PETROLOGY OF THE MASSILLON SANDSTONE AT THE TYPE LOCALITY

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The Massillon sandstone, an arenite of commercial importance in northeastern Ohio, is a winnowed low-rank graywacke at its type locality, Massillon, Stark County, Ohio. High quartz content, medium granularity, and good sorting indicate a high-energy environment of deposition. Consistent north-northeast dip-direction of cross- and incline-beds suggests longshore currents as the agent of deposition and makes a southwestern source of the sediment probable. Petrographically similar Mississippian arenites may have been the source materials.

In the summer of 1951 the author began a general study of the Massillon sandstone of northeastern Ohio under the auspices of the Ohio Division of Geological Survey. The object of this investigation was the determination of stratigraphic relationships, areal extent, range in lithologic character, and origin of the Massillon sandstone. Early in this project observations were made and a suite of specimens was collected from the abandoned Warthorst or Everhard quarry of the Industrial Silica Corporation, located in NE¼ NW¼ section 7, Perry Township, Stark County, Ohio, in the outskirts of the town of Massillon. The rocks in this quarry were designated by Newberry (1878, p. 166–167) as typical Massillon sandstone. A section measured in the north end of the newer workings shows 51 ft. of low-rank graywacke (defined by Krynine, 1948, table 3). When the quarry was in operation as much as 75 ft. of the rock was exposed, overlying the Number 1 (Sharon) coal and shale unconformably (Newberry, 1878, p. 166–167).

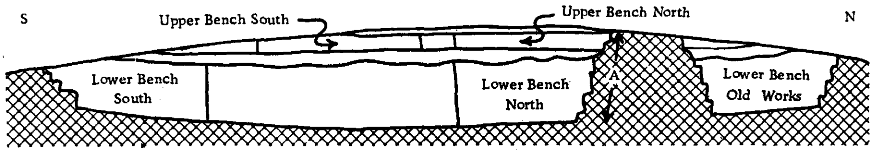

FIGURE 1. Profile of west wall of Warthorst quarry, not to scale. Length of diagram approximately 2,000 feet. Stratigraphic section was measured and lithologic samples were collected at locality A. Areas in which dip-directions of cross- and incline-beds were measured are labeled.

The quarry face consists of two benches. The lower bench, of which 30 ft. is exposed, is medium-grained quartzose graywacke. Above this lies 6 to 9 ft. of fine-grained graywacke interbedded with thin light-gray shale. The upper bench, which is as much as 12 ft. thick, is medium-grained quartzose graywacke. Glacial drift a few feet thick constitutes the overburden.

A stratigraphic section was measured by tape and hand-level and samples were collected in the north end of the newer workings (fig. 1). The units of subdivision used for description and sampling were sets of beds (defined by McKee and Weir, 1953), which are about the equivalent of "courses" of stone in quarrymen's nomenclature. Conspicuous horizontal or nearly horizontal parting surfaces separate the units. Composition, texture, and structure of each unit were described.

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TABLE 1

Comparison of field and laboratory estimates of composition and texture. Units (sets of beds) are listed in ascending order. Lower bench, units 1–20; shaly break, units 21–30; upper bench, units 31–38.

Unit number	Thickness (feet)	Quartz content		Median grain size		Sorting coefficient Sieve analysis
		Field est.	Thin section	Field estimate	Sieve analysis	
1.	1.0	80%	—	Coarse	.4 mm.	1.1
2.	2.2	75	—	Medium-coarse	.38	1.2
3.	1.4	75	77%	Medium-coarse	.35	1.2
4.	0.7	75	—	Coarse	.36	1.3
5.	1.0	80	—	Medium-coarse	.35	1.2
6.	1.0	80	87	Medium-coarse	.28	1.2
7.	1.3	84	—	Medium-coarse	.38	1.2
8.	2.2	85	—	Medium	.31	1.2
9.	1.6	85	—	Medium-coarse	.36	1.2
10.	5.0	85	—	Medium-coarse	.31	1.2
11.	1.1	85	—	Medium-coarse	.33	1.1
12.	2.7	85	88	Medium-coarse	.30	1.2
13.	0.5	85	—	Medium-fine	.22	1.2
14.	1.4	85	—	Medium-coarse	.27	1.3
15.	0.6	85	86	Medium-fine	.21	1.3
16.	1.6	78	—	Medium-coarse	.28	1.2
17.	1.3	78	—	Medium-coarse	.26	1.2
18.	1.5	78	—	Medium	.28	1.2
19.	1.3	80	—	Medium-coarse	.29	1.1
20.	1.1	80	87	Medium-coarse	.26	1.2
21.	0.1	Shale	—	—	—	—
22.	0.4	80	—	Medium-coarse	.33	1.2
23.	0.4	85	—	Medium-coarse	.29	1.2
24.	1.7	85	88	Medium-coarse	.30	1.2
25.	1.3	75	—	Medium-fine	.17	1.4
26.	0.2	Shale	—	—	—	—
27.	1.4	75	—	Medium-fine	.14	1.6
28.	0.4	Covered	—	—	—	—
29.	0.8	80	73	Medium-fine	.13	1.8
30.	2.5	Covered	—	—	—	—
31.	2.9	85	—	Medium-coarse	.34	1.3
32.	1.6	85	—	Medium-coarse	.27	1.3
33.	2.0	82	—	Medium	.21	1.3
34.	0.5	82	—	Medium-coarse	.36	1.4
35.	1.9	82	—	Medium-coarse	.32	1.1
36.	0.6	82	88	Medium	.19	1.3
37.	0.6	82	—	Medium	.20	1.3
38.	1.5	82	—	Medium-coarse	.23	1.3
Total	51.3					
Weighted average		81.5%	85.0%	Medium-coarse (.46 mm.)	.29 mm.	1.2
Portion of thickness represented.		94%	19%	94%	94%	94%

PETROLOGY

Composition. Composition was estimated in the field by examination of hand specimens. Quartz grains make up most of the rock, (table 1), but considerable clay is present as coatings on the quartz grains, as matrix, and as detrital aggregates of about the same size as the grains. Selective staining of some of the clay by limonite gives a speckled appearance to the coarser graywackes. Muscovite, secondary quartz crystal overgrowths, and unidentified dark grains are present in small quantities and iron oxides are abundant locally.

Eight thin sections were analyzed under the petrographic microscope by the point-count method (Chayes, 1949). Six to eight traverses, totaling more than 1,100 individual points, were made across each slide. This allows 95 percent confidence limits of ±2.5 percent for the major constituents. Quartz content ranges from 73 to 88 percent and averages about 85 percent (table 1). Of this, approximately 70 percent is individual quartz grains, 14 percent is aggregates (mostly quartzites with sutured contacts between the grains), and 1 percent is either very fine-grained quartzite or chert.

Clay content ranges from 11 to 26 percent and averages about 15 percent. Six clay types are recognized, but the distinctions between them are too slight to allow quantitative determination. These types include 1) fairly large (up to 0.1 mm.) flakes of sericite (?) that have medium relief and high birefringence and show no compactional disturbance; 2) finely crystalline, parallel-oriented aggregates of sericite (?) or illite (?) flakes that show slight iron-staining and some crushing due to compaction; 3) very finely crystalline, iron-stained, parallel-oriented aggregates of illite (?) or sericite (?) flakes that commonly are much distorted due to squeezing between the enclosing quartz grains; 4) amorphous (?) ferruginous clay masses that may be exceedingly fine-grained illitic or sericitic aggregates; 5) undisturbed aggregates of kaolinite (?) that have a mosaic pattern, low relief, very low birefringence, and undulatory extinction, and 6) clear, undisturbed, apparently amorphous aggregates which may be exceedingly fine-grained kaolinite mosaics. Type 3 appears to be most abundant.

Comparison of field and laboratory estimates of composition shows that minor constituents were consistently over-estimated in the field. Accessory minerals, such as muscovite and secondary quartz crystal overgrowths, were reported in quantities up to 2 percent in the field but were rarely seen in thin section. Field estimates seem fairly reliable for the major component, however (table 1); of the eight field estimates of quartz content which were checked microscopically, half fall within 5 percent and all fall within 10 percent of the value determined by point-count. A t test of the significance of the differences (Snedecor, 1946, p. 62–68) indicates that the mean difference, about 3 percent, is probably not significant ($t = 1.71$, p. $= 0.14$). The t test allows an evaluation of the probability that two different groups of observations could have been drawn by chance from two larger groups (populations) that are not different.

Seven of eight field estimates showed lower quartz content than was measured in thin section. If the single over-estimate (unit 29) is disregarded, the mean difference between field and microscopic estimates becomes highly significant ($t = 4.45$, $P < 0.01$). It seems probable, therefore, that an over-estimate of less abundant constituents, notably clay, led to a rather consistent under-estimate of the quartz content.

Texture. Grain size was estimated in the field by comparison with standard samples (table 1). A spot-sample collected from each unit was analyzed by sieving. Disaggregation under water and preliminary wet-sieving reduced losses to less than 0.5 percent. Dry sieving of the +0.062 mm. portion of the sample was done with standard 8 inch sieves (Wentworth classes, 1 phi intervals) on a Cenco-Meinzer machine with automatic timing (20 min. interval). The family of cumulative curves thus determined is represented in figure 2 by the limiting curves and the mean of all curves. Comparison of the field estimate of grain size and the median size as determined by sieving shows a very consistent bias of 0.7 phi or about ¾ of a Wentworth class in favor of the coarser sizes. This bias probably is a result of overestimation of the quantity of the larger and more conspicuous grains, estimation based on the long axes rather than on the intermediate axes of inequidimensional grains, or both. A *t* test indicates a probability of less than 1 percent that this bias does not exist.

The median grain size of the graywackes ranges from 0.13 mm. to 0.40 mm. The mean of the medians, weighted for thickness of the unit represented by each, is 0.29 mm. Distribution of the medians about the mean approaches log-normal, but is skewed toward the fine sizes. Median size generally decreases from bottom to top of the quarry face, with local increases at the base of the upper bench and at the bottom of zones of cut-and-fill bedding such as units 16 and 22 (table 1). Grain size of the shales is not reported because shales are quantitatively insignificant and cannot be analyzed by a comparable technique.

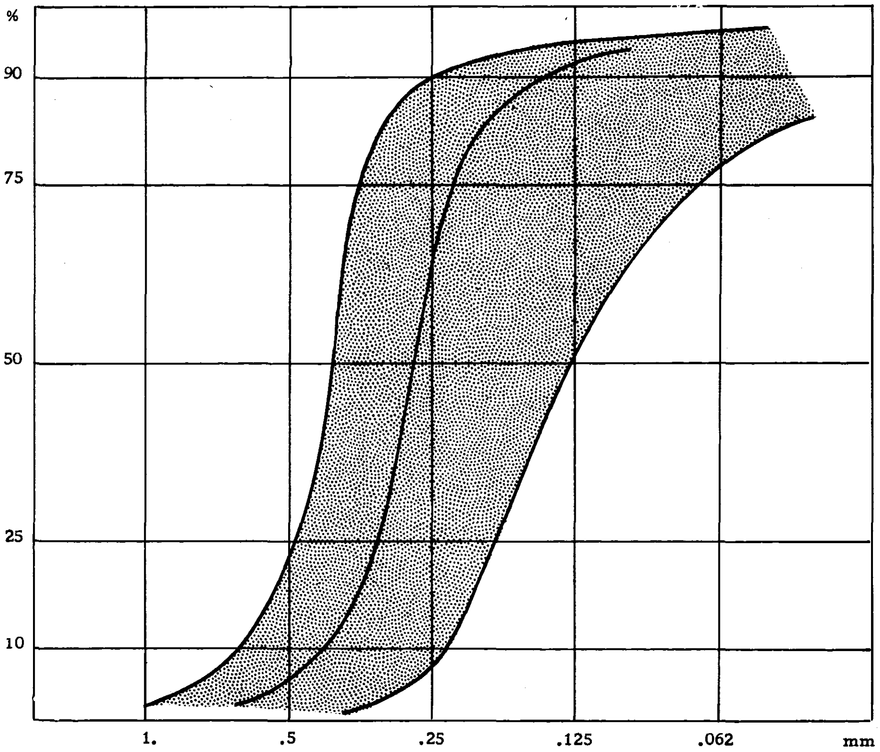

FIGURE 2. Limiting and mean cumulative curves in family of 34, Warthorst quarry, Massillon, Ohio.

Sorting coefficients (Trask, 1932, p. 71–72) range from 1.1 to 1.8. The mean is about 1.2, which indicates good sorting. Fine material is generally poorly sorted, but some of the coarser arenites also exhibit large coefficients of sorting (table 1).

Sphericity and roundness of 25 grains from each of eight thin-sections were estimated by visual comparison with a standard chart (Krumbein and Sloss, 1951, fig. 4–9). Sphericity of individual grains ranges from 0.3 to 0.9 and roundness ranges from 0.1 to 0.9; both characters thus run the gamut of the chart. Variations from slide to slide are small, however. Mean sphericity per slide ranges from 0.54 to 0.66; the grand mean is 0.60. Mean roundness per slide ranges from 0.20 to 0.31; the grand mean is 0.26. A series of t tests indicates that none of the sphericity and roundness means per slide departs significantly from the corresponding grand mean (For both sphericity and roundness, maximum $t = 1.3$; minimum $P = 0.20$). The shape of the quartz grains in the Massillon may therefore be characterized as sub-equant and angular to sub-angular.

Grain-contact types were investigated by the method proposed by Taylor (1950). Tangential and long contacts were readily determined, but concavo-convex and sutured types were not. The last two types were therefore combined for analysis. Contacts of 25 grains on each of eight thin sections were counted. The number of contacts per grain ranges from 0 to 8, the mean per slide ranges from 2.7 to 3.7, and the grand mean of eight slides is 3.2. About 14 percent of the contacts are tangential, 49 percent are long, and 37 percent are concavo-convex or sutured. Variation from slide to slide is somewhat larger than expectable sample variation, probably due at least in part to uncertainties arising from the irregular shape of many grains and the abundance of clay matrix.

TABLE 2

Long-axis orientation of elongate grains in thin-section. Two slides, 100 grains each, 30° classes. Zero arbitrarily defined as the long dimension of the slide.

Class (degrees)	Unit 3	Unit 6
0– 29	22%	19%
30– 59	33	19
60– 89	21	12
90–119	9	10
120–149	6	26
150–179	9	14
Total	100%	100%

Elongate grains show a tendency toward orientation in thin-section. Long-axis directions of 100 grains from each of two slides are shown in table 2. A chi-square test (Snedecor, 1946, p. 21–23) indicates that the distribution differs significantly from a random arrangement (Max. x^2, unit 3, 16.4, unit 6, 5.2; min. P, unit 3, <0.01, unit 6, 0.02). The chi-square test allows an evaluation of the probability that a group of observations of apparently non-random distribution could have been drawn by chance from a larger group (population) with random distribution. Accurate and efficient measurement of this property requires the use of oriented thin sections. Work was therefore suspended pending the collection of oriented specimens.

Structure. Most of the lower bench consists of continuous incline-bedded banks (defined by Andersen, 1931, *in* Pettijohn, 1949, p. 126) from 0.5 to 5 ft. in thickness. Individual beds range from 1.0 to 20 mm. thick. In the upper part of the lower bench bedding is less regular and some shallow cut-and-fill channels may be seen. Above the lower bench trough-type cross-bedding (defined by McKee and Weir, 1953, p. 387) in lenticular sets up to 3 ft. thick is the rule.

Thickness of the sets of cross- and incline-beds show a nearly log-normal distribution about a mean of 1.2 ft. In general, the thickness of the sets decreases from the bottom of the exposure to the base of the upper bench, where it increases abruptly and remains fairly constant to the top of the quarry wall (table 1). Median grain size shows somewhat similar variation, but there ap-

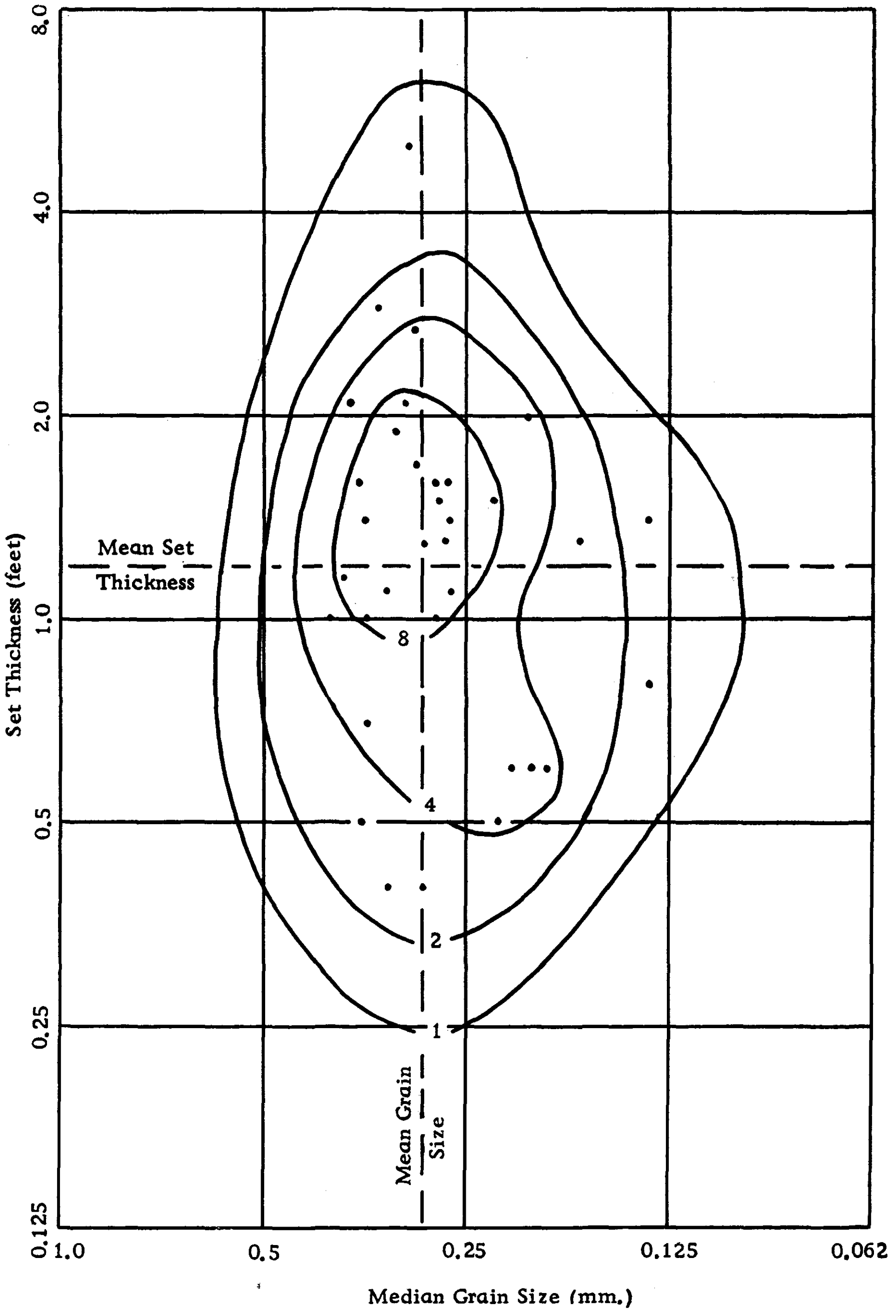

FIGURE 3. Thickness of Sets and Median Grain Size. Contours indicate relative density of observations.

pears to be no direct correlation between set thickness and median size (fig. 3). This suggests independence of the two measures.

Dip-direction distribution of cross- and incline-beds was investigated primarily as a possible criterion for correlation. Five groups of measurements were made, three in the lower bench and two in the upper bench, as shown in the sketch (fig. 1). From 11 to 24 measurements were made in each group. These groups were reduced to equal size by random selection of 11 items from each. Statistics derived are shown in table 3.

TABLE 3

Statistics of samples of dip-directions of cross- and incline-beds.

	Lower Bench			Upper Bench	
Statistic (see Snedecor, 1946, chs. 3 and 4)	South	North	Old Works	South	North
Mean direction ($\bar{x}$)	N 56° W	N 23° W	N 84° W	N 81° E	N 64° E
Number of measurements (n)	11	11	11	11	11
Standard deviation (s)	15°	26°	43°	15°	30°
Standard error ($s\bar{x}$)	4.5°	7.8°	12.9°	4.5°	9°

TABLE 4

Test of precision of individual measurements of dip-direction on the same bedding surface.

Statistic	Gray	Schlein
Mean ($\bar{x}$)	N 76.95° W	N 78.10° W
Number of measurements (n)	20	20
Standard deviation (s)	3.21°	3.18°
Standard error ($s\bar{x}$)	0.72°	0.71°
Difference of means	1.15°	
Standard error of difference of means	1.01°	
t	1.14 (not significant)	

Values of t and corresponding probabilities were calculated for geologically significant combinations of these groups of measurements. In most cases the value of t, which ranges from 1.65 to more than 40.0, indicates significant differences in the means of the populations sampled. Only the two groups from the upper bench indicate a significant probability that two more divergent groups than these could have been drawn from identical populations ($t = 1.65$, $P = 0.20$). It may therefore be inferred that only these groups (which were more closely spaced than any other correlative pair) were drawn from populations which were not significantly different and that cross-bedding studies will probably be of little value in correlation.

The mean direction of the groups of incline-bedding measurements seems not to show any systematic variation, but the standard deviation (table 3) shows a consistent increase northward in both benches. From nearby exposures it is seen that the medium-grained, incline-bedded graywacke disappears a few hundred feet north of the old works and its place is taken by interbedded gray shale and very fine-grained graywacke. The increased dispersion of incline-bedding dip-directions may result from proximity to the edge of the body of graywacke.

In order to test the precision of dip-direction measurements, a series of 20 measurements was made on the same incline-bedding surface by the author and by Mr. Frederick A. Schlein, who assisted in part of the field work. The statistics (table 4) indicate small limits of error for individual measurements and insignificant operator variation.

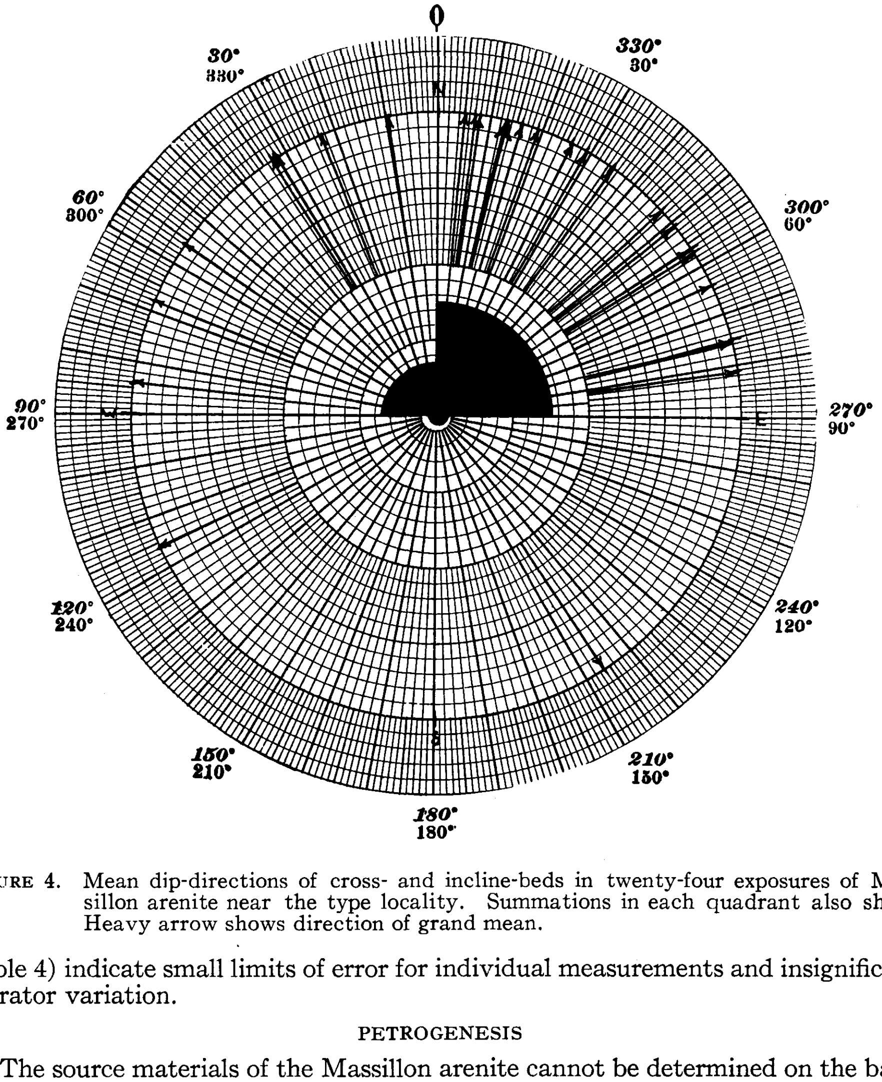

FIGURE 4. Mean dip-directions of cross- and incline-beds in twenty-four exposures of Massillon arenite near the type locality. Summations in each quadrant also show. Heavy arrow shows direction of grand mean.

PETROGENESIS

The source materials of the Massillon arenite cannot be determined on the basis of mineral composition alone because most of the components are of common types and too few grains reveal their origin. The direction of the source may be indicated, however, by a vector property such as dip-direction of cross- and incline-beds. A source material may then be sought in the indicated source area.

In addition to the five groups of dip-direction measurements made at the Warthorst quarry, nineteen other exposures, all within 20 miles of Massillon, were tested (fig. 4). The mean dip-direction for each exposure was calculated from

9 to 30 individual measurements. Fifteen of these means (63 percent) fall in the northeast quadrant and 7 (29 percent) fall in the northwest quadrant. The remaining 2 fall in the southeast and southwest quadrants (4 percent each). A southwestern or southern source of the Massillon of this area is therefore indicated.

Southwest of the type area the Massillon arenite lies at or near the base of the Pennsylvanian system and unconformably overlies Mississippian arenites. Some of the coarser Mississippian clastics may have been a source of the Massillon. The Black Hand sandstone, for example, is a low-rank graywacke similar to the Massillon in composition and texture and is indicated as a possible source because it is well developed in the area from which the Massillon may have been derived.

The environment of deposition of the Massillon arenite can be suggested on the basis of the composition, texture, and structure of the rock. The Massillon is among the most quartzose, best sorted, and most coarse-grained of the many lithologic types in the lower Pennsylvanian; this, together with the numerous unconformities and zones of cut-and-fill, both at the base and within the arenite, indicates a high-energy environment of deposition, such as is characteristic of beaches and stream channels.

Consistency of dip-direction in the cross- and incline-beds is favorable to the hypothesis of a beach environment; marine currents are generally more uniform than fluvial currents. The mean dip-direction is about N 13° E, and is approximately parallel to the strike of the rocks and to the general trend of the contact of the Pennsylvanian with the underlying Mississippian rocks. Longshore currents are therefore probable agents of transport and the physiographic environment may have been an offshore or longshore bar.

Diagenetic changes included the deposition of a small amount of secondary quartz as crystalline overgrowths and the development of flakes and aggregates of sericite (?) and kaolinite (?) which are not distorted and hence probably formed after compaction of the rock. Locally a hydrous iron oxide tentatively identified as goethite was introduced. In one thin-section where goethite is abundant it apparently has shattered and partially replaced the quartz and clay. Replacement of quartz by sericite (?) was indicated in one thin-section, but the time of this replacement could not be determined. It is considered diagenetic (?) primarily because of associated undisturbed interstitial sericite (?) flakes.

Taylor (1950) considers the number and type of grain contacts as an indication of the probable depth of burial of the arenites. Comparison with Taylor's data allows the suggestion that the Massillon may have been buried to a depth of 4,000 ft. or more. Because this is more than twice the known thickness of all possible overlying Pennsylvanian and Permian rocks in the Appalachian Basin, it seems likely that other factors, such as grain shape, may have more influence on grain-contact relations than Taylor recognized.

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