can be deduced from the composition, and physical properties of the Sylvania rocks, and from the formations position relative to other beds.

Landes (1951) states that:

> The general practice of geologists in describing the subsurface stratigraphic section in the Michigan basin between the Dundee formation and the Bass Island and Salina formations is to refer to the evaporite sequence of rocks within the Detroit River group as the "Detroit River" and the underlying carbonate rocks as the "Sylvania formation" which overlies the "Sylvania sandstone" where present.

So the reader will not become confused, the use of the terms "Sylvania sandstone" or "Sylvania formation" in this study is restricted to the sandy phase bounded above and below by carbonates. This sandy phase is the "Sylvania sandstone" referred to by Landes.

PREVIOUS WORK

The origin and age of the Sylvania sandstone have been under discussion for many years. Newberry (1870), working in Ohio, correlated a white, 20 foot bed of sandstone, generally lacking in fossils with the Oriskany sandstone, the lowest member of the Devonian in New York. This sandstone was later named Sylvania by Edward Orton in 1888, State Geologist of Ohio. Grabau and Sherzer (1907) presented evidence for an eolian origin of the Sylvania sandstone. They spoke of a new fauna of late Siluric age with Devonian affinities in higher beds. Sherzer and Grabau (1908, pp.540-553) placed the Sylvania in the Silurian and showed that the strata contained upper "Siluric" fauna with precessive "Devonic" forms, and that the Sylvania was not the equivalent of the Devonian Oriskany sandstone. Carman (1927, pp.481-506) concluded that the Sylvania was stratigraphly and faunally so closely related to the overlying Detroit River group that whatever age is assigned to the Detroit River that the Sylvania sandstone should go with it. On faunal evidence, Carman concluded that the base of the Sylvania was the Devonian-Silurian systemic boundry in Ohio.

Stella W. Alty (1932, pp.289-300) studied the heavy mineral content of the Sylvania both subsurface and surface in Michigan, as well as outcrops in Ohio. Alty pointed out that at Sylvania Ohio, a more varied suite of heavy minerals existed, and that they were slightly more plentiful than at the Rockwood and Steiner outcrops in Michigan. Carman (1936, pp.253-266) working in northwestern Ohio, felt that the Sylvania represented the basal member of the Detroit River group in a transgressive overlap by the Sylvania sea to the southeast. He gave as evidence the fact that the fauna becomes younger to the south.

Enyert (1949), on the basis of the heavy minerals, concluded that the Sylvania was a wind-transported, water-reworked sand, carried east from the Wisconsin Highlands into the Sylvania sea. Landes (1951) based his conclusion of a wind-blown origin for the Sylvania sandstone largely on Enyert's study. Landes also proposed that Sylvania be assigned to the lower-middle Devonian and that it should be considered the basal member the Amhersburg formation. Landes also states that it is the general consensus of most practicing geologists to consider the Sylvania as a marine sand having an origin similar to modern beach and barrier sand, with currents selectively transporting the sand to the deposition site.

STRATIGRAPHY

The Sylvania sandstone has a linear pattern which extends from the southwest portion of Michigan well into the northern half of the lower peninsula where it ends in Roscommon County. This sandy unit thins quite rapidly east and west and grades laterally into carbonates. Where ever the Sylvania can be identified it lies between carbonates. The Sylvania formation grades upward with diminishing sand content and without a sharp break into the Amherstburg dolomite of the Detroit River group. The Sylvania is considered conformable with the overlying Amherstburg formation (Carman, 1936, Landes et.al. 1945). The conformable relationship with the overlying Detroit River group caused Landes (1951) to propose that the Sylvania be considered the basal member of the Detroit River group. The Sylvania sandstone is overlain by the Amherstburg formation, except in Hillsdale County where the Lucas formation rests directly on the Sylvania (Landes, 1951).

Throughout most of lower Michigan the Sylvania rests unconformably on the Bois Blanc formation. To the east and south, it overlaps the Silurian Bass Island formation (Landes, 1951). According to G. A. Cooper et.al. (1942),

> If this unconformity is followed to its farthest limits of the Michigan basin province, the base of the "Sylvania" basal sand will rise in the column, this far-out "Sylvania" sand is probably to be found in the Pendleton of Indiana, the

> Hillsboro sandstone of southern Ohio, and the Springvale sandstone in the region around Cayuga, Ontario.

In Ohio, where the Sylvania crops out, it rests unconformably on the Bass Island formation. Carman (1936) stated:

> The contact surface has irregularities of only a few inches with sandstone fitting closely down over the irregularities. The contact is sharp, there is no sand in the dolomite below the contact, but above is a pure quartz sandstone. Further, the sandstone has commonly a basal conglomerate, the pebbles of which were derived from the underlying dolomite.

The unconformable relationship of base of the Sylvania is shown (Figure 1) as it exists in lower Michigan. Ehlers (1945), proposed the names Garden Island (Oriskany age) and Bois Blanc for the two formations identified which were found to be older than the Sylvania. The Garden Island and the Bois Blanc have now been incorporated in the Michigan Stratigraphic Column. The nomenclature of the Michigan formations appears in Figure 2.

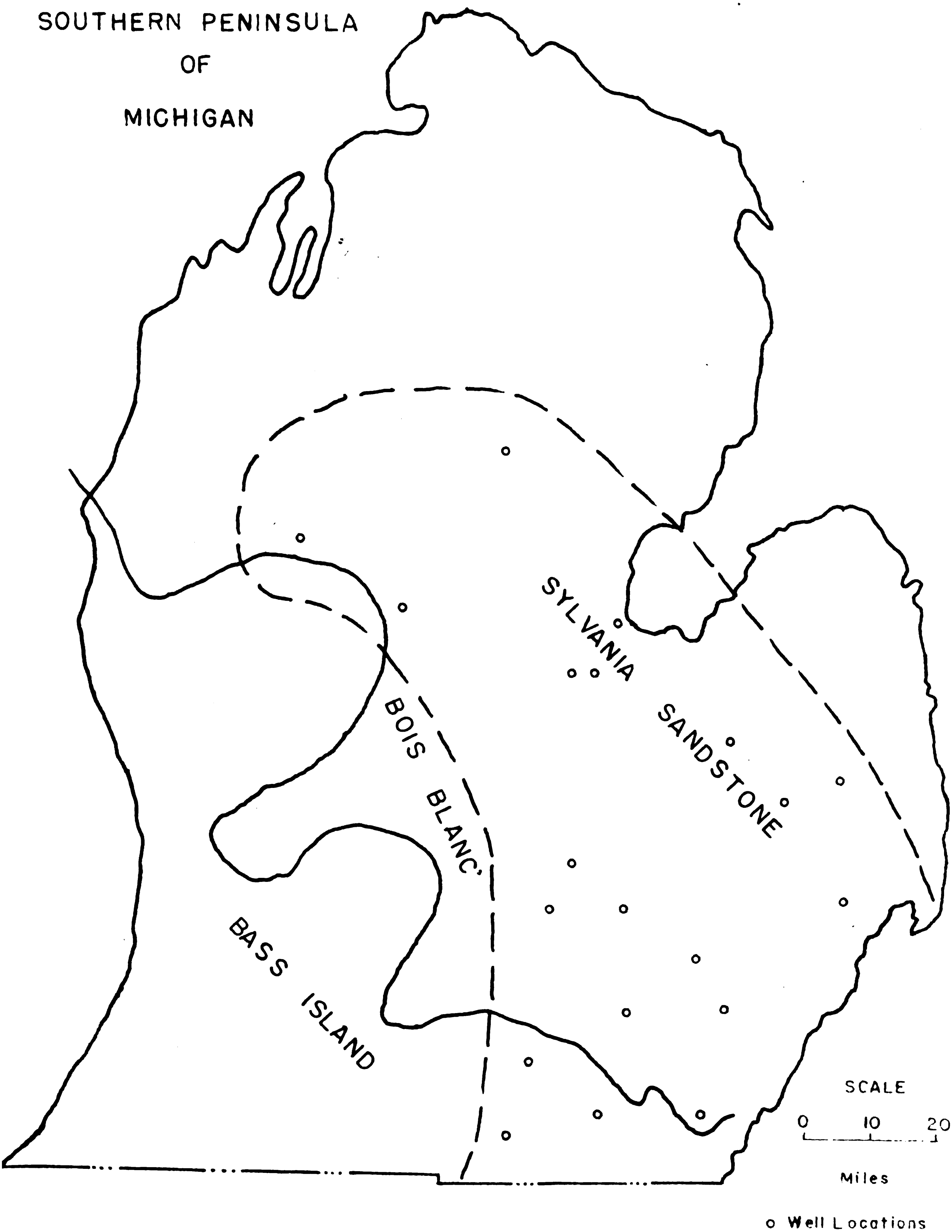
SOUTHERN PENINSULA
OF
MICHIGAN
SYLVANIA
SANDSTONE
BOIS
BLANC
BASS
ISLAND
SCALE
0 10 20
Miles
o Well Locations

Figure 2. - Nomenclature of Michigan Formations

DEVONIAN	MIDDLE	Hamilton	Traverse group	Thunder Bay	Petoskey fm. Charlevoix st. fm.
					Thunder Bay ls. Potter Farm fm. Norway Point fm. Four-Mile Dam ls.
				Alpena	Alpena ls.
					Koehler ls.
					Rockport Quarry ls.
					Bell Shale
					Rogers City fm. Dundee fm.
		Onondaga	Detroit River gr.		Anderdon ls. fm. Lucas dol. fm. Amherstberg dol fm.
			Sylvania fm.		
			Bois Blanc fm.		
	LOWER	Oriskany	Garden Island fm.		
SILURIAN	UPPER	Bass Island fm. Salina fm.	Pt. Aux Chenes		
	MIDDLE	Niagaran	Lockport dol. Clinton fm.		
	LOWER	Cataract fm.	Cabot Head sh. mem. Manitoulin dol. mem.		

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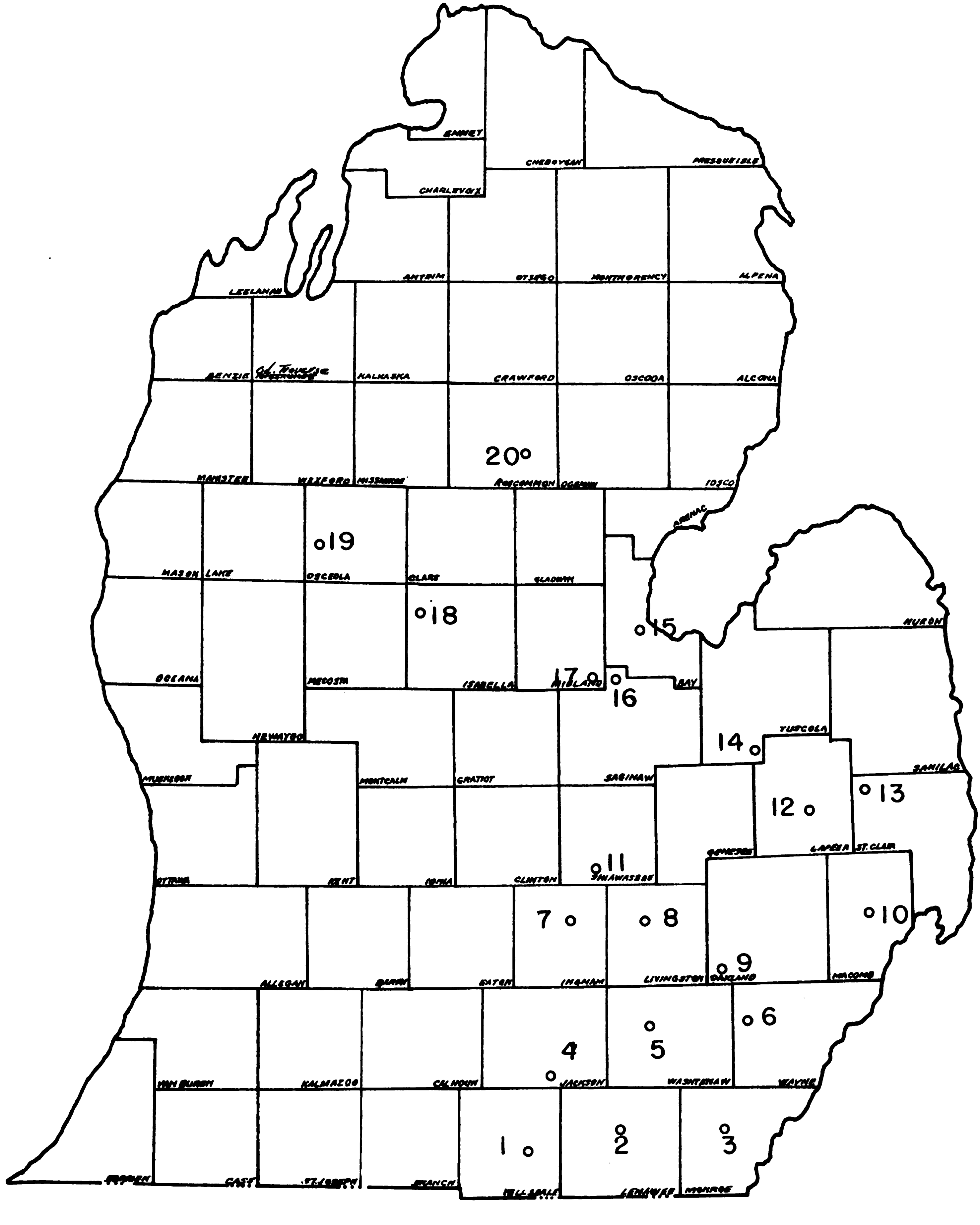
Figure 3.- Location of Wells used in Analysis



SEDIMENTARY ANALYSIS

Purpose

Before the origin of a sedimentary unit can be ascertained, one has to explore and investigate the sedimentary and lithologic characteristics of the unit. The paleogeography at the time of deposition must be explored in the light of the present stratigraphic knowledge and the characteristics of the sedimentary unit. The reconstruction of the paleogeography, consistant with the stratigraphy, structural, and sedimentary data should lead to a high degree of accuracy in interpreting the over-all conditions present and governing the sedimentary unit at the time of deposition.

It is the goal of the writer to determine the origin of the Sylvania sandstone by a quantitative facies and sedimentary analysis of the unit. From the results of the analysis and the present geological information, it is felt that the sedimentary conditions present during Sylvania time can be interpreted with a fair degree of accuracy.

Selection of Wells and Intervals

The wells utilized to obtain the composite samples for this study were obtained from the Michigan Geological Survey, Lansing, Michigan. The spacing of wells from those available was chosen to give the most representative coverage of the area (Figure 3).

The interval selected for study is the sandy Sylvania sequence bounded both above and below by carbonate rocks. The Sylvania sandstone grades upward into carbonate rocks causing the upper contact to be extremely difficult to determine accurately. Robert Ives, Michigan Geological Survey, gave valuable assistance to the author in selecting the interval for study. The top of the unit was picked with the aid of the binocular microscope at the point where the sandy unit could be safely differentiated from the overlying carbonates of the Detroit River group. The bottom of the unit was selected at the top of the underlying Bois Blanc or the top Bass Island formation where the Bois Blanc is missing. The unconformable relationships of these units and the approximate areal distribution of the Sylvania in Michigan is shown in Figure 1. A tabulated list of the wells used in this analysis appears as Table I.

Sylvania Sandstone

The unit studied has been discussed in the literature and described as a "very pure" quartz sand. Carman (1936, p.264) stated:

> The Sylvania is typically a pure quartz sandstone but it shows all gradations from sandstone through dolomitic sandstone and areanceous dolomite to dolomite.

TABLE I

WELLS USED IN ANALYSIS

Sample Number	Permit Number	County	Company, farm, and number	Location: Section	Location: Township	Location: Range	twp
1	18056	Hillsdale	E. Edwin Brehm. V.A.M. Sharp #1	16	7S	2W	Jefferson
2	9766	Lenawee	Adrian Oil & Gas. Dinus #1	24	6S	3E	Lincoln
3	19263	Monroe	Dow Chemical Co. G. Kopka #1	7	6S	7E	Dundee
4	19079	Jackson	McClure Oil Co. Grumper #1	19	4S	1W	Liberty
5	19391	Washtenaw	P. Dongenther. E. Monk #1	33	2S	4E	Lima
6	19379	Wayne	The Petrolia Corp. Fowler #1	7	2S	8E	Canton
7	19011	Ingham	Voorhees Drlg. Co. Glaser #1	14	3N	1E	Wheatfield
8	12603	Livingston	Panhanile Pipeline M.J. McPherson #1	35	3N	4E	Howell
9	19055	Oakland	C. W. Collin. Gowans et al #1	35	1N	7E	Lyon
10	17605	Macomb	Panhandle Eastern. Crawford #1	28	3N	13E	Macomb
11	16736	Shiawassee	Panhandle E. Pipe Line Co. Stephan Nemick #1	23	5N	2E	Perry
12	17786	Lapeer	Brazos Oil & Gas Co. Smith Et. Ox #1	14	7N	11E	Attica
13	18561	St. Clair	Basin Oil Co. Bert Arms #1	20	8N	13E	Lynn
14	20209	Tuscola	Don Rayburn Watchorn & Wells Comm. #1	5	10N	9E	Watertown

TABLE I (CONT.)

WELLS USED IN ANALYSIS

Sample Number	Permit Number	County	Company, farm, and number	Location			twp
				Section	Township	Range	
15	10551	Bay	Gulf Oil Co. Salina #1	34	15N	4E	Kawkawlin
16	Dow#33	Saginaw	Dow Chemical Co. Dow fee #33	6	13N	3E	Titabawassee
17	DC#63	Midland	Dow Chemical Co. Dow salt #63	7	13N	2E	Ingersoll
18	394b	Isabella	Pure Oil Co. Latham #1	35	15N	6W	Sherman
19	12302	Osceola	Ohio Oil Co. P.N. Steadman #3	29	18N	10W	Lincoln
20	13973	Roscommon	Sun Oil Company Meldrum #1	23	22N	2W	Backus

In subsurface sections the Sylvania probably contains more dolomitic cement than where it is exposed to the leaching action of surface waters. The "sand" of the Sylvania is relatively free of impurities but in certain wells considerable chert, silt, and shale were found. Under a binocular microscope the grains appear to be well-rounded with characteristic frosted and pitted surfaces. Many of the grains show secondary enlargement and the development of sharp crystal faces.

Carman (1936), after examining much of the sand with the aid of the petrographic microscope found hundreds of quartz grains but only a few grains of other minerals. Alty (1932), while studing the Sylvania, found a decrease in the amount of heavy minerals from the southeast to the northwest. The author's study verified Alty's work. Several attempts to separate heavy minerals from the sand produced only a few heavy mineral grains. Because of the scarcity of heavy minerals and the limited supply of sample, no heavy mineral study was made. Quartz grains from the subsurface are not as well rounded as those at the outcrops. This characteristic was observed by Newcombe (1933, p.162) and Enyert (1949); the work of the author substantiates this observation. Enyert (1949) found that the Sylvania contained a maximum of 40 per cent dolomite. This study revealed that in places the subsurface Sylvania contains a maximum of 83.10 per cent carbonate.

Chert is found in larger quantities in the subsurface Sylvania than in the outcrops in southeastern Michigan and Ohio. Much of the chert may be attributed to the erosion of underlying cherty Bois Blanc (Landes, 1951). This study revealed that larger amounts of silt and clay size particles were obtained from subsurface samples, than from those taken at the outcrop.

LABORATORY PROCEDURE

Method of Sampling

The well samples utilized for this study came from the Michigan Geological Survey in trays containing about twenty-five vials of sediment representing the drilled interval. Each vial held three to eight grams of cuttings which represented a five foot drilled interval. The contents of each vial was put through a microsplit, the sample was halved or quartered until a little more than a one gram sample remained. This split sample was treated with an electromagnet to remove iron fragments from the drilling tools (which contaminated most samples). At this time, a few large, black shale cavings were removed. The sample was then put into a previously weighed and numbered 400 ml. beaker. Each vial of sediment was treated in the above manner until a composite sample representing the Sylvania from each well was compiled. The composite samples were then dried and weighed to the nearest thousandth of a gram.

Removal of Acid Solubles

With the weight for each of the composite samples known, the acid solubles could now be removed. Each sample was treated several times with 3N hydrochloric acid. When the acid was spent it was siphoned from the beaker and fresh acid applied. When chemical action ceased, the samples were warmed on an electric plate for several hours to insure that all of the solubles were taken into solution. After all the carbonate had dissolved, the acid was siphoned from the beaker, water added, and the sample agitated. The sample was allowed to settle over-night and the water siphoned off. The washing was repeated a second time. The samples were then dried and weighed. The loss of weight from the original weight of the sample was recorded and tabulated as the acid solubles (Table II).

Removal of Clay and Silt

Several hundred milliters of water was added to the samples from which the carbonates had been removed. The samples were then placed on an electric hot plate and allowed to boil. Approximately 50 ml. of ammonium hydroxide was added to the water to help deflocculate the clay particles. The samples were then wet-sieved through the 230 mesh sieve to remove the clay and silt. Examination with aid of the binocular microscope showed aggrates of clay particles still remained. The sample was disaggrated by placing it on a soft pine block and gently rubbing another pine block over the top. This method probably caused less adverse effects than other methods of disaggregation described in the literature. After the second attempt to wet sieve the samples, examination revealed almost perfect removal of the clays. The samples

TABLE II

QUANTITATIVE ANALYSIS

Sample	Per Cent Carbonate	Per Cent Silt & Shale	Per Cent Chert	Per Cent Sand	Total Per Cent
1	77.19	.42	.41	24.19	100.21
2	73.69	4.46	6.48	15.24	99.85
3	65.39	.01	.05	33.70	99.15
4	78.22	1.70	5.63	14.60	100.15
5	75.82	2.69	11.92	9.46	99.89
6	53.34	9.23	3.07	34.11	99.75
7	46.47	11.21	35.07	6.95	99.70
8	66.77	3.87	16.78	12.39	99.81
9	27.45	4.42	3.19	64.64	99.70
10	48.46	1.07	4.14	45.84	99.51
11	71.07	.71	14.62	13.54	99.93
12	61.66	1.66	5.99	30.48	99.79
13	22.56	.26	3.65	72.97	99.44
14	83.10	3.40	5.77	7.58	99.85
15	24.32	.49	22.25	52.75	99.81
16	33.13	4.78	6.72	55.00	99.63
17	28.38	3.01	18.49	50.02	99.90
18	61.99	2.78	26.77	8.33	99.87
19	59.45	4.55	25.34	11.29	100.63
20	66.41	2.76	20.01	10.53	99.71

were then dried and weighed. This loss of weight from the previous weighing represented the clay and silt fraction of the sample.

Separation of Chert and Sand

With the removal of carbonates, clay and silt, from the sample, only sand and chert remained. It was noted that in many samples chert was a major component. It was further observed that the chert varied in texture and color. Some of the weathered chert fragments could probably be considered with the quartz sand and may have had the same origin and sedimentary environment as the quartz. Some chert could have been primary and should not be considered as a part of the detrital sand.

It was decided to separate the chert from the quartz since it was obvious that with such large quantities of chert it could very well mask the true environmental character of the sand. A search of the literature to find an acceptable method for rapidly separating such closely allied substances was to no avail. Experimenting with various concentrations of potassium hydroxide on the theory that the difference in texture might cause the chert to be more soluable than the quartz grains proved, for all practical purposes, unsatisfactory. It was found that solutions of potassium hydroxide strong enough to take chert into solution also dissolved the quartz grains.

A method similar to that used to separate and concentrate ore was tried. It was hoped that differences in the texture and surface area of the chert might bring about a separation of the chert from the quartz sand in flowing water. Based on the assumption that moving water might transport the chert yet allow the quartz grains to settle, a piece of glass apparatus was designed for this experiment. The two substances were placed in the center of the glass elutriater which had the water flowing upward, out the top, and into a catch basin. Some degree of success was accomplished with this rising-water elutriater, but it was still not satisfactory.

The method for separation utilized the differences in optical properties as well as texture of the two substances. After the samples were sieved, a representative sample of each size was mounted on a glass slide in Canada balsm, 200 grains were counted to determine the percentage of the quartz sand and chert. Because of the texture, shape, and amorphous chert, it was easily distinguished from the quartz and other minerals with the aid of the petrographic microscope. This method, of course, did not physically separate the chert from the quartz and some error in determining the over-all composition of the Sylvania may have been introduced at this point. The samples containing much chert generally had 30 to 50 per cent of it larger than 40 mesh, which could be weighed directly. Therefore, most of the chart would not be subject to any error induced by the count method.

SIZE ANALYSIS

Sieve Analysis

After the removal of the silt and clay particles, the remaining chert and quartz was sieved by hand in a nest of U.S. Standard sieves, sizes 40, 60, 80, 100, 120, 140, and 200. The sediment from each sieve was weighed and placed in a small labeled vial. From each of the vials containing the sediment, 300 to 500 grains were mounted on a single glass slide. A frequency count of 200 grains of chert and quartz was then made. With the percentage of chert and quartz known, the amount by weight of each mineral was determined from the total weight of the particular sieve size. The weights of the sand fractions computed in this manner could then be plotted on two stage semi-logarithmic paper for the purpose of constructing cumulative curves. The quartile calculations determined from the data on the cumulative curves are tabulated on Table III.

Cumulative Curve Analysis

In constructing the cumulative curves, the U.S. sieve sizes were converted to Tyler sieve sizes with the aid of a comparison table (Leroy et.al. p.137). The diameters of the grains in millimeters were plotted logarithmically along the horizontal axis and the cumulative weight

TABLE III

QUARTILE CALCULATIONS

Sample	Q_1	Q_2	Q_3	P_{10}	P_{90}
1	.240	.133	.147	.320	.110
2	.275	.209	.140	.330	.090
3	.242	.190	.151	.318	.115
4	.280	.202	.147	.360	.115
5	.178	.122	.101	.284	.083
6	.250	.155	.128	.342	.110
7	.135	.110	.092	.165	.076
8	.198	.137	.105	.230	.082
9	.272	.190	.145	.357	.114
10	.210	.170	.132	.250	.101
11	.135	.108	.092	.165	.080
12	.250	.213	.170	.320	.150
13	.200	.171	.142	.267	.111
14	.211	.138	.099	.290	.085
15	.196	.168	.143	.256	.118
16	.225	.170	.133	.300	.103
17	.258	.190	.145	.330	.112
18	.133	.108	.090	.160	.074
19	.255	.130	.117	.262	.069
20	.160	.115	.086	.253	.075

percentages plotted arithmetically along the vertical axis (Table V). With the data plotted and cumulative curves drawn, five values were obtained: the median, Md; the first and third quartiles, Q_1 and Q_3; and the tenth and ninetieth percentiles, P_{10} and P_{90}. The median size, sorting, skewness, and kurtosis, are widely used quartile measures for describing and comparing samples. Sorting was computed using the geometric form introduced by Trask (1938). He called it the sorting coefficient "S_o", which is defined as:

$$S_o = Q_1/Q_3$$

The quartile skewness which expresses the assymmetry of the curve was computed using the geometric equation below:

$$SK_q = Q^1 \quad Q^3/M_d{}^2$$

Kurtosis, unlike the first two, measures are usually expressed in the arithmetic form, Krumbein (1938). This measure is expressed as:

$$K_{qa} = (Q_1 - Q_3) \quad /2 \; (P_{10} - P_{90})$$

Kurtosis is a measure of the Central portion of the curve as compared to the curve as a whole, or more commonly referred to as a measure of the peakedness of the frequency curve (Krumbein, 1938). The statistical measures are tabulated in Table V.

TABLE IV

DATA FROM SIEVE ANALYSIS

Well	-40	40-60	60-80	80-100	100-120	120-140	140-200	200-230	Total
#1 wt.(g)	0.060	0.713	0.974	0.653	0.302	0.213	0.190	0.057	3.162
wt.%	1.89	22.55	30.30	20.65	9.55	6.74	6.01	1.80	99.99
cum.%	1.89	24.44	55.24	75.89	85.44	92.18	98.19	99.99	99.99
#2 wt.(g)	0.016	0.874	0.410	0.323	0.126	0.112	0.183	0.079	2.128
wt.%	1.27	7.68	25.49	25.97	9.98	8.87	14.49	6.25	100.00
cum.%	1.27	8.95	34.44	60.41	70.39	79.26	93.75	100.00	100.00
#3 wt.(g)	0.100	1.662	2.597	1.441	.574	.445	.356	.103	7.283
wt.%	1.37	22.82	35.65	19.78	7.88	6.11	4.88	1.43	99.97
cum.%	1.35	24.19	59.84	79.62	87.50	93.61	98.49	99.97	99.97
#4 wt.(g)	0.004	0.215	0.177	0.079	0.078	0.027	0.033	0.012	0.625
wt.%	0.64	34.40	28.32	12.64	12.48	4.32	5.28	1.92	100.00
cum.%	0.64	35.04	63.36	79.00	88.48	92.80	98.08	100.00	100.00
#5 wt.(g)	-	0.566	1.983	1.080	0.642	0.574	0.483	0.065	5.393
wt.%	-	10.49	36.77	20.02	11.90	10.64	8.96	1.21	99.99
cum.%	-	10.49	47.26	67.23	79.18	89.82	98.78	99.99	99.99

TABLE IV (CONT.)

Well	-40	40-60	60-80	80-100	100-120	120-140	140-200	200-230	Total
#6 wt.(g)	0.355	2.916	2.247	2.263	2.435	1.846	0.802	0.072	12.986
wt.%	2.73	22.45	17.30	17.43	19.13	14.22	6.17	.55	99.98
cum.%	2.73	25.18	42.48	59.91	79.04	93.26	99.43	99.93	99.93
#7 wt.(g)	-	0.026	0.082	0.157	0.241	0.395	0.441	0.129	1.471
wt.%	-	1.77	5.57	10.67	16.38	26.85	29.98	8.77	99.99
cum.%	-	1.77	7.34	18.01	34.39	61.24	91.22	99.99	99.99
#8 wt.(g)	-	0.484	0.640	0.583	0.435	0.761	0.709	0.201	3.813
wt.%	-	12.69	16.78	15.29	11.41	19.96	18.59	5.27	99.99
cum.%	-	12.69	29.47	44.76	56.17	76.13	94.72	99.99	99.99
#9 wt.(g)	0.520	6.525	6.083	3.886	2.428	1.754	1.005	0.177	22.378
wt.%	2.32	29.16	27.18	17.36	10.85	7.84	4.47	0.79	99.99
cum.%	2.32	31.48	58.66	76.02	86.87	94.71	99.20	99.99	99.99
#10 wt.(g)	-	0.566	1.983	1.080	0.642	0.574	0.483	0.065	5.393
wt.%	-	10.49	36.77	20.02	11.90	10.64	8.96	1.21	99.99
cum.%	-	10.49	47.26	67.28	79.18	89.82	98.78	99.99	99.99

TABLE IV (CONT.)

Well	-40	40-60	60-80	80-100	100-120	120-140	140-200	200-230	Total
#11									
wt.(g)	-	0.145	0.205	0.464	0.624	1.409	1.239	0.241	4.327
wt.%	-	3.35	4.74	10.72	14.42	32.56	28.63	5.57	99.99
cum.%	-	3.35	8.09	18.81	33.23	65.79	94.42	99.99	99.99
#12									
wt.(g)	0.060	2.165	3.386	1.331	0.279	0.128	0.101	0.060	7.510
wt.%	0.80	28.83	45.09	17.72	3.71	1.70	1.34	0.80	99.99
cum.%	0.80	29.63	74.72	92.44	96.15	97.85	99.19	99.99	99.99
#13									
wt.(g)	-	0.873	2.117	1.903	0.699	0.453	0.382	0.106	6.533
wt.%	-	13.36	32.40	29.13	10.70	6.93	5.85	1.62	99.99
cum.%	-	13.36	45.76	74.89	85.59	92.52	98.37	99.99	99.99
#14									
wt.(g)	-	0.490	0.502	0.301	0.279	0.350	0.594	0.205	2.721
wt.%	-	18.01	18.45	11.06	10.25	12.86	21.83	7.53	99.99
cum.%	-	18.01	36.46	47.52	57.77	70.63	92.46	99.99	99.99
#15									
wt.(g)	-	1.734	4.474	4.809	2.152	1.126	0.583	0.095	15.023
wt.%	-	11.87	29.81	32.01	14.32	7.49	3.88	.63	100.01
cum.%	-	11.87	41.68	73.69	88.01	95.50	99.38	100.01	100.01

TABLE IV (CONT.)

Well	-40	40-60	60-80	80-100	100-120	120-140	140-200	200-230	Total
#16 wt.(g)	-	1.970	2.622	1.975	1.448	0.975	0.758	0.144	9.892
wt.%	-	19.91	26.51	19.96	14.64	9.85	7.66	1.45	99.99
cum.%	-	19.91	46.42	66.38	81.02	90.88	98.54	99.99	99.99
#17 wt.(g)	0.078	2.892	2.871	1.854	1.154	0.822	0.601	0.113	10.385
wt.%	0.75	27.85	27.64	17.85	11.11	7.92	5.79	1.09	100.00
cum.%	0.75	28.60	56.24	74.09	85.20	93.12	98.91	100.00	100.00
#18 wt.(g)	-	0.024	0.052	0.182	0.239	0.335	0.477	0.137	1.445
wt.%	-	1.66	3.59	12.59	16.54	23.18	33.01	9.48	100.05
cum.%	-	1.66	5.25	17.84	34.38	57.56	90.57	100.05	100.05
#19 wt.(g)	0.096	0.385	0.362	0.241	0.129	0.150	0.208	0.076	1.647
wt.%	5.83	23.38	21.98	14.63	7.83	9.11	12.63	4.61	100.00
cum.%	5.83	29.21	51.19	65.82	73.82	82.76	95.39	100.00	100.00
#20 wt.(g)	-	0.113	0.106	0.134	0.116	0.121	0.346	0.077	1.013
wt.%	-	11.15	10.46	13.23	11.45	11.94	34.15	7.60	99.98
cum.%	-	11.15	21.61	34.84	46.29	58.23	92.38	99.98	99.98

TABLE V

STATISTICAL MEASURES

Sample	So	Log So	Skg	Log Skg	Kga
1	1.28	.107	1.030	+.013	.219
2	1.40	.146	.929	-.032	.283
3	1.26	.100	1.000	+.000	.221
4	1.38	.140	1.000	+.000	.269
5	1.33	.124	1.010	+.004	.189
6	1.40	.146	1.153	+.063	.262
7	1.21	.079	1.000	+.000	.235
8	1.34	.127	1.025	+.011	.207
9	1.37	.137	1.039	+.016	.259
10	1.26	.100	.982	-.008	.262
11	1.21	.079	1.000	.000	.164
12	1.21	.079	.977	-.020	.235
13	1.19	.075	.982	-.008	.136
14	1.46	.164	1.049	+.021	.136
15	1.17	.068	1.000	+.000	.188
16	1.30	.114	1.015	+.006	.284
17	1.33	.124	1.027	+.043	.257
18	1.22	.086	1.000	+.000	.244
19	1.47	.167	1.187	+.074	.261
20	1.36	.133	1.039	+.016	.208

The median size, which is the diameter of the middle-most particle, represents an average of the group. This value corresponds to the point directly below where the 50 per cent line crosses the cumulative curve (Krumbein, 1938).

The first quartile (here meaning the value of the diameter which has 75 per cent of the distribution smaller than itself, and 25 per cent larger than itself, and which corresponds to the intersection of the 25 per cent line of the cumulative curve) is used for comparing the samples. Krumbein (1938) states: "Isopleth maps may be prepared with any variable which shows a continuous gradational value."

Shape Analysis

Several hundred quartz grains between the U.S. sieve sizes 60 to 80 were mounted on glass slides with aroclor (n-1.66) for the purpose of measuring roundness and sphericity. The slides were placed on a petrographic microscope specially adapted for projecting the image on a wall or other smooth white surface. All measurements were made directly from the projected grain image. Fifty quartz grains from each sample were measured for roundness and sphericity. The measuring of fifty grains was suggested by Krumbein (1938, p.69). The roundness of each grain was determined by using Wadell's roundness formula: $p = \frac{r/n}{R}$ (Wadell, 1935). Where;

R = radius of maximum inscribed circle.

r = radius of curvature of individual corners.

n = number of corners measured.

The sphericity of each grain was determined using Riley's formula $s = \frac{i}{c}$ (Riley, 1941). Where:

i = radius of largest inscribed circle.

c = radius of smallest circumscribed circle.

The average roundness and sphericity are compiled for each sample (Table VI).

TABLE VI

AVERAGE ROUNDNESS AND SPHERICITY

Sample No.	Roundness	Sphericity
1	.563	.816
2	.537	.834
3	.495	.824
4	.602	.829
5	.403	.842
6	.510	.848
7	.445	.825
8	.453	.827
9	.466	.803
10	.513	.827
11	.390	.835
12	.440	.853
13	.436	.829
14	.524	.861
15	.423	.827
16	.470	.845
17	.487	.821
18	.427	.785
19	.463	.940
20	.384	.827

INTERPRETATION OF THE DATA

For presentation of the data, the author constructed a series of percentage maps showing the distribution of the constituents of the sedimentary unit. Median grain size and the statical measures of the sand are also presented as contour maps. The maps show in a simple and precise manner the lithologic and sedimentary characteristics of the unit.

The isochore map shows the variations in the stratigraphic thickness of the formation and the approximate areal distribution of the Sylvania (Figure 4). This map was constructed from the thicknesses of the drilled intervals guided by measured sections where the unit crops out. It shows a gradual thinning in all directions from a central thick area but the rate of thinning to the southwest is considerably less than in other directions.

The structural map shows, by means of contours, the configuration of the bottom of the Detroit River sediments or the top of the Sylvania sandstone where it is present (Figure 5). The Howell anticline, in the southwest portion of Michigan, is the most interesting structural feature in the area.

Percentage Maps

A percentage contour map is similar to a ratio map, except that the number used for contouring is the percentage

Figure 4.- Isopach Map Sylvania Sandstone.

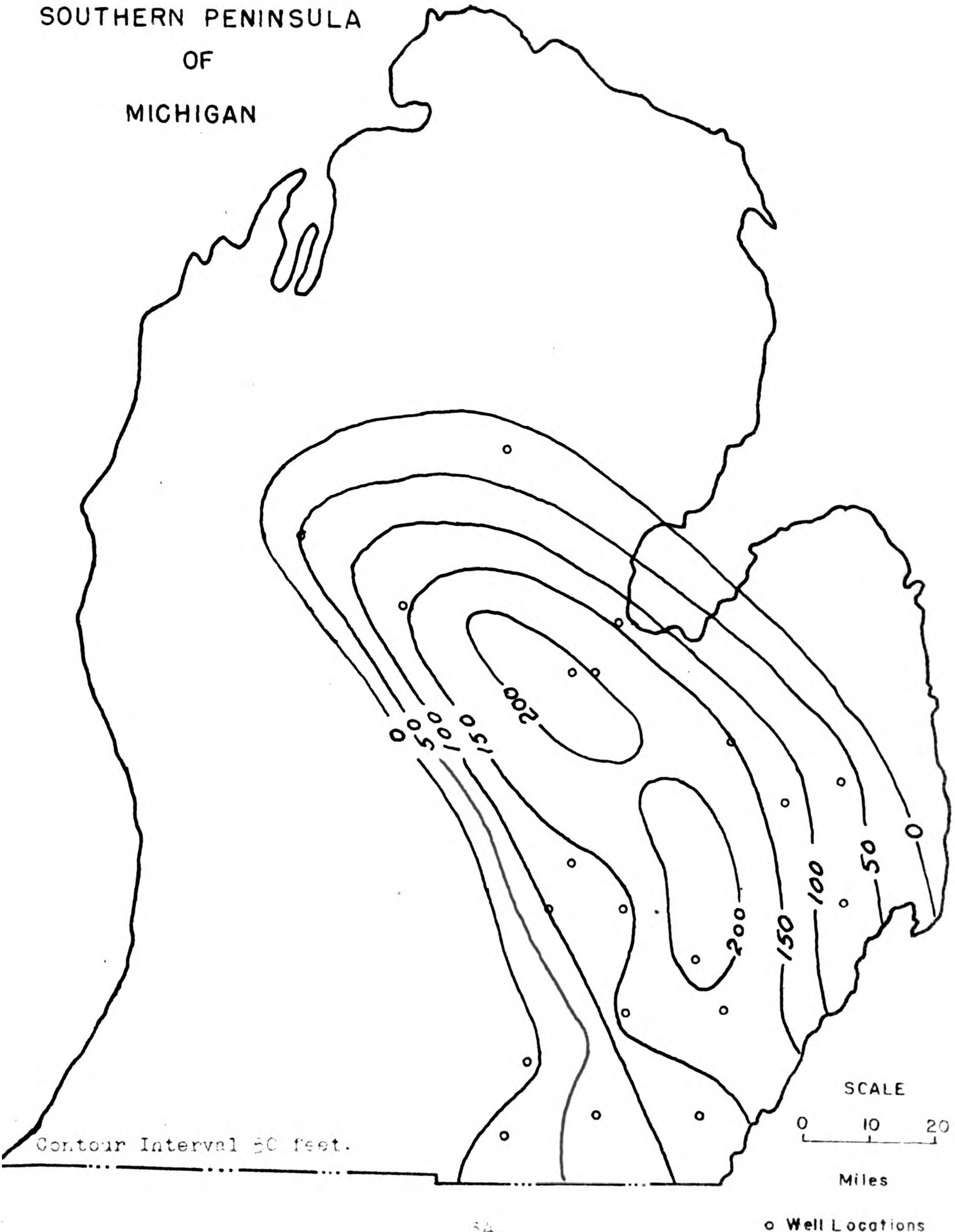
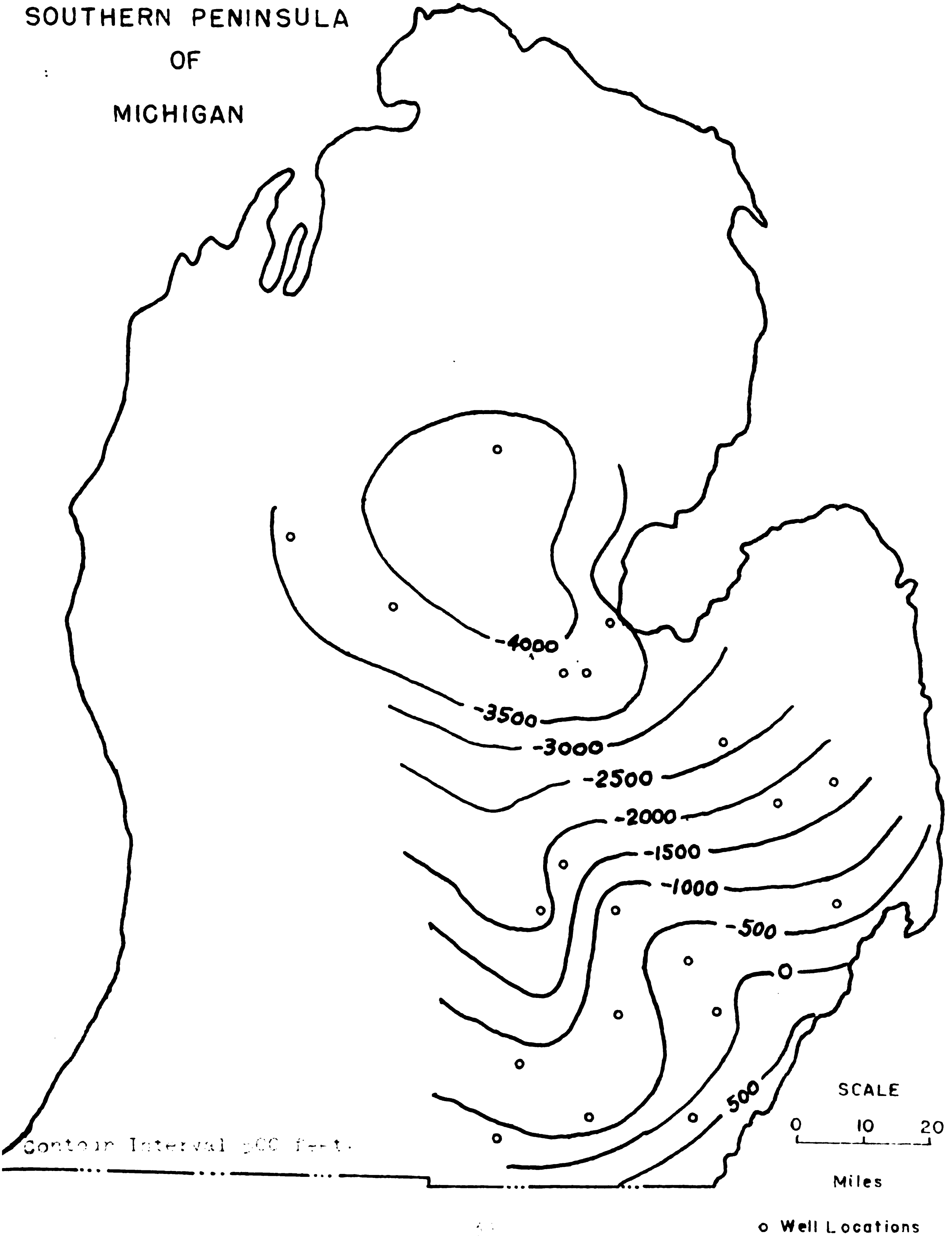


Figure [illegible]. Structural Contour Map Top of Sylvania.



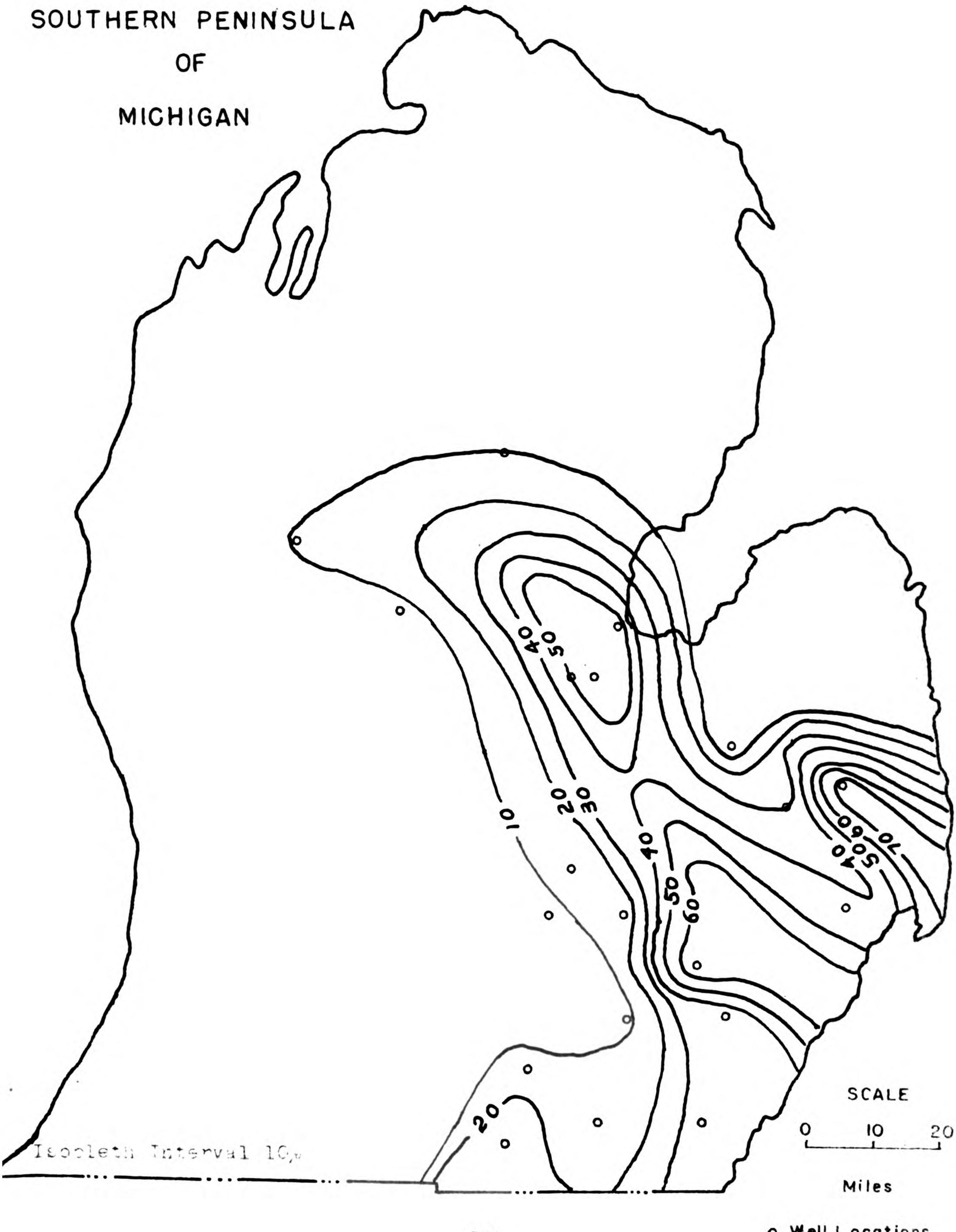
value of the lithology of interest (LeRoy et.al. 1951).

The sand percentage map shows considerable parallelism with the isochore map (Figure 6). Where the unit is thicker, higher percentages of sand are found. However, beyond this generalization marked departures can be observed. Higher percentages of sand than might be expected are recorded on the southeast edge of the map and a lesser "high" is noted in the area around Hillsdale County. The higher percentages of sand in the southeast which does not correspond with the thickness map, leads the author to infer a source for the sediment lies to the southeast.

The carbonate and sand percentage maps are very similar (Figure 7). If only carbonate and sand made up the formation, the two maps should come out exactly opposite. The carbonate map shows in general, the tendency for the carbonate content to decrease where the formation is thicker, it also decreases with increase of sand. Less carbonate is found in Ingham County, which is not reflected by higher sand percentage. This lack of carbonate represents an anomaly when compared with the sand percentage map.

The shale and silt percentage map (Figure 8), brings out several interesting features. The smallest percentage value for the fine sizes was obtained from a well in Monroe County. This is consistant with other workers (Carman, 1936, and Enyert, 1949) who found very little shale or silt in their study at the outcrops in Monroe County. There is a definite tendency for the finer sizes to form an arch around

Figure 6.- Sand Percentage Map



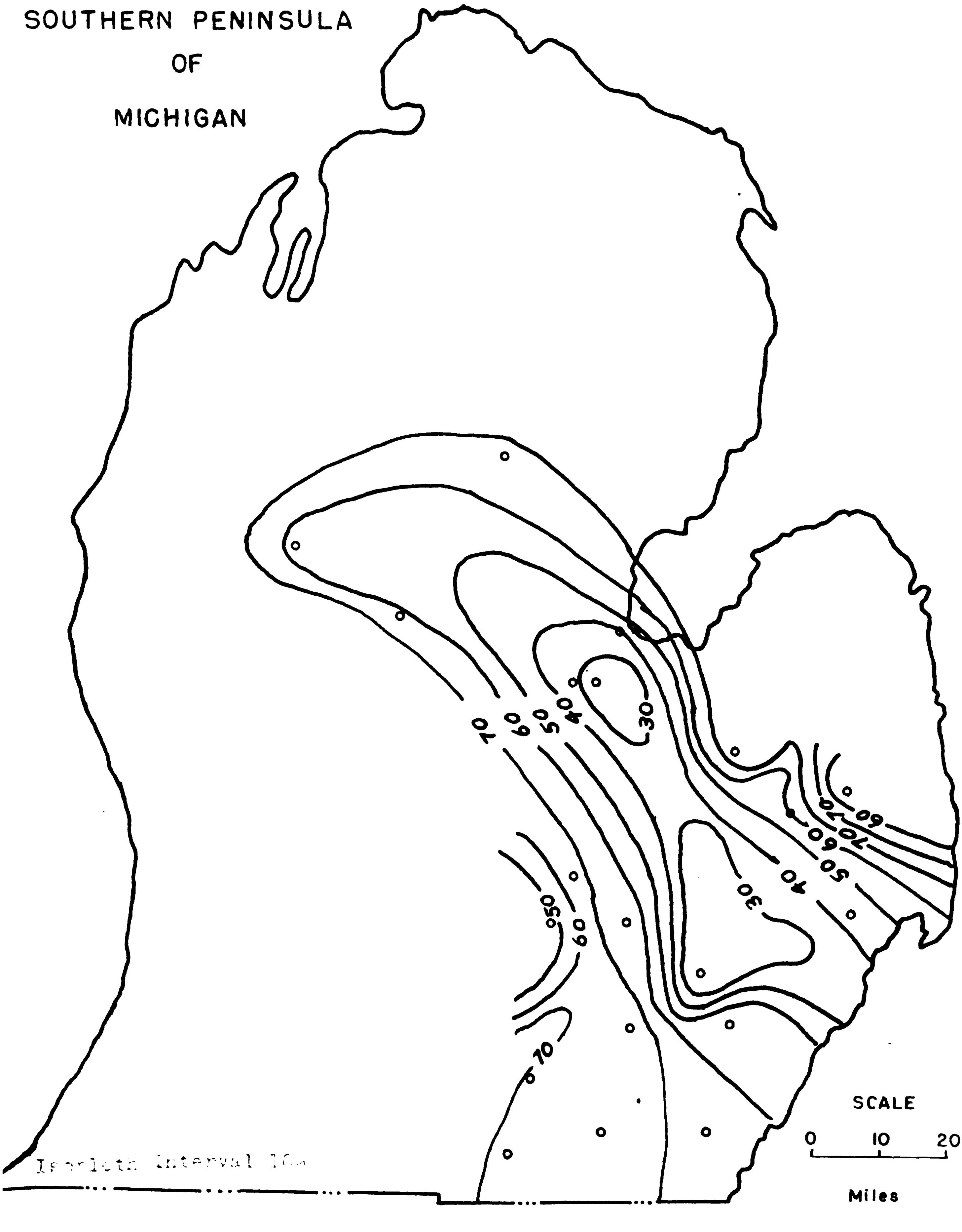

SOUTHERN PENINSULA
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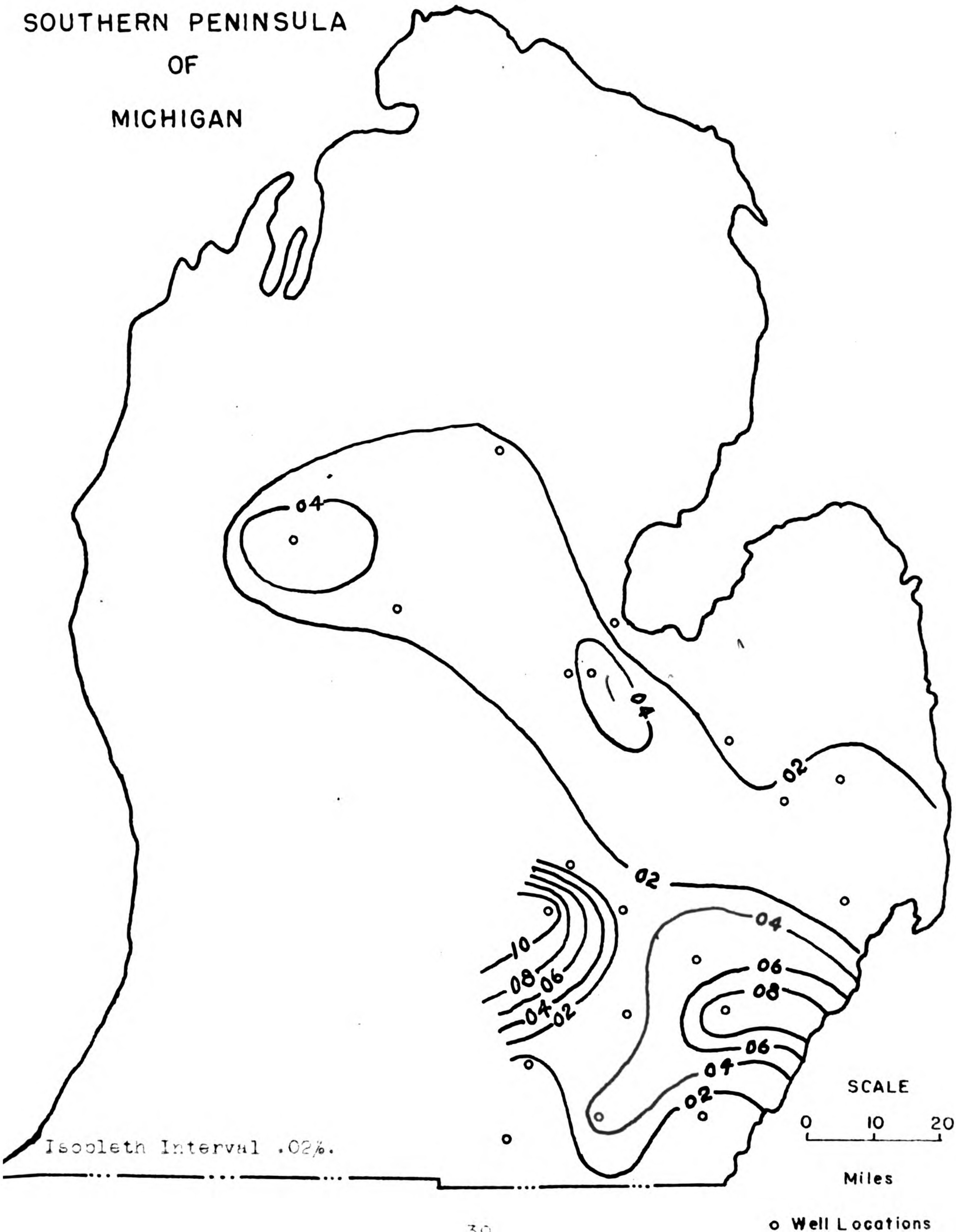
Figure 8.- Shale and Silt Percentage Map.



Monroe County perhaps indicating that the transportating agent was afforded better opportunity for winnowing out of the fines in this region. If the Sylvania sandstone was deposited under marine conditions, the Monroe County area was probably near shore. This shore feature may be the northern nose of the Findlay arch, just south of the Chatham sag. The largest percentage of fine sizes occur in Ingham County which shows some evidence for a source of clastics to the west.

The chert percentage map, in general, reveals a relatively low percentage on the southwest side (Figure 9). Here again the lowest chert value is recorded in Monroe County. Ingham County has the highest percentage of chert followed by the area around Isabella and Mecosta Counties and the Saginaw Bay region. Landes (1951) states that most of the chert in the Sylvania was probably derived from the underlying cherty Bois Blanc formation.

Conclusions drawn from percentage maps:

1) The percentage of sand becomes less in all directions away from its maximum in the southeast; this indicates a source from the southeast.

2) The carbonate percentage map may show two things: a) it could support Newcombe's conclusion (1933) that carbonates were deposited by percolating waters in the wind

Figure 9.- Chert Percentage Map.

deposited sandstone, or b) the carbonates may have deposited simultaneously under marine conditions with the Sylvania sands.

3) The clay and silt were derived from a western and a southeastern source. The low percentage of clay and silt in Monroe County can best be explained by a winnowing out of the fines due to wave action near a beach, probably on the west flank of the Findlay arch.

The low percentage value observed in St. Clair County may also be attributed to wave action along a beach. This area of low value corresponds with the northern nose of the Findlay arch. The isolated high in Saginaw County is difficult to explain but is more likely the result of current action than wind. The high values in Mecosta County could be contoured to open out to the west inferring a source from that direction.

4) The chert in the Sylvania is primarily derived from the reworked Bois Blanc formation.

Isopleth Maps

The sieve analysis data, computed from the cumulative curves, is presented in the form of isopleth maps. An isopleth has been defined by Krumbein (1933, p.201) "as a line of equal abundance or magnitude". Isopleth maps are useful for depicting the areal variation of sedimentary characteristics and for comparative purposes.

Because the values for sorting and skewness were expressed in the geometric form as shown on page 24, the numbers do not lend themselves directly to a visualization of what they signify in terms of the actual spread of the curve (Krumbein, 1933). Before the geometric sorting may be compared directly as on an isopleth map, the logs of the sorting values are used to form an arithmetic series so that all sorting values may be compared (Krumbein, 1938).

The Median size isopleth map shows larger median sizes to the southeast; these larger sizes extend into the Saginaw Bay area (Figure 10). The median sizes increase in Osceola County, revealing perhaps a new influx of sediments from the west. It should be pointed out that the distribution of the median sizes opposes Landes' idea of a northwest source for a wind blown Sylvania sandstone.

The first quartile isopleth map, here representing the largest 25 per cent of the sizes of the sample (Figure 11), follows the median size map quite closely. Here again a new source of sediment may be interpreted for the well

Figure 10.- [illegible]

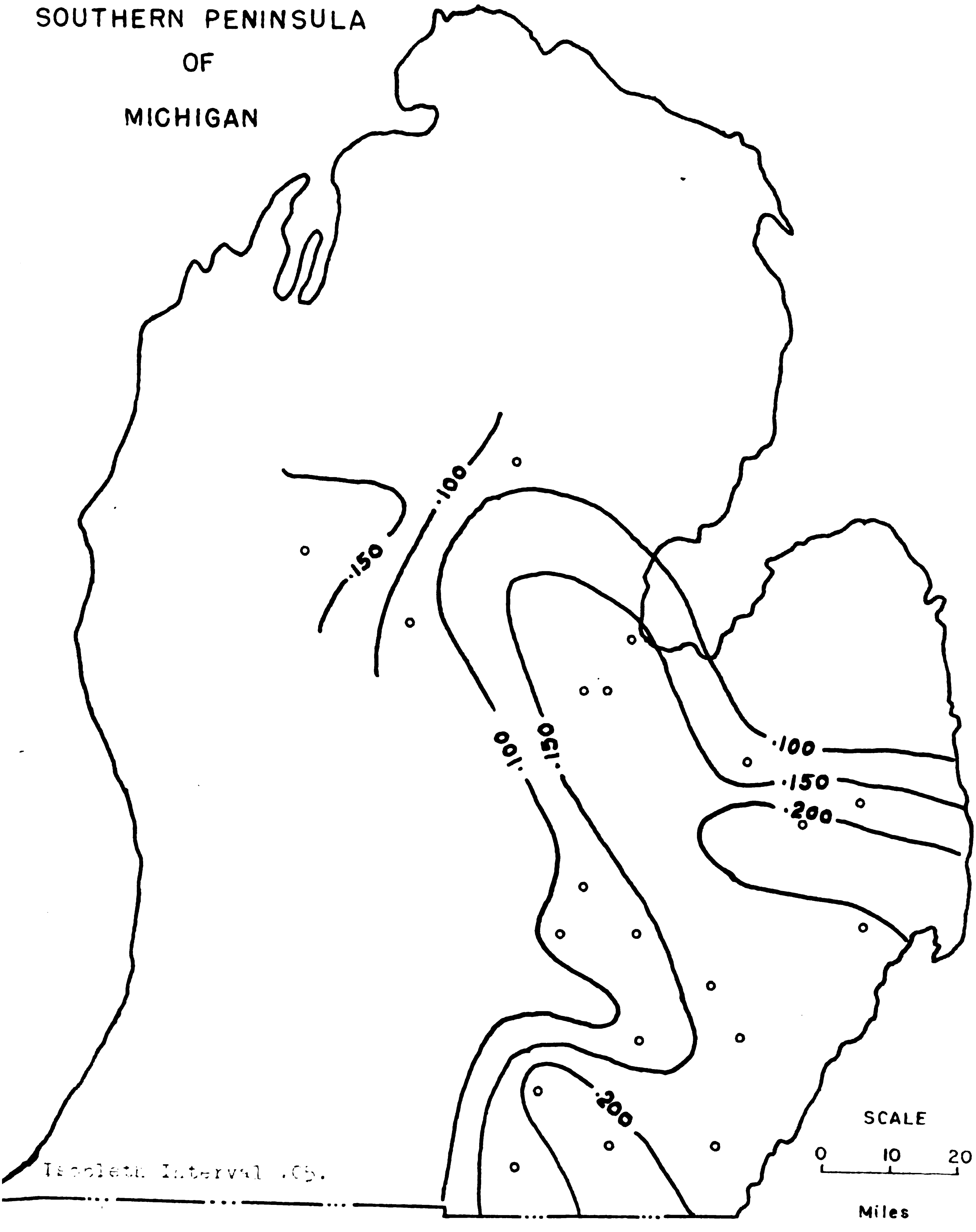

SOUTHERN PENINSULA
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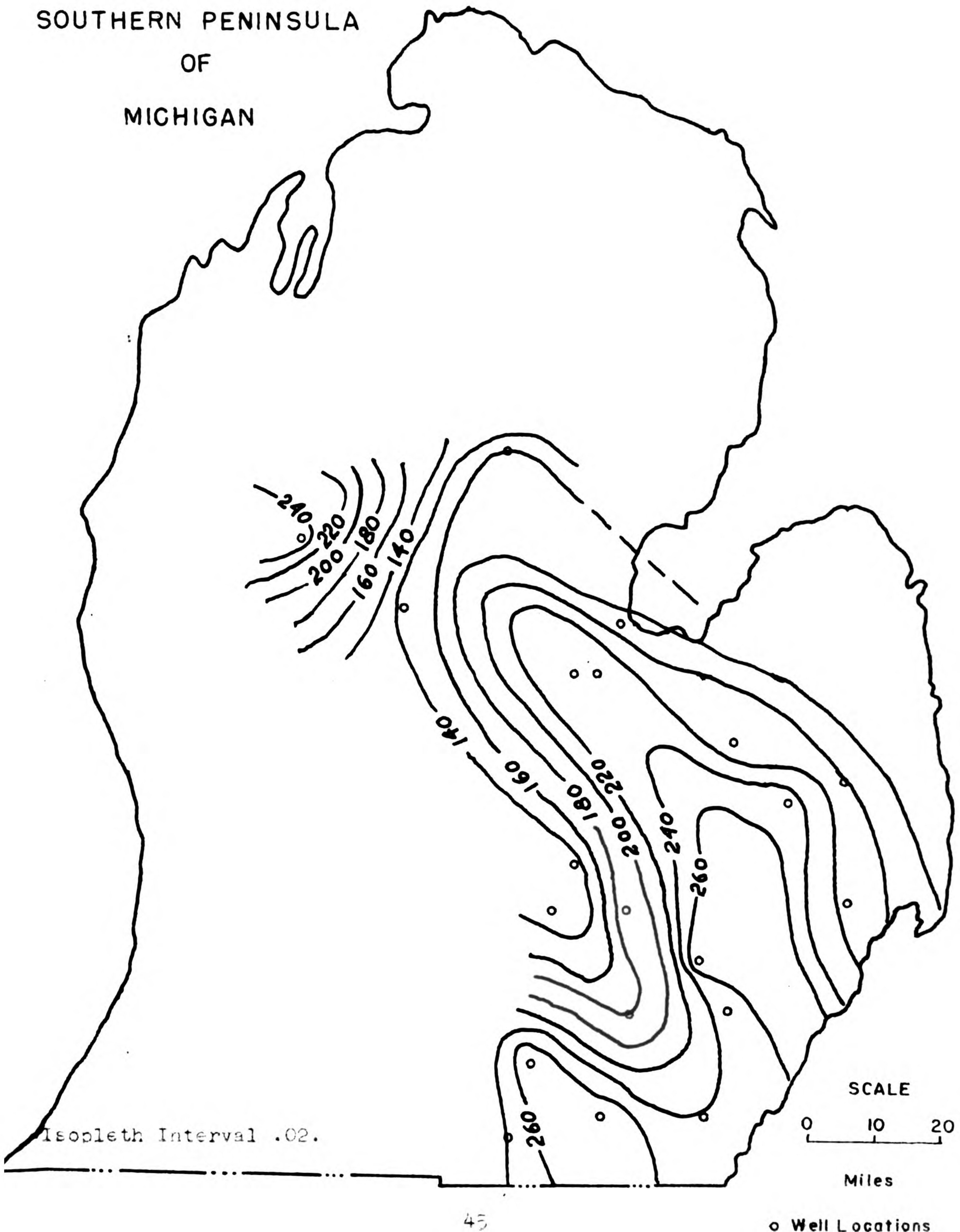
Figure 11.- 1st. Quartile Map.



shown in Osceola County. The major portion of the largest grains occur to the southeast.

The sorting isopleth map (Figure 12), shows the best sorting along the edges of the unit and the "poorest" sorting generally where the sediment is thickest. The sample with the poorest sorting was from Osceola County. It is possible to contour this well similar to the map showing median sizes and here again this may be an indication of sediment being derived from a westward source. The better sorting values on the edges of the unit probably are the result of wave action, which selected and winnowed the sediment. Note too, the high sorting value near the Findlay arch in Monroe County.

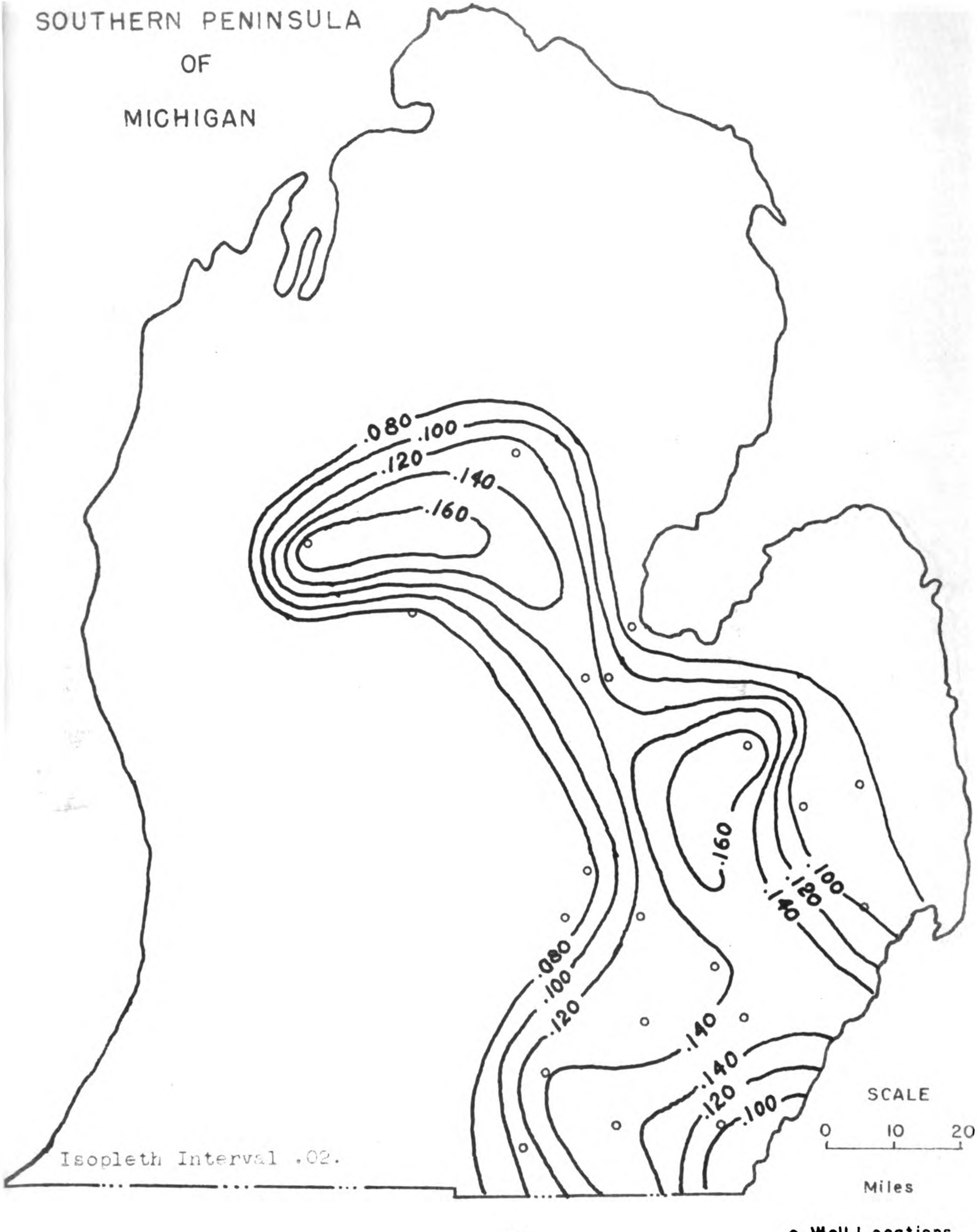
The skewness map is included with but limited interpretation (Figure 13). Krumbein (1938) states:

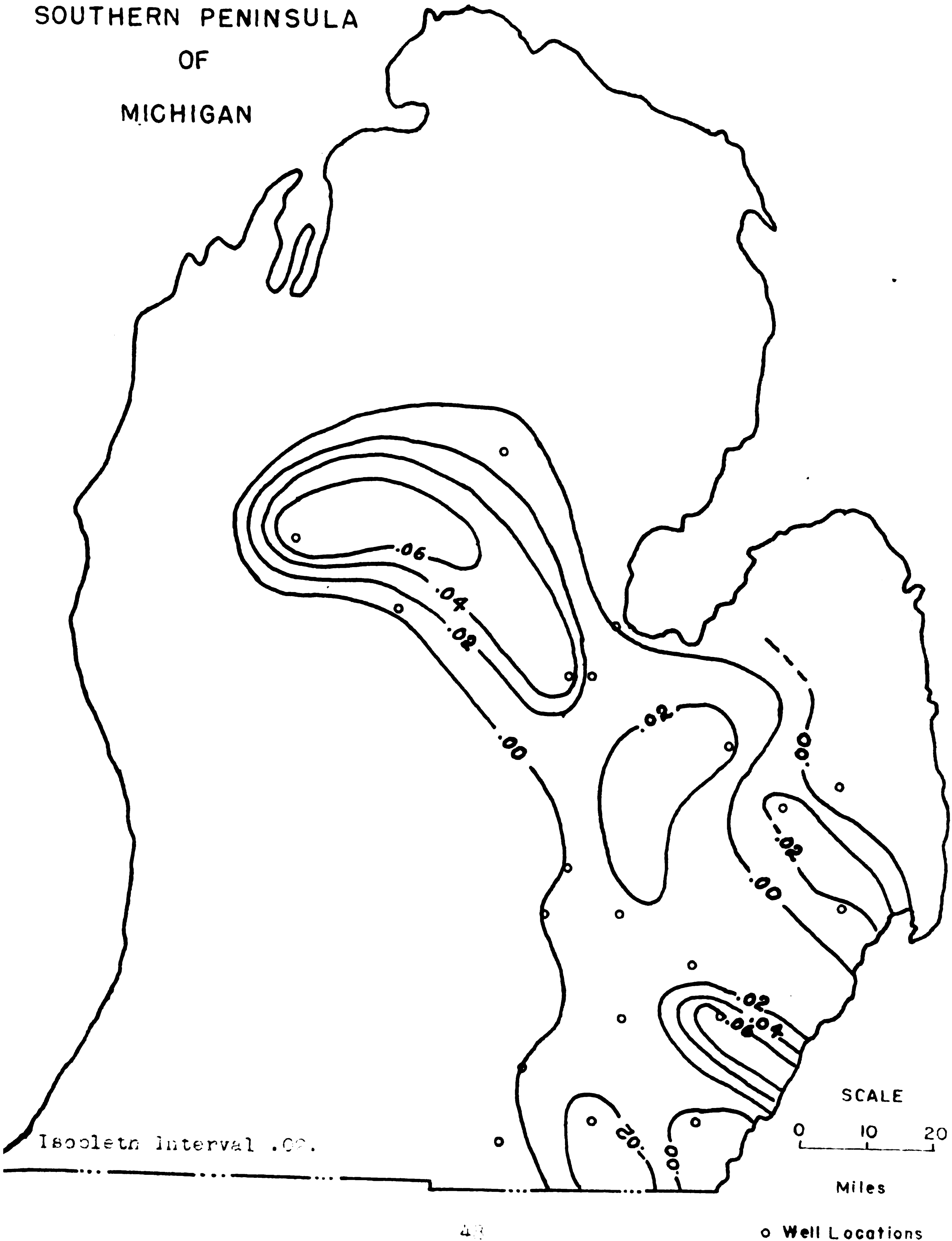
> Relatively few studies have been made of the areal variation of skewness within given deposits, and the data are perhaps too meager for generalizations. The almost universal presence of skewness in sediments, especially in terms of diameter as the independent variable, suggests that there is a genetic relation between agent and skewness, and that the skewness may vary areally in accordance with definite laws.

There exists some relationship between the positive values of skewness and the larger sizes.

The kurtosis values do not lend themselves to interpretation in the form of an isopleth map. The values are presented numerically with interpretation left to the reader (Table VII). Krumbein (1938) states:

Figure 12 - [illegible] sorting map.





SOUTHERN PENINSULA
OF
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o Well Locations

> Not much is known about the significance of kurtosis in sediments. It appears to be related to the selective action of the geological agent, but the sum total of the factors entering into the selective process are not known.

The areal variation in roundness and sphericity are shown as isopleth maps (Figures 14 and 15). These two maps will be considered together because they represent the characteristic shape of the sand. The roundness map shows the sand to be more rounded to the southwest. This may be a function of the distance of travel or the result of chemical activity. There seems to be some correlation between the better rounding and the larger sizes. The question is, would wind transport larger, more rounded particles further than smaller more angular particles? This would have to be true to support Landes theory. The sphericity map seems to add little to the history. There seems to be little or no relationship between roundness and sphericity values. If the sphericity is connected in any way with the mode of transport it is not apparent. The sphericity map has the tendency to show higher values where the sand is thickest.

A westward influence is apparent from the well sample in Osceola County.

Conclusions drawn from isopleth maps are:

1) The average size of the sand grains is greater in the southeast portion of Michigan, indicating a source from that

Figure 14.- Average Roundness Map.

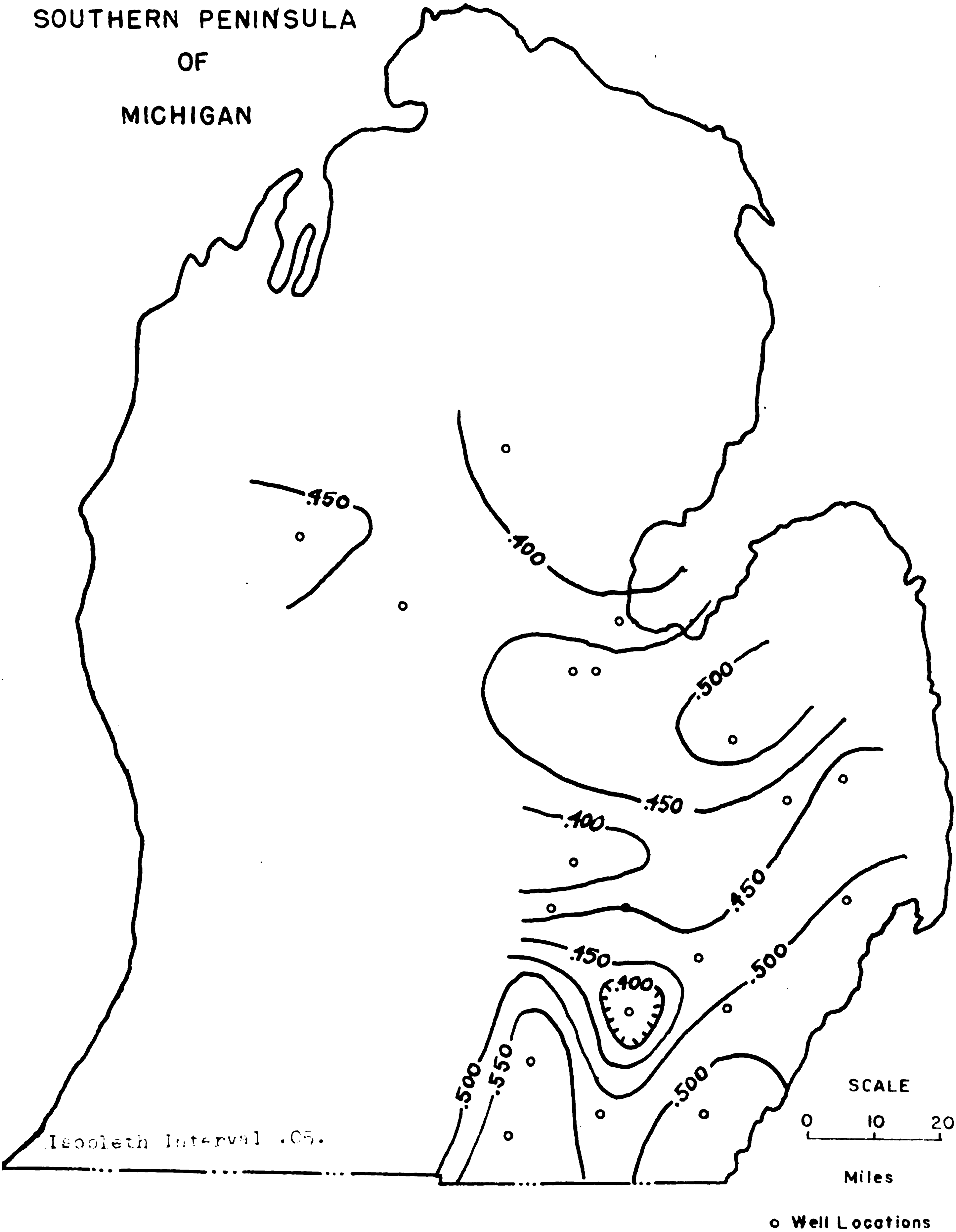
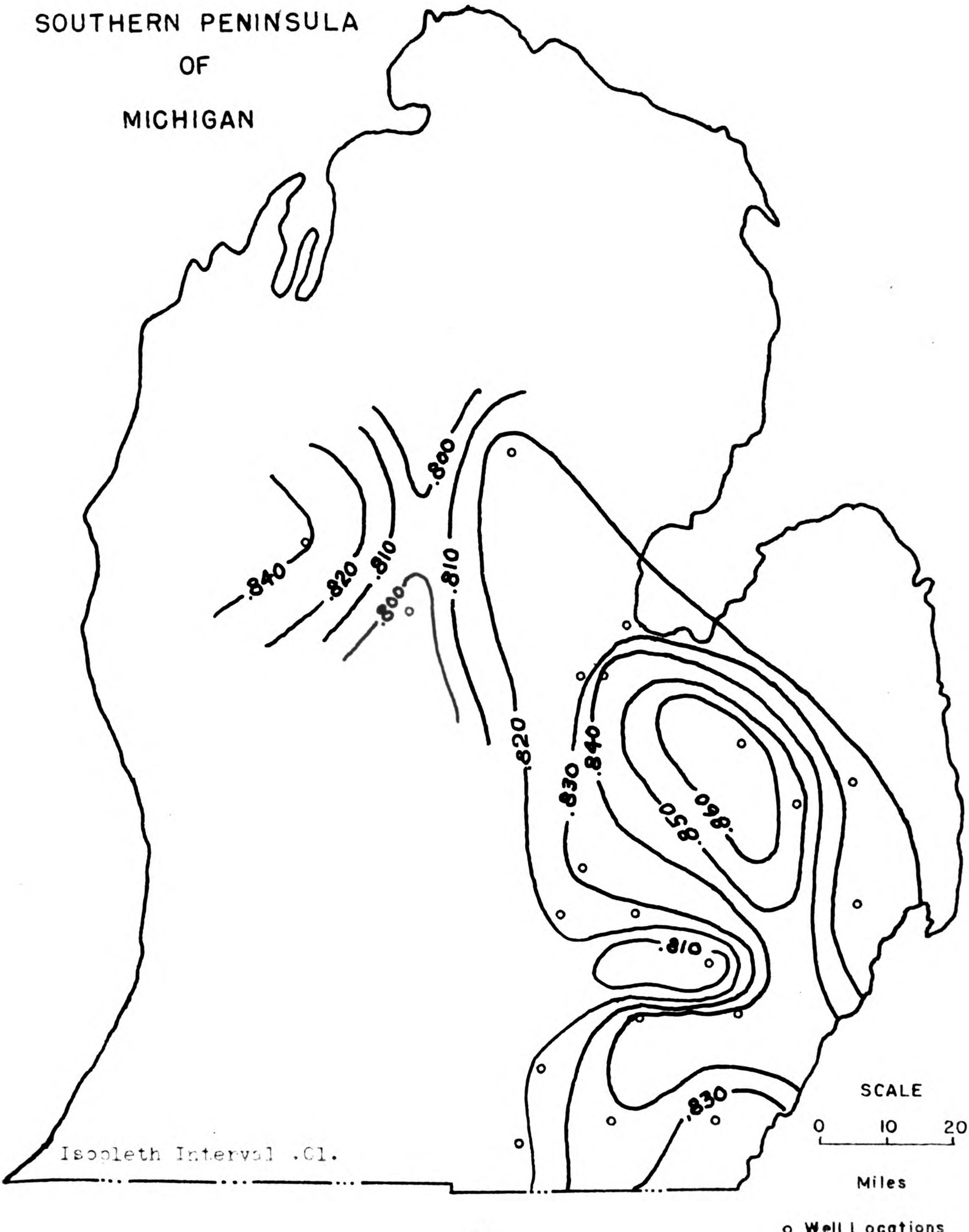


Figure 15.- Average Sphericity Map.



direction. The large average sizes shown in Osceola County may show the influx of some sand from the west.

2) The largest 25 per cent of the sample (first quartile isopleth map) shows generally a concentration to the southeast, and again shows sediment may have been derived from the west in Osceola County.

3) The better sorting generally confined to the edges of the sedimentary unit is believed to be the result of wave action. The more "poorly" sorted material in the central portion of the Sylvania Sea was not greatly effected by wave action.

4) The skewness and kurtosis values are probably a result of the transporting agent, and conclusions as to direction and mode of transport are left to the reader.

5) The best rounding is confined to the southeast section of Michigan.

6) The sphericity distribution is erratic and may be negative evidence for a wind blown origin, for wind is more selective than water as an agent of transport.

TECTONIC FRAMEWORK OF LATE SILURIAN

The tectonic features, in early Cayugan (Salina time) which were effective in restricting the Michigan Basin persisted but were less prominent during Bass Island time. The Cincinnati arch, or Findlay arch, extending from central Ohio to southwest Ontario lay to the east of the Michigan basin. Prior to Bass Island deposition, a sag developed in the Findlay arch (Chatham sag) which persisted during Bass Island time. The deepest portion of the Chatham sags during Trenton time was near Chatham, Ontario, and the Lake St. Clair region of Michigan and Ontario. At the southern end of the Michigan basin another tectonic feature existed, most frequently referred to as the Kankakee arch. Green (1957) points out that the Kankakee arch might better be called the Indiana-Ohio platform which extends from east-central Ohio through northern Indiana into Illinois.

To the west, in central Wisconsin, a positive feature referred to as the Wisconsin dome prevailed during late Silurian and according to Eardley (1951) was uplifted following the deposition of Silurian beds. Apparently, the regions to the north of Michigan were flat, low-lying stable areas.

GEOLOGIC HISTORY OF THE SYLVANIA SANDSTONE

The pertinent history of the Sylvania sandstone begins with Bass Island time. After the Bass Island dolomite was deposited over an area much greater than the present Michigan Basin, withdrawal of the sea exposed the newly formed rocks to erosion. About this time, according to Eardley (1951), the Wisconsin dome was uplifted. During the period of emergence, some of the upper-most Bass Island sediments were removed. The first Devonian sea entered lower Michigan during Oriskany time (Schuchert, 1954). This sea spread westward from the Allegany trough into lower Michigan. The Garden Island formation was deposited, probably covering a much wider area than its present extent (Ehlers, 1945). Post Oriskany erosion removed nearly all of the Garden Island formation. The Onondaga sea followed and spread over lower Michigan covering the eroded Garden Island and the twice eroded Bass Island sediments and in so doing deposited the Bois Blanc formation. Minor downwarping took place at this time with the result that the thickest Bois Blanc sediments were deposited immediately north of Saginaw Bay area (Landes, 1951).

Marine withdrawal followed the deposition of the Bois Blanc dolomite. Subsequent erosion of considerable magnitude completely removed the Bois Blanc from the flanks of the Findlay arch and the Indiana-Ohio platform (Landes, 1951).

The paleogeology prior to the encroachment of the Sylvania sea is shown on Figure 1.

According to Landes (1951):

> A downwarp along a northwest-southeast axis from central Michigan into northern Ohio permitted the entrance of marine waters.

Landes continues by saying, that it was into this shallow trough that wind transported sand, which had drifted eastward from Wisconsin across the intervening emergent land, was deposited and preserved in the Sylvania sea.

Landes' theory presupposes two conditions, 1) there was but scant vegetation due to near desert conditions, and 2) during the Devonian the prevailing wind was from the west as today.

The writer's data does not support Landes' views. The data obtained from the analysis indicates a water laid sediment with the major source area to the southeast.

The writer believes, the Sylvania sea moved into the lower peninsula of Michigan from the east through the Chatham sag which existed throughout Detroit River time. The Findlay arch was a well-defined ridgelike feature which extended north and south away from the Chatham sag. During Sylvania time it acted as a physical barrier allowing the Sylvania sea to encroach over lower Michigan only through a depression within the arch since called the Chatham sag. The Sylvania sea entering Michigan was thus quite restricted with it's only opening to the southeast through the Chatham sag.

The deposition of the Sylvania sandstone ended gradually as the sea encroached farther over the land and the lower Detroit River sediments were deposited.

SUMMARY AND CONCLUSIONS

The origin and age of the Sylvania sandstone have been discussed for many years. Two radically different schools of thought have developed. Some writers favor an eolian origin for the following reasons:

1) The surface characteristics of the sand grains are like present day wind-blown sands.

2) The apparent isolation of the sand from possible source areas.

3) The small amount of finer clastics (muds or clays) usually associated with current transported sands.

An eolian origin with marine reworking of the sand was recently postulated by several writers.

Still, other geologists stick to a straight marine origin for the Sylvania saying, that it is a transgressive sand or an accumulation resulting from current and wave action such as modern beach and barrier sands.

The writer's data indicates the major source area for the Sylvania sandstone was to the southeast of lower Michigan. This does not exclude the fact that some sediment was derived from the west for this, too, is apparent from the data. The Sylvania sandstone is probably a marine sand where both wave action and current influenced it's distribution in lower Michigan. The percentage maps could be interpreted as evidence that current action was the most influential force governing the deposition of the sand. While the Sylvania sea was restricted with its one opening through the Chatham sag, strong currents could have developed similar to those present at the straits of Gibraltar today. The water, warmed in the Sylvania sea may have moved back into the Allegany trough carring away much of the finer sediment, while colder deeper currents moved sand into lower Michigan. Tidal action may have played an important role.

A southeast source is inferred from the analysis. The sand was probably of second or third generation; perhaps the grains were modified chemically.

To speculate on a source area for the Sylvania sandstone, in light of the present geologic knowledge, is a difficult task. It may be that the Sylvania is reworked Oriskany sand; it is also possible that the upper Bois Blanc beds, now eroded, were sandy enough to supply the Sylvania sea with sand.

Although Sherzer and other geologists believe that the Sylvania sand received its unusual shape and surface characteristics as a result of wind activity, this writer would not exclude the possibility that the surface textures originated from chemical activity. It is to be remembered that large quantities of chert were deposited during Devonian time. Many workers believe that tropical conditions are necessary to induce such large quantities of silica into solution or the colloidal state. Tropical conditions would also support the idea postulated here that thermal currents and tides were generated in the restricted Sylvania sea, thus producing strong currents through the Chatham sag.

The concept of currents as a means of transporting the sand of the Sylvania sandstone to its site of deposition may seem objectionable to the reader. A similar explanation for sands occuring in the Powder River Basin of Wyoming was given by Partridge (1957), who states:

> The sand patterns of the 1st Wall Creek and Parkman sands indicate a "Channel" in the area of the Casper arch through which currents brought sands from the southwest and spread them eastward across the Powder River basin.

The 1st Wall Creek and Parkman sands compare in size and thickness to the Sylvania. The "channel" referred to is similar to the Chatham sag in size.

In conclusion, the author believes the Sylvania sandstone to be marine in origin with the major source to the southeast, that current action was the most important factor governing the transportation and deposition of the sand.

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