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AN INVESTIGATION OF THE EFFECT OF THE BAUER HURRICANE PULVERIZER-CLASSIFIER ON A KAOLINITIC SAND FROM ARBORG, MANITOBA

INTERNAL REPORT

by

R. S. DEAN

MINERAL PROCESSING DIVISION

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AN INVESTIGATION OF THE EFFECT OF THE BAUER HURRICANE PULVERIZER-CLASSIFIER ON A KAOLINITIC SAND FROM ARBORG, MANITOBA

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SUMMARY OF RESULTS

Use of the Bauer "Hurricane" apparatus in the treatment of the Arborg kaolinitic quartz sand resulted in quartz of the coarser fraction being ground to finer particle sizes. Within all but the coarsest portion of the subsieve size range, a multifold increase in the proportion of quartz was detected in all "Hurricane"-treated material.

The "Accept" products obtained from this apparatus were found to be almost entirely free of +325 mesh particles but their total quartz content was relatively high (17%). The behaviour of the Arborg kaolin in aqueous suspension was apparently altered by the dry-grinding treatment.

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INTRODUCTION

On February 26, 1964, four samples were submitted to the Mineral Processing Division, Mines Branch, by Mr. A.S. Dawson, 405 Waverley St., Winnipeg 9, Manitoba. The first of these, designated as "Feed" material, was a partially consolidated kaolinitic sand, which varied in colour from white to light grey or light reddish-brown. This sample had been collected on Section 14, Township 24, Range 1 East of the Principal Meridian, Manitoba, from what appears to be a buried river channel. The remaining samples, "W-3 Rejects", "W-3 Accepts" and "W-5 Accepts", represent the products obtained when "Feed" material was subjected to dry grinding and size classification in the Bauer Hurricane Pulverizer-Classifier at the plant of The Bauer Bros. Co. (Canada) Ltd. in Brantford, Ontario.

The principal object of this investigation is the study of the effect of the "Hurricane" treatment on the relative proportions and mineralogical composition of the various size fractions of the kaolinitic sand.

PROCEDURE

Particle Size Investigations

The sample designated as "Feed" was separated into fractions coarser and finer than 5 mesh (4.0 mm). The +5 mesh portion, which consisted of fairly well consolidated aggregates, was repeatedly passed through a Denver No. 1 jaw crusher. Following each passage of the +5 mesh material through the crusher, the -5 mesh fraction was separated. This procedure was continued until the whole of the "Feed" sample had been reduced to -5 mesh.

Representative portions (200-300 grams) of "W-3 Rejects" and -5 mesh "Feed" were cut in a Jones sample splitter. After being weighed, each of these two samples was divided into three approximately equal portions in 600 ml beakers. 300 ml of distilled water were added to each of the six beakers and the resultant slurries were stirred magnetically for 30 minutes.

The slurries were subsequently transferred to a 325 mesh (0.044 mm) sieve and wet-sieved with the aid of a jet of distilled water. The -325 mesh material from each sample was retained within a large flask.

Microscopic examination of the +325 mesh "Feed" revealed the presence of quartz-clay aggregate grains within the +45 mesh (0.35 mm) fraction. This (+45 mesh) fraction was separated by wet sieving and stirred

magnetically in distilled water until disintegration of the aggregates was apparently complete. The -325 mesh material released by this treatment was added to the flask containing the remainder of the -325 mesh "Feed". No aggregates were detected within the "W-3 Rejects" slurry.

The +325 mesh portions of the "W-3 Rejects" and "Feed" samples were dried and separated into various size fractions by sieving and weighing. A size class interval of 0.5 on the Krumbein phi scale (1) was utilized in this operation. The relationship of the phi notation to the ASTM standard sieve openings is shown in Table 1. Note that $\phi = -\log_2 d$, where d is the particle (or opening) diameter in millimetres.

As predicted by Krumbein and Pettijohn (2, p. 142) dry sieving of the "W-3 Rejects" and "Feed" samples yielded further quantities of -325 mesh material. This was added to the -325 mesh suspension.

Representative portions (about 50 grams) were split from the two remaining samples, "W-3 Accepts" and "W-5 Accepts". These were stirred briefly in distilled water, wet-sieved through a 325 mesh screen, and subsequently placed in large flasks. In both cases, only a very small proportion of the sample proved to be coarser than 325 mesh.

The volumes and approximate total sediment content of the four -325 mesh suspensions were determined. Measured portions of each suspensions were siphoned from their containers into separate 1000 ml graduated cylinders. During the course of this operation, the suspensions within the large flasks were constantly agitated by means of a mechanical stirrer.

TABLE 1

Metrical Equivalents of Krumbein Phi Scale Units and Standard ASTM Sieve Openings

ASTM Mesh No.	Millimetres	Phi (ϕ)
7	2.83	-1.5
10	2.00	-1.0
14	1.41	-0.5
18	1.00	0.0
25	0.71	+0.5
35	0.50	+1.0
45	0.35	+1.5
60	0.250	+2.0
80	0.177	+2.5
120	0.125	+3.0
170	0.088	+3.5
230	0.062	+4.0
325	0.044	+4.5
	0.031	+5.0
	0.0221	+5.5
	0.0156	+6.0
	0.0110	+6.5
	0.0078	+7.0
	0.0055	+7.5
	0.0039	+8.0
	0.00276	+8.5
	0.00195	+9.0
	0.00138	+9.5
	0.00098	+10.0
	0.00069	+10.5

A strong tendency toward clay flocculation was observed in the "W-3 Rejects" and both "Accepts" suspensions. In order to counteract this, standard ammonia solution was added to each of the four suspensions so that the concentration of NH_4OH, after dilution of the suspensions to 1000 ml, was 0.008 N. This value is close to the optimum ammonia concentration reported by Whitehouse and Jeffrey (3, p. 275) in their studies of the peptization of kaolinite suspensions. Ammonia was chosen as the peptizing agent chiefly because it leaves no residue upon evaporation, and thus cannot interfere with mineralogical analyses of dried suspensions.

The total sediment content of each 1000 ml suspension was determined by evaporation of a 20 ml aliquot (Table 2). The total concentration of suspended material within the "W-3 Rejects" suspension exceeded the 25 gram/litre value suggested as a maximum by Krumbein and Pettijohn (2, p. 99). A high total sediment content was chosen in this case when it became evident that the greater part of the suspended material fell within the size classes immediately below +4.5 ϕ (325 mesh).

Mechanical analyses were made of the four peptized suspensions by the pipette method, as outlined by Krumbein and Pettijohn (2, pp. 166-168). As before, a size class interval of 0.5 ϕ was chosen. Settling velocities of the different sizes of particles were calculated from Stokes' equation, as modified by Wadell (4, p. 407). Temperature corrections for variations in the viscosity of water were made to the nearest 2°C. The size of the pipette sample varied inversely with the maximum particle size:

TABLE 2

Total Sediment Content of 1000 ml Suspensions of -325 Mesh Material

Sample	Weight (grams)
Feed	16.98
W-5 Accepts	18.75
W-3 Accepts	17.44
W-3 Rejects	49.01

10 ml, (greater than +7.0 ϕ); 20 ml, (between +7.0 and +9.0 ϕ); 50 ml, (less than +9.0 ϕ). In the latter case, the suspended material was dewatered by centrifugation at 12,000 rpm in a Servall Superspeed Centrifuge.

In the case of the "W-3 Rejects" and "Feed" suspensions, an abnormally large quantity of sediment was reported within the +4.5 to +5.0 ϕ fraction. This included all material which had passed a 325 mesh (+4.5 ϕ) screen and yet had a settling velocity greater than that calculated for a +5.0 ϕ particle. A second pipette analysis of these two suspensions was made within the size range +3.5 to +5.5 ϕ. This study revealed that a considerable amount of material previously reported as +4.5 to +5.0 ϕ actually had settling velocities within the +4.0 to +4.5 ϕ size range. The weight of material thus determined as +4.0 to +4.5 ϕ was added to that of the sieved fraction for this size interval. These seemingly anomalous results illustrate one of the difficulties encountered in comparing particle size measurements as determined by sieving with those obtained by settling

techniques. The former method tends to sort particles according to their minimum cross-sectional dimensions whereas the opposite is more nearly true in the latter case.

X-ray Diffraction Analyses

Upon completion of the mechanical analyses by the pipette method, the material within each of the small drying beakers was removed and briefly ground, in order to homogenize quartz-clay mixtures which might have become partially segregated by sedimentation. Small portions of the homogenized mixtures were finely ground in an agate mortar. Mounts for a Guinier-deWolff 4-sample X-ray powder diffraction camera(5) were prepared utilizing 0.015 grams of the finely ground mixtures in each case. Fourteen standard mixtures of potter's flint (quartz) and quartz-free kaolinite (A.P.I. Project 49, S-1, H-4) with quartz contents ranging from 0.1% to 80% were also prepared. The standards were ground and mounted in the same manner as were the unknowns. All mounts were irradiated for an equal period of time and a uniform film development procedure was followed. Visual comparison of the X-ray films of the unknown mixtures with those of the quartz-kaolinite standards allowed the quartz content of the unknowns to be estimated.

In order to identify minor mineral constituents the -5 micron size fraction was separated from a portion of the -325 mesh "Feed" suspension by centrifugation. An oriented clay mineral mount was prepared by drying a suspension of the -5 micron material on a borosilicate-glass

slide. This was scanned with a North American Philips High Angle X-ray Diffractometer when air-dry, glycol-saturated, and after heating for one-half hour at 580°C.

The remaining -5 micron material was dried, crushed, and heated for one-half hour at 580°C. Subsequently, free iron oxides were removed from the heat-treated clay by the dithionite-citrate method of Mehra and Jackson(7). The differential dissolution (NaOH) treatment of Hashimoto and Jackson(8) was then employed in order to dissolve dehydroxylated kaolin minerals and any interlayer alumina which might be present within expanded mica-type clay minerals. A Guinier X-ray powder photograph was made of the residue. An oriented clay mineral mount was also prepared from the same material (on borosilicate glass) and this was scanned with the X-ray diffractometer before and after being heated for one-half hour at 580°C.

RESULTS

Particle Size Investigations

Histograms showing the particle size distribution within each sample are shown in Figures 1 to 4. In all cases the column on the extreme right represents the total quantity of material having an equivalent settling diameter of less than +10.5 ϕ. The data utilized in the construction of these diagrams are presented in Tables 3 and 4.

TABLE 3

Particle Size Distribution in "Feed" and "W-3 Rejects" Samples

Size Interval (Phi Units)	"Feed" Weight Percentages	"W-3 Rejects" Weight Percentages
-1.5 to -1.0	0.10	-
-1.0 to -0.5	0.59	0.01
-0.5 to 0.0	1.09	0.02
0.0 to +0.5	2.17	0.08
+0.5 to +1.0	3.52	0.34
+1.0 to +1.5	6.28	0.98
+1.5 to +2.0	15.13	4.43
+2.0 to +2.5	16.46	8.87
+2.5 to +3.0	8.66	11.47
+3.0 to +3.5	5.72	13.21
+3.5 to +4.0	5.34	15.69
+4.0 to +4.5	4.81	12.22
+4.5 to +5.0	2.08	9.37
+5.0 to +5.5	1.58	6.36
+5.5 to +6.0	1.08	2.92
+6.0 to +6.5	1.60	1.35
+6.5 to +7.0	1.54	1.15
+7.0 to +7.5	1.40	0.78
+7.5 to +8.0	1.33	0.71
+8.0 to +8.5	1.23	0.51
+8.5 to +9.0	1.38	0.64
+9.0 to +9.5	1.55	0.63
+9.5 to +10.0	2.84	1.41
+10.0 to +10.5	5.15	3.02
Finer than +10.5 ϕ	7.37	3.83
Total	100.00%	100.00%

TABLE 4

Particle Size Distribution in "W-5 Accepts", "W-3 Accepts", and Minus +4.5Ø Fraction of "Feed" and "W-3 Rejects" Samples

Size Interval (Phi Units)	"W-5 Accepts" Weight Percentages	"W-3 Accepts" Weight Percentages	Minus +4.5Ø "Feed" Weight Percentages	Minus +4.5Ø "W-3 Rejects" Weight Percentages
+4.0 to +4.5	0.01	0.02	-	-
+4.5 to +5.0	1.44	0.57	6.90	28.67
+5.0 to +5.5	2.56	3.90	5.24	19.47
+5.5 to +6.0	5.76	3.15	3.59	8.94
+6.0 to +6.5	6.61	6.88	5.30	4.14
+6.5 to +7.0	6.99	5.30	5.12	3.51
+7.0 to +7.5	6.91	6.19	4.65	2.40
+7.5 to +8.0	5.55	6.25	4.42	2.16
+8.0 to +8.5	5.57	5.22	4.09	1.57
+8.5 to +9.0	4.75	5.33	4.56	1.96
+9.0 to +9.5	5.50	5.17	5.14	1.92
+9.5 to +10.0	8.90	8.92	9.43	4.32
+10.0 to +10.5	18.90	20.57	17.09	9.24
Finer than +10.5Ø	20.56	22.53	24.46	11.72
Total	100.01%	100.00%	99.99%	100.02%

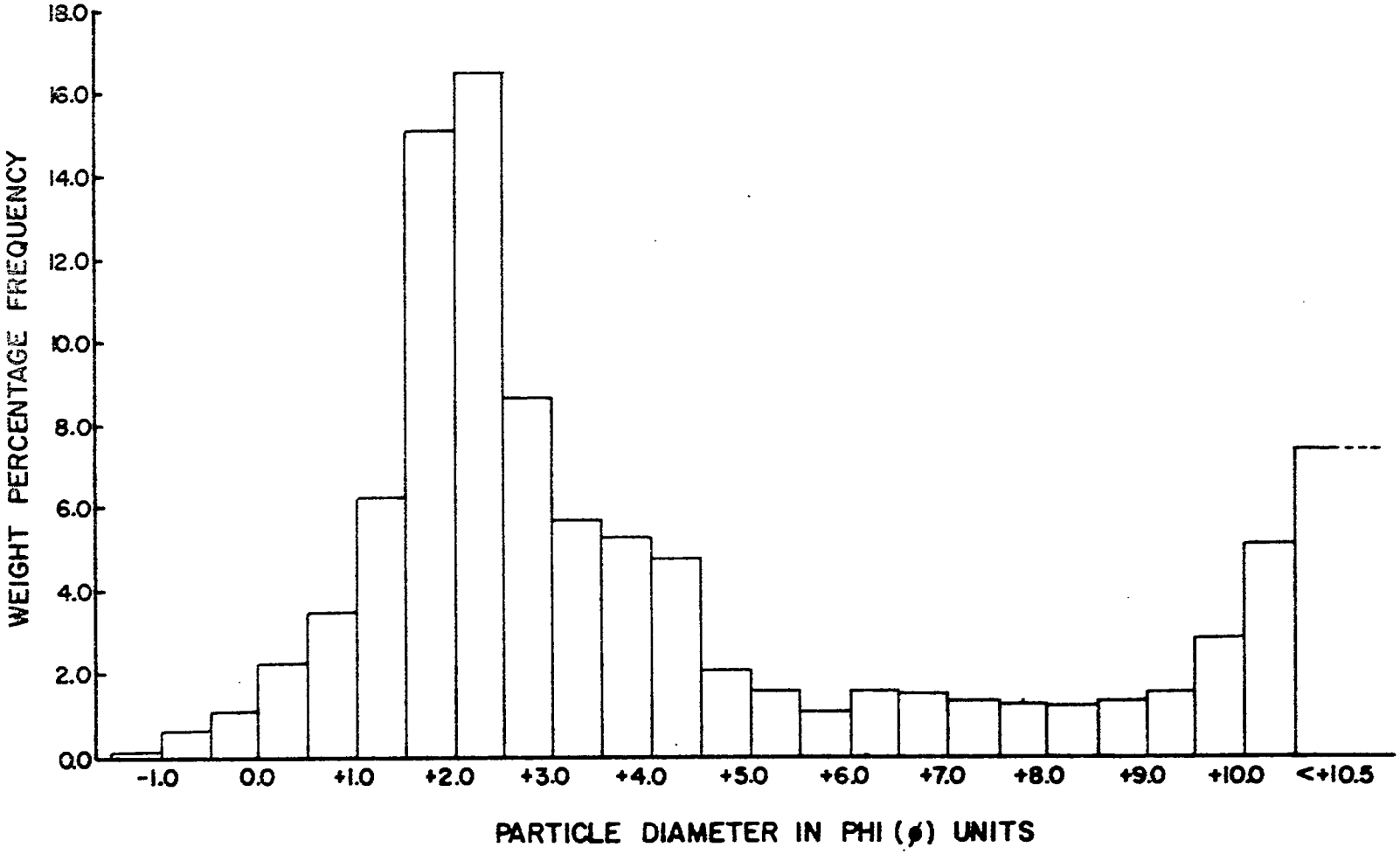

Figure I. Histogram Showing Particle Size Distribution in "Feed" Sample.

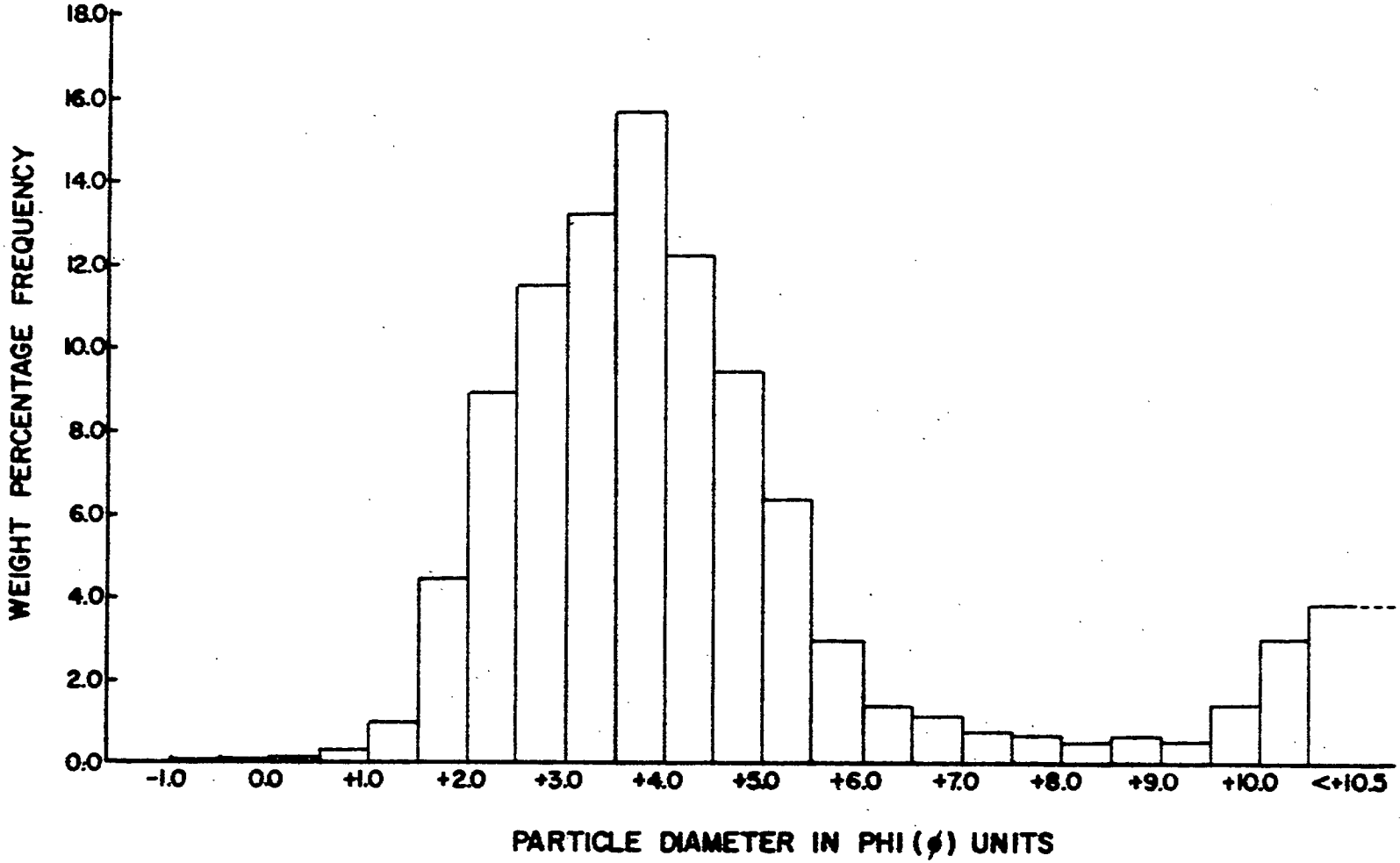

Figure 2. Histogram Showing Particle Size Distribution in "W-3 Rejects" Sample.

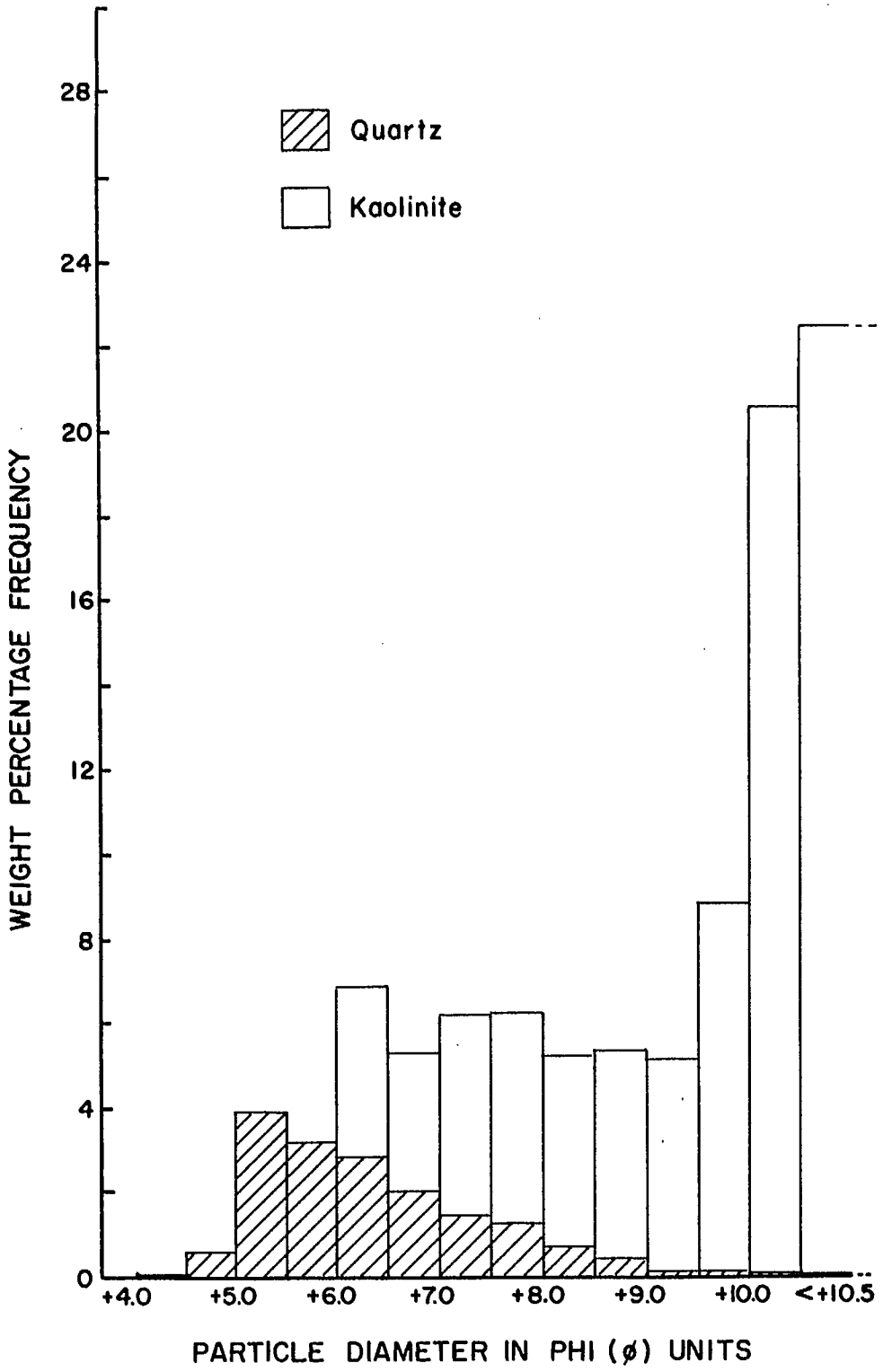

Figure 3. Histogram Showing Particle Size and Quartz –Kaolinite Distribution in "W–3 Accepts" Sample.

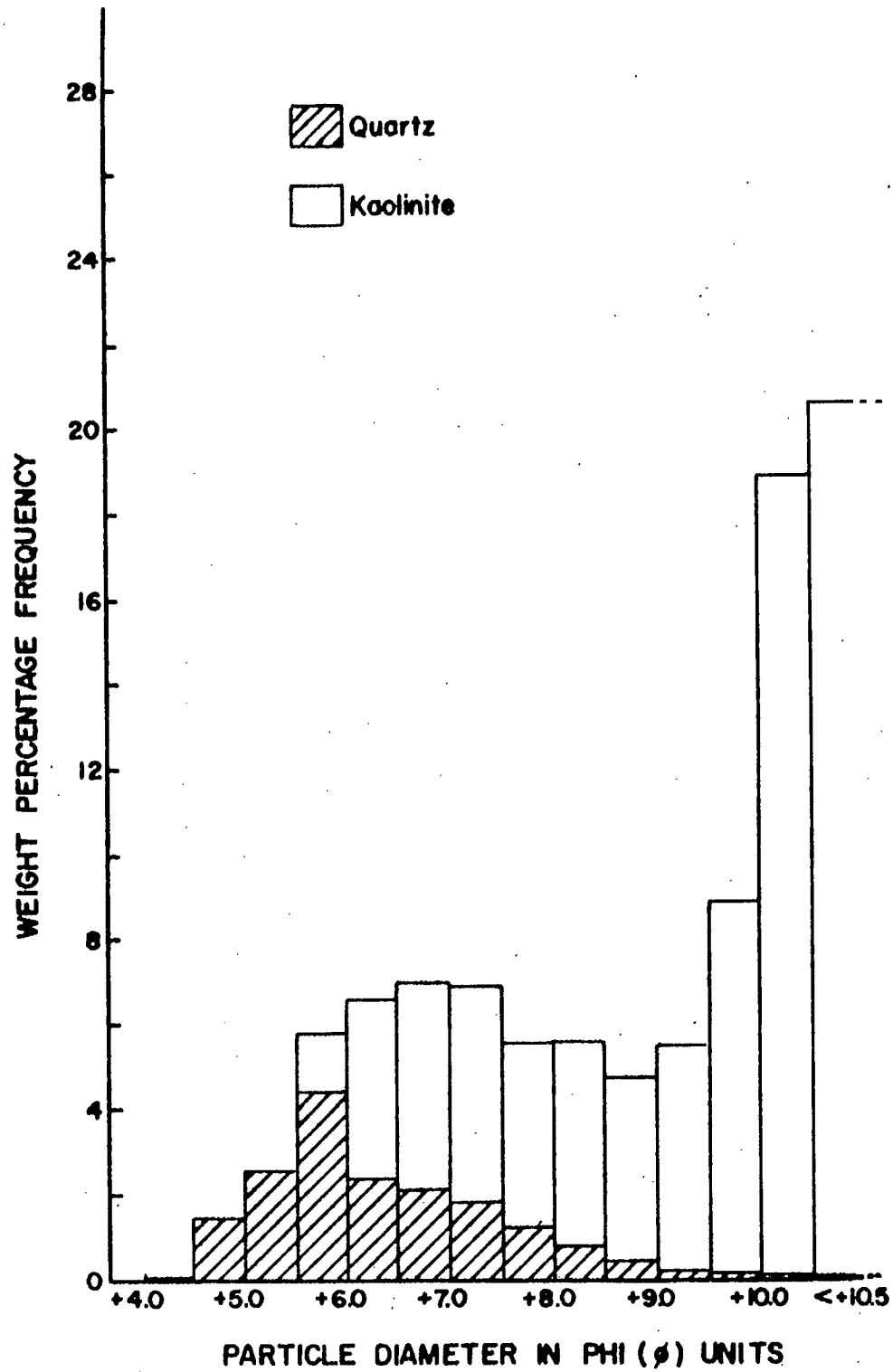

Figure 4. Histogram Showing Particle Size and Quartz – Kaolinite Distribution in "W-3 Accepts" Sample.

A comparison of Figures 1 and 2 reveals that the "W-3 Rejects" sample has lost both material coarser than +2.5 ϕ and finer than +6.0 ϕ relative to the "Feed". The loss of the coarser particles is undoubtedly the result of grinding by the Bauer "Hurricane" pulverizer, whereas the finer (less than +6.0 ϕ) material has been partially removed as "Accepts" by the Bauer particle classifier.

Figures 3 and 4 show that both "Accepts" samples lie almost entirely within the subsieve (finer than +4.5 ϕ) particle size range. In order to compare the particle size distribution in the "Accepts" samples with that in the equivalent portion of the "W-3 Rejects" and "Feed" samples, the minus +4.5 ϕ fractions of both the latter were recalculated as separate whole samples (Table 4, Figures 5 and 6). A comparison of the minus +4.5 ϕ "Feed" histogram with those of the "Accepts" samples reveals that the Bauer "Hurricane" treatment has resulted in no appreciable concentration of the finest (less than +9.5 ϕ) fraction relative to the coarser (+4.5 to +9.5 ϕ) material. The presence of very fine-grained material within the "W-3 Rejects sample indicates that the size separation process is incomplete, although its efficiency cannot be estimated in the absence of data on the relative proportions of "Accepts" and "Rejects" produced.

Quartz Determinations

Table 5 lists the estimated percentages of quartz within the dried sediment withdrawn in the course of the pipette analyses. Values for the quartz content of the material within each 0.5 ϕ size interval (Table 6, Figures 3 to 7) were obtained by comparing the increments in total quartz

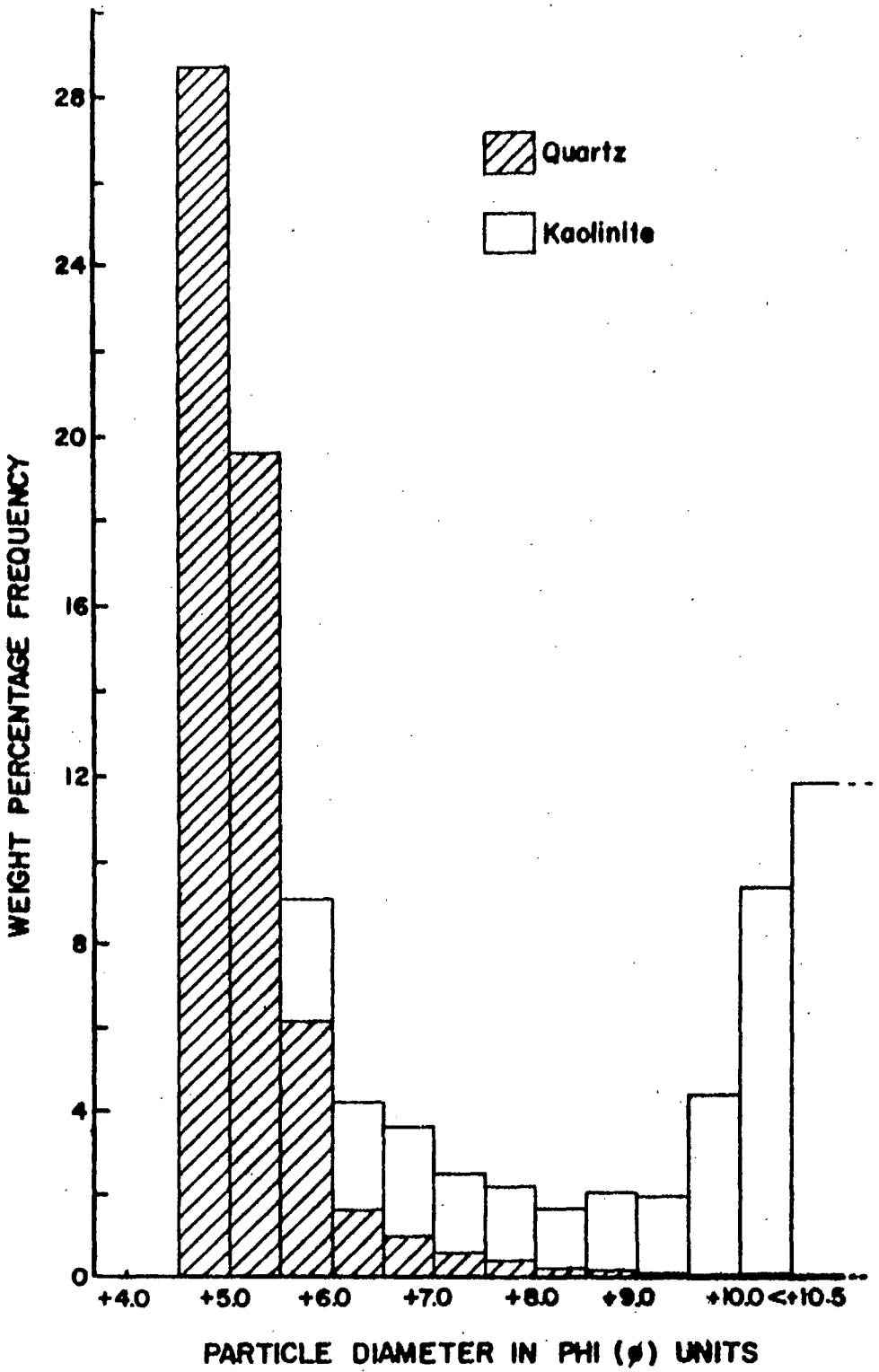

Figure 5. Histogram Showing Particle Size and Quartz – Kaolinite Distribution in the Minus +4.5 ϕ Fraction of the "W-3 Rejects" Sample.

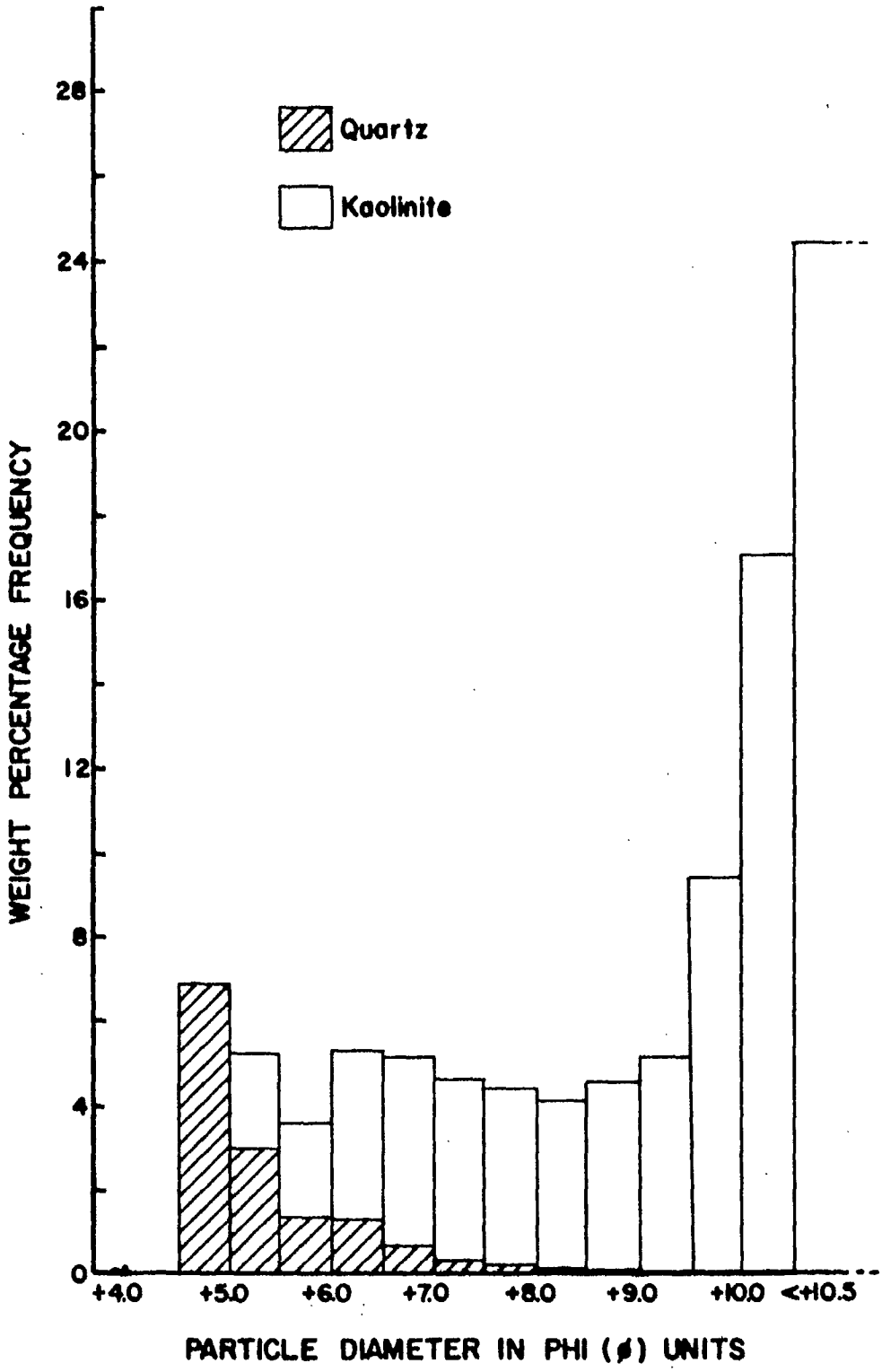

Figure 6. Histogram Showing Particle Size and Quartz – Kaolinite Distribution in the Minus + 4.5 ϕ Fraction of the "Feed" Sample.

TABLE 5

Estimate of Quartz Content of Pipette Analysis Samples
by X-ray Diffraction

Maximum Settling Diameter of Particles in Sample (Phi Units)	"W-5 Accepts" Per Cent Quartz	"W-3 Accepts" Per Cent Quartz	"Feed" Per Cent Quartz	"W-3 Rejects" Per Cent Quartz
+ 4.5	17 1/2	17	14 1/2	55
+ 5.0	16 1/2	16 1/2	8	40
+ 5.5	14	13	5	20
+ 6.0	10	10	3 1/2	10
+ 6.5	8	7 1/2	2	7
+ 7.0	6	5 1/2	1.2	5
+ 7.5	4	4	0.8	3 1/2
+ 8.0	2 1/2	2 1/2	0.5	2 1/2
+ 8.5	1.5	1.5	0.3	1.7
+ 9.0	0.8	0.8	0.2	1.0
+ 9.5	0.6	0.6	0.10	0.7
+10.0	0.4	0.4	0.05 (approx)	0.5
+10.5	0.2	0.2	Not Detected*	0.2

*Probably less than 0.05% quartz

TABLE 6

Estimated Quartz Content of the Various Size Fractions

Size Interval (Phi Units)	"W-5 Accepts" Per Cent Quartz	"W-3 Accepts" Per Cent Quartz	"Feed" Per Cent Quartz	"W-3 Rejects" Per Cent Quartz
+4.5 to +5.0	100	100	100	100
+5.0 to +5.5	100	100	58	100
+5.5 to +6.0	77	100	40	68
+6.0 to +6.5	35	42	26	38
+6.5 to +7.0	30	37	14	27
+7.0 to +7.5	26	23	7.2	26
+7.5 to +8.0	21	20	5.2	18
+8.0 to +8.5	13	14	3.5	17
+8.5 to +9.0	9.4	9.0	1.5	11
+9.0 to +9.5	2.6	2.8	1.2	5.0
+9.5 to +10.0	1.4	1.6	0.32	1.7
+10.0 to +10.5	0.63	0.62	$0.09 \pm 0.03\%$	0.88
Finer than +10.5 ϕ	0.20	0.20	0.00 to 0.04	0.20

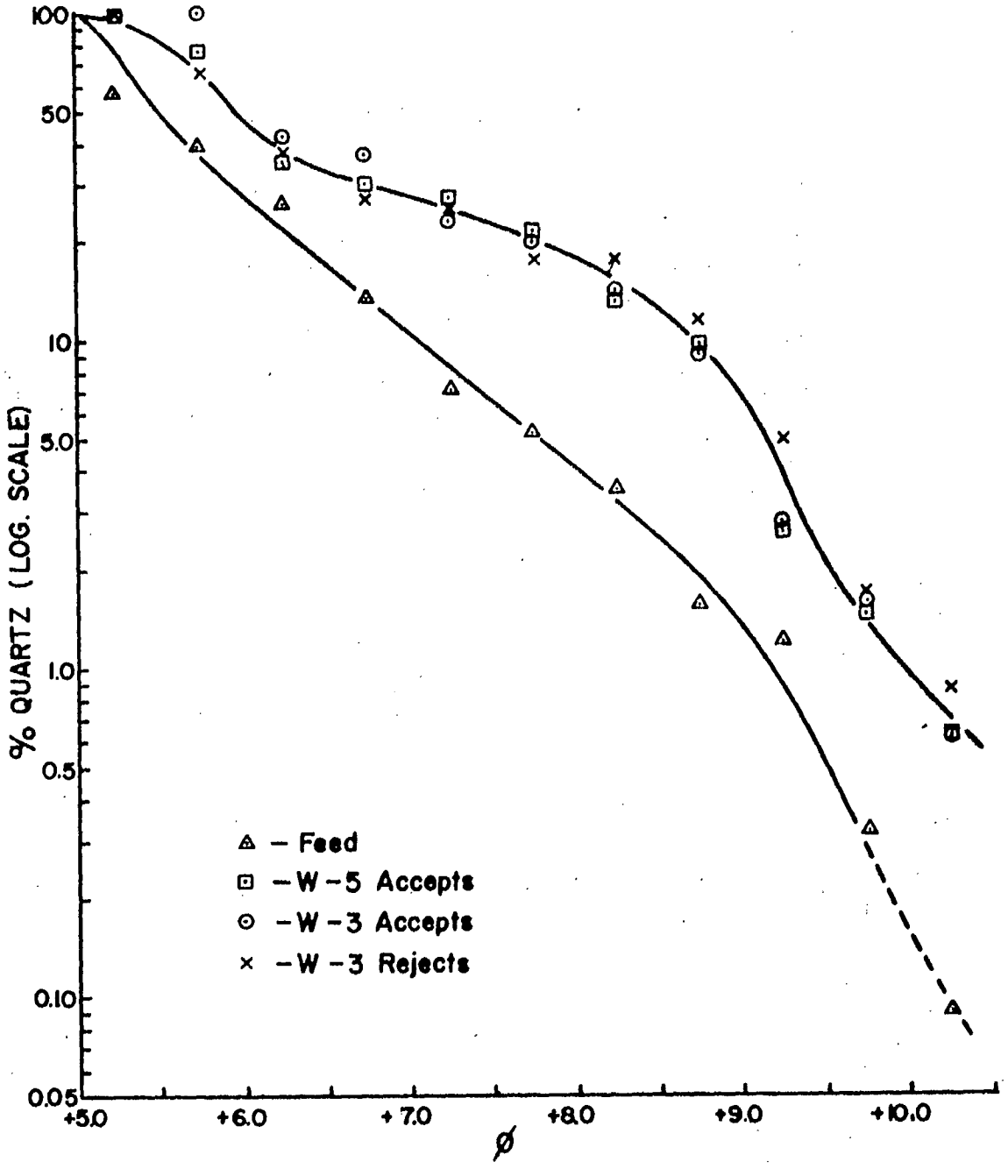

Figure 7. Percentage Quartz in the Various Size Fractions

content (Table 5) with the particle size distribution data (Table 4). It should be noted that the quartz values which are obtained in this manner become progressively less accurate toward the coarser fractions. In some cases, impossible or highly unlikely percentage quartz values were obtained for a given size fraction, whereupon the total quartz figures (Table 5) were adjusted. Under no circumstances did these changes exceed the probable error of the total quartz estimate.

Table 6 shows that in all sizes finer than +5.0 ϕ, the proportion of quartz within every size fraction is less in the "Feed" sample than in any of the remaining three. This is best illustrated in Figure 7, where the percentages of quartz in the different size fractions of all samples have been plotted. On this diagram it is readily seen that the "Feed" and all "Hurricane"-treated samples follow separate and distinct percentage quartz trends, each of which can be represented by a line.

Mineralogy

The minerals identified within the minus +4.5 ϕ fraction of the "Feed" sample are listed in Table 7. In addition to these constituents, considerable quantities of metal chips were collected by the magnetic stirring bar during the dispersion of the three "Hurricane"-treated samples in water.

TABLE 7

Mineralogy of Minus +4.5 ϕ "Feed" Sample

Mineral	Abundance
Kaolinite	Very abundant
Quartz	Common
Micaceous Clay Mineral	Minor
Anatase	Minor
Dolomite	Minor
Rutile	Trace

The X-ray diffractometer study of the heat-treated residue from the 580°C NaOH differential dissolution analysis treatment(8) of the -5 micron "Feed" material suggested the presence of a very poorly crystallized micaceous clay mineral. The Guinier X-ray powder photograph of the same material revealed the presence of a small quantity of rutile.

As is usually the case in sedimentary kaolin deposits, anatase was detected in every sample containing significant quantities of kaolinite.

Dolomite was identified within the coarser fractions of all samples. It occurred only in trace quantities in sizes finer than +8.0 ϕ and was not detected in material smaller than +10.0 ϕ.

Portions of the minus +10.0 ϕ fraction of each of the four samples were re-examined with the Guinier X-ray powder camera. In this case, however, the usual preliminary grinding was omitted, in order to avoid artificially disordering the kaolin. It was found that the X-ray powder

TABLE 8

X-ray Powder Diffraction Data for Minus +10.0 ϕ "Feed" Kaolinite*

d(Å)	Intensity	
7.17	vs	diffuse
4.46-4.14	m	band
4.46	ms	
4.36	ms	
4.18	m	
4.14	vw	
3.84	w	
3.74	vw	
3.57	s	diffuse
3.37	vw	
2.561	m	
2.561-2.553	w	band
2.530	w	
2.496	ms	
2.382	vw	
2.346-2.336	s	band
2.294	m	
2.252	vvw	
2.199-2.184	vvw	band
1.997-1.980	w	band
1.940	vw	diffuse
1.840	vw	
1.787	vw	
1.689-1.677	w	band
1.668-1.651	m	diffuse band
1.619	w	
1.582	vvw	
1.487	s	

*Guinier powder camera; Co radiation; quartz standard.

patterns given by the kaolins from all four samples were virtually identical.

The unground minus +10.0 ∅ "Feed" was also re-run adjacent to a mount of the same material to which 8% finely ground quartz (potter's flint) had been added. The X-ray powder data for the "Feed" kaolin was subsequently compiled (Table 8) utilizing the quartz reflections as standards. Comparison of the data in Table 8 with that presented by Brindley (9, p. 111) indicate that the kaolin mineral in these samples is, at least in part, well-crystallized kaolinite. Some degree of resolution of the 4.18 and 4.14 Å reflections is evident, which is characteristic of well-ordered kaolinite (9, p. 62). On the other hand, the fairly prominent band within the 4.46-4.14 Å region suggests that disordered kaolin is also present.

CONCLUSIONS

(1) Grinding of the "Feed" quartz in the course of the Bauer "Hurricane" treatment has displaced the modal size class from +2.0-+2.5 ∅ down to +3.5-+4.0 ∅ (Figures 1 and 2).

(2) The "Hurricane" has greatly increased the quartz content of the finer size fractions. Table 6 indicates that within identical size fractions finer than +7.0 ∅, the three pulverized samples contain up to six times as much quartz as does the "Feed". This relative increase in quartz content persists to the very finest size fractions.

(3) Both "Accepts" samples have a total quartz content of about 17% (Table 5) and contain only a trace of material coarser than +4.5 ∅.

The "Hurricane" treatment resulted in no apparent concentration of the kaolin-rich very fine (minus +9.5 ϕ) fractions relative to the remaining (+4.5 to +9.5 ϕ) material.

(4) The presence of minus +4.5 ϕ particles within the "W-3 Rejects" sample indicates that the removal of this fine-grained material as "Accepts" was incomplete.

(5) Within similar size classes finer than +6.0 ϕ, the relative proportions of quartz and kaolinite are approximately the same for both "Rejects" and "Accepts" samples (Table 6, Figure 7). This would indicate that within the minus +6.0 ϕ range the Bauer particle classifier was non-selective, allowing both quartz and kaolinite particles to pass with equal facility.

(6) Distilled water suspensions of "Hurricane"-treated clay showed a much greater tendency to flocculate than did those of untreated ("Feed") clay. Although a 13 gram/litre distilled water suspension of the "Feed" did not visibly flocculate, a preliminary pipette analysis revealed that the bulk of the "Feed" clay mineral fraction occurred as +5.5 to +7.5 ϕ aggregates. The extreme tendency to flocculate exhibited by the "Hurricane"-treated clays is similar to that which has been observed by the writer (10, p. 65) among dry-pulverized shales.

(7) Besides kaolinite and quartz, the minus +4.5 ϕ fraction of the "Feed" sample was found to contain minor amounts of anatase, dolomite and a very poorly crystallized micaceous clay mineral. A trace of rutile was also detected. The kaolin group was represented by what appeared to be

a mixture of well-ordered and partially disordered kaolinite.

(8) All three "Hurricane"-treated samples contained a relatively high proportion of powdered metal (steel?), which was presumably derived from the pulverizer.

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