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PETROGRAPHICAL INVESTIGATIONS OF THE SALT WASH SEDIMENTS

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Abstract

This report is Part I of a series in which is described the comparison of ore-bearing with barren samples of Salt Wash sediments in terms of petrographic characteristics. This part contains a discussion of mineral composition and packing characteristics of 50 samples of Salt Wash sandstones 25 of which are ore-bearing and 25 barren.

The main differences in composition are the greater amount of matrix (which contains the ore) in ore-bearing than barren sediments and the greater amounts of clay "pebbles" reflecting slump disturbance of ore-bearing sediments. The excess matrix and clay "pebbles in ore-bearing sediments is also reflected in the excess of quartz and feldspar in the barren sediments.

The packing characteristics are highly correlated with corresponding items of composition such as the grain to matrix contacts with per cent of matrix and the grain to cement contacts with per cent of cement. Hence packing measured in this way is largely a function of mineral composition.

Grain to void contacts which reflect the porosity of the sediments are higher in barren sediments than in ore-bearing and, as far as investigated, this packing characteristic appears to be independent of the compositional elements.

Part I: Introduction

The objective of this final part of the petrographic investigation of Salt Wash Sediments is to attempt to establish by statistical analysis which petrographic properties are most important in differentiating ore-bearing from barren rocks. From our earlier reports the differences are of degree, not kind and need quantitative analysis by techniques which are demonstrably in control.

The first step is to choose the most important properties and in general this leads to the selection of five properties common to all aggregates, namely, composition, grain size, shape, orientation and packing (Griffiths, 1952a). A detailed quantitative petrographic analysis should contain information on all five properties and the first part of the present report contains a description of the variation in these properties for two sets of samples, barren and ore-bearing. The next step is to find the inter-relationships between these five properties and from a statistical point of view to determine which of the items studied are likely to be informative in segregating ore-bearing from barren sediments. Finally, these selected items are combined into an index and this index is tested to determine if it will discriminate between ore-bearing and barren sediments.

The index which we will call (P) comprises a linear combination of the selected items and is designed so that the variation within each group, ore-bearing and barren, is minimized while the variation between the groups is maximized (Hoel, 1949, Fisher, 1948); the resulting equation which will be of the form:

$$P = b_1X_1 + b_2X_2 + \text{-------} \; b_2X_n$$

is called a discriminant function and if it discriminates satisfactorily then the range of values of P for the ore-bearing samples will be different from the range of values of P for the barren rocks.

Differentiation by means of a discriminant function has been used in various fields such as genetics, archaeology, soil sciences and the social sciences; an example of its use in sedimentary petrography to differentiate oil-bearing from barren sediments has recently been described (Emery and Griffiths, 1954).

The advantage of this approach is that it enables the investigator to check the index and to decide the importance of the several variables in differentiating ore-bearing from barren sediments. The results are, of course, reproducible by anyone capable of performing the petrographic analysis.

ii) Program

Setting up the function as basis for the discriminant is an important step; in the present case we may formulate the basic equation as follows:

$$P = f\,(m, s, sh, o, p) \quad \ldots\ldots\ldots\ldots \quad (1)$$

wherein we state the index (P) is some function of the mineral composition (m), grain size (s) and shape (sh), and the fabric of the sediment reflected in grain orientation (o) and packing (p). Now it is necessary to select techniques for the measurement of the five properties m, s, sh, o, p; and suitable techniques are mentioned in our various reports and publications (Emery and Griffiths, 1954; Kahn, 1954; Griffiths, 1952a, b; Griffiths and Rosenfeld, 1950, etc.).

It is also necessary to select a suitable sampling program; in the present case 25 samples of ore, mostly oxidized types, and 25 samples of barren sediments were chosen from the collection at the Pennsylvania State University gathered by the senior author during visits to the Colorado Plateau. The detailed lithology, locality and catalogue numbers are given in Appendix table 1; the samples come from three main areas which have been described and discussed in our earlier reports namely the Bull Canyon area, Monogram Mesa, Colorado; the Montezuma Canyon area, Monticello, Utah; and the Lukachukai Mountains, Cove School, Arizona.

These 50 samples were analyzed petrographically and the detailed description of the data is included in part iii below. It should be obvious that without our preparatory work (RME 3032, 3054, 3070, 3097, 3106 it would not have been possible to decide what mineral constituents to use in describing the composition, and secondly without prior knowledge of the techniques for measurement of the other properties and some familiarity with the range of variation to be expected it would not have been possible to set up the analysis leading to the discriminant function. It is most important to understand the inter-relationships among the various properties so that some reduction in the number of variates can be achieved, and this aspect is discussed in Part (e) of the report. In simple terms, if the variation in any two items is highly correlated then there is little point in including both in the discriminant since the additional information from the second variate is small. This principle is utilized in selecting which variates are most important in differentiating ore-bearing from barren sediments.

iii) <u>Description of the Petrographic Properties of 25 samples of ore-bearing and 25 samples of barren Salt Wash Sediments</u>.

The petrographic properties of the fifty samples of Salt Wash Sediments are described in order commencing with mineral composition, then size, shape, orientation and packing, and the various conclusions established on the basis of each property are summarized after each section.

A(a) Mineral Composition

Thin sections of each of the fifty samples of Salt Wash sediments were analyzed for mineral composition by point count (Griffiths, et al, RME 3097, Part I). The constituents chosen as a basis for the quantitative estimates are:

i) Quartz and feldspar (not separately identified).

ii) Rock fragments (in toto).

iii) Quartzite fragments, composed of fragments of pre-existing quartzites.

iv) Chert fragments composed of fine grained siliceous aggregates.

v) Volcanic fragments composed of fragments of pre-existing volcanic materials.

vi) Clay "pebbles", aggregates comprised of clay particles.

These six items include the bulk of the detrital fragments which were carried into the basin of deposition.

Genetically they are not all from the same source nor did they all have identical histories and their associations are best evaluated by describing their inter-relationships (pp. 32 et seq).

vii) In addition to these discrete detrital fragments there are fine grained constituents not readily identified beyond the descriptive title of clay minerals, and this material based on its irregular morphological characteristics and distribution in thin section is called matrix. It is presumably detrital in origin but may also be, at least in part, clastic and perhaps also formed in situ.

(viii, ix) Finally, the cementitious elements which are chemically precipitated comprise principally silica and carbonate. This classification is very much simplified because various sulphates and much hydrated iron oxide also belong in this class; volumetrically however, carbonate and silica are the dominant cements.

In point counting the various thin sections there were always more or less other constituents not included in the above list and these were classified in a special group called Miscellaneous. This group included rare rock fragments of sandstone, granite, and limestone, and accessory minerals such as opaques, zircon, rutile, garnet, etc. The frequency of this class was generally small and never exceeded 2 per cent in the samples examined. The amounts of each constituent in each sample are summarized in tables 2a and b (pp. 33, 34).

A(b) Procedure

The technique of point counting has been described in earlier reports (RME 3054, p. 34 et seq., RME 3097, Part I). The most important aspect is the choice of sampling program and some initial information of the variability to be expected is necessary in order to set up a suitable sampling interval. The objective is to be able to detect a difference of say 3-4 per cent in the quartz-feldspar group between the ore-bearing and barren samples. Since each set of samples contains 25 thin sections this number is large enough to detect the difference, but to reduce the variation between traverses within thin sections five traverses per thin section proved barely enough (RME 3097, pp. 13-25), hence, 6 traverses per thin section were analyzed. The success of this program in achieving its limited objective (p. 27) indicates the value of setting up a suitable sampling program before commencing the analysis.

The proportion of rock fragments appears to be more variable than the quartz-feldspar (RME 3097, op. cit.) so that more information is necessary to bring this item into control.; to use more traverses would have been impracitcable within the time at our disposal so it was decided to increase the length of traverse, and in an attempt to allow for sporadic variation it was decided not to use a fixed number of points per traverse but to count the number of rock fragments per 100 grains of quartz and feldspar in each of the 6 traverses. Thus the rock-fragment proportions are variable in precision from traverse to traverse depending on the proportion of quartz and feldspar. The proportions were reduced to percent in Appendix tables 2a and b but were used without adjustment in some of the graphs (e.g. figs. 3, 4, 5, and 6).

The order of analysis of the fifty thin sections was randomized, and the 6 traverses per section were chosen by randomly selecting the first traverse and spacing the remainder an equal number of traverses away from each other. The traverses were arranged so that they yielded a representative sample of the entire section.

A(c) Expression of the Results

Each traverse of each thin section yields an estimate of the amount of constituents; for all 50 thin sections containing six traverses each there are 300 estimates, and these are subdivided into two sets of 150 estimates for the 25 ore-bearing and 25 barren samples respectively. In the frequency distributions that follow the entire set of 300 and the two subsets of 150 are sometimes graphed or alternately only the subsets of 150.

The frequency distributions are also summarized by means of descriptive statistics (table 3); the first column explains whether the statistics apply to all 300 estimates or only to the 150 ore-bearing and barren estimates. Column 2 contains the mean or average value which may be in per cent or in proportions based on counts of 100 quartz and feldspar grains. This latter scale is confined to the rock fragments. Column 3 of table 3 contains the standard deviation in the same scale units as the mean, and column 4 contains the coefficient of variation (Cv) in per cent. This statistic expresses the variation (standard deviation) as a proportion of the mean ($\bar{X}$) and is useful as an indicator for comparing the variability among different items; it is independent of scale and is usually expressed in per cent. A coefficient of variation of less than 10 per cent generally implies a uniform material, of 10-30 per cent moderately variable material. Many properties of sediments fall in this range. A coefficient of variation of over 30 per cent indicates highly variable material and when over 50 per cent the variation among the items is too large for the comparison of sets of items. The coefficient of variation may also be used to estimate the number of samples necessary to reduce the variability to some desired low value - in general the higher the Cv. the larger the number of samples necessary to reduce the variability to any given value.

Fig. 1.

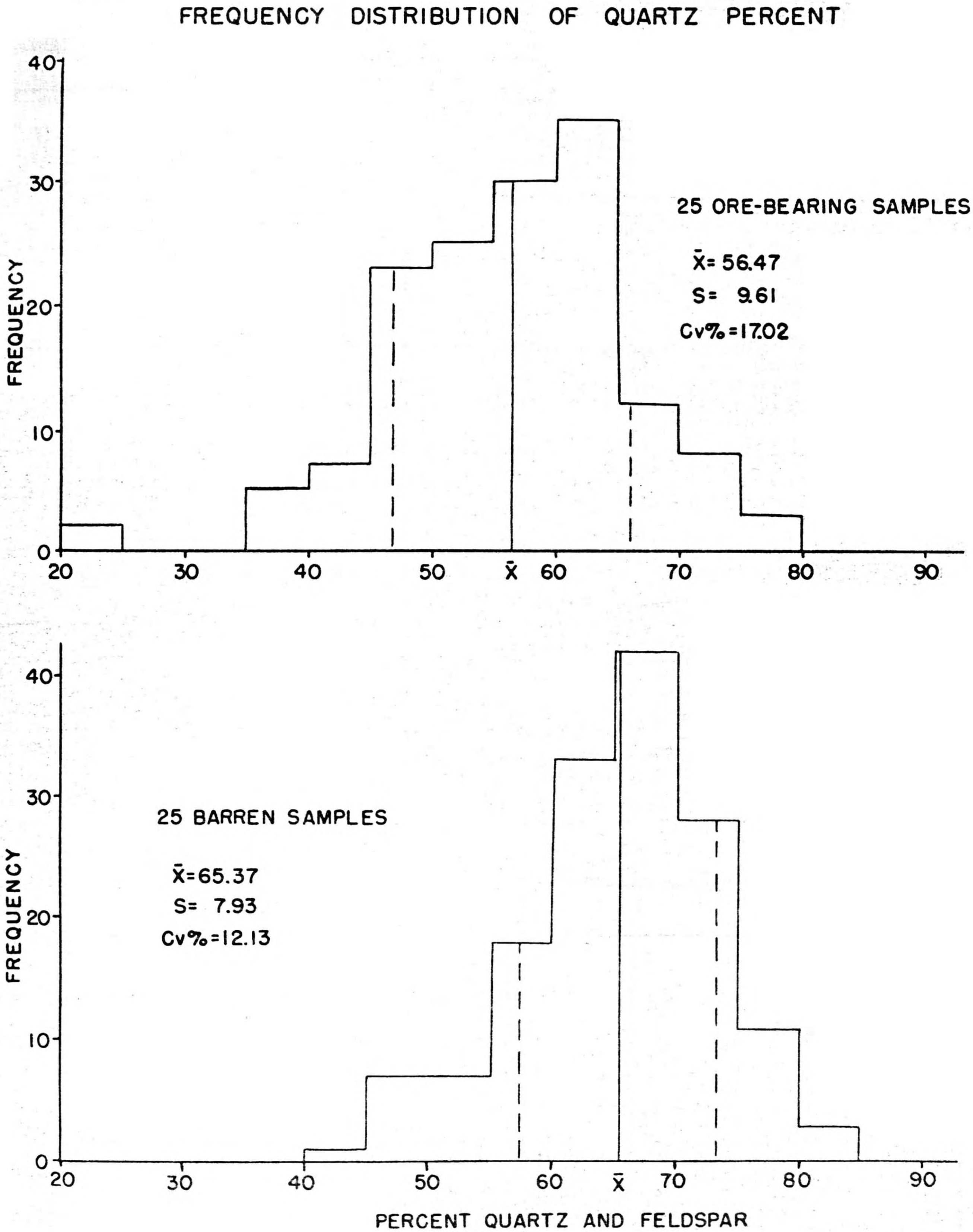

FREQUENCY DISTRIBUTION OF QUARTZ PERCENT
25 ORE-BEARING SAMPLES
X̄= 56.47
S= 9.61
Cv% =17.02
FREQUENCY
0
10
20
30
40
20
30
40
50
X̄
60
70
80
90
25 BARREN SAMPLES
X̄=65.37
S= 7.93
Cv% =12.13
PERCENT QUARTZ AND FELDSPAR

Fig. 2

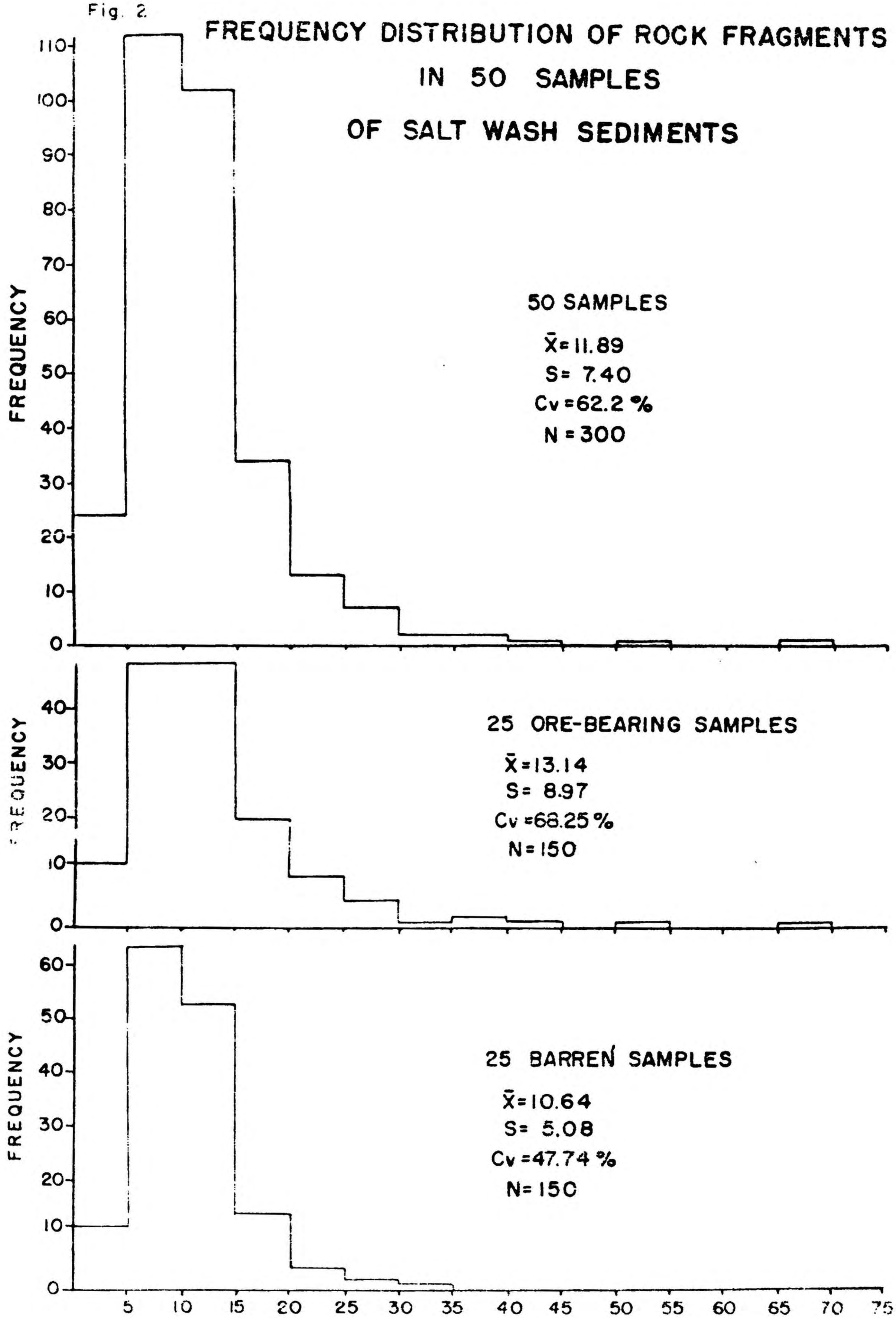
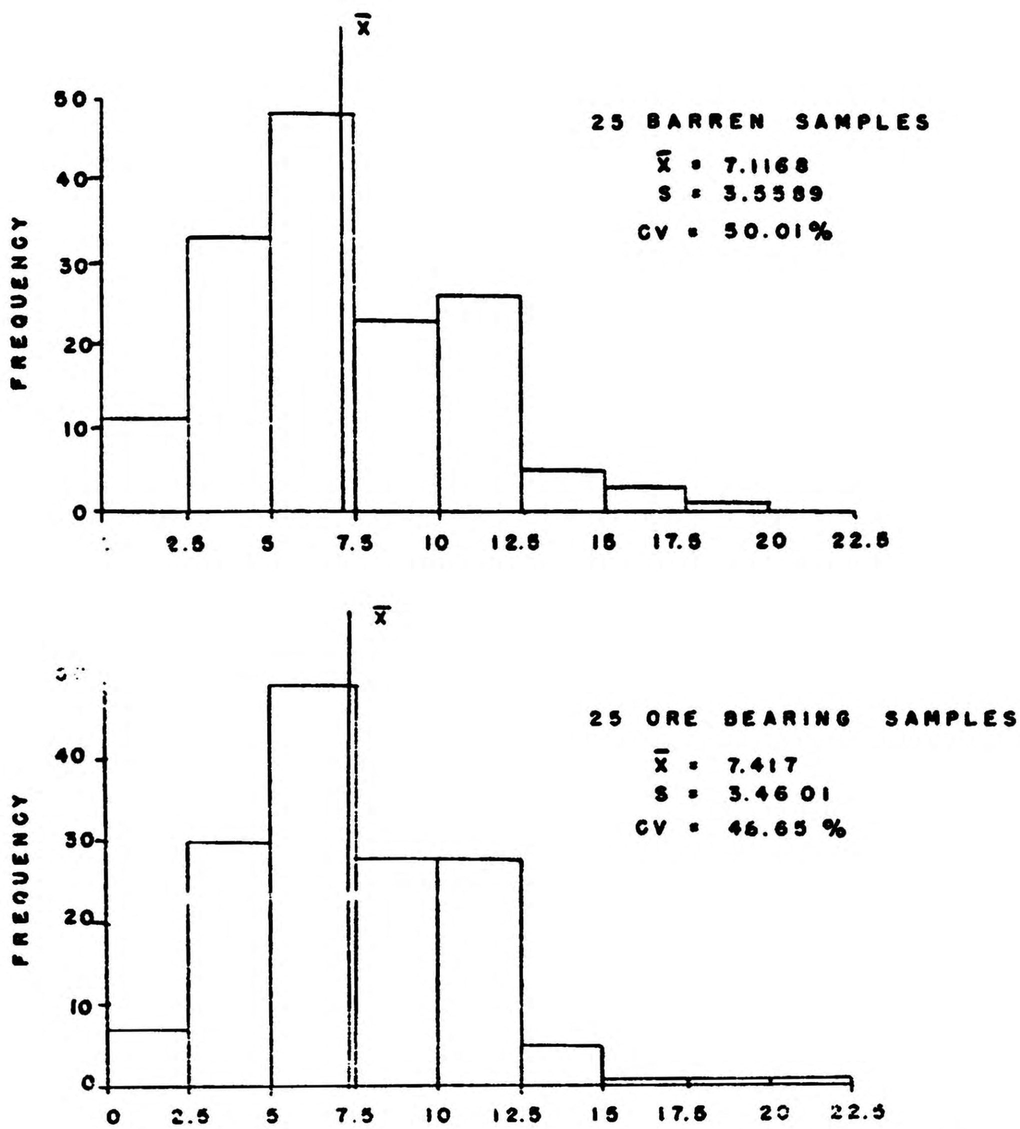

FREQUENCY DISTRIBUTION OF ROCK FRAGMENTS
IN 50 SAMPLES
OF SALT WASH SEDIMENTS
50 SAMPLES
X̄ = 11.89
S = 7.40
Cv = 62.2 %
N = 300
25 ORE-BEARING SAMPLES
X̄ = 13.14
S = 8.97
Cv = 68.25 %
N = 150
25 BARREN SAMPLES
X̄ = 10.64
S = 5.08
Cv = 47.74 %
N = 150
FREQUENCY
0
10
20
30
40
50
60
70
80
90
100
110
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75

Fig 3

ROCK FRAGMENTS — QUARTZITE



NUMBER OF POINTS PER TRAVERSE OF 100 QUARTZ GRAINS

Fig. 4

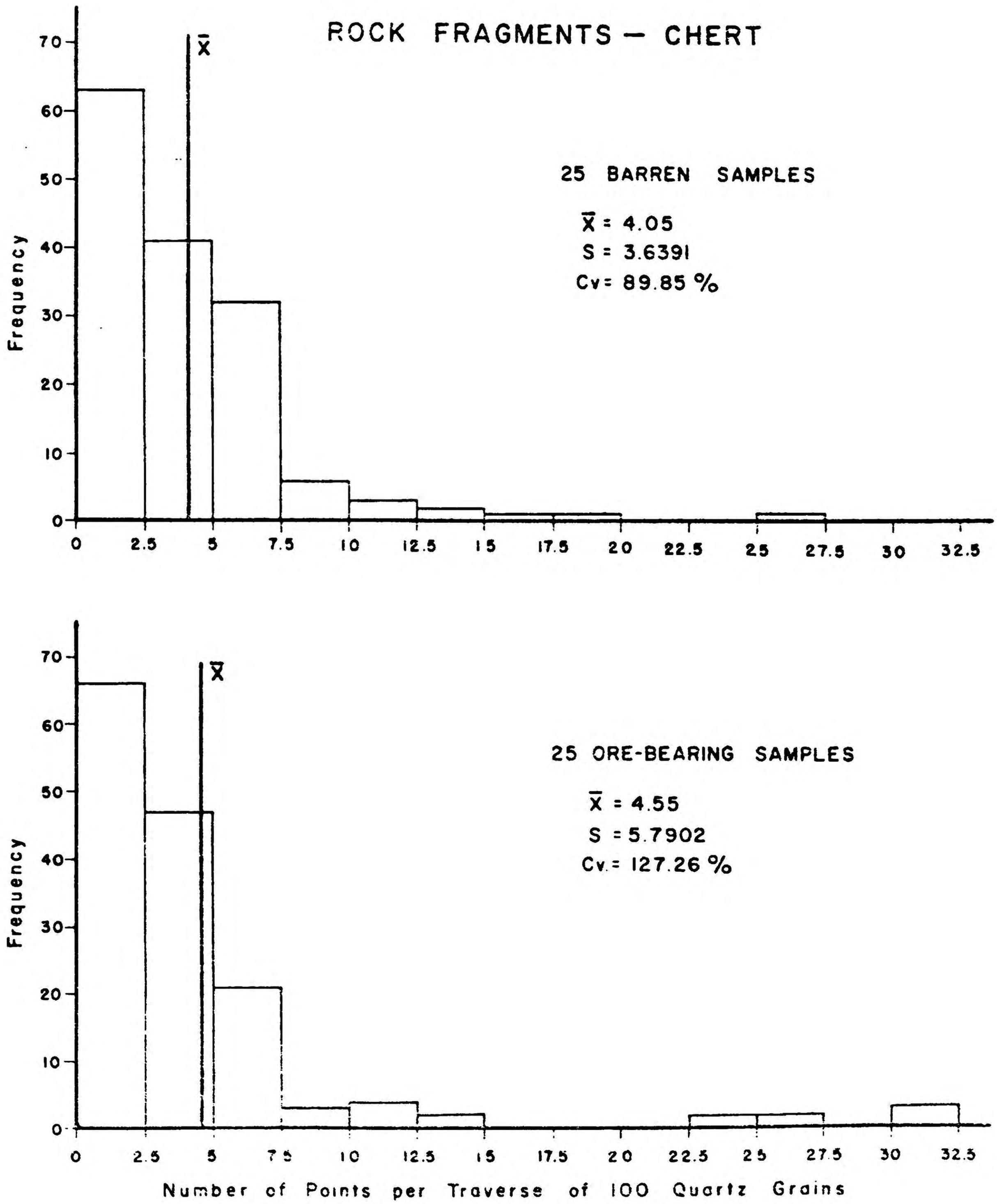
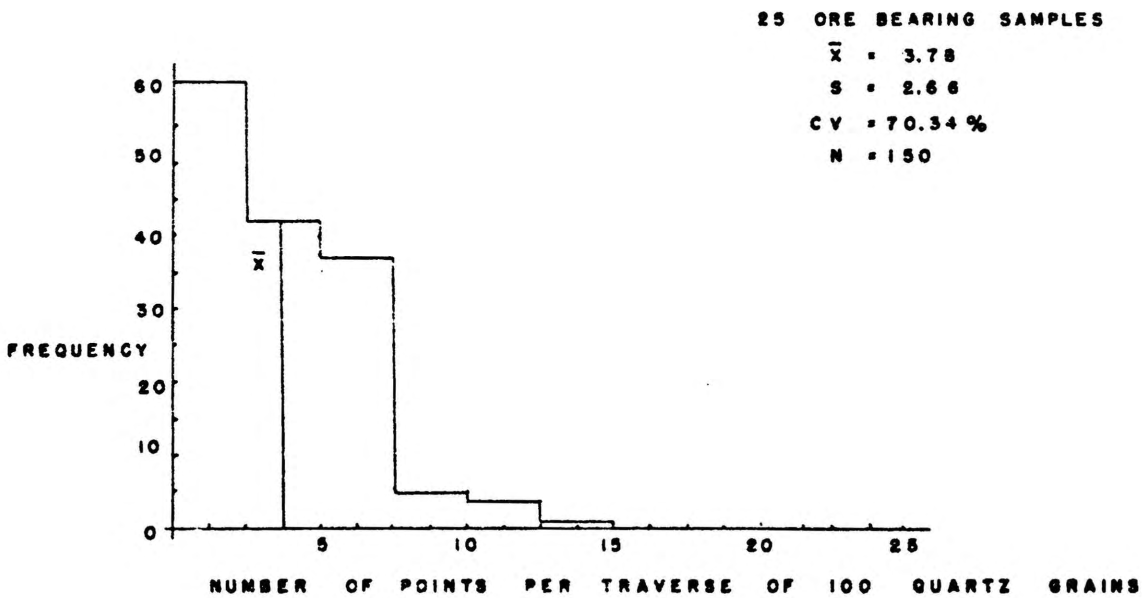

ROCK FRAGMENTS — CHERT
25 BARREN SAMPLES
$\bar{X}$ = 4.05
S = 3.6391
Cv = 89.85 %
Frequency
0 2.5 5 7.5 10 12.5 15 17.5 20 22.5 25 27.5 30 32.5
25 ORE-BEARING SAMPLES
$\bar{X}$ = 4.55
S = 5.7902
Cv. = 127.26 %
Frequency
0 2.5 5 7.5 10 12.5 15 17.5 20 22.5 25 27.5 30 32.5
Number of Points per Traverse of 100 Quartz Grains

Fig. 5

FREQUENCY DISTRIBUTION OF VOLCANIC ROCK FRAGMENTS IN 50 SAMPLES OF SALT WASH SEDIMENTS



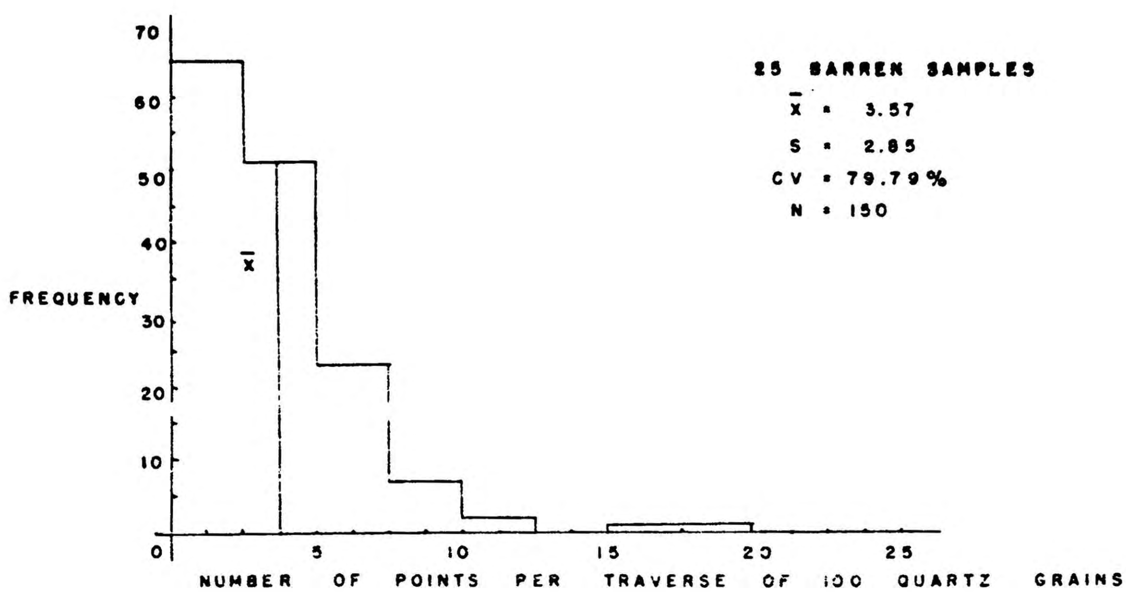
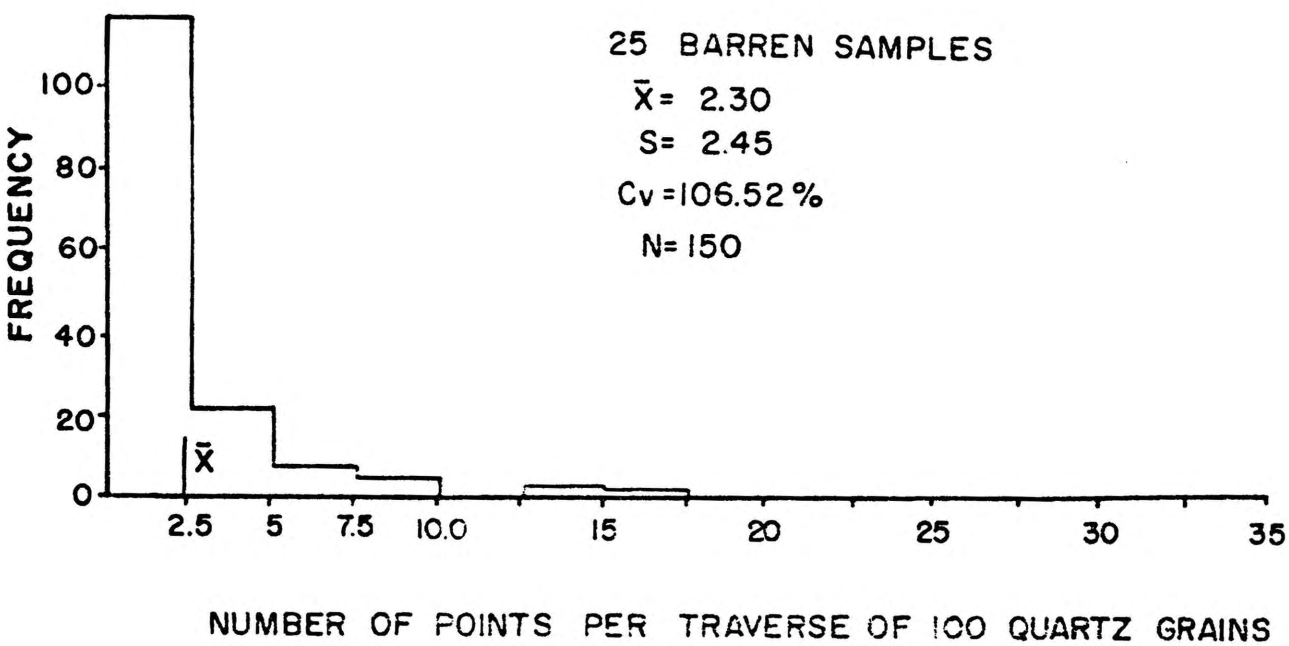
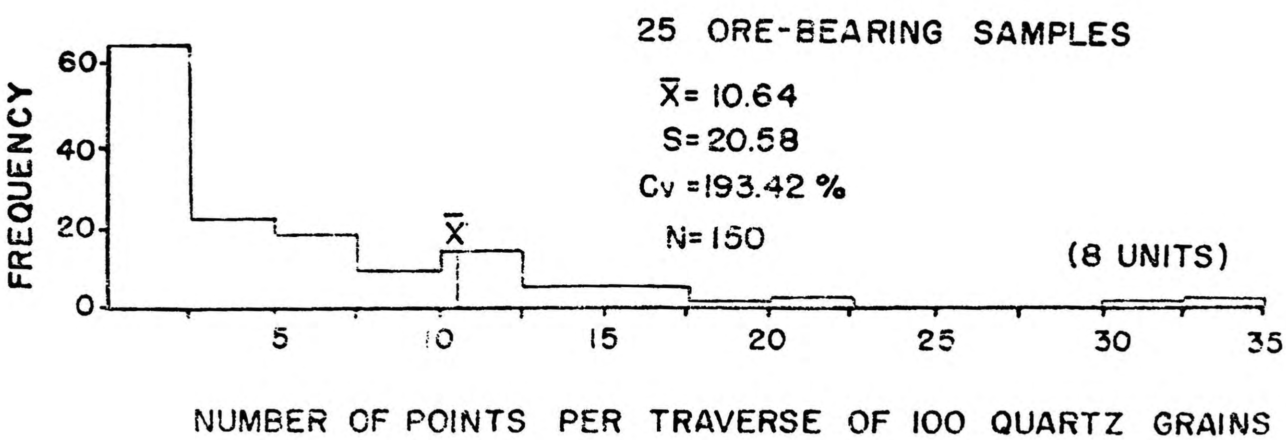
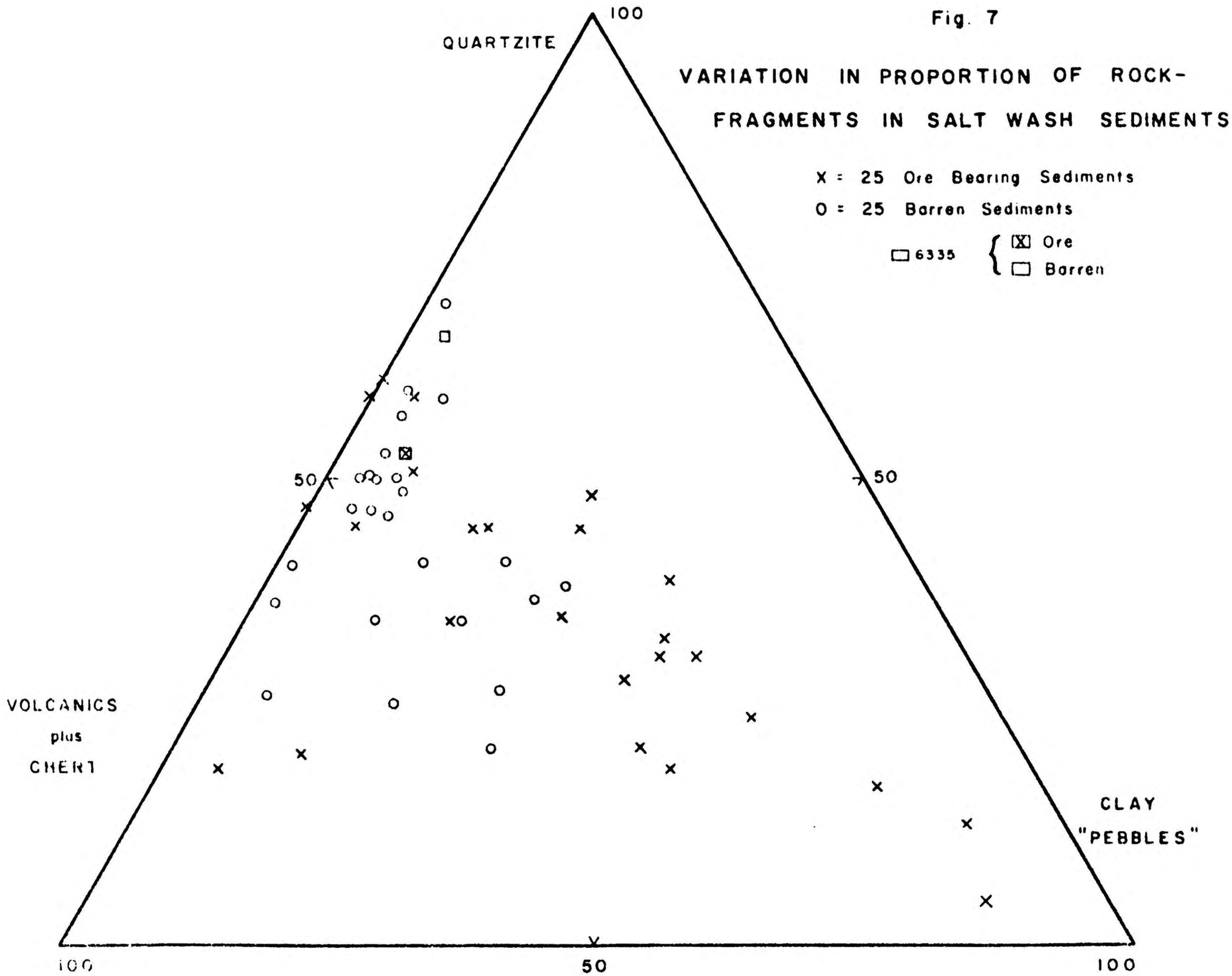


Fig 6

FREQUENCY DISTRIBUTION OF CLAY "PEBBLES" IN SALT WASH SEDIMENTS.






100
QUARTZITE
Fig. 7
VARIATION IN PROPORTION OF ROCK-FRAGMENTS IN SALT WASH SEDIMENTS
X = 25 Ore Bearing Sediments
O = 25 Barren Sediments
6335
Ore
Barren
50
50
VOLCANICS plus CHERT
CLAY "PEBBLES"
100
50
100

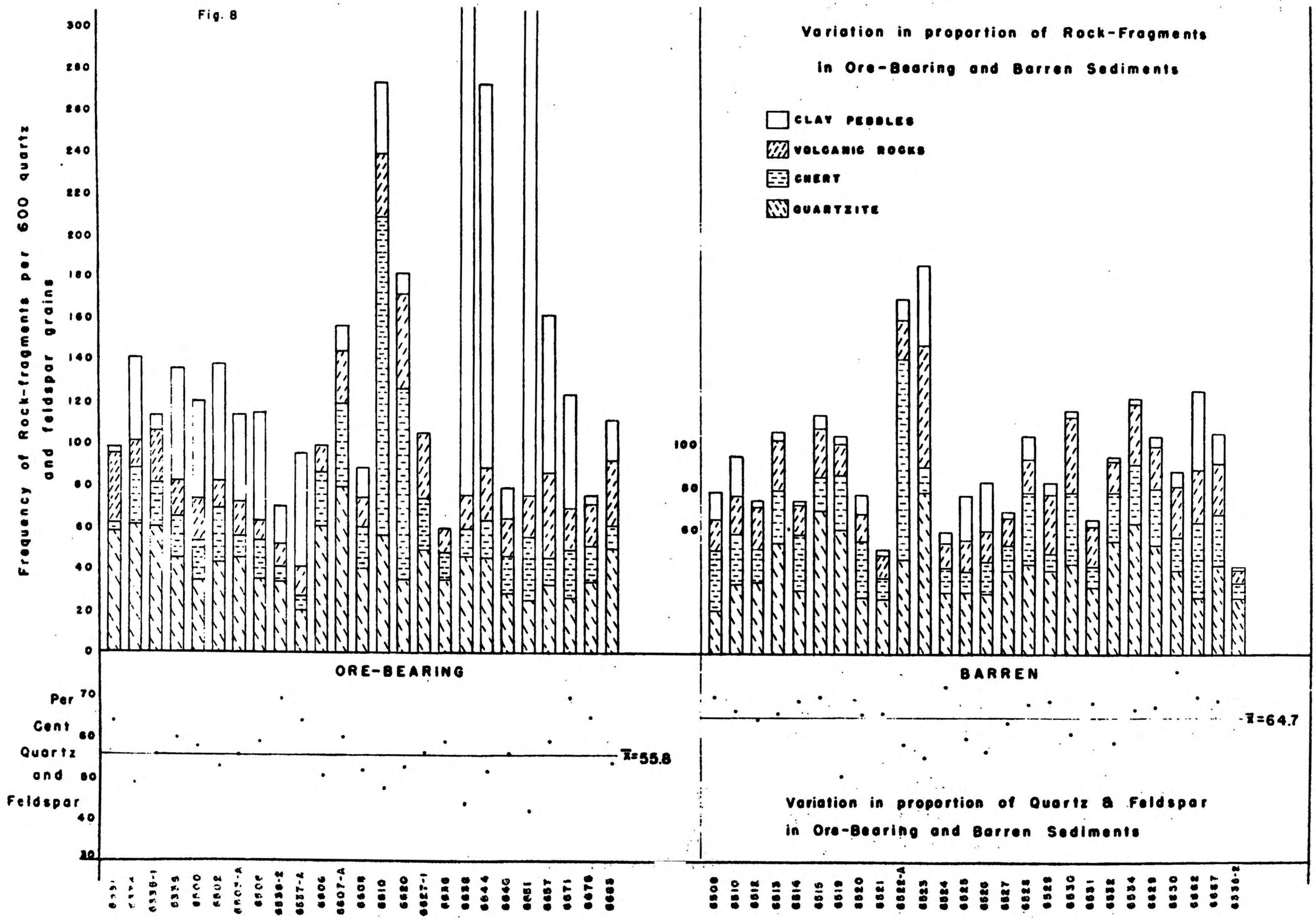


Fig. 8
Variation in proportion of Rock-Fragments
in Ore-Bearing and Barren Sediments
CLAY PEBBLES
VOLCANIC ROCKS
CHERT
QUARTZITE
Frequency of Rock-fragments per 600 quartz and feldspar grains
ORE-BEARING
BARREN
Per Cent Quartz and Feldspar
x̄=55.8
x̄=64.7
Variation in proportion of Quartz & Feldspar
in Ore-Bearing and Barren Sediments

FREQUENCY DISTRIBUTION OF MATRIX (PERCENT) IN SALT WASH SEDIMENTS

Fig. 9

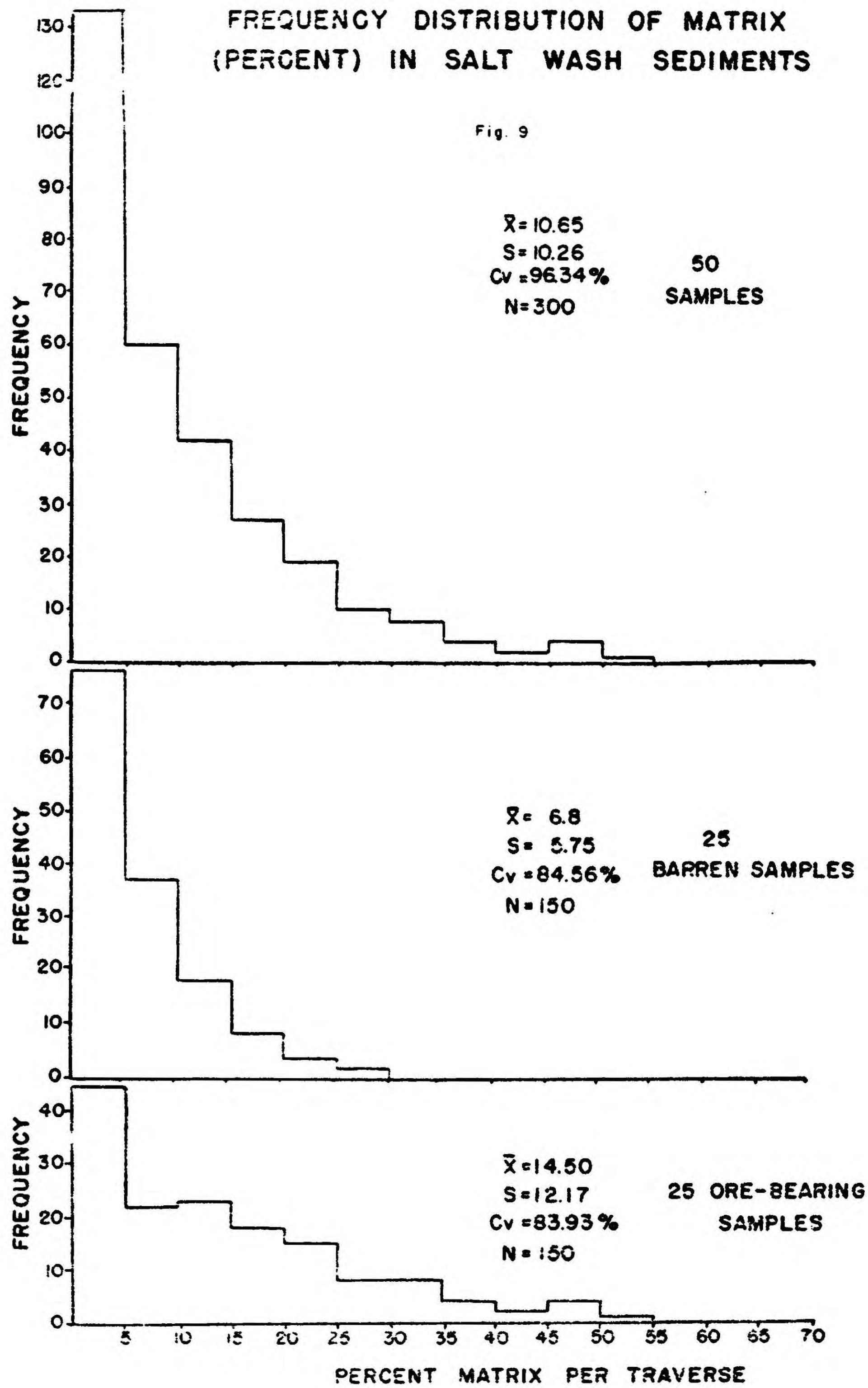


Fig. 10

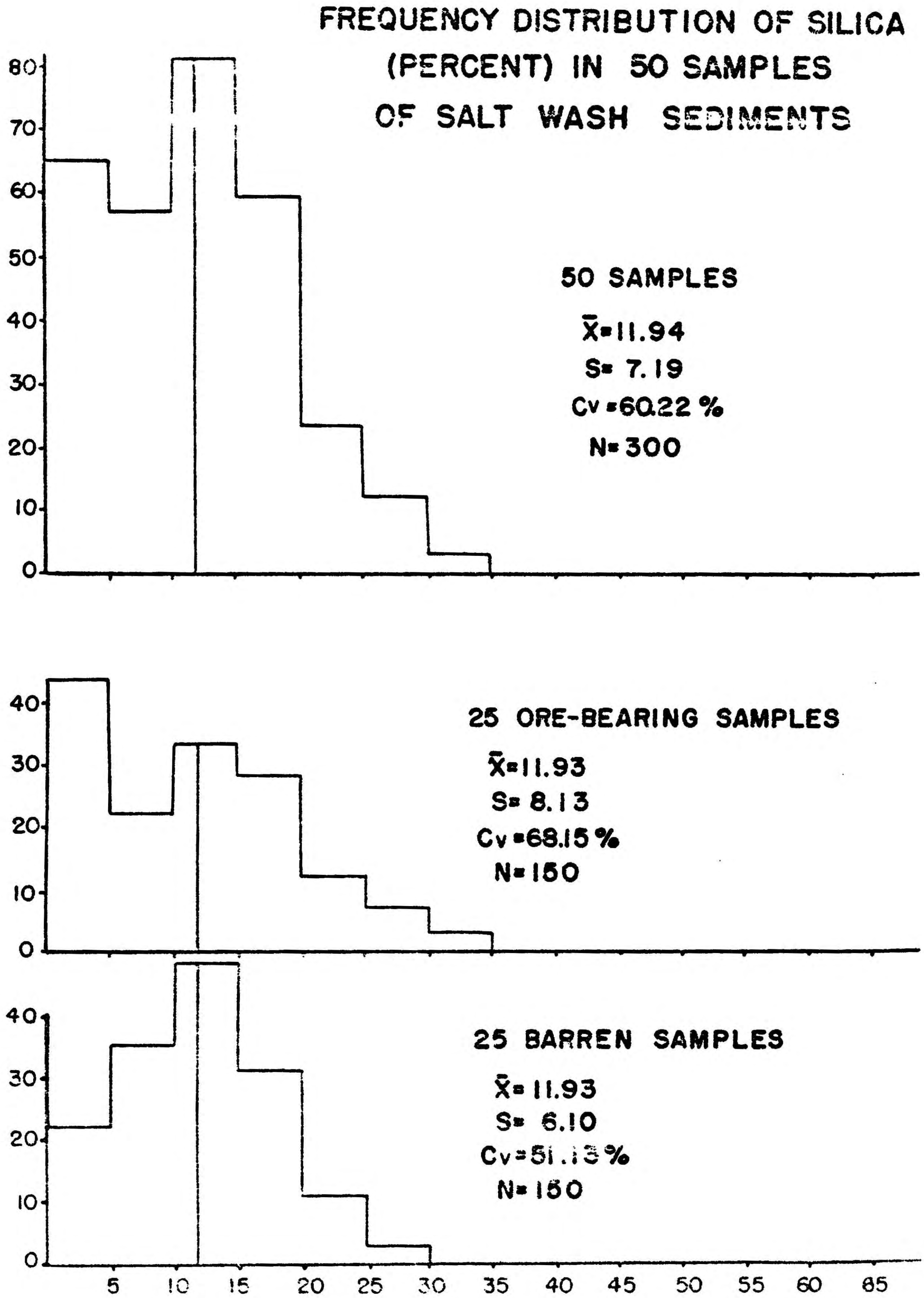

FREQUENCY DISTRIBUTION OF SILICA
(PERCENT) IN 50 SAMPLES
OF SALT WASH SEDIMENTS
50 SAMPLES
X̄=11.94
S= 7.19
Cv =60.22 %
N=300
25 ORE-BEARING SAMPLES
X̄=11.93
S= 8.13
Cv =68.15 %
N=150
25 BARREN SAMPLES
X̄= 11.93
S= 6.10
N= 150
0
10
20
30
40
50
60
70
80
5
10
15
20
25
30
35
40
45
50
55
60
65

Fig 11

FREQUENCY DISTRIBUTION OF CARBONATES IN
50 SAMPLES OF SALT WASH SEDIMENTS

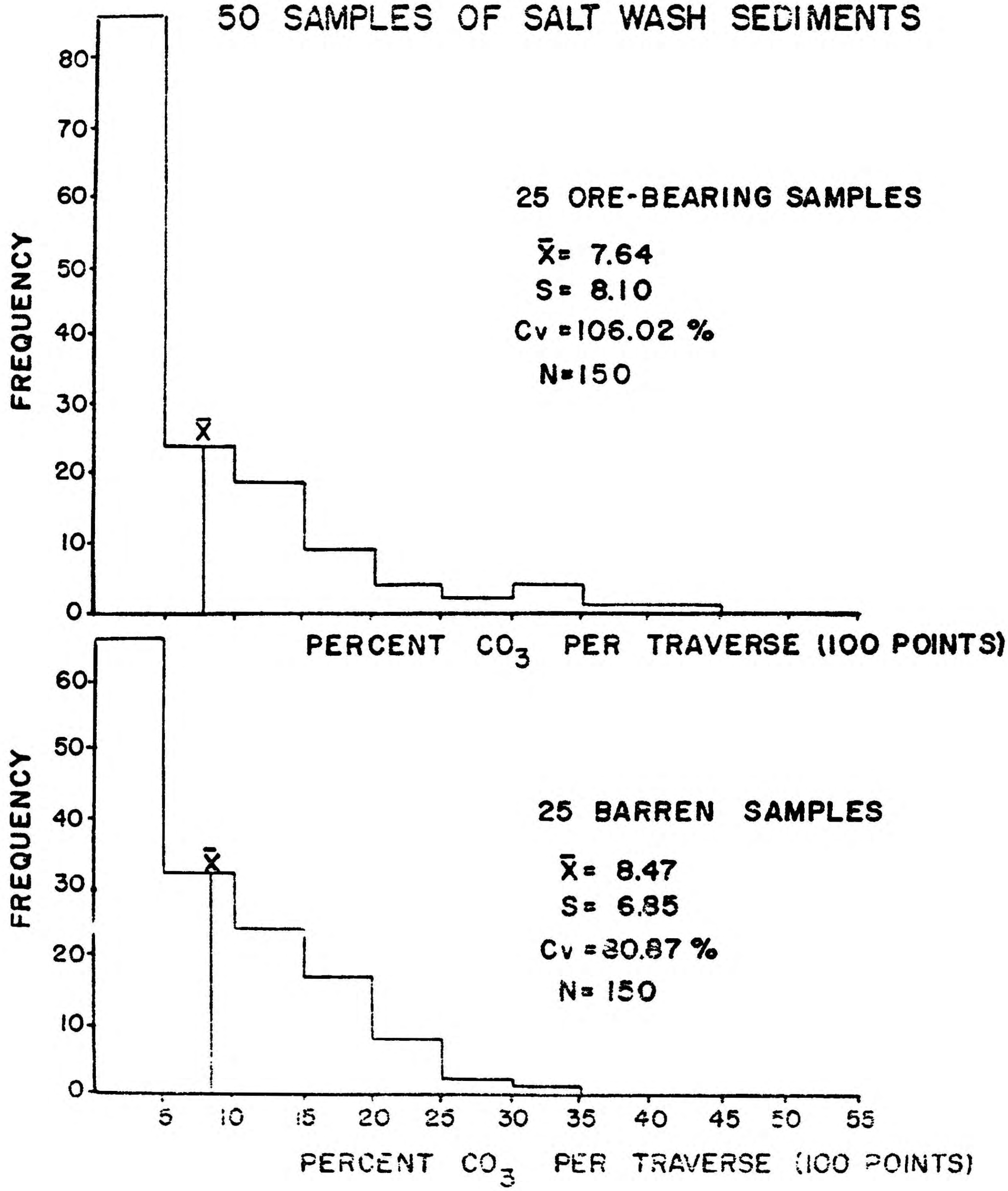


Fig 12

VARIATION IN PROPORTION OF GRAINS, MATRIX, AND CEMENT IN SALT WASH SANDSTONES. (IN %)

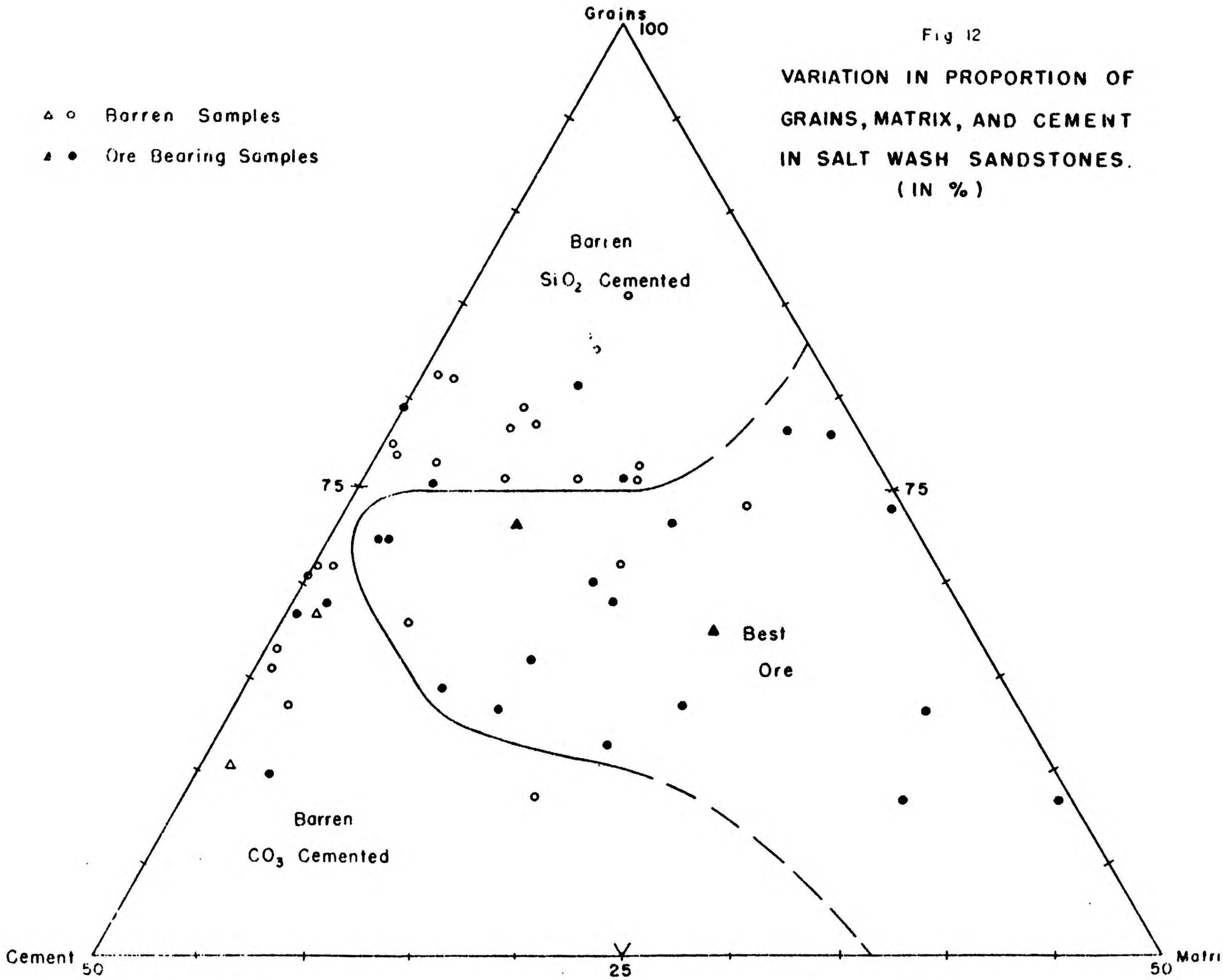


Table 3 - Statistical summaries of frequency distributions of mineral composition of 50 thin sections of Salt Wash sediments.

Column 1	2	3	4	5	6	7	8	9	10
Samples	$\bar{X}$ %	S %	Cv. %	Sk	K	g_1	g_2	N	Item
All 50	60.92	9.87	16.20	-0.269	0.624	-0.541**	0.6550*	300	Qtz. and feldspar
25 ore-bearing	56.47	9.61	17.02	-0.244	0.816	-0.492**	0.884*	150	" " "
25 barren	65.37	7.93	12.13	-0.208	0.073	-0.419**	0.117	150	" " "
All 50	11.89	7.40	62.2	1.391	13.97	2.798**	14.25**	300	Rock fragments
25 ore-bearing	13.14	8.97	68.25	1.312	10.62	2.65**	11.02**	150	" "
25 barren	10.64	5.08	47.74	0.588	2.59	1.19**	2.72**	150	" "
All 50	7.27	3.51	48.34	0.315	0.587	0.6340**	0.6173*	300	Quartzite
25 ore-bearing	7.42	3.46	46.65	0.363	1.14	0.7327**	1.220**	150	"
25 barren	7.12	3.56	50.01	0.277	0.072	0.5593**	0.1156	150	"
All 50	4.30	4.84	112.6	1.660	13.33	3.382**	13.57**	300	Chert
25 ore-bearing	4.55	5.79	127.3	1.586	10.471	3.205**	10.87**	150	"
25 barren	4.05	3.64	89.9	1.277	10.12	2.579**	10.50**	150	"
All 50	3.675	2.757	75.02	0.7831	4.0240	1.574**	4.113**	300	Volcanic
25 ore-bearing	3.78	2.66	70.37	0.5007	0.8844	1.0116**	0.9558*	150	"
25 barren	3.57	2.84	79.74	1.0223	6.5831	2.0645**	6.8493**	150	"
All 50	6.87	15.80	219.93	3.029	41.181	6.089**	41.900**	300	Clay Pebbles
25 ore-bearing	10.633	20.6	193.4	2.120	19.322	4.284**	20.024**	150	" "
25 barren	2.300	2.454	106.7	1.613	11.908	3.259	12.356	150	" "
All 50	10.65	10.26	96.3	0.893	2.467	1.80**	2.53**	300	Matrix
25 ore-bearing	14.50	12.17	83.93	0.515	0.438	1.04**	0.494	150	"
25 barren	6.8	5.75	84.6	0.731	1.743	1.476**	1.844**	150	"
All 50	11.94	7.19	60.22	0.220	-0.352	0.441**	-0.337	300	Silica
25 ore-bearing	11.93	8.13	68.15	0.254	-0.578	0.513**	-0.557	150	"
25 barren	11.93	6.10	51.13	0.026	-0.439	0.052	-0.413	150	"
All 50	8.05	7.51	93.29	0.8052	2.6613	1.619**	2.727**	300	Carbonate
25 ore-bearing	7.64	8.10	106.02	0.993	1.889	2.006**	1.994**	150	"
25 barren	8.47	6.85	80.87	0.517	0.365	1.044**	0.418	150	"

Columns 5 and 6 list the moment statistics which exhibit the assymetry or skewness (Sk) of the distribution and the peakedness or kurtosis (K) respectively. They are calculated as described by Krumbein and Pettijohn (1938, p. 251).

The Fisher "g" statistics of columns 7 and 8 are also reflections of the characteristics of frequency distributions; g_1 is an estimate of skewness and is approximately twice Sk in numerical value. Kurtosis is expressed by the value of g_2 which is usually equal to or numerically a little larger than K. The advantage of the "g" statistics arises from the simple test of significance which may be used with them. In future petrographic analysis Sk, and K can be usefully replaced by g_1 and g_2 respectively (Griffiths, 1955).

Column 9 contains the number of items used in computing the statistics and this information is necessary for the test of significance of the "g" statistics and to estimate the reliability of mean and standard deviation. Finally in the last column (column 10) the mineral constituent described by the statistics is indicated.

A(d) Frequency Distributions of Different Mineral Constituents

(1) Variation in proportion of quartz and feldspar.

The variation in proportion of quartz and feldspar is illustrated in figure 1 and the relevant statistics are tabulated in the first three rows of table 3. The entire 300 traverses yield a mean value of 60.92 per cent with a standard deviation of 9.87 per cent. The coefficient of variation of 16.20 per cent is a typical value for properties of sediments. The frequency distribution is negatively skewed as shown by the value of Sk, and g_1 is significant beyond the 1 per cent probability level. The kurtosis expressed as g_2 reflects a significant peakedness but this statistic is more affected by variation in the tails in the present example than peakedness in the center.

It is reasonably obvious from the graphs that the frequency distributions of the subsets are not identical. The difference in means is approximately 9 per cent, about the same order of magnitude as the standard deviation of the 300 items. The skewness (g_1) is negative, and similar in both, implying that there are more low percentages than would be expected. The peakedness is very different, g_2 is significant for ore-bearing but not for barren sediments.

The entire data may be tested by means of analysis of variance to establish if the mean difference is significantly greater than accidental variation. For this purpose we may compare the variation among thin section means with the variation among traverses, and similarly we may compare variation among subsets with variation among thin section means. The analysis of variance follows a completely randomized design and is summarized in table 4.

Table 4. Analysis of Variance of Proportions of Quartz and Feldspar in Ore-bearing and Barren Sediments.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value [2]
Between groups[1]	1	5,994.3	5,994.3	24.24**
Between samples within groups	48	11,868.7	247.3	6.09**
Between traverses within samples	250	10,145.2	40.58	--
Total	299	28,808.2	96.35	--
Grand Mean	$\bar{\bar{X}}_G$ = 60.26%	s_e = 6.4%	Cv% = 10.06	

[1]The term "groups" refers to ore-bearing and barren sample subsets respectively.

[2]Asterisks in the statistical tables are used conventionally to represent levels of significance; * significant at the 5 per cent level; ** significant at the 1 per cent level; *** significant at the 0.1 per cent level.

It seems clear that variation among thin sections exceeds variation among traverses within thin sections, and differences between subsets (groups in table 4) is significantly greater than differences among thin section means. The ore-bearing set contains significantly less quartz and feldspar than the barren set.

Several other features emerge from this analysis; the successful establishment of a significant difference indicates that the sampling program based on 6 traverses per thin section and 25 sections per subset is adequate. The error variation, s_e = 6.4 per cent, indicates the amount of reduction achieved and the coefficient of variation of 10.06 per cent, based on error standard deviation, shows good experimental control.

The fact that the frequency distributions are different in form and that both skewness (g_1) and kurtosis (g_2) are different suggests, however, that the mean differences are not the important feature in this case; there is a systematic difference between the ore-bearing and barren sets of sediments which is not only a difference in average quartz and feldspar content, but there are more traverses with lower proportions of quartz and feldspar in the ore-bearing than barren sediments.

2) Variation in Proportion of Rock-fragments

The frequency distributions for all rock-fragments taken together are illustrated in figure 2 and the relevant statistics are included in rows 4 to 6 of table 3. the curves for 300 traverses and for the ore-bearing and barren sediments taken separately are markedly skewed and peaked (g_1 and g_2 highly significant). The skewness is positive in contrast to the quartz and feldspar frequency distributions which are negative; this indicates that there are many more high values than expected in a symmetrical distribution. These frequency distributions are also highly peaked (g_2 large) and they approximate J-shaped distributions. This implies that there are many traverses with a low proportion of rock-fragments, very few with none, and some with very high proportions. The frequency distribution for ore-bearing sediments has a larger standard deviation, skewness and kurtosis than the barren sediments showing that there are more traverses with high proportions of rock fragments in the former than the latter. It is also noteworthy that the variability expressed as coefficient of variation is greater in ore-bearing than barren sediments. The mean difference is small and unlikely to be important in this case.

It is somewhat more informative to consider the different kinds of rock-fragments separately because the peculiar features of the frequency distributions of the total rock-fragments are largely due to a single type of rock-fragment, the clay "pebbles".

3) Variation in Proportion of Quartzite Rock-fragments.

The variation in proportion of rock-fragments of quartzite are illustrated by the frequency distributions of fig. 3 and the descriptive statistics are listed in rows 7 through 9 of table 3. The form of the curves and the statistics are very similar although the ore-bearing samples are more skewed and peaked. The averages, standard deviations and coefficients of variation are similar for both ore-bearing and barren sediments. On the whole therefore, it appears that the quartzite rock-fragments do not differ in proportion among ore-bearing and barren sediments.

4) Variation in Proportion of Chert Rock-fragments.

The frequency distributions exhibiting the variation in proportion of finegrained siliceous rock fragments is given in figure 4 and the accompanying statistical summary in rows 10 through 12 of table 3.

The distributions are more markedly J-shaped than the rock-fragments as a whole as is shown by their high positive skewness (g_1) and kurtosis (g_2). In this case there are many traverses in the thin sections with no chert fragments and there are a few with large amounts. Conglomerates in the Salt Wash member generally contain abundant "chert" fragments comprising most of the larger grains and pebbles. However, these pebbles are not true cherts but silicified rock fragments of limestone and volcanic material.

The differences in "chert" content of ore-bearing and barren sediments are not large but there appears to be greater variability in the ore-bearing than barren sediments; this is largely a reflection of the fact that there are more traverses with high proportion of chert in the ore-bearing than barren sediments.

5) Variation in proportion of Volcanic Rock-fragments.

Variation in proportion of volcanic rock fragments is shown in the frequency distributions of fig. 5 and the relevant statistics are summarized in rows 13 to 15 of table 3.

It was expected that there would be more volcanic rock-fragments in ore-bearing than barren sediments but this expectation is not borne out in the graphs or statistics. Indeed the barren samples show a distribution with higher positive skewness (g_1) and kurtosis (g_2) suggesting more traverses with high values of volcanic detritus in the barren than ore-bearing sediments. The difference in averages is however small and the variabilities (both s and Cv %) are very similar.

6) Variation in proportion of clay "pebbles".

The proportion of clay "pebbles" in the Salt Wash sandstones are displayed in frequency distributions in fig. 6 and the associated statistical summary is given in rows 16 through 18 of table 3. There are obviously more clay "pebbles" in the ore-bearing sediments than the barren sediments and this difference is exhibited in all the statistics. The average clay "pebble" content (10.64 per cent) of the ore-bearing sediments greatly exceeds the average content (2.30 per cent) of the barren sediments. Accompanying this difference the variabilities are also different, the ore-bearing sediments being much more variable (compare s and Cv per cent) than the barren sediments. In addition the ore-bearing sediments possess a much more positively skewed and peaked frequency distribution than the barren sediments. These features of the frequency distributions show that not only are there more clay "pebbles" on average in ore-bearing samples but that there are more traverses with higher contents.

This feature is almost certainly a reflection of the prevalence of slumping in the ore-bearing sediments.

7) Variations in Proportion of the different kinds of Detritus

The variations in the principal detrital and clastic elements of the Salt Wash sediments may now be investigated so that the overall variation, and particularly any differences between ore-bearing and barren sediments, may be emphasized.

Firstly the three components, quartzite, volcanic and chert fragments and the clay "pebbles" are plotted in a triangular diagram in fig. 7; the ore-bearing samples are represented as crosses and the barren sediments as circles. The points are spread across the center of the triangle, but there is a strong tendency for the samples with more clay "pebbles" to be ore-bearing. In other words, the bulk of the variation which may be used to differentiate ore-bearing from barren sediments is contained in the content of clay "pebbles". This is, of course, indicative of the prevalence of slumping in the ore-bearing samples.

The content of volcanics plus chert versus the content of quartzite rock fragments show no systematic subdivision into ore-bearing and barren sediments so that we may deduce that variation in these components is similar in both types.

One sample (Cat. No. 6335) was subdivided into a barren carbonate-cemented subsample and a friable ore-bearing subsample. In this case the ore-bearing subsample shows higher content of volcanic detritus and chert than the barren subsample. This feature is not necessarily a function of difference in source material but reflects the replacement of most non-silica components in the carbonate-cemented barren subsample.

A second diagram, fig. 8 summarizes this information in a different way. In the top part the rock fragment proportions per sample are plotted against sample number and the tremendous variation in clay "pebbles" content in ore-bearing sediments is very obvious. There are, however, some samples of ore-bearing sediment with very few clay "pebbles" and, on the other hand, there are practically no samples of barren sediments completely free of clay "pebbles". The difference is, therefore, one of degree not kind between the two sets of samples.

The bottom part of figure 8 shows the variation in quartz and feldspar content of the ore-bearing and barren sediments. It is again clear that there is an overlap among ore-bearing and barren sediments and while there is a clear difference in average values, some samples of ore-bearing sediments contain the same quantity of quartz and feldspar as some of the barren sediments.

The differences in detrital constituents between ore-bearing and barren sediments are therefore very small and the only major differences in the constituents so far described is the greater amount of clastic material i.e. clay "pebbles" formed in place by slumping, in the ore-bearing samples.

8) Variation in proportion of Matrix.

The frequency distributions of proportion of matrix (fig. 9) are in general J-shaped, but there is a large difference in form of the distributions for ore-bearing and barren sediments. This is reflected in the summary statistics (rows 19-21, table 3); firstly there is a larger average in the ore-bearing sediments and a larger variability (s and Cv %). The positive skewness and the kurtosis is also larger. Here again there is more matrix and more traverses with larger amounts of matrix in the ore-bearing than barren samples.

Matrix in this case is similar in general composition to clay "pebbles" and in many cases this excess in the ore-bearing sediments may be attributed to slumping. However, some bedded barren samples also contain moderate quantities of matrix material. The difference is once more quantitative and there is an overlap.

9) Variation in proportion of secondary silica cement.

Silica cement around the quartz grains is present in most samples and occasionally accounts for some 30 per cent of a traverse. The frequency distributions for ore-bearing and barren sediments are, however, very different in form. The average silica content in both ore-bearing and barren sediments is very similar and the variabilities, in terms of standard deviation and coefficient of variation are also alike. Here the similarity ceases for although both frequency distributions possess positive skewnesses the barren sediments are almost symmetrical (g_1 not significant) whereas the ore-bearing are significantly assymetric. Again both distributions are less peaked than a symmetrical normal distribution but the ore-bearing are more negatively peaked than the barren sediments.

From the graph (fig. 10) it can be seen that there are more traverses with zero silica and more with high proportions of silica in ore-bearing than barren sediments.

If we may now assume that the distribution of silica cement in barren sediments represents the typical case then the silica cement in the ore-bearing sediments has been redistributed; some layers, particularly those with ore contain no silica cement, whereas those with less ore are rich in silica. Such an arrangement would lead to a frequency distribution in which there are many traverses with zero silica and others with very high amounts of silica.

If this is the correct explanation then the silica cement has been redistributed in ore-bearing sediments. There appears to be no reason to suggest that silica has been introduced from outside sources but that the silica originally present has been redistributed.

10) Variation in proportion of Carbonate Cement.

The frequency distributions of carbonate cement in ore-bearing and barren sediments (see fig. 11) are similar to that of silica. The means in per cent, standard deviations and coefficients of variation are similar in both distributions but the frequency distributions of ore-bearing sediments possesses a higher positive skewness and kurtosis than the barren sediments. Here again there are more traverses with zero carbonate and some with higher proportions (up to 45 per cent) of carbonate in ore-bearing than barren sediments. It again appears as if the carbonate has been redistributed in the ore-bearing sediments with ore-bearing layers almost free from carbonate and nearby layers very rich in carbonate. There does not appear to be any necessity for introduction of new material from outside sources.

11) Variation in Grains, Matrix and Cement.

We may now compare the ore-bearing and barren sediments in terms of grains (quartz, feldspar, and rock fragments) matrix, and cement (carbonate and silica) by means of a triangular diagram (fig. 12). The barren sediments are represented by open circles and the ore-bearing by solid circles. The differences between barren sediments and ore-bearing are not large and the bulk of the samples fall near the lefthand side of the triangle showing a wide range in grains and cement. The major difference between ore-bearing and barren sediments is in amount of matrix the ore-bearing sediments containing more matrix than the barren sediments. The "best" ores occur towards the lower right hand corner on this account. The ore-bearing "area" of the triangle is outlined approximately by a solid line.

In general the silica cemented samples contain less total cement than the carbonate-containing sediments and there is a tendency for the barren samples in the top half of the triangle to be silica cemented while the samples in the lower left hand corner are carbonate cemented.

Two samples can be subdivided into ore-bearing and barren subsamples and these are plotted as triangles on the diagram (fig. 12). It is noteworthy that the ore-bearing subsamples (filled-in triangles) contain less carbonate cement and more matrix than the barren subsamples (open triangles).

In summary then, the major differences in mineral composition are the relatively high content of clay "pebbles" and matrix in ore-bearing compared with barren sediments. Other differences in mineral composition are minor and unlikely to be defined precisely without detailed quantitative analysis. The major difference is a reflection of the prevalence of slump textures among the ore-bearing sediments.

A(e) Inter-relationships among the Mineral Constituents.

It is instructive at this stage to attempt to explain the inter-relationships between the various constituents described in the previous sections. Some general notions on associated constituents and some suggestions regarding parallel genesis may be extracted from these inter-relationships. In addition, if any two items are highly correlated there is little point in using both items in subsequent analysis because when relating variations in proportion of one item, to, say, grain size, the relationship of a highly correlated second item may be predicted. In this way some reduction in the number of items to be handled may be usefully achieved.

1) Relationships among the detrital grains.

i) Quartz and Feldspar versus rock-fragments.

The relationship between the frequency of quartz and feldspar and total rock fragments, both measured in per cent is illustrated in fig. 13. The samples plotted include the fifty samples herein described (circles for barren sediments, "x" for ore-bearing) and, in addition, two further sets of samples, one from our earlier description of thin sections of

Table 2a - Mineral Composition of 25 Ore-bearing Samples of Salt Wash Sandstones.

Cat. No.	Quartz & Feldspar	Rock Fragments	Matrix	CEMENT Silica	Carbonate	Total
6331-2	63.4	9.6	8.4	12.2	6.4	100.0
6334	48.2	10.0	34.0	7.8	-	100.0
6335 (1)	55.8	12.2	6.0	18.0	8.0	100.0
6336	59.5	13.8	15.8	10.8	-	99.9
6500	56.7	12.7	15.0	15.7	-	100.1
6502	52.7	13.3	12.7	12.7	8.7	100.1
6503A	55.5	9.3	9.2	16.7	9.3	100.0
6506	58.2	11.8	13.4	16.7	-	100.1
6536-2	69.0	9.3	18.5	3.2	-	100.0
6537A	63.8	4.3	0.8	28.3	2.7	99.9
6606	50.2	8.2	41.4	0.3	-	100.1
6607A	59.2	16.0	3.5	15.3	6.0	100.0
6608	51.3	12.0	21.0	7.3	8.3	99.9
6610	47.6	25.3	2.3	12.8	11.8	99.8
6620	52.5	16.5	1.5	18.5	11.0	100.0
6627-1	56.0	18.0	25.5	0.5	-	100.0
6636	58.2	5.2	1.1	2.5	33.0	100.0
6636 ore	59.7	8.0	20.5	5.7	6.0	100.1
6638	43.2	20.0	12.2	5.5	19.2	100.1
6644	51.5	8.3	3.7	16.0	20.5	100.0
6646	55.2	7.8	32.3	3.7	1.0	100.0
6651	42.0	36.0	20.8	1.2	-	100.0
6657	58.7	17.0	12.2	10.3	1.8	100.0
6671	69.0	11.7	7.3	8.2	3.8	100.0
6675	64.8	7.3	2.8	22.2	2.8	99.9
6683	53.3	8.2	18.5	19.7	0.3	100.0

Table 2b - Mineral Composition of 25 Barren Samples of Salt Wash Sandstones.

Cat. No.	Quartz & Feldspar	Rock Fragments	Matrix	Silica	Carbonate	Total
6335-2	55.8	4.3	1.3	1.0	37.5	99.9
6508	69.7	8.3	5.7	12.7	3.5	99.9
6510	65.7	10.2	12.8	6.7	4.7	100.1
6512	63.8	7.2	1.0	6.8	21.2	100.0
6513	65.7	12.0	0.3	17.7	4.3	100.0
6514	68.5	7.7	12.7	9.7	1.5	100.1
6515	69.3	14.0	6.6	7.8	2.2	99.9
6519	50.3	8.5	16.2	4.7	20.3	100.0
6520	65.8	8.3	18.7	2.7	4.5	100.0
6521	65.2	5.3	-	22.3	7.2	100.0
6522A	58.2	17.5	10.0	3.8	10.5	100.0
6523	55.8	21.3	3.0	13.5	6.8	99.9
6524	71.8	7.8	-	12.7	7.7	100.0
6525	59.6	6.8	0.7	17.3	15.5	99.9
6526	56.3	7.5	2.2	16.3	17.7	100.0
6527	64.0	7.0	0.3	15.3	13.3	99.9
6528	68.0	13.3	0.6	10.7	7.3	99.9
6529	68.3	11.0	5.5	14.8	0.3	99.9
6530	61.0	10.0	14.3	6.7	8.0	100.0
6531	69.2	6.5	6.5	14.3	3.5	100.0
6532	58.3	7.0	0.8	18.8	15.0	99.9
6534	66.2	10.8	1.0	8.8	13.2	100.0
6629	66.8	11.5	6.5	14.3	0.8	99.9
6630	75.3	10.2	7.8	6.7	-	100.0
6662	69.5	12.8	7.5	8.7	1.5	100.0
6667	68.5	12.5	1.7	11.0	6.3	100.0

sediments containing limonite "spots" (symbol △ RME 3054, p. 29) and the second from a description of thin sections of samples from zones 2 and 4 Bull Canyon Well 155C (symbol □ Zone 2, ■ Zone 4; RME 3097, p. 20).

The relationship between proportion of quartz and feldspar and rock fragments is inverse, as one increases the other decreases. It is noteworthy that the samples high in proportion of rock fragments are conglomerates either chert pebble conglomerates (CGL) or clay "pebbles" conglomerates (CS). The latter are, of course, reflections of local penecontemporaneous slumping. This inverse arrangement is therefore, at least in part, a reflection of differences in grain size, the finer grained sediments containing more quartz and feldspar, the coarser grained sediments containing rock fragments. This is more or less an expected trend.

There is no striking difference between ore-bearing and barren sediments except that the ore-bearing tend to contain more rock fragments which, in general, reflects the presence of a higher proportion of clay "pebbles" (see pp. 29, 30).

It should be emphasized that the counts directed toward evaluation of limonite "spots" (samples from RME 3054) are low in rock fragments although not outside the general trend and this suggests that some variation in operator decision may be involved. One specimen from zone 4 (Bull Canyon Well 155C, RME 3097) is unusually low in rock fragments whereas one sample from zone 2 has unusually high proportion of rock fragments. Evidently variability from sample to sample within one small zone is high.

ii) Quartz and Feldspar versus quartzite rock fragments

The frequency of quartz and feldspar in per cent is plotted against number of quartzite rock fragments in a traverse count of 600 quartz and feldspar grains in fig. 14. The diagram contains the 50 samples analyzed for this report. The inverse trend is again present showing increasing quartzite fragments with decreasing amounts of quartz and feldspar grains. There is no obvious difference between ore-bearing and barren sediments and the inverse trend is more diffuse. There appears to be more high quartzite-containing samples among the ore-bearing than the barren sediments although the difference cannot be large from the graphs of the two individual constituents (figs. 1 and 3).

iii) Relationships between quartzite and chert rock fragments

Quartzite and chert rock fragments are common to most sedimentary rocks and are often the sole aggregate constituents of orthoquartzite sediments (Krynine, 1948). In general, therefore, it would be expected that the relationships between the frequencies of quartzite and chert rock fragments would be sympathetic - as one increased so should the other. The relationship observed in these 50 samples of Salt Wash sediments is illustrated in fig. 15 and it seems obvious that the frequency of the two constituents varies independently. There is no segregation between ore-bearing and barren sediments.

This would suggest that the sources of the two constituents are different, a rather unusual feature.

IV) Relationship between chert and volcanic rock-fragments.

Volcanic rock-fragments in the Salt Wash sediments are almost certainly derived from some fresh volcanic source and are probably not from the same source as the main proportion of the detritus such as the quartz, feldspar and quartzite rock-fragments.

When the frequency of chert and volcanic fragments are plotted in a scatter diagram (fig. 16) they show a marked sympathetic relationship as one increases in amount so does the other with a few exceptions in which there are unusually high proportions of volcanic rock fragments. It seems likely therefore, that the association between volcanic detritus and chert and the lack of association between chert and quartzite rock-fragments may be taken to indicate that the source of the chert and volcanic fragments was the same and different from that of the quartzite rock fragments. It must also be emphasized that the term "chert" in these sediments is somewhat misleading; most of the material is finegrained silica with aggregate polarization typical of normal sedimentary chert, but in a number of examples recognizable textures remain in these "chert" pebbles. The textures are often palimpsest after organic limestones in which both fossil organisms and limestone textures are preserved in the silicified replacement. In other cases the textures are equally clearly palimpsest after textures of volcanic igneous rocks, particularly porphyritic types with or without flow parallelism of feldspar laths. Silicified tree fragments are not uncommon in these sediments.

This suggests that most of the chert is derived from the secondary silicification of pre-existing rock fragments. Of course, most of the "chert" pebbles do not possess relict textures and their origin cannot be decided, but it seems likely from their direct association in frequency with volcanic detritus that the silica and volcanic fragments have the same source and when one increased in amount so did the other. The bulk of the "secondary" silica cement which grows around detrital quartz grains may also have been originally derived from volcanic sources.

Once more there is no segregation of ore-bearing from barren sediments; both possess the same characteristics in terms of volcanic rock-fragments and chert and their interrelationship.

V) Relationship between volcanic rock fragments and clay "pebbles"

Some of the clay "pebbles" are a decomposition product derived from the replacement of volcanic rocks by clay materials and if this were the only source of clay "pebbles" the volcanic detritus and clay "pebbles" would show antipathetic (or inverse) relationships. The scatter diagram (fig. 17) shows no such relationship, and although there is a diffuse trend suggesting both constituents tend to increase in sympathy this may be due to increase in clay "pebbles". It would be prudent at this stage to suggest that the frequency fluctuations of these two items are independent.

VI) Relationships between other pairs of rock-fragments.

Various other plots among rock-fragment constituents showed no definite association i.e. implied that these constituents varied independently in frequency. The pairs tested graphically were:

Quartzite versus volcanics
" " chert plus volcanics
" " clay "pebbles"

2) Relationships between matrix and detrital constituents.

From the analysis of the frequency variations among detrital constituents and their mutual inter-relationships we may subdivide the dominant materials into three groups on the basis of provenance; firstly there is the "normal" sedimentary detritus from a pre-existing source rock comprising quartz, feldspar and quartzite rock fragments. Secondly there is a contribution from volcanic sources which from the association of volcanic fragments and silica (chert) suggest penecontemporaneous volcanic activity, and finally there is material such as clay "pebbles" formed locally by local disturbance of wet sediment (clastic as opposed to far-travelled detrital). The matrix material is similar in composition to the clay "pebbles" and may be formed at the same time by the same process differing only in morphology from the clay "pebbles". If such were the case one would expect to find a sympathetic variation in frequency among these two constituents.

The variation in frequency of clay "pebbles" and matrix is plotted as a scatter diagram in fig. 18, and certainly presents no obvious trend. The only striking feature is that ore-bearing samples (x) show high proportions of both clay "pebbles" and matrix, but the two constituents appear to vary independently.

The lack of relationship in this case is somewhat suspicious and suggests that the difficulty lies in the technique. The only reliable criterion for differentiating clay "pebble" and matrix is morphology, and as there is a complete transition from disordered arrangement called matrix to clusters, clumps and aggregates, called clay "pebbles" it seems likely that variation in operator decision may be the confusing factor. It would be safer then to consider these two items together and not attempt to separate them in future analyses unless a much clearer operational definition, based on readily recognizable criteria, can be established.

When quartzite and volcanic plus chert are plotted against matrix no obvious relationship appears and it would be safer in this case because of the doubt about true implications of the term matrix to draw no conclusions.

3) Relationship among the Cements

From thin section observations it is clear that there are many examples of replacement among the cements and generally the evidence suggests that the silica cement was replaced by carbonate thus ordering the arrival of the two constituents. Replacement of one item by another means an inverse arrangement, one item increasing at the expense of the other. There are two common hypothetical models for such inverse arrangements; one showing linear trends and one curvilinear. The curvilinear trend will generally be of hyperbolic character (see for example Smithson, 1939, p. 309) and represents the most intense antipathy. It appears likely that this relationship will be common in cases of replacement.

As a somewhat simple case the samples analysed by thin section analysis from Bull Canyon Well 155C zones 2 and 4 are plotted in fig. 19. The trend is vague but extreme points are high in carbonate or high in silica i.e. the relationship is inverse and probably curvilinear. It is noteworthy that in the "ore zone" (zone 4) silica is the common cement, in the barren zone (zone 2) carbonate is generally dominant.

The cement content for the 50 samples analysed for this report are plotted in fig. 20; those samples high in carbonate are low in silica, while those high in silica are low in carbonate; there are very many samples showing no pronounced trend. Furthermore there does not appear to be any segregation of ore-bearing from barren sediments. The extremes are obvious, the less extreme widely scattered.

Such an arrangement would develop if the replacement were not complete; it may be presumed that where replacement is complete the trend would be hyperbolic and where incomplete the cement content may show a confused relationship. Part of this confusion may be resolved by considering two samples which could be subdivided into subsamples, one subsample of each sample being ore-bearing and the other barren. These subsamples are plotted on the diagram as circles with crosses inside them. In both cases the very high carbonate content occurs in barren sediments and in one the silica content is high in the ore-bearing subsample. In these cases carbonate is late and replaces both ore and silica cement.

4) Relationship between detritus and cements.

Plots of quartzite versus silica cement and chert versus silica cement showed no clear trend, and since these items are similar in chemical composition they would be expected to show a trend. Apparently the frequency distribution of silica cement is largely independent of detritus. The inverse trend between quartz and feldspar and quartzite rock fragments together with the independence of quartzite and silica cement suggests that quartz and feldspar frequency variation is independent of silica cement frequency variation.

5) Relationship between matrix and cements.

Silica cement and matrix is plotted in fig. 21 and there appears to be an inverse trend, as silica cement increases matrix content decreases. The trend is approximately linear. The main exceptions are represented by a few barren samples low in silica and matrix content. It is noteworthy that the trend in barren samples is similar in form but displaced towards the origin. In other words in both barren and ore-bearing samples there is an inverse relationship between matrix content and silica cement, but the trend in ore-bearing samples indicates more silica cement and more matrix on average than the trend in barren sediments.

The frequency of matrix and carbonate is plotted in fig. 22 and if any trend is present it is certainly not linear. There are a few samples very rich in carbonate with very little matrix and a few very rich in matrix with very little carbonate. The trend is curvilinear inverse and could be approximated by a hyperbola. Again, as in the case of silica versus carbonate (fig. 20), this implies antipathetic relationships.

In summary then, silica and matrix are antipathetic and carbonate and matrix are much more strikingly antipathetic. From their arrangement in thin section it appears that matrix replaces silica, but both exist together in the same traverse, whereas carbonate replaces matrix and silica and the replacement is usually complete. The order of events is silica followed by matrix followed by carbonate. Now since the ore is matrix material the sequence may be interpreted as normal sediment with much silica and some matrix followed by increase in matrix (by slumping) and replacement of silica; subsequently carbonate replaces either or both. These characteristics are true of both barren and ore-bearing samples.

Part of the confusion in the central areas of the graphs reflects the fact that replacement is not complete; in some cases layers rich in carbonate occur in thin sections of ore-bearing samples and these layers are barren. Sample 6335 is striking in this respect in having an area ("roll"?) containing flood carbonate (37.5 per cent) and no ore; while outside the carbonate rich area the sample is rich in ore and silica cement. Similar features are observed in one and the same thin section and when a thin section mean is used to plot the results the two kinds of layers both enter the mean value yielding relatively high carbonate and ore.

A(f) Summary of Conclusions Concerning

Variation among Mineral Constituents.

The mineral constituents of these fifty samples of Salt Wash sandstones are subdivided into grains, matrix and cement (Krynine, 1948). The grains comprise the detrital constituents quartz and feldspar, quartzite, chert and volcanic rock fragments and the clastic components, clay "pebbles". There are minor differences among the ore-bearing and barren sediments except in the frequency of clay "pebbles" which are much greater in the ore-bearing than barren sediments.

From the inter-relationships among these constituents there appears to be three main sources of material: 1) far travelled detritus comprising quartz, feldspar, and quartzite rock fragments; 2) volcanic rock-fragments and chert from penecontemporaneous volcanic outbursts and; 3) clastic material, the clay "pebbles" formed by slumping while the sediment was wet.

Matrix material is composed of the same minerals, largely clay minerals, as the clay "pebbles" and in part is derived by local slumping. In this sense it belongs in the clastic fragments in terms of provenance. There is nearly always more matrix in ore-bearing than barren sediments.

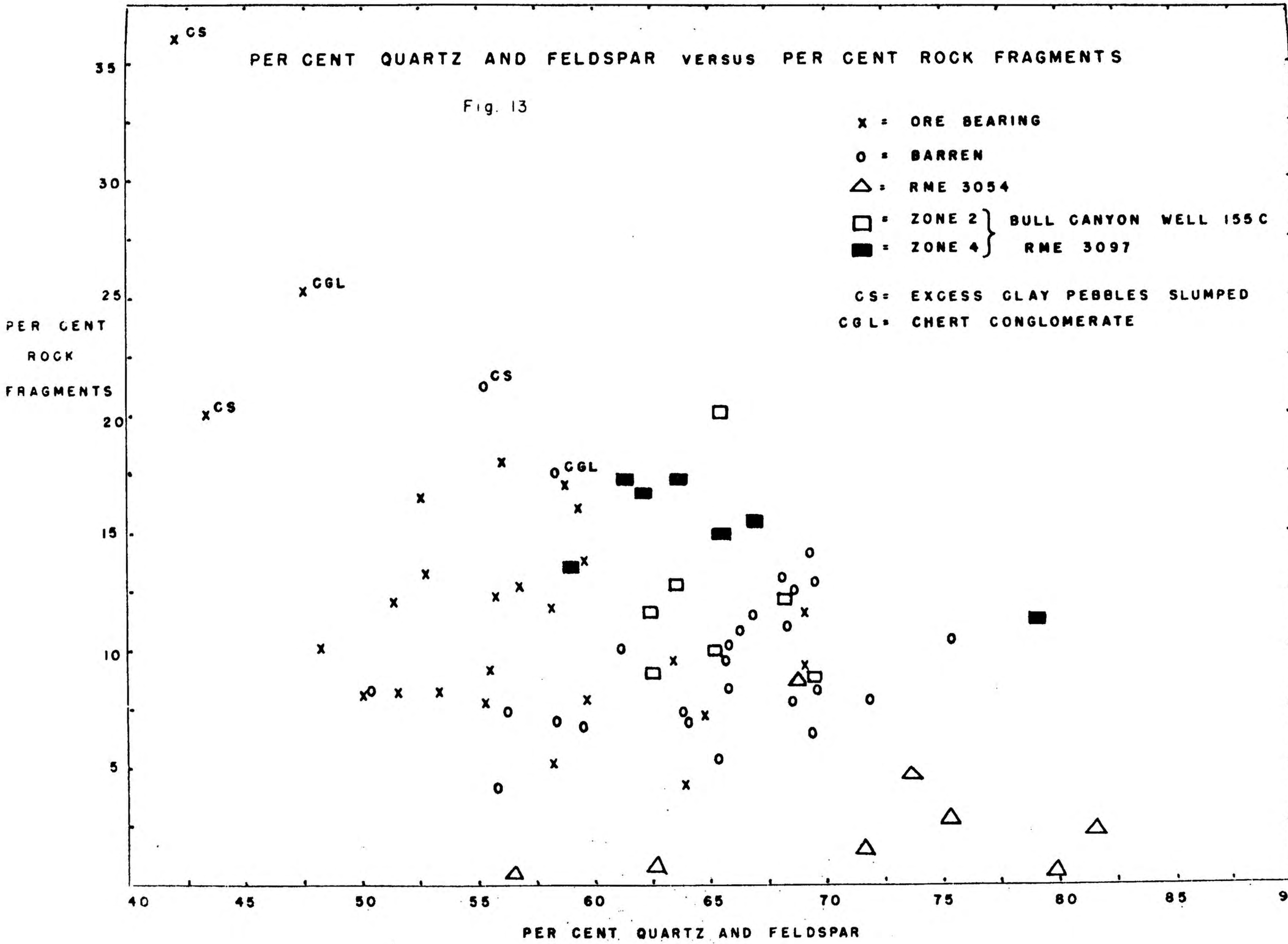
Finally, the dominant chemical cements are carbonate and silica cement. Both have been redistributed in ore-bearing sediments although there appears to be no reason for suggesting an introduction of new material from other than immediately local sources. Silica cement can exist along with matrix more readily than carbonate cement and the order of replacement is silica by carbonate.

Matrix, in part, and particularly in a slumped area, replaces part of the silica, particularly in ore-bearing sediments. Carbonate replaces both matrix and silica and is an ore-remover.

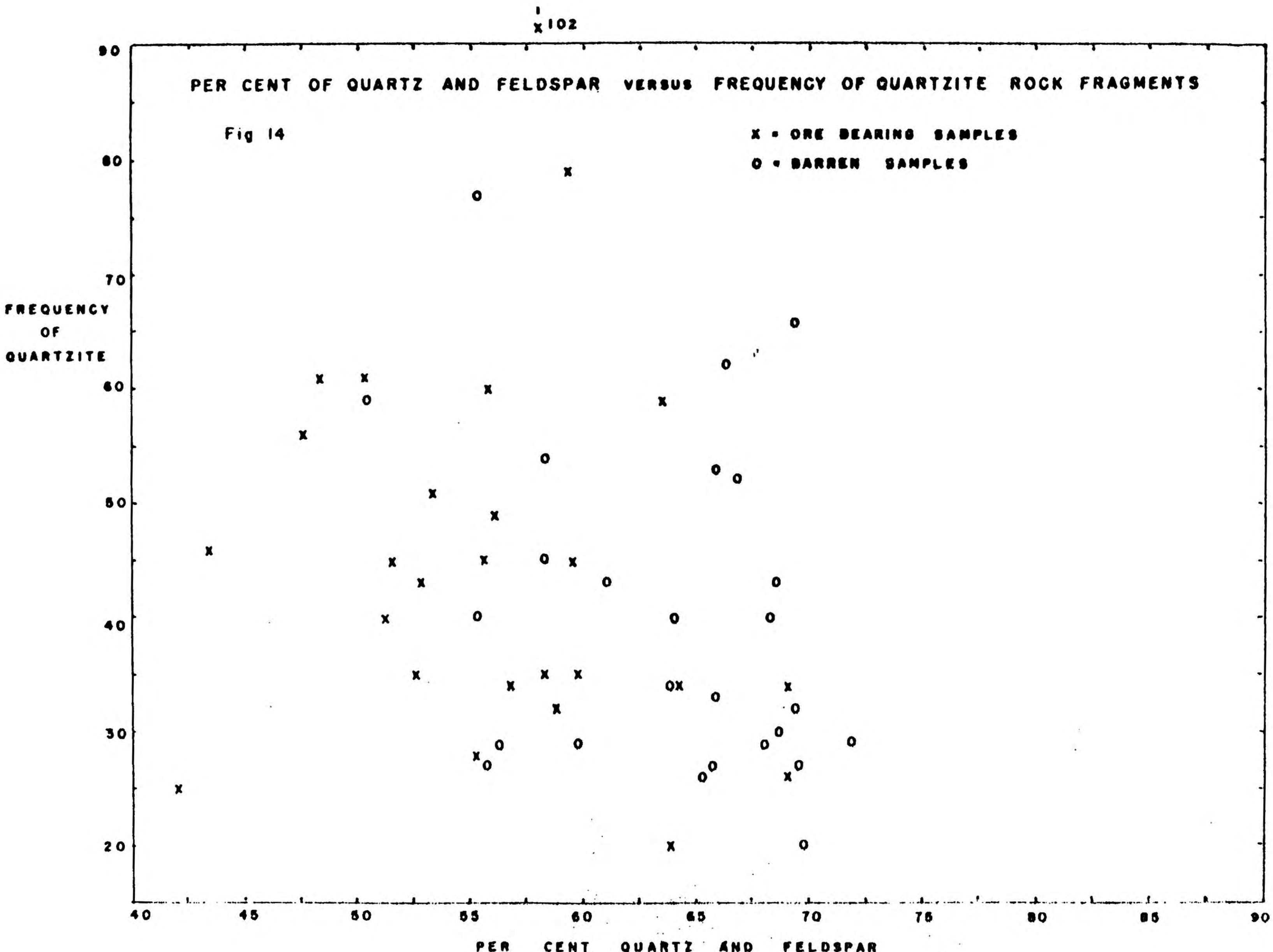
On the basis of the above observations there appears to be no reason for the introduction of material from outside, local redistribution would account for the present disposition of the mobile constituents. Most of the physical activity (slumping) leading to clay "pebbles" and matrix was penecontemporaneous and most of the chemical redistribution was concurrent with this phenomenon. Such features are common in areas of active slumping and mud volcanoes.

In terms of differentiating ore-bearing from barren sediments the only constituents likely to prove of use are the clay "pebbles" and matrix, and since these appear to be related in origin and very difficult to separate by the technique used, it is safer to consider them together in attempting to discriminate between ore-bearing and barren sediments.

It should also be emphasized that all the major differences so far mentioned between ore-bearing and barren sediments are local differences and no regional pattern can be established on this basis.



PER CENT QUARTZ AND FELDSPAR VERSUS PER CENT ROCK FRAGMENTS
Fig. 13
X = ORE BEARING
O = BARREN
△ = RME 3054
□ = ZONE 2
■ = ZONE 4
BULL CANYON WELL 155C
RME 3097
CS = EXCESS CLAY PEBBLES SLUMPED
CGL = CHERT CONGLOMERATE
CS
CGL
PER CENT ROCK FRAGMENTS
PER CENT QUARTZ AND FELDSPAR
35
30
25
20
15
10
5
40
45
50
55
60
65
70
75
80
85
90


x 102
PER CENT OF QUARTZ AND FELDSPAR versus FREQUENCY OF QUARTZITE ROCK FRAGMENTS
Fig 14
X = ORE BEARING SAMPLES
O = BARREN SAMPLES
FREQUENCY OF QUARTZITE
PER CENT QUARTZ AND FELDSPAR
90
80
70
60
50
40
30
20
40
45
50
55
60
65
70
75
80
85
90

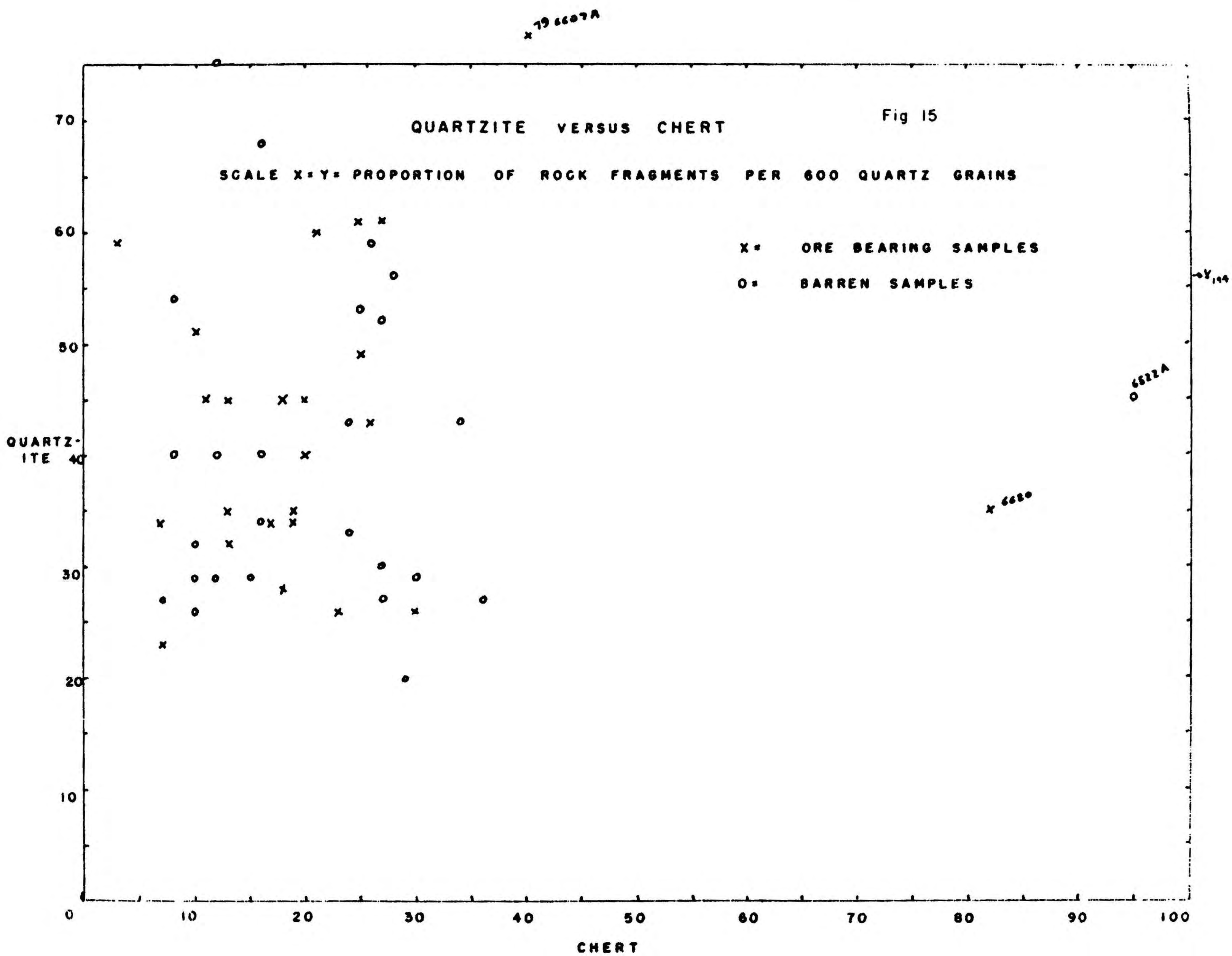


Fig 15
QUARTZITE VERSUS CHERT
SCALE X = Y = PROPORTION OF ROCK FRAGMENTS PER 600 QUARTZ GRAINS
X = ORE BEARING SAMPLES
O = BARREN SAMPLES
QUARTZITE
CHERT
0
10
20
30
40
50
60
70
80
90
100
6680
6622A

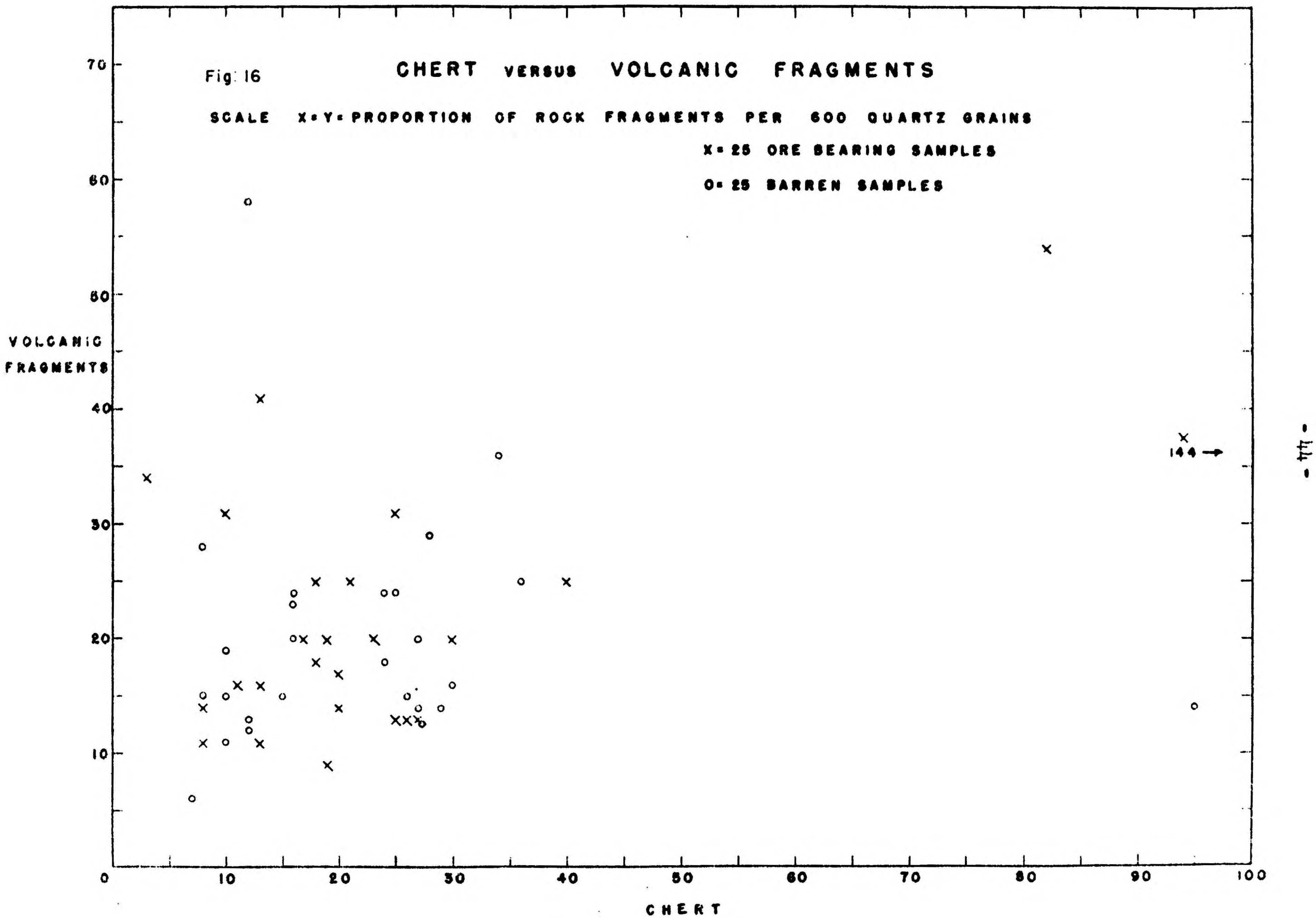


Fig. 16
CHERT versus VOLCANIC FRAGMENTS
SCALE X=Y=PROPORTION OF ROCK FRAGMENTS PER 600 QUARTZ GRAINS
X=25 ORE BEARING SAMPLES
O=25 BARREN SAMPLES
VOLCANIC FRAGMENTS
CHERT
144 →
0
10
20
30
40
50
60
70
80
90
100

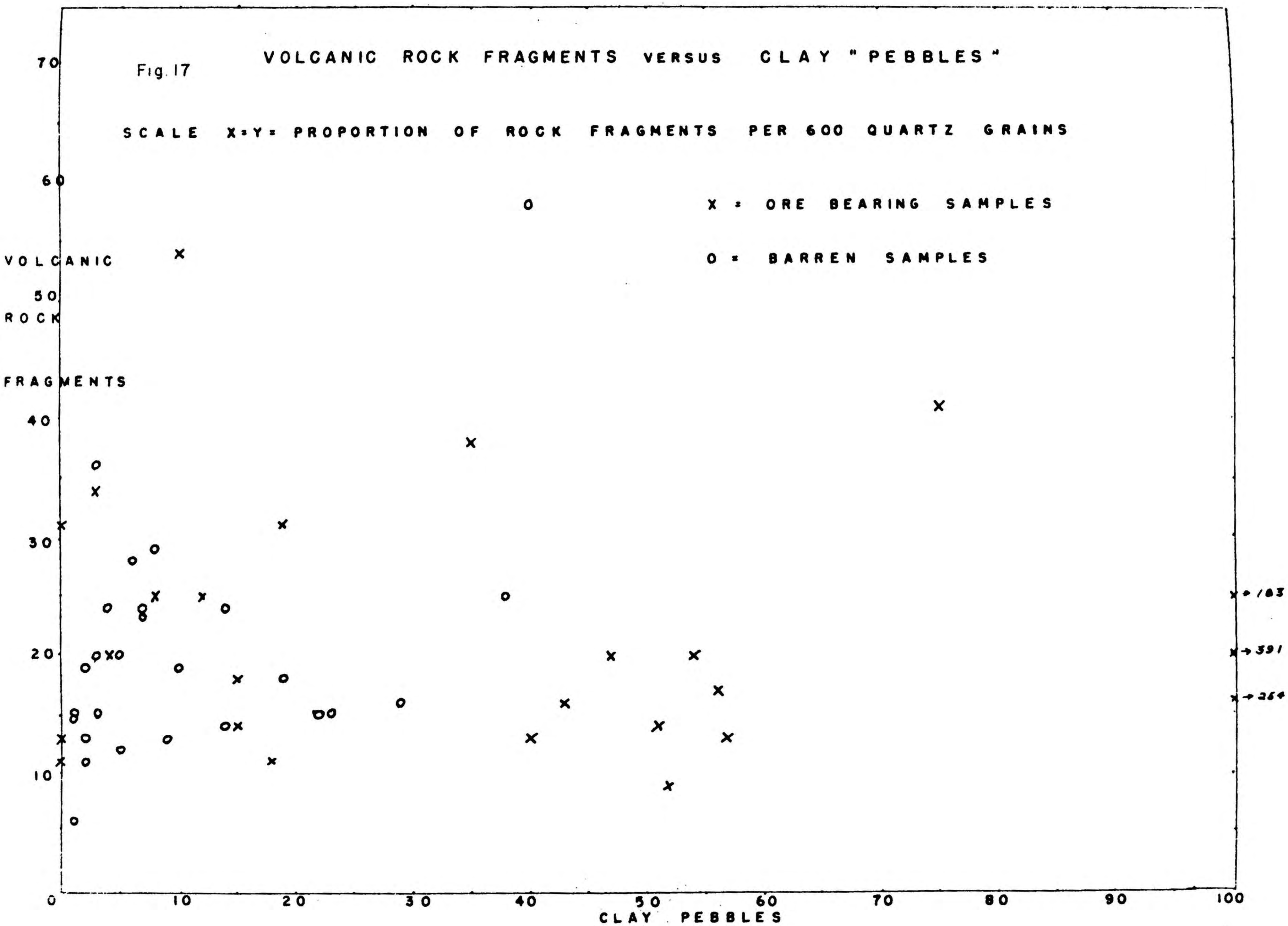


Fig. 17
VOLCANIC ROCK FRAGMENTS VERSUS CLAY "PEBBLES"
SCALE X=Y= PROPORTION OF ROCK FRAGMENTS PER 600 QUARTZ GRAINS
X = ORE BEARING SAMPLES
O = BARREN SAMPLES
VOLCANIC ROCK FRAGMENTS
CLAY PEBBLES
0
10
20
30
40
50
60
70
80
90
100
→ 183
→ 391
→ 254

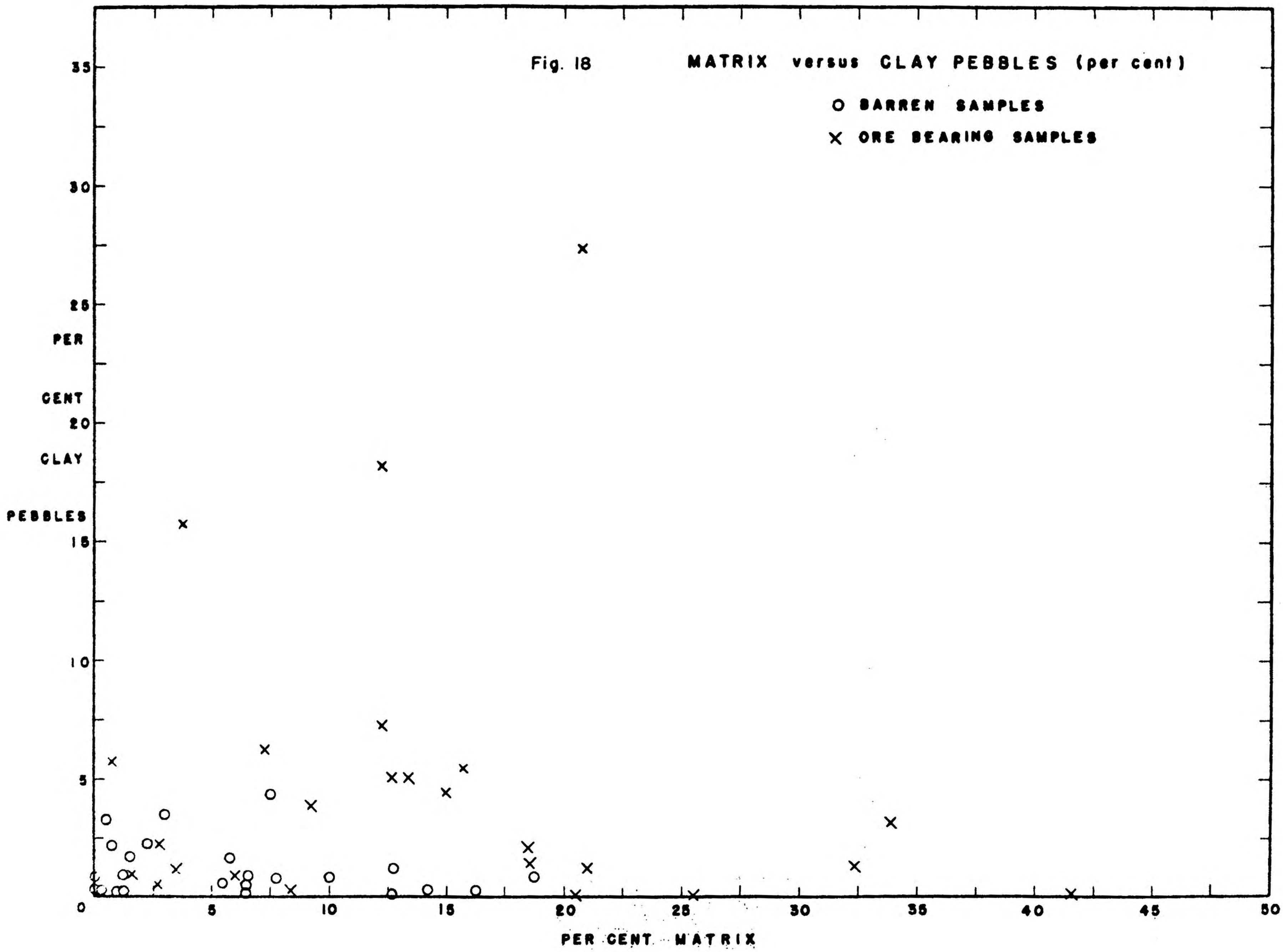


Fig. 18
MATRIX versus CLAY PEBBLES (per cent)
O BARREN SAMPLES
X ORE BEARING SAMPLES
PER CENT CLAY PEBBLES
PER CENT MATRIX
0
5
10
15
20
25
30
35
40
45
50

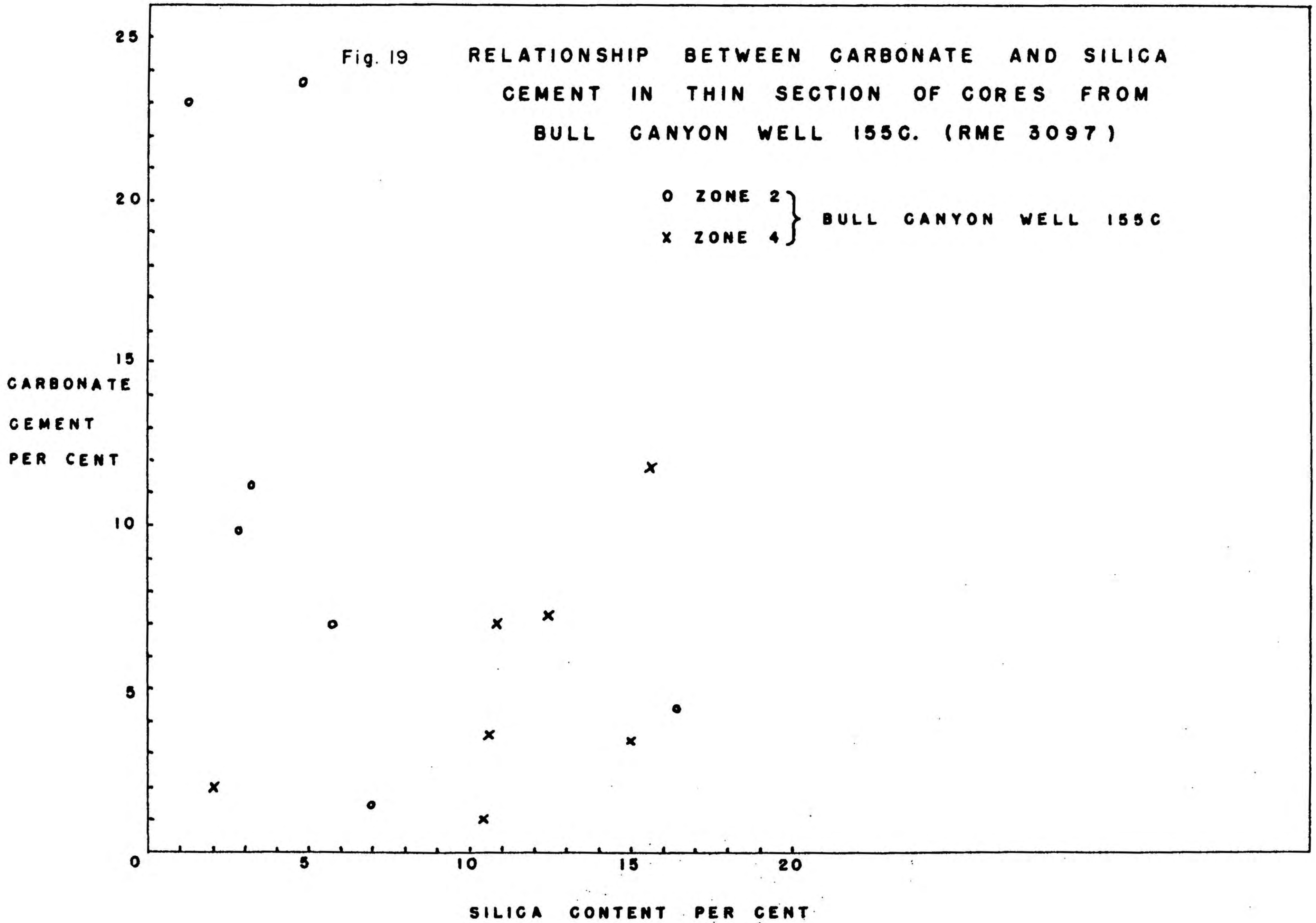
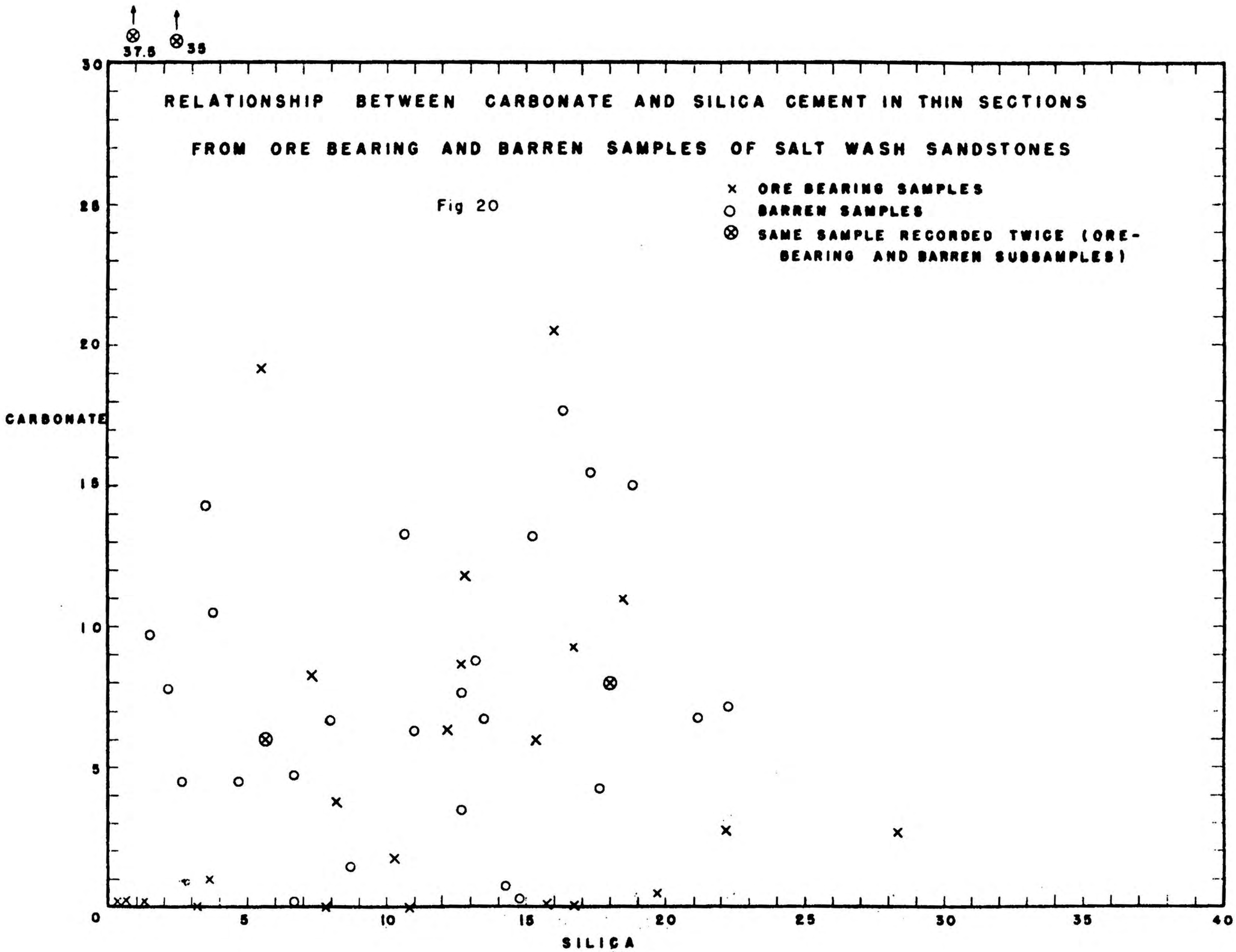
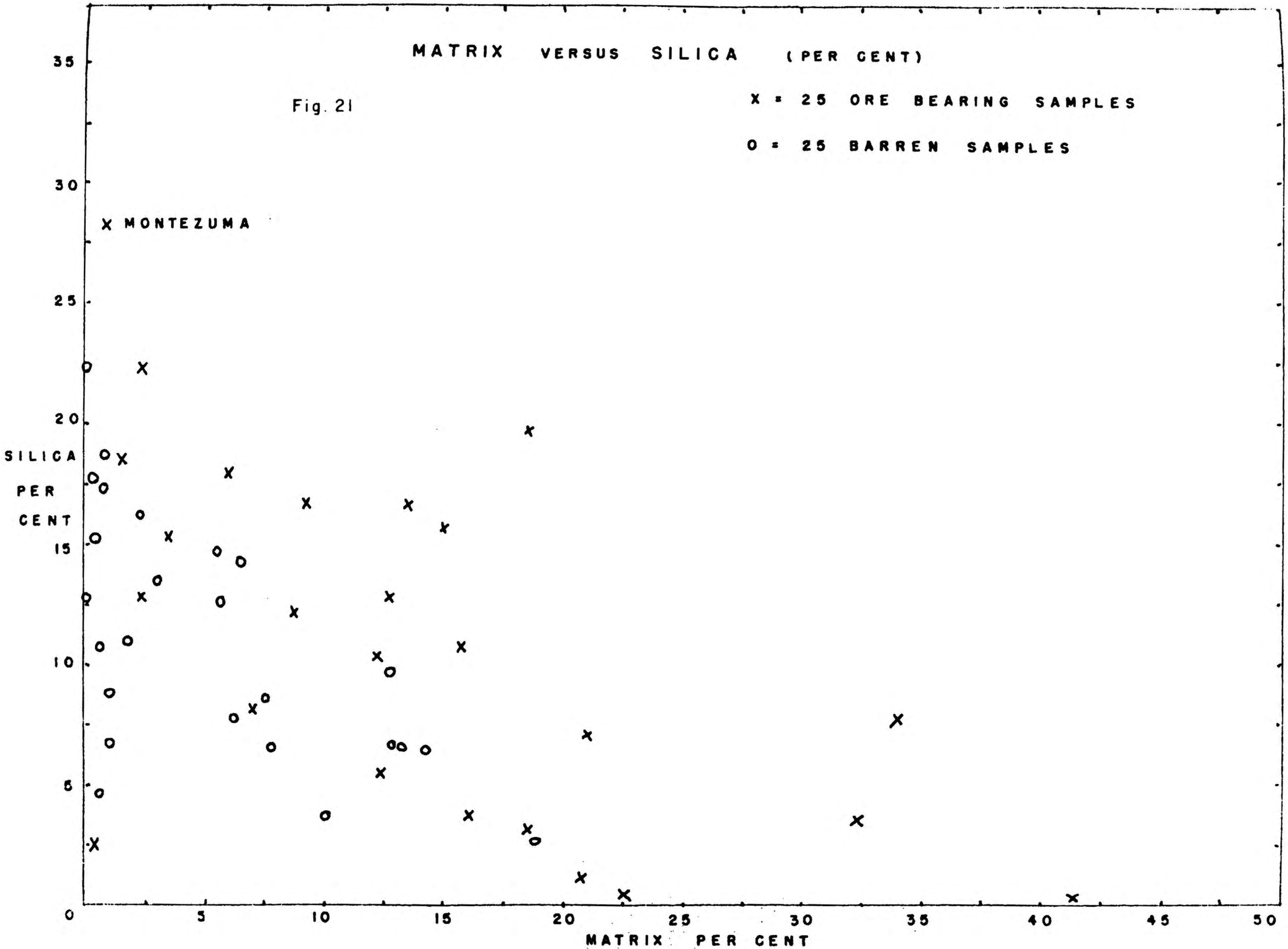


Fig. 19 RELATIONSHIP BETWEEN CARBONATE AND SILICA CEMENT IN THIN SECTION OF CORES FROM BULL CANYON WELL 155C. (RME 3097)


RELATIONSHIP BETWEEN CARBONATE AND SILICA CEMENT IN THIN SECTIONS
FROM ORE BEARING AND BARREN SAMPLES OF SALT WASH SANDSTONES
Fig 20
× ORE BEARING SAMPLES
○ BARREN SAMPLES
⊗ SAME SAMPLE RECORDED TWICE (ORE-BEARING AND BARREN SUBSAMPLES)
CARBONATE
SILICA
37.5
35
0
5
10
15
20
25
30
35
40


MATRIX VERSUS SILICA (PER CENT)
Fig. 21
X = 25 ORE BEARING SAMPLES
O = 25 BARREN SAMPLES
X MONTEZUMA
SILICA PER CENT
MATRIX PER CENT
0
5
10
15
20
25
30
35
40
45
50

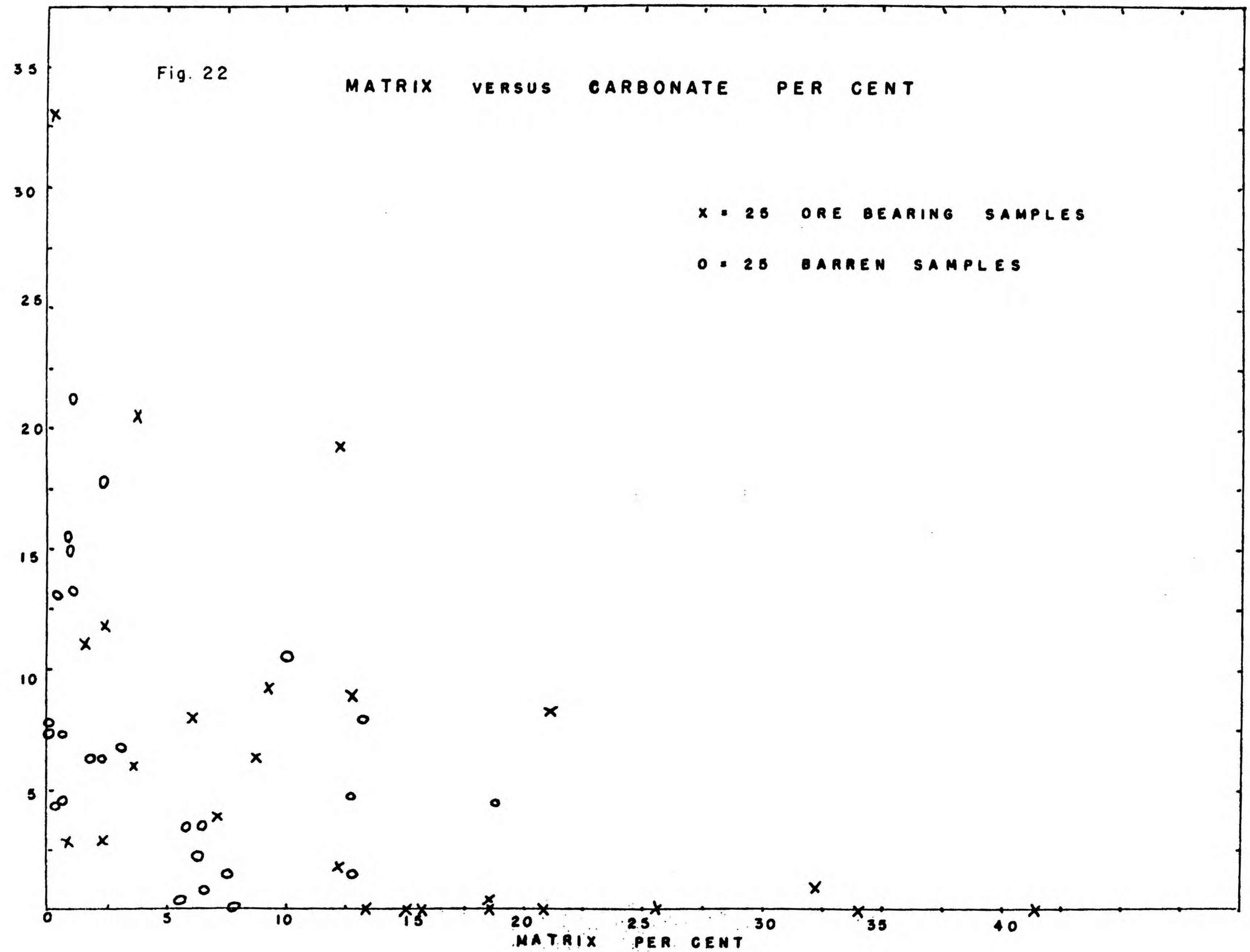


Fig. 22 MATRIX VERSUS CARBONATE PER CENT

B. Grain Packing

(a) Introduction

Measurement of grain packing in sediments has been discussed in an earlier report (Griffiths et al, RME-3106) and on the basis of this work the characteristic which appears to offer the greatest amount of information is the kind of contact present; in particular the number of contacts between grain and grain, grain and matrix, grain and cement and grain and void were chosen for evaluation. The number of contacts, per traverse of 100 grains, in four traverses per thin section, for each of the 50 samples was estimated and the results are summarized as a mean per slide in tables 5 and 6.

It seems reasonable to suppose that grain to grain contacts are some function of the number of grains present, on the other hand with some certain number of grains the arrangement of these grains to yield contacts may vary widely. Hence some correlation may be expected between grain volume (or, more strictly number) and grain to grain contacts. In order to establish packing characteristics as independent measures of fabric it would be necessary to remove, say by regression technique, the effect of composition but grain size and shape may also play a part. In the present investigation it was decided that if the estimates of the volume of components by point count were correlated with the estimates of packing then one of the measures should be discarded in applying the discriminant function approach. On the other hand, it is realized that the discriminant may reject a variable whether it is correlated or not with another so that the final decision will be by means of the efficacy of the discriminant function. This approach was used in an earlier investigation (Emery, 1954; Emery and Griffiths, 1954) where quartz and matrix were inversely correlated in some Mississippian sediments, and when quartz content and packing were both used in the discriminant the quartz content was rejected. The discriminant is designed so that it will choose the variable supplying the greatest amount of information, and hence it is some guarantee of efficiency if the decision is made by the discriminant function. It must be emphasized that the measurement of packing used by Emery (op. cit.) is different from that used by Kahn (1954) and Kahn's technique was used in the present case.

B(b) Technique and Procedure

The technique has been described in our earlier report (Griffiths, et al, RME-3106) and the sampling interval of four traverses per thin section is also based on Kahn's work (see RME-3106, p.33 and the analysis of variance tables 3.6 and 3.7).

B(c) Frequency Distributions of the Different Packing Characteristics

The frequency distributions of each packing characteristic, grain to grain, grain to matrix, grain to cement, and grain to void contacts are summarized in figs. 23 to 26 respectively and the summary descriptive statistics are given in table 7.

The ore-bearing samples possess less grain to grain contacts than the barren samples. This tendency is emphasized by the significant positive skewness (g_1 significant) in the ore-bearing samples whereas the skewness is not significant in the barren samples. This implies that not only are there more grain to grain contacts on average in barren than ore-bearing samples, but that there are more low values in ore-bearing and less in barren samples (see fig. 23).

The grain to matrix contacts show the opposite arrangement, as would be expected, because there is more matrix in ore-bearing than barren sediments. Thus the mean value and the mode for grain to matrix contacts in ore-bearing samples is much higher than in barren samples. Again the mode is on the low side of the mean (negative g_1) in barren sediments and the reverse is true of ore-bearing sediment (positive g_1). These skewness values are however not significant on the basis of the tests of the g statistics. Both the ore-bearing and the barren samples possess significant negative kurtosis values showing that the curves are platykurtic (flat-topped) with a wide spread.

Presumably the relationships between volume of grains and volume of matrix is largely responsible for these variations in grain to grain and grain to matrix contacts (see below).

The grain to cement contacts are similar in both ore-bearing and barren sediments in terms of mean value and the spreads (s) are not very different. The skewness of the ore-bearing sediment is, however, significant whereas that of the barren samples is not. The kurtosis is negative (not significant) in both. It seems clear that there are less grain to cement contacts in ore-bearing than barren sediments, and this may be some function of less cement in ore bearing than barren sediments.

Finally the grain to void estimate is an approximation to the number of pores present in the samples and again, as would be expected, the barren samples contain more open pores than the ore-bearing samples - presumably therefore they possess a higher porosity. While both ore-bearing and barren samples yield significant values for skewness and both are positive, the skewness of the ore-bearing sediments is larger than for the barren samples. In addition, the ore-bearing samples possess a highly significant positive kurtosis whereas the kurtosis for the barren samples is not significant. These features reflect the fact that the ore-bearing samples not only possess a lower average grain to void contact value, but also there are many more zeros (emphasized particularly by the highly significant positive kurtosis) in the ore-bearing than barren samples.

It seems clear that the packing characteristics are largely tied in with the compositional variation in these 50 samples. In order to reduce the number of variables involved it is therefore prudent to examine the inter-relationships, first among the packing characteristics and, secondly, between the packing characteristics and mineral composition estimates.

B(d) Inter-relationships among the Packing Characteristics

Since the amount of matrix presumably affects the number of grain to grain contacts it seems likely that the inter-relationship between grain to grain contacts and grain to matrix contacts should be inverse. The scatter diagram (fig. 27) illustrating this inter-relationship confirms the expected arrangement. The coefficient of medial correlation (see Quenouille, p. 44) is -0.469 and is significant at the one per cent level. The inverse association is therefore present and real.

The grain to grain contacts when plotted against the grain to cement contacts show no trend and presumably these two packing characteristics vary independently.

The grain to matrix contacts vary inversely as the grain to cement contacts (fig. 28); the coefficient of medial correlation is -0.792 and highly significant. Here again the trend is presumably related to the variation in amount of both matrix and cement.

The grain to void contacts show no relationship either to grain to grain, grain to matrix, or to grain to cement contacts. Apparently the arrangement of the voids is independent of other constituents although there are more voids and hence more grain to void contacts in the barren than ore-bearing sediments.

B(e) Relationships between Packing Characteristics and Mineral Composition

When per cent quartz and feldspar are plotted against grain to grain contacts no trend appears (coefficient of medial correlation is zero) and these two items vary independently. Similarly the grain to grain contacts show no obvious relationship to total grains (quartz, feldspar and rock fragments).

Table 5 - Mean values for packing characteristics in 25 samples of ore-bearing Salt Wash Sediments.

SAMPLE	A	B	C	D
6331-2	17.75	51.50	28.00	2.75
6334	13.25	64.00	17.00	5.75
6335-1	20.00	36.50	41.75	1.75
6336	14.75	59.75	21.00	4.50
6500	21.50	58.50	19.25	0.75
6502	14.50	49.25	34.25	2.00
6503A	22.75	53.00	23.50	1.75
6506	24.00	58.50	12.50	5.00
6536-2	20.75	71.25	5.00	3.00
6537A	14.00	22.00	55.25	8.75
6606	16.75	70.25	12.75	0.25
6607A	34.50	38.25	26.25	1.00
6608	17.00	63.50	17.25	2.25
6610	26.50	20.25	47.50	5.75
6620	31.50	23.75	40.75	4.00
6627-1	7.50	82.25	9.50	0.75
6636	12.25	45.75	39.75	2.25
6638	7.00	69.25	23.25	0.50
6644	18.50	33.75	45.50	2.25
6646	17.50	74.50	7.75	0.25
6651	12.00	70.25	17.25	0.50
6657	17.50	57.50	14.75	10.25
6671	22.50	42.75	23.75	11.00
6675	11.50	29.25	51.75	7.50
6683	19.25	42.25	30.50	8.00

A = mean of grain to grain contact

B = " " matrix " "

C = " " cement " "

D = " " void " "

Table 6 - Mean values for packing characteristics in 25 samples of barren sediments.

SAMPLE	A	B	C	D
6508	26.25	29.25	36.00	8.50
6510	26.00	51.25	20.75	2.00
6512	22.25	22.25	45.75	9.75
6513	32.50	11.50	43.75	12.25
6514	21.25	67.25	11.00	0.50
6515	35.50	33.00	20.00	11.50
6519	22.50	68.25	9.25	0.00
6520	29.50	41.25	19.25	10.00
6521	31.25	25.75	36.50	8.50
6522A	27.00	55.75	14.25	3.00
6523	32.00	20.25	32.50	15.25
6524	24.50	27.25	24.75	23.50
6525	16.50	26.75	41.75	15.00
6526	28.20	41.25	26.75	3.50
6527	27.00	20.75	50.00	2.25
6528	25.50	30.25	36.00	8.25
6529	13.00	70.50	15.75	0.75
6530	19.00	59.00	19.50	2.50
6531	23.00	38.50	31.50	7.00
6532	40.00	19.25	40.50	0.25
6534	21.00	34.25	25.25	19.50
6629	23.00	41.50	26.00	9.50
6630	16.75	60.25	10.25	12.75
6662	15.75	51.00	20.75	12.50
6667	23.50	29.00	18.75	28.75

A = mean of grain to grain contact

B = " " matrix " " "

C = " " cement " " "

D = " " void " " "

Table 7 - Summary Statistics for the distribution of packing characteristics in 50 samples of Salt Wash Sandstones.

Item	$\bar{X}$ %	S 6/o	Cv. .%	Sk	K	g_1	g_2	N	Samples
Grain/Grain	22.05	8.52	38.63	0.2038	$\bar{0}$.1252	0.4106*	0.0977	200	50
" "	18.60	7.73	41.57	0.3016	0.3016	5.6124*	0.3973	100	25 ore
" "	25.50	7.84	30.75	0.2146	0.0541	0.4358	0.1194	100	25 barren
Grain/matrix	45.60	19.06	41.79	0.4203	$\bar{1}$.1253	0.8471**	$\bar{1}$.1234**	200	50
" "	51.95	18.37	35.36	$\bar{0}$.1134	$\bar{1}$.0036	$\bar{0}$.2304	$\bar{0}$.9932*	100	25 ore
" "	39.25	17.56	44.73	0.1860	$\bar{0}$.9522	0.3777	$\bar{0}$.9392*	100	25 barren
Grain/cement	27.33	13.69	50.09	0.2304	$\bar{0}$.6648	0.4643**	$\bar{0}$.6511*	200	50
" "	26.95	14.70	54.52	0.2561	$\bar{0}$.7170	0.5199*	$\bar{0}$.6917	100	25 ore
" "	27.70	12.59	45.44	0.2011	$\bar{0}$.5544	0.4084	$\bar{0}$.5207	100	25 barren
Grain/void	7.50	6.60	57.94	0.7907	2.5489	1.5936**	2.6447**	200	50
" "	4.80	3.84	79.90	0.7651	1.3249	1.5536**	1.4561**	100	25 ore
" "	10.20	7.60	74.48	0.5393	0.4427	1.0951**	0.5281	100	25 barren

* Significant at the 5 per cent level

** Significant at the 1 per cent level

Fig. 23

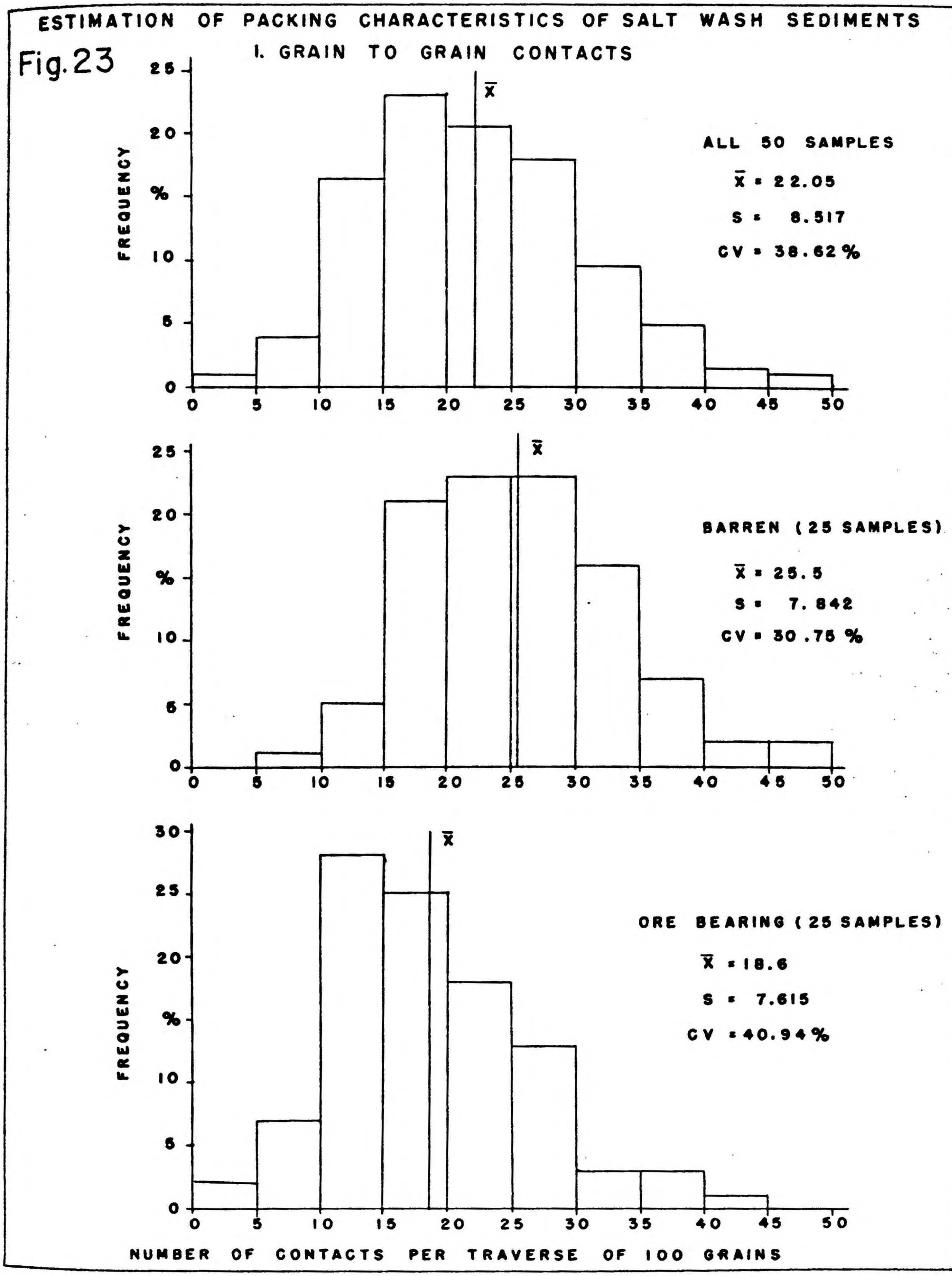

ESTIMATION OF PACKING CHARACTERISTICS OF SALT WASH SEDIMENTS
I. GRAIN TO GRAIN CONTACTS
ALL 50 SAMPLES
X̄ = 22.05
S = 8.517
CV = 38.62 %
BARREN (25 SAMPLES)
X̄ = 25.5
S = 7.842
CV = 30.75 %
ORE BEARING (25 SAMPLES)
X̄ = 18.6
S = 7.615
CV = 40.94 %
FREQUENCY %
NUMBER OF CONTACTS PER TRAVERSE OF 100 GRAINS

Fig. 24

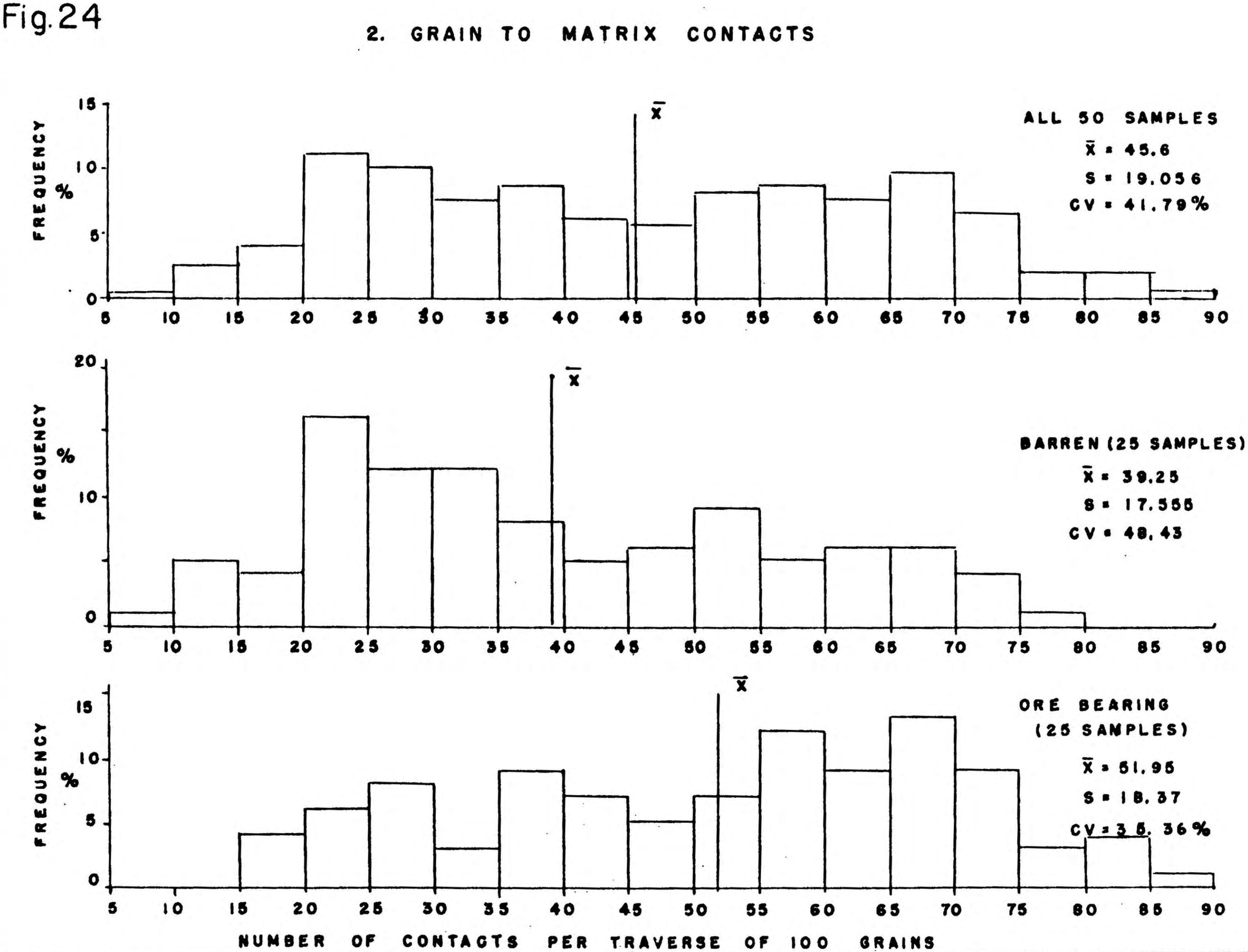

2. GRAIN TO MATRIX CONTACTS
FREQUENCY %
ALL 50 SAMPLES
X̄ = 45.6
S = 19.056
CV = 41.79%
BARREN (25 SAMPLES)
X̄ = 39.25
S = 17.555
CV = 48.43
ORE BEARING
(25 SAMPLES)
X̄ = 51.95
S = 18.37
CV = 35.36%
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90
NUMBER OF CONTACTS PER TRAVERSE OF 100 GRAINS

Fig. 25

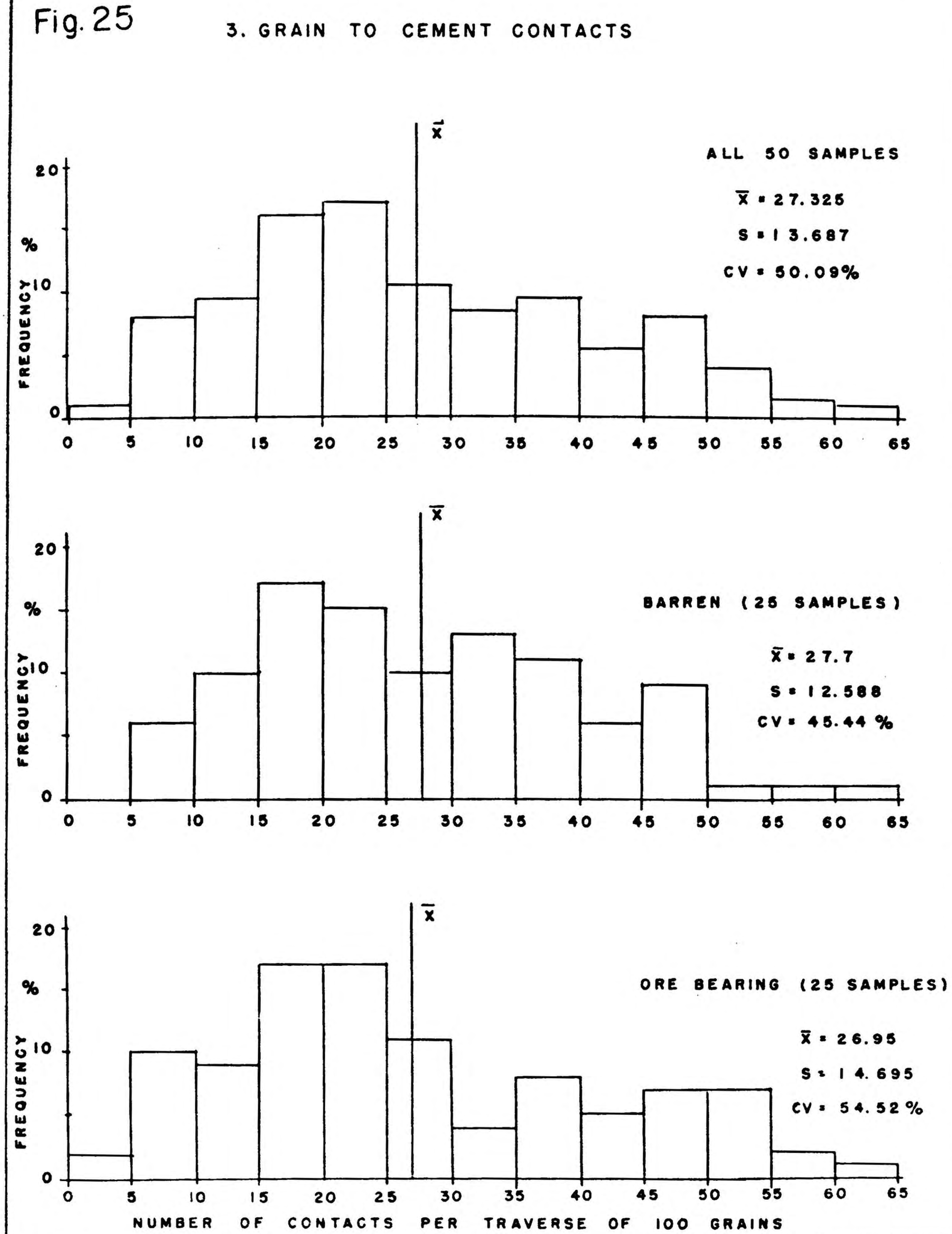
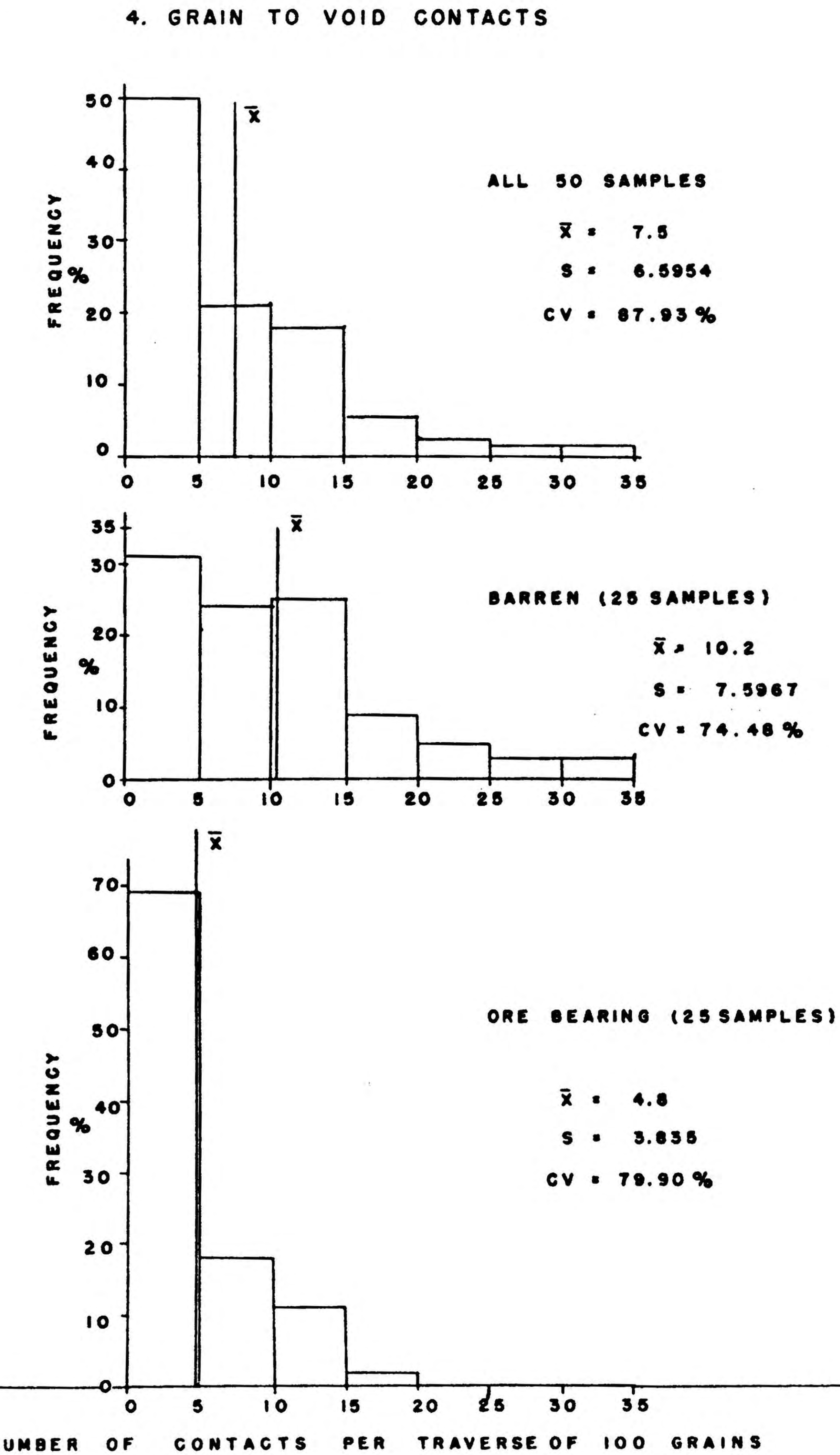

3. GRAIN TO CEMENT CONTACTS
ALL 50 SAMPLES
X̄ = 27.325
S = 13.687
CV = 50.09%
BARREN (25 SAMPLES)
X̄ = 27.7
S = 12.588
CV = 45.44 %
ORE BEARING (25 SAMPLES)
X̄ = 26.95
S = 14.695
CV = 54.52 %
FREQUENCY %
NUMBER OF CONTACTS PER TRAVERSE OF 100 GRAINS

Fig. 26


4. GRAIN TO VOID CONTACTS
FREQUENCY %
50
40
30
20
10
0
x̄
ALL 50 SAMPLES
x̄ = 7.5
S = 6.5954
CV = 87.93 %
0 5 10 15 20 25 30 35
35
30
20
10
0
BARREN (25 SAMPLES)
x̄ = 10.2
S = 7.5967
CV = 74.48 %
0 5 10 15 20 25 30 35
70
60
50
40
30
20
10
0
ORE BEARING (25 SAMPLES)
x̄ = 4.8
S = 3.835
CV = 79.90 %
0 5 10 15 20 25 30 35
NUMBER OF CONTACTS PER TRAVERSE OF 100 GRAINS

The relationship between grain to matrix contacts and amount of matrix is curvilinear and positive with a coefficient of medial correlation of +0.837 (significant). The trend (fig. 29) indicates that the grain to matrix contacts increase with increase in matrix to about 15 percent by volume of matrix, and then the matrix increases rapidly with much less change in grain to matrix contacts. There seems little reason for including both grain to matrix contacts and volume of matrix in the discriminant function.

Similarly the volume of cement is positively associated with the grain to cement contacts (coefficient of medial correlation +0.760, significant). The trend is apparently linear. There is no relationship between the grain to cement contacts and the amount of grains (quartz, feldspar and rock fragments).

B(f) Summary of the Conclusions on Packing Characteristics

It seems evident that composition and packing characteristics are related. In terms of composition the amount of matrix was selected as the variable to enter into the discriminant; hence there appears to be little reason for including the grain to matrix contacts (positively correlated with the amount of matrix) or the grain to cement contacts (positively correlated with the amount of cement). The grain to voids contacts are more common in barren sediments, again presumably because of the lack of matrix. For purposes of designing a discriminant function therefore, the packing characteristics may be represented by the grain to grain contacts. Any relationship between grain to grain contacts and some other variable will be inverse to grain to matrix contacts which follows from the inverse correlation between these two packing characteristics.

Packing characteristics measured as contacts between grains and different elements of composition are unlikely to yield independent estimates of fabric unless the samples analyzed have approximately similar compositions. The comparisons of zones 2 and 4 of Bull Canyon well 155C described by Kahn (op. cit.) is not necessarily typical of ore-bearing and barren sediments. It will be necessary to follow these packing characteristics through zones 2 and 4 of wells 155 A and B before the gradients from barren to ore-bearing sediments can be evaluated.

Fig. 27

RELATIONSHIP BETWEEN GRAIN TO GRAIN AND GRAIN TO MATRIX CONTACTS IN 50 SAMPLES OF SALT WASH SANDSTONES

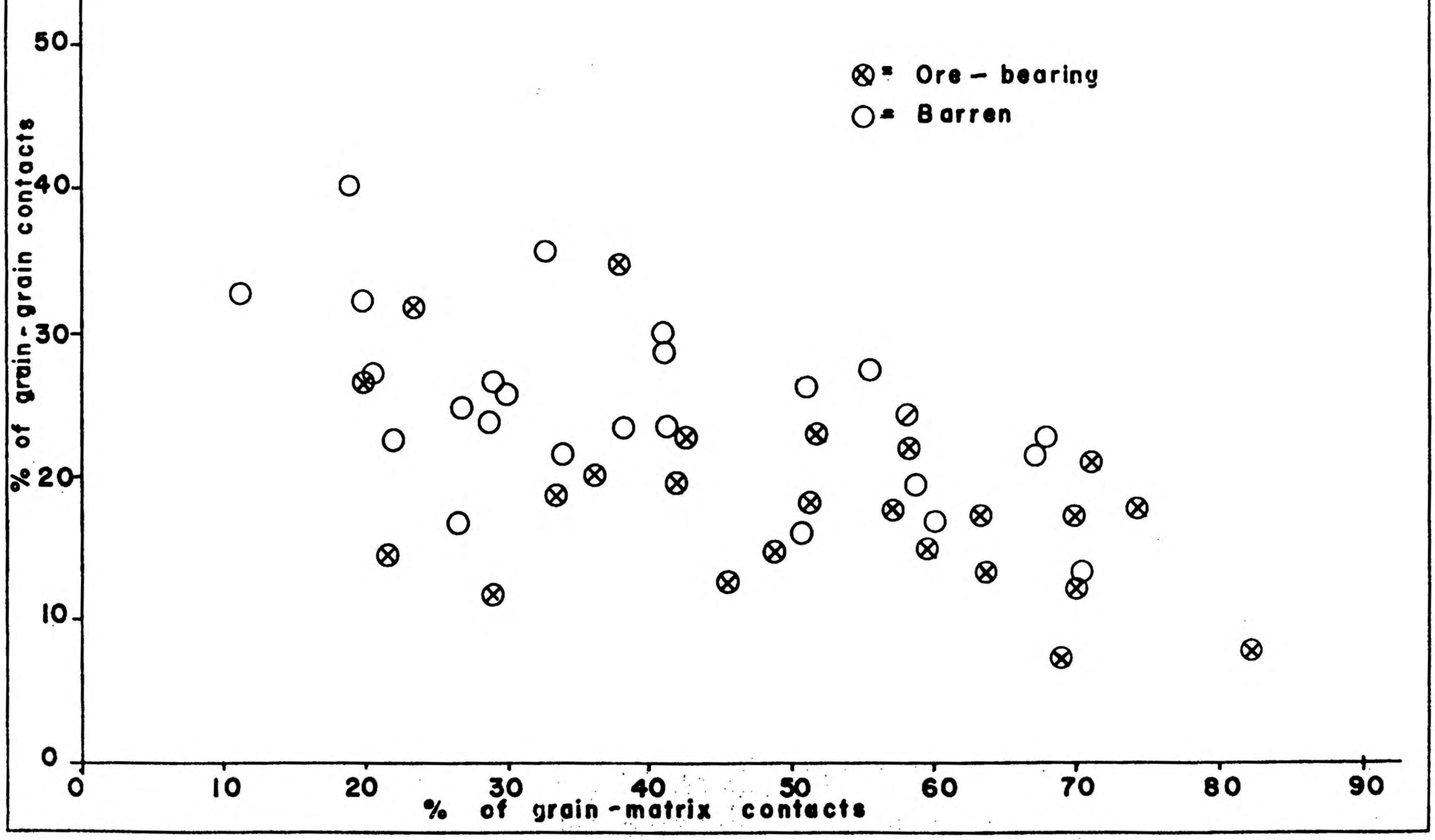
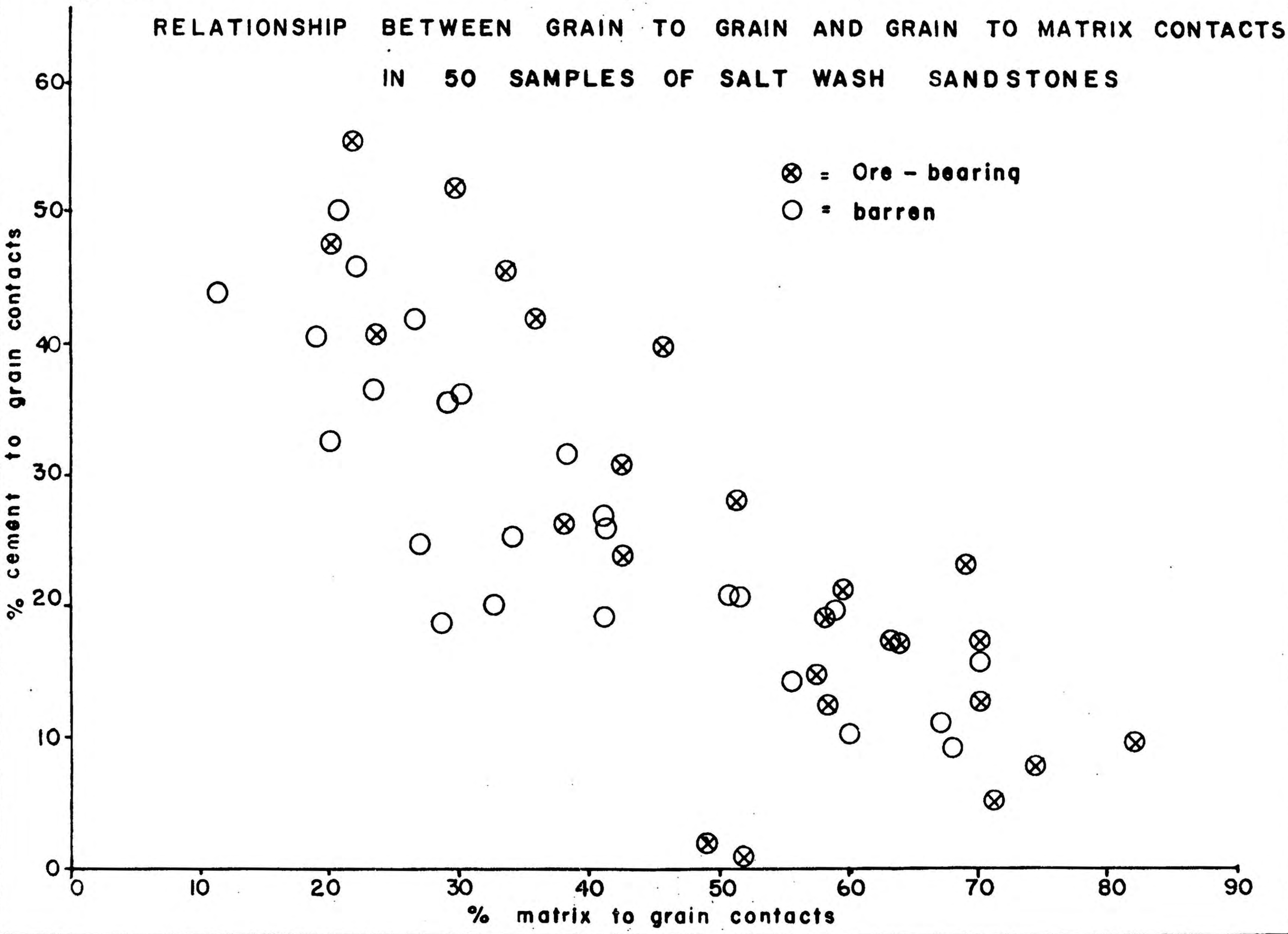


Fig 28


RELATIONSHIP BETWEEN GRAIN TO GRAIN AND GRAIN TO MATRIX CONTACTS
IN 50 SAMPLES OF SALT WASH SANDSTONES
⊗ = Ore - bearing
○ = barren
% cement to grain contacts
% matrix to grain contacts
0
10
20
30
40
50
60
70
80
90

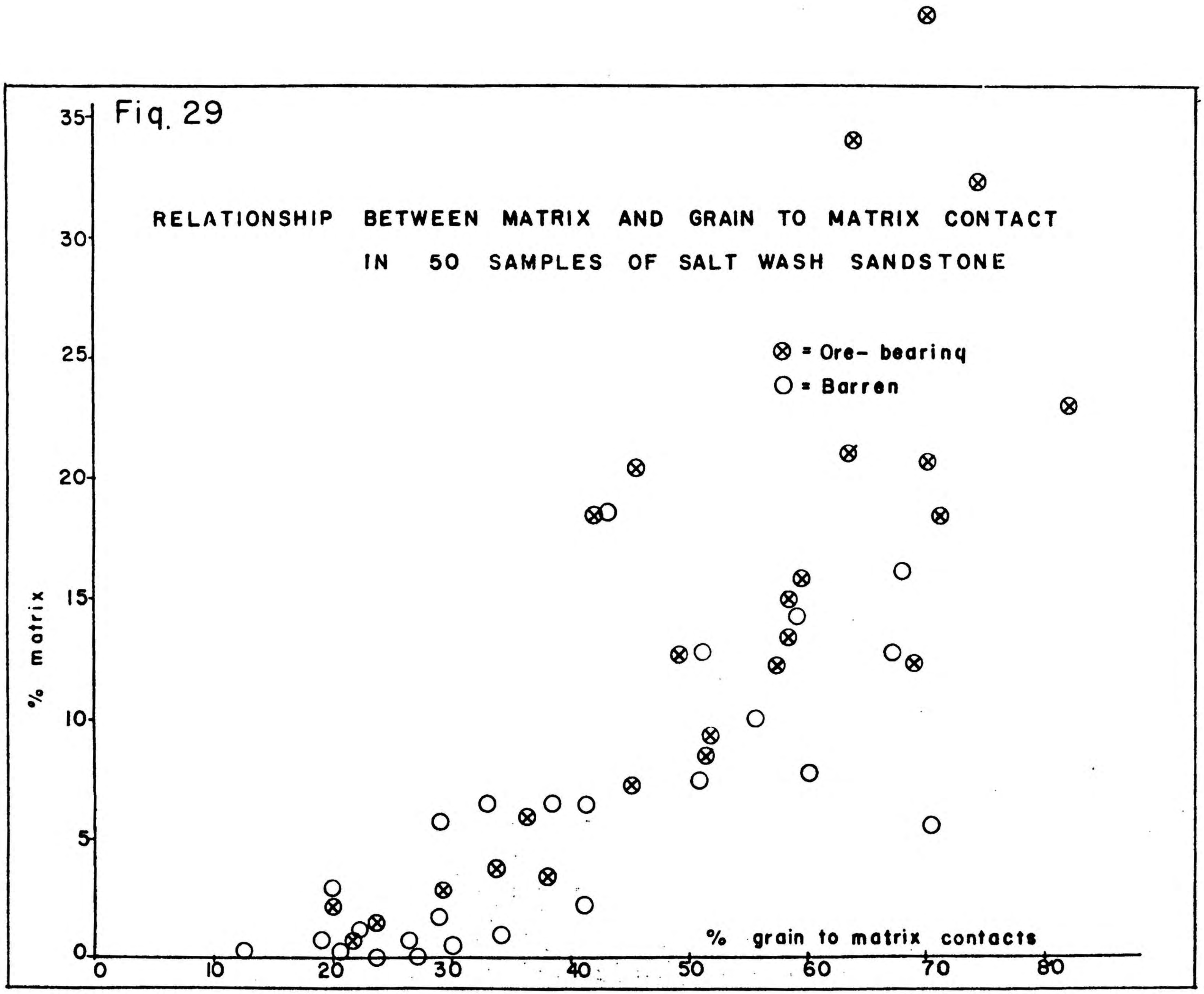


Fig. 29
RELATIONSHIP BETWEEN MATRIX AND GRAIN TO MATRIX CONTACT
IN 50 SAMPLES OF SALT WASH SANDSTONE
⊗ = Ore- bearing
○ = Barren
% matrix
% grain to matrix contacts
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80

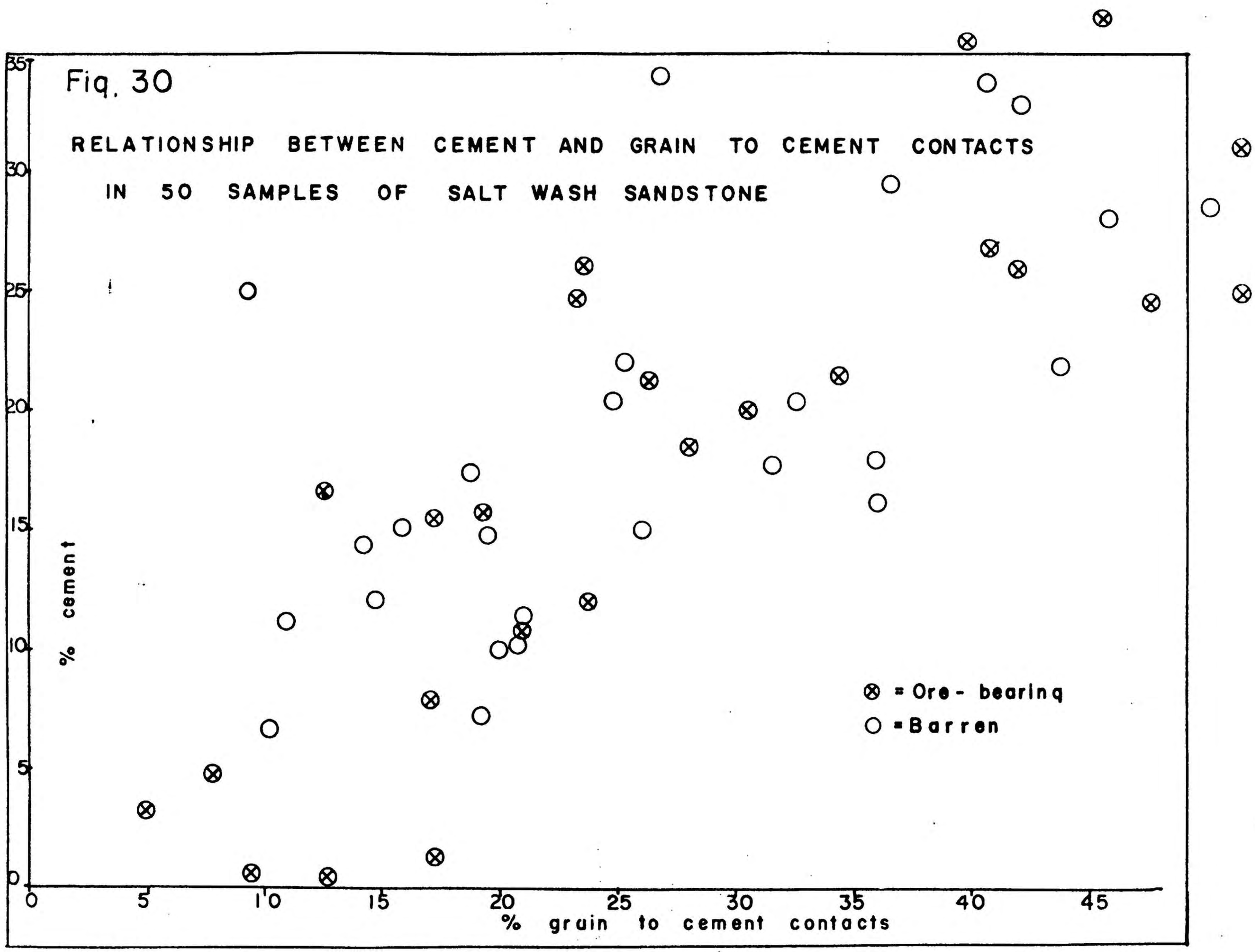


Fig. 30

RELATIONSHIP BETWEEN CEMENT AND GRAIN TO CEMENT CONTACTS IN 50 SAMPLES OF SALT WASH SANDSTONE

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Appendix Table 1a - Locality and Lithology of Samples of Ore-bearing Salt Wash sediments.

Penn State Cat. No.	Locality and Lithology
6331-2	Main Street No. 1 Mine, Wedding Bell Group, Bull Canyon, Colorado. Type sample of bedded or "book" ore; dark gray sandstone with bedding emphasized by vanadium-containing micaceous ore.
6334	Main Street No. 1 Mine, Wedding Bell Group, Bull Canyon, Colorado. "Trashy" ore; slumped sand with clay pebbles, ore arranged in yellow and gray patches. Nearby is a fossil tree fragment completely replaced by carbonate.
6335	Main Street No. 3 Mine, Wedding Bell Group, Bull Canyon, Colorado. Ore roll, with carbonate cemented lens surrounded by friable sandstone. The margin of the carbonate cemented area appears to transect bedding but actually follows the terminations of lenses of different grain size. (See RME 3070, pp. 84-89, and figs. 8 and 9). Most of the ore occurs in the friable sandstone outside the cemented "roll"; within the cemented "roll" there is very little ore. The exposed face of the cemented area, presumably a fracture face, is coated with gray and yellow ore probably precipitated by acid water solutions attacking the carbonate. 6335 (1) Subsample from friable area outside "roll". 6335 (2) Subsample from cemented area inside "roll".
6336	Main Street No. 1 Mine; Wedding Bell Group, Bull Canyon, Colorado. Gray sandstone with white specks and patches; the distribution of gray ore is patchy. In areas where there is ore there is little silica cement but in light colored areas there is considerable amounts of silica cement.
6500	Mine Sample, Bull Canyon supplied by Dr. R. J. Wright.

Penn State Cat. No.	Locality and Lithology
	Gray very fine grained silty sandstone with ore in dark and light gray areas. This is a typical bedded ore sample but on close inspection it can be seen that the "bedding" is not regular but lensed and the lenses are inclined and not parallel over the whole sample. Bedding slightly disturbed.
6502	Mine Sample from Bull Canyon area supplied by Dr. R. J. Wright.
	Variegated gray fine grained sandstone; bedded ore with bedding accentuated by dark and light gray layering. Ore occurs mainly in fine grained layers; some carbonate and little ore in the coarse grained layers.
6503 (A)	Mine Sample from Bull Canyon area supplied by Dr. R. J. Wright.
	Bedded ore; dark and light gray yellowish tinted sandstone. The layers are not persistent through the whole sample but occur as lenses. Considerable quantities of silica cement occur.
6506	Mine Sample from Bull Canyon area supplied by Dr. R. J. Wright.
	Dark gray to white fine grained sandstone; the mineralization emphasizes inclined (cross) bedding. Yellowish mineralization patchy, much silica cement.
6536	Ore Sample from Montezuma Canyon, Monticello, Utah supplied by Dr. R. J. Wright.
	Large slab of sandstone with main portion showing well marked light and dark layering parallel to bedding. Central portion inclined (cross) bedding. Pink spots and areas in places through sample are free from ore and strongly cemented by silica cement.
	One corner of the specimen shows the bedding curved and disturbed, an area of penecontemporaneous slumping. This area contains in one square inch both pink and gray patches.
	6536-2 sample from bedded area.

Penn State Cat. No.	Locality and Lithology
6537	Ore Sample from Montezuma Canyon, Monticello, Utah, supplied by Dr. R. J. Wright. Dark gray friable ore sandstone passing gradually over to hard, compact pink silica cemented sandstone. The pink area is generally free from ore but contains a few small gray spots.
6606	Queen Mary No. 2 Mine, Bench Claims, Lisbon Valley, Utah. Dark gray very silty sand with large gray clay "pebbles" and some yellow impregnations interstitially among the grains.
6607	Queen Mary No. 2 Mine, Bench Claims, Lisbon Valley, Utah. Trashy type ore between two layers of bedded ore. Buff gray white friable sandstone with brown clay pebbles and yellow impregnations; some silica cement.
6608	Queen Mary No. 2 Mine, Bench Claims, Lisbon Valley, Utah. Trashy type ore among bedded ore. Light gray friable sandstone with layers containing clay pebbles showing strong ore impregnation.
6610	Queen Mary No. 1 Mine, Bench Claims, Lisbon Valley, Utah. Gray to pink conglomeratic sandstone with many pink "chert" pebbles. Gray areas are impregnated, pink areas silica cemented; some yellow staining along fracture planes. Trash pile type ore.
6620	Wilson Group, Dry Valley Camp, near Lisbon Valley, Utah. Gray white sandstone conglomerate, very strongly disturbed and slumped with fossil remains of bones and plants. Ore is mainly vanadium gray type.
6627	Westcliff House No. 8 Mine, Coalbed Canyon, near Monticello, Utah. Gray friable sandstone with white specks and containing large dark gray clay pebbles along with brown clay; badly slumped. Trashy type ore-bearing sandstone.

Penn State Cat. No.	Locality and Lithology
	A disturbed green mudstone split occurred above and below ore-bearing layer and red mudstone occurred outside the green. The whole mudstone series strongly slumped.
6636	Kerr McGee Mine, Lukachukai Mountains, Cove School, Arizona.
	Purplish pink carbonate cemented medium to fine grained sandstone with thin layers containing yellow ore impregnation. The layers with ore contain very little carbonate while the cemented layers contain very little ore. The carbonate cement shows lustre-mottling with patches of carbonate in similar orientation.
6638	Kerr McGee Mine, Lukachukai Mountains, Cove School, Arizona.
	Sample of "best" ore in the mine; gray sandstone with yellow impregnation and very many purplish brown and gray clay "pebbles". Texture strongly disturbed; slumped sediment.
6644	Kerr McGee Mine, Lukachukai Mountains, Cove School, Arizona.
	Gray white carbonate cemented sandstone with yellow ore; many clay "pebbles" zoned purplish red and gray green.
6648	Climax Mine, north side of Mesa IV1/2 (near compressor shack) Lukachukai Mountains, Cove School, Arizona.
	Gray greenish very silty compact sandstone with red lenses and zones. Coloration irregular and following the lenses of sand grains. Most ore confined to gray greenish area.
6651	Climax Mine, Mesa IV1/2, (South Mine) Lukachukai Mountains, Cove School, Arizona.
	Gray fine grained sandstone crowded with clay pebbles; some of the clay pebbles are purplish pink to deep red in color while others are pale green to gray and some are zoned with both colors, the red generally inside and surrounded by the gray green color. The sandstone is impregnated with yellow ore.
	A strongly slumped ore-bearing sandstone.

Penn State Cat. No.	Locality and Lithology
6657	Mine, Camp Mesa, Lukachukai Mountains, Cove School, Arizona. Pink, purplish very friable fine grained silty sandstone with yellow ore mineral impregnation concordant with bedding and both arranged in lenses. The lenses are not continuous for much more than 1-2 inches.
6671	Kerr McGee Mine on North rim; Lukachukai Mountains, Cove School, Arizona. Pink purplish friable sandstone with gray clay stringers and lenses through it, concordant with bedding in sandstone but not persistent laterally. Gray clay layers pass over to clay "pebbles" also aligned in bedding. This resembles 6657 but may not be ore-bearing.
6675	Kerr McGee Mine on North rim; Lukachukai Mountains, Cove School, Arizona. Buff to pink silica cemented very slightly friable sandstone with area of greenish ore impregnation which is much more friable. Small spots of dark gray ore occur in buff sandstone.
6683	Well core, depth 206 feet, Well NC 649A, North rim Lukachukai Mountains, Cove School, Arizona. Supposedly typical ore; gray buff well-bedded friable sandstone with dark gray clay lenses, very roughly concordant with bedding but often inclined to bedding. Yellow ore impregnation in sandstone lenses between gray clay lenses.

Appendix Table Ib - Locality and Lithology of Barren SaltWash Sediments.

Penn State Cat. No.	Locality and Lithology
6508	Core, Depth 107.3-107.9 feet, Well 261, Area "D", Bull Canyon, Colorado. Very fine grained white compact sandstone with white specks. The white specks are either weathered carbonate patches or weathered rock-fragments (compare to patinated "cherts").
6510	Core, Depth 126.1-126.6 feet, Well 272, Area "D", Bull Canyon, Canyon, Colorado. Fine grained friable white sandstone cp. 6508. Lenses of black fine grained material (organic matter and/or heavy minerals) inclined and crossbedded.
6512	Core, Depth 80.4-80.9 feet, Well 272, Area "D", Bull Canyon, Colorado. Contact between white coarse grained sandstone, cemented by carbonate and red mudstone with green lenses. The contact is slumped and clay pebbles occur in the sandstone associated with the slumping. The contact is inclined to horizontal. Sample analyzed from coarse sandstone.
6513	Core, Depth 49.5-50.0 feet, Area "A", Bull Canyon, Colorado. White very fine grained sandstone with white specks (see 6508). Compact and cemented in part by silica and in part by carbonate. Some of the grains are closely clustered and cemented by silica in patches with more open texture surrounding them.
6514	Core, Depth 94.0-94.3 feet, Well 261, Area "D", Bull Canyon, Colorado. Light yellow to buff brown and red medium grained sandstone with red mudstone partings (< 1 mm. thick) and red and green clay "pebbles" and lenses.
6515	Core, Depth 101.6-102.0 feet, Well 272, Area "D", Bull Canyon, Colorado.

Penn State Cat. No.	Locality and Lithology

Light red to brown medium grained slightly friable sandstone with many white specks. The white specks emphasize crude layering, otherwise the sandstone is massive.

6519 Core, Depth 89.5-90.0, Well 272, Area "D", Bull Canyon, Colorado.

Deep brown red very silty compact sandstone. Vague layering by red clayey lenses in core.

6520 Core, Depth 122.3-123.2 feet, Well 272, Area "D", Bull Canyon, Colorado.

Contact between coarse grained white compact, massive sandstone and red fine grained sandstone showing crude layering. Areas of white sandstone occur in red. At the contact the color is greenish interlayered with red; the white color ends abruptly adjacent to both green and red while the latter alternates over about 1/2 inch of core before becoming completely red.

Sample analyzed from contact. The red contains more matrix material than white.

6512 Core, Depth 84.2-84.6 feet, Well 66, Area "A", Bull Canyon, Colorado.

Gray white coarse grained, massive, carbonate cemented sandstone with gray to brown and black spots some of which are heavy minerals; others are associated with carbonate specks and are limonite spots (see RME 3054, pp. 34 ff).

6522 Core, Depth 63.5-64.1, Well 261, Area "D", Bull Canyon, Colorado.

White medium grained compact sandstone interbedded with pink to purplish red finer grained sandstone.

Sample analyzed, 6522A, purplish red sandstone.

6523 Core, Depth 47.4-47.8 feet, Well 261, Area "D", Bull Canyon, Colorado.

Penn State Cat. No.	Locality and Lithology
	Gray white to buff brown medium grained compact sandstone; brown and green mudstone "galls" or "pebbles" in buff sandstone.
	Sample analyzed gray white sandstone.
6524	Core, Depth 85.7-88.2 feet, Well 261, Area "D", Bull Canyon, Colorado.
	Buff gray to pink gray limonite stained massive sandstone with brown limonite spots. Compact and not friable.
	Sample analyzed from pink area.
6525	Core, Depth 67.6-68.0 feet, Well 272, Area "D", Bull Canyon, Colorado.
	Pale pink white compact massive sandstone with brown clay galls.
6526	Core, Depth 48.7-49.2 feet, Well 261, Area "D", Bull Canyon, Colorado.
	White cemented sandstone with reddish silty cross bedded sandstone and thin layer of gray shale.
	Sample analyzed from white sandstone.
6527	Core, Depth 36.2-36.8 feet, Well 66, Area "A", Bull Canyon, Colorado.
	Medium grained white to creamy yellow carbonate cemented sandstone; the creamy yellow areas are stained by limonitic stain; some silica cement.
6528	Core, Depth 34.0-34.4 feet, Well 261, Area "D", Bull Canyon, Colorado.
	Light pink gray white speckled compact sandstone with many red mudstone "pebbles" crudely aligned along inclined or cross beds.
6529	Core, Depth 70.0-70.4 feet, Well 66, Area "A", Bull Canyon, Colorado.

Penn State Cat. No.	Locality and Lithology
	Cream to buff white very fine grained compact silty sandstone with many fine laminae of gray silty mudstone inclined bedding. Small lens of very coarse white sandstone in gray mudstone showing disturbed bedding and slumped.
	Sample analyzed from very fine grained silty sandstone.
6530	Core, Depth 27.5-28.1 feet, Well 66, Area "A", Bull Canyon, Colorado.
	Red silty to clayey sandstone massive, irregular small patches and blocks of red mudstone.
6531	Core, Depth 10.1-10.7 feet, Well 66, Area "A", Bull Canyon, Colorado.
	Friable, pink fine grained sandstone with dark gray to black laminae showing inclined bedding. Laminae cross and bifurcate.
6532	Core, Depth 13.0-13.5 feet, Well 261, Area "A", Bull Canyon, Colorado.
	Very fine grained carbonate cemented gray sandstone, massive with traces of inclined bedding and an inclined irregular fracture.
6534	Core, Depth 68.6-69.3 feet, Well 261, Area "D", Bull Canyon, Colorado.
	Reddish stained medium grained compact sandstone with lenses, and "pebbles" of red mudstone not continuous for more than 1" length. Bedding slightly inclined. Rare green "pebbles" of clay.
6629	Outcrop sample; sandstone 8' above red mudstone near bore hole No. 242, Montezuma Canyon, near Monticello, Utah.
	Very friable gray white medium grained massive sandstone.
6630	Outcrop sample; sandstone 5' above red mudstone at bore hole 242, Montezuma Canyon, near Monticello, Utah.
	Very friable gray white to buff medium grained massive sandstone.

Penn State Cat. No.	Locality and Lithology
6662	Core, Depth 387-387.5 feet, well 143, Lukachukai Mountains, Cove School, Arizona. Very friable medium grained buff sandstone with faint gray lenses aligned as bedding but not continuous across the core.
6667	Core, Depth 237.5-238 feet, Well 629, Lukachukai Mountains, Cove School, Arizona. Very friable medium to coarse grained massive buff sandstone.

RME-3122
Part II

Petrographical Investigations of the Salt Wash Sediments

Part II. Size, shape and orientation of quartz grains in 50 samples of Salt Wash Sandstones.

Annual Technical Report for

April 1, 1954 to April 1, 1955

by

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Since nontechnical and nonessential prefatory material has been deleted, the first page of Part II is page 5.

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Table of Contents (Continued)

Abstract

This part of the report describes the analysis of 15,000 measurements of grain size, shape (axial ratio) and orientation (axial inclination) of quartz grains from 25 samples of ore-bearing and 25 samples of barren Salt Wash sandstones.

No difference in mean grain size, standard deviation of grain size, axial ratio or inclination of long axes of these quartz grains can be discerned between ore-bearing and barren sediments. However it appears that the sets of grains within each microscope field differ more in size in ore-bearing than barren sediments.

Again while there is no obvious difference in perfection of orientation between the sets of 25 samples for ore-bearing and barren sediments there is a difference in relationship between some items of composition and orientation among ore-bearing and barren sediments.

It seems evident that ore may occur in sediments of any quartz grain size, any axial ratio and any orientation when the sediments are examined regionally. All the differences so far observed between ore-bearing and barren sediments are entirely local in character i.e. while at any one locality ore-bearing and barren sediments may differ, integrated over all localities this difference vanishes. It seems clear that disposition of the ore in these sediments is not controlled by any regional factor but purely by local differences in size, and fabric within small volumes of sediments. This is, of course, what we expect if the ore-bearing sediments are stratigraphic (≡ petrographic) traps.

i) Introduction

Part I of this report deals with mineral composition and grain packing characteristics of 50 samples of Salt Wash sediments, 25 of which were ore-bearing and 25 barren. To complete the petrographic description of these 50 samples Part II contains a description of the size and shape distributions and the orientation of the grains in these sediments.

ii) Measurement of Grain Size

Measurement of grain size in sediments may be performed by a number of techniques some of which are more suitable to certain specific problems than others; for example in the present case pipette sedimentation and sieving would yield measurements of the size distribution of the constituents but in this procedure all mineral constituents are treated alike and the size obtained is somewhat difficult to interpret. It was decided that the most suitable technique for the present investigation would be one which yielded size information independent, as far as practicable, of composition and, as the size measurement is to be used for correlation with the composition, the use of the same sample would be an advantage. Hence measurement of grain size of "quartz" grains in thin section was the technique chosen; the main difficulty here is to select some axis of the grain which can be defined by an unequivocal operation so that the "same" axis may be selected for all measurements. In all cases the length of axes measured in thin section is a function of size, shape, orientation of the grains and direction of section and packing of the grains (Griffiths, 1952a) so it is important to choose a suitable means of selecting a unique axis.

In general it has been found that a suitable definition may be based upon an operation which includes selecting the narrowest diameter of the grain by means of trial and error with a calibrated parallel rule and measuring the longest axis perpendicular to this short diameter (Griffiths and Rosenfeld, 1950). A considerable source of variation in operator selection of long axis is reduced by this procedure. The two axes are measured yielding an estimate of two dimensional shape (or area) and the inclination of the long axis to a fixed reference direction is then used to yield a measure of orientation.

iii) Procedure

The first question which arises concerns the problem of sampling and with 50 samples and at least fifty grains per sample this would lead to 2500 grain measurements of each axis and inclination. There is no guarantee that this is enough; in quartzose rocks such as the Salt Wash sediments variation from layer to layer is large and the layers are thin (e.g. more than one in each microscope field), hence it is necessary to sample a few grains from many layers (Griffiths, 1955b).

Very little information exists on the exact sampling pattern to be used in this case so it was decided, as some insurance of success, to perform a large number of measurements. Ten microscope fields were selected from each sample (thin section) by means of a random grid, and a number of quartz grains (15 or more) outlined on a photographic plate enlarged to suitable magnification. A series of operators were subdivided into 3 groups and then these groups were assigned to select at random 10 grains. Hence for each sample there are 3 operators, 10 fields and 10 grains per field leading to a total of 300 measurements per sample. The thin sections and fields are examined by all 3 operators but the grains are not necessarily common to all operators. This arrangement affects the experimental design and analysis (see mathematical model, Table II-1). The fifty samples with 300 measurements of long axis on each lead to 15,000 measurements; there are, therefore, 15,000 measurements of long axis, short axis and inclination as the total set of data.

The subdivision of a large number of operators into three groups is a new feature based on our experiences with variation among operators (Griffiths and Rosenfeld, 1954). It is obviously necessary to use a large number of operators to obtain the 15,000 items of data; on the other hand we have learned that operator variation must be segregated by means of suitable experimental design. In this respect we have found that the optimum number of operators for most of our techniques lies between 3 and 5. More than 5 frequently leads to the introduction of more variability than the addition is worth; less than 3 is equally disadvantageous in terms of the experimental design because two operators can be very similar or very different and may not yield a good estimate of operator variation. Actually, when practicable, 4 to 5 appears to be the ideal number. In the present case, because the work is temporary, operators may leave before they complete the set of measurements and so each group consists of say five operators, each of whom measured a part of the set of data. For purposes of analysis each set of operators, i.e. each group, was treated as an individual. It is, of course, necessary to use a large number of personnel to accomplish the number of measurements within a limited time and with a large number of personnel changes are bound to occur, the work team fluctuating from period to period, hence it is well to arrange the experimental design to reduce or remove as much of this "source of variation" as possible.

The data accruing from this experimental analysis was recorded on cards designed for the purpose (Fig. II-1) and classified into frequency distributions, one for each axis, and inclination per sample. When the size data are plotted as frequency histograms using a millimeter scale they are markedly skewed and so the measurements were transformed to a logarithmic phi scale.

The entire set of data was then transferred to Hollerith cards and the analysis was performed on the International Business Machine digital computer at the Pennsylvania State University. With 15,000 items of data automatic computer analysis is faster, more accurate and less costly than processing by desk calculators. The experimental design and subsequent analysis of the data is summarized as a mathematical model in table II-1.

Fig. II-1. Reference card for tabulating measurement data of size, shape and orientation of quartz grains in thin section.

			X_1	X_2	X_3	X_4	X_5	X_6	X_7	
SAMPLE	OP.	FLD.	a	b	b/a_μ	INCL.	a_ϕ	b_ϕ	b/a_ϕ	

Table II-1. Mathematical Model of Analysis of Variance Summarizing the Experimental Design used to Compare Quartz Grain Size in Ore-bearing and Barren Sediments.

No. of Items	Source of Variation	Degrees of Freedom		Sum of Squares	Mean Square
k = 2	Among Ore-bearing and Barren sample sets	(k-1)	1	$\sum_{1}^{k} (\sum_{1}^{pmfg} X)^2/pmfg$ - C.T.	$SS_k/(k-1)$
p = 3	Among Operators (p)	(p-1)	2	$\sum_{1}^{p} (\sum_{1}^{kmfg} X)^2/kmfg$ - C.T.	$SS_p/(p-1)$
	Among Operators from set to set	(k-1)(p-1)	2	$\sum_{1}^{kp} (\sum_{1}^{mfg} X)^2/mfg$ - C.T.-SS_k-ss_p	$SS_{kp}/(k-1)(p-1)$
m = 25	Among samples (within sets)	k(m-1)	48	$\sum_{1}^{km} (\sum_{1}^{pfg} X)^2/pfg$ - C.T.-SS_k	$SS_m/k(m-1)$
	Among Operators from sample to sample	k(m-1)(p-1)	96	$\sum_{1}^{kmp} (\sum_{1}^{fg} X)^2/fg$ - C.T.-SS_k-SS_p-SS_{kp}-SS_m	$SS_{mp}/k(m-1)(p-1)$
f = 10	Among fields (within samples etc.)	km(f-1)	450	$\sum_{1}^{kmf} (\sum_{1}^{pg} X)^2/pg$ - C.T.-SS_k-SS_m	$SS_f/km(f-1)$
	Among Operators from field to field	km(f-1)(p-1)	900	$\sum_{1}^{kmfp} (\sum_{1}^{g} X)^2/g$ - C.T.-SS_k-SS_p-SS_{kp}-SS_m-SS_{mp}-SS_f	$SS_{fp}/km(f-1)(p-1)$
g = 10	Among grains (Error)	kmfp(g-1)	13,500	SS_{tot} - all others	$SS_g/kmfp(g-1)$
	All sources	(kmfpg-1)	14,999	$\sum_{1}^{kpmfg} X^2$ - C.T.	

$$C.T. = (\sum_{1}^{kmpfg} X)^2/kmpfg$$

A Description of Grain Size Data

The grain size distributions of quartz grains measured in thin section are largely unexplored; the present investigation yields a large body of data which may be used as an example of the results to be expected. In order to achieve maximum efficiency from the statistical analysis the data should represent random samples from a normal population and the observations may be tested against these requirements. Furthermore knowledge of the distribution function of these measurements is of considerable value in understanding the sedimentological conditions represented by Salt Wash detritus. In addition one of the most urgent and important problems in sedimentary petrography concerns the definition of the most efficient sampling program. Finally, on the basis of this exhaustive analysis, the grain size of ore-bearing samples may be compared with the grain size of barren sediments.

A(i) Measurements of Long "a" Axis

The operational definition and accompanying procedure for measuring the long "a" axis of quartz grains in thin section has already been described (p. 10). The 15,000 measurements comprising 10 grains in 10 fields of 50 samples measured by 3 operators may be grouped into a frequency distribution. If the micron size scale is used the resulting curve is highly skewed (Fig. II-2). Such a distribution is difficult to handle and interpret and when the size scale is transformed to phi-units the curve is much more symmetrical (Fig. II-3). In this case the peakedness estimated by g_2 is non-significant but the assymmetry or skewness, estimated by g_1 is small and highly significant[1]. It may be deduced that the size distribution closely approaches that of a normal curve except for the small negative skewness.

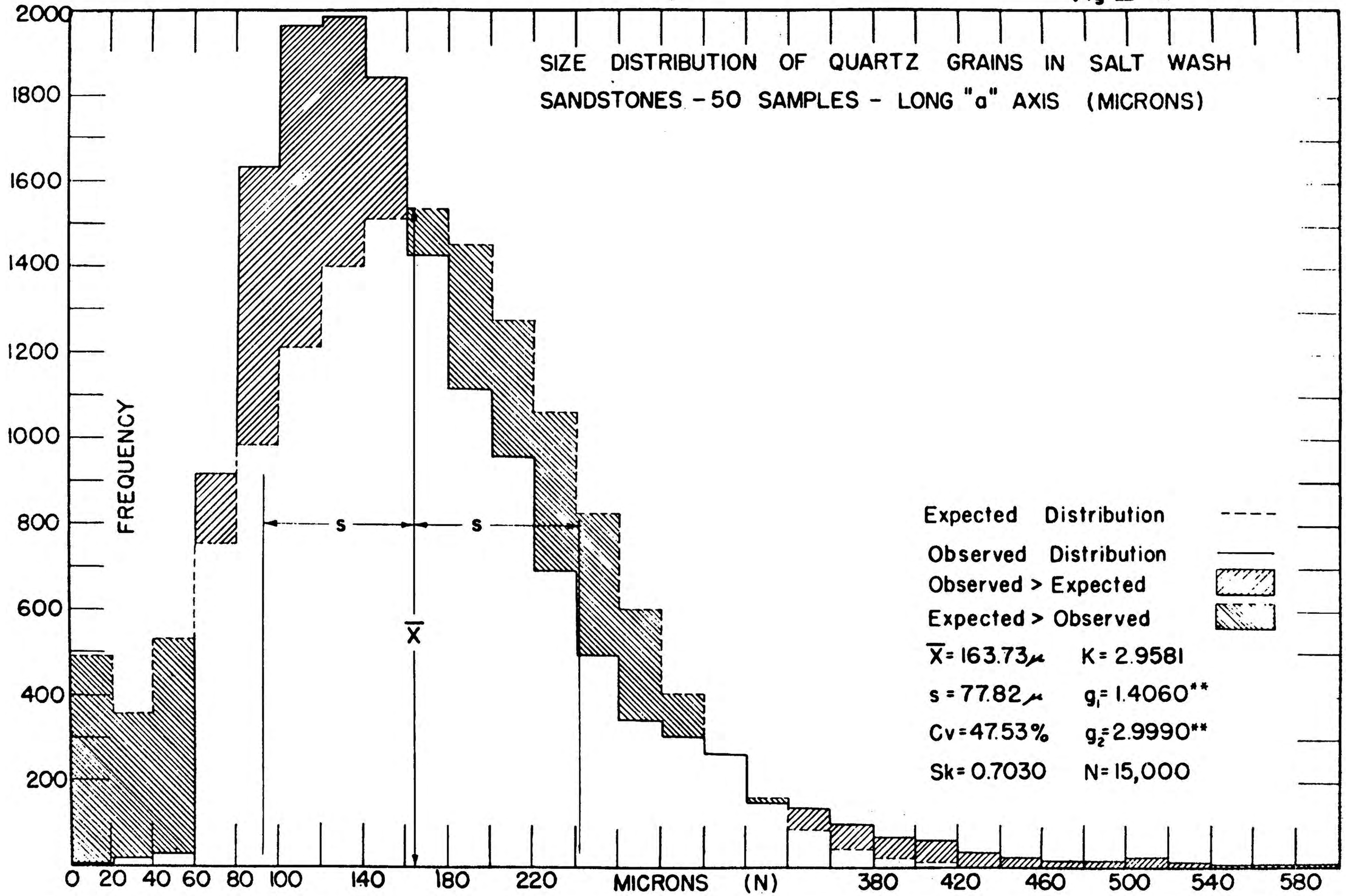
A(ii) Measurement of Short "b" Axis

Here again the 15,000 measurements expressed in phi-units is very closely normal (Fig. II-4) and neither the skewness nor the kurtosis is significantly greater than we would expect in a normal distribution (g_1 and g_2 non-significant).

In both cases then we may use statistical analysis with some assurance that the major requirement of normalcy is very closely

[1] The "g" statistics were first recommended by Fisher (1948); procedures for interpretation and examples of their use in geology were recently described by Griffiths (1955a).

Fig II - 2


SIZE DISTRIBUTION OF QUARTZ GRAINS IN SALT WASH
SANDSTONES - 50 SAMPLES - LONG "a" AXIS (MICRONS)
FREQUENCY
MICRONS (N)
2000
1800
1600
1400
1200
1000
800
600
400
200
0 20 40 60 80 100 140 180 220 380 420 460 500 540 580
s
s
X̄
Expected Distribution
Observed Distribution
Observed > Expected
Expected > Observed
X̄ = 163.73μ
K = 2.9581
s = 77.82μ
g1 = 1.4060**
Cv = 47.53%
g2 = 2.9990**
Sk = 0.7030
N = 15,000

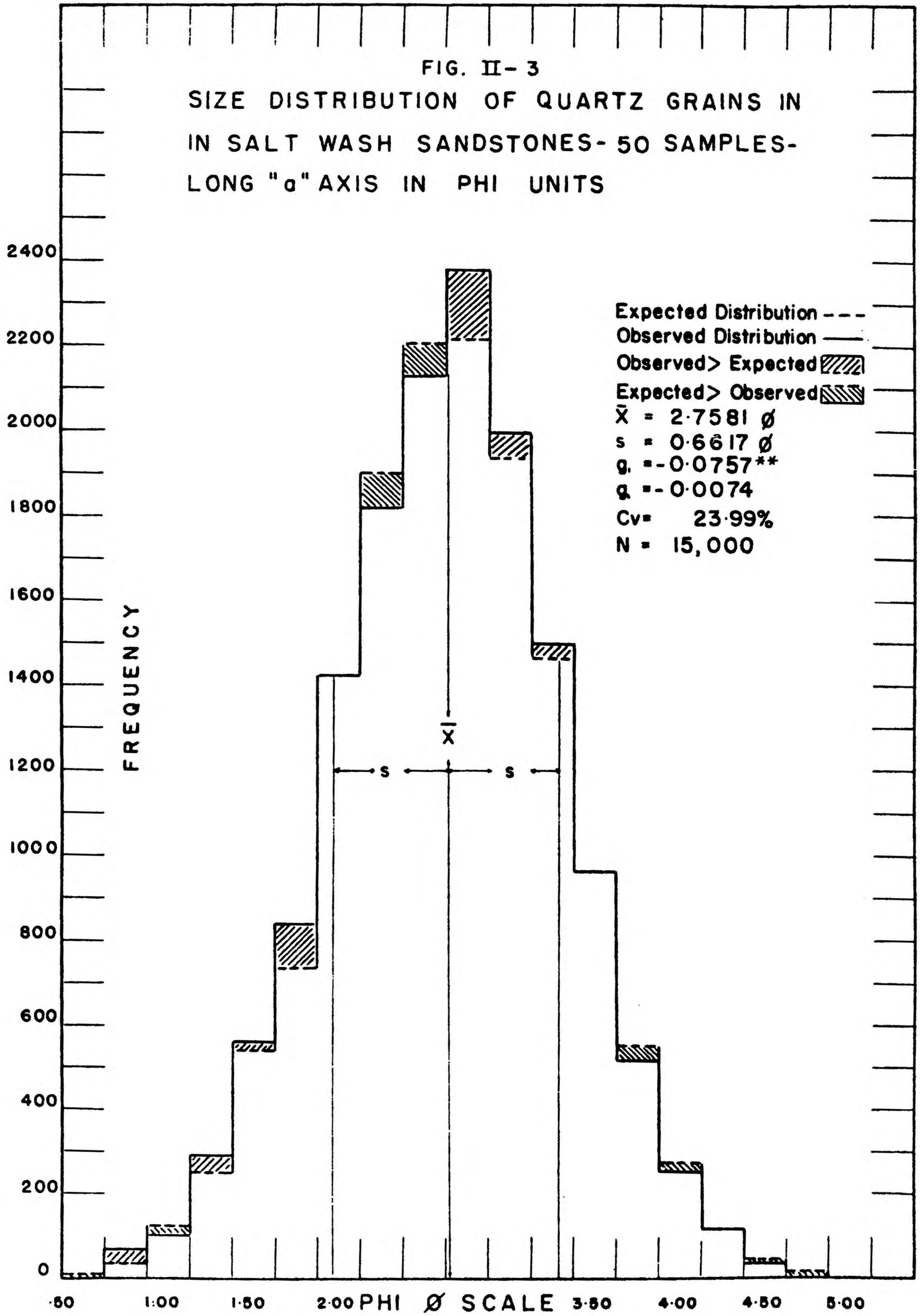


FIG. II- 3
SIZE DISTRIBUTION OF QUARTZ GRAINS IN
IN SALT WASH SANDSTONES- 50 SAMPLES-
LONG "a" AXIS IN PHI UNITS
Expected Distribution ---
Observed Distribution ——
Observed> Expected
Expected> Observed
X̄ = 2·7581 ø
s = 0·6617 ø
g. =-0·0757**
g =-0·0074
Cv= 23·99%
N = 15,000
FREQUENCY
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
X̄
s
s
·50
1·00
1·50
2·00
PHI Ø SCALE
3·50
4·00
4·50
5·00

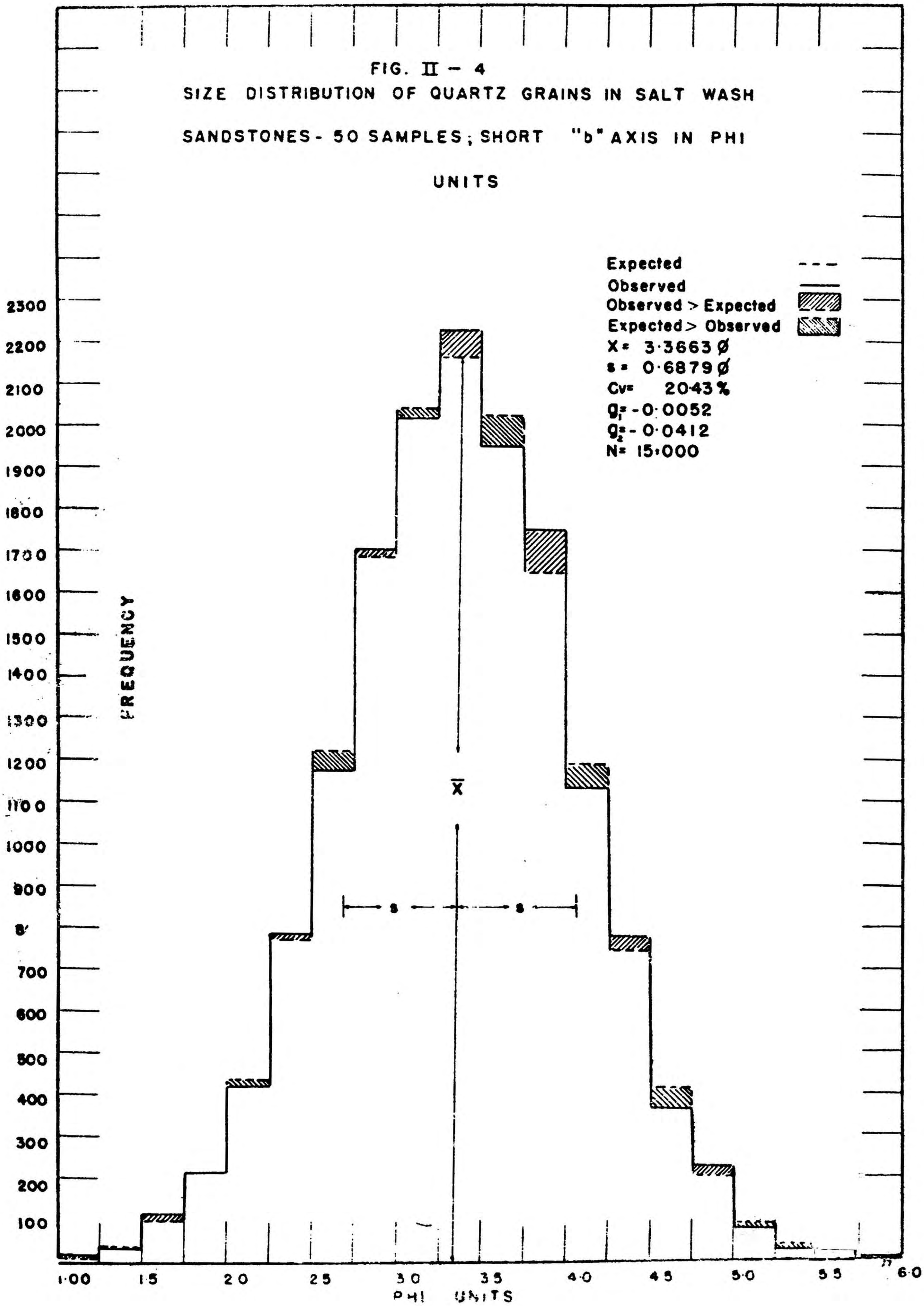


FIG. II - 4
SIZE DISTRIBUTION OF QUARTZ GRAINS IN SALT WASH
SANDSTONES - 50 SAMPLES; SHORT "b" AXIS IN PHI
UNITS
Expected
Observed
Observed > Expected
Expected > Observed
X = 3·3663 Ø
s = 0·6879 Ø
Cv = 20·43 %
g1 = -0·0052
g2 = -0·0412
N = 15,000
FREQUENCY
PHI UNITS
X̄
s
s
2300
2200
2100
2000
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100
1·00
1·5
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2·5
3·0
3·5
4·0
4·5
5·0
5·5
6·0

approximated when the lengths of axes of the grains are expressed in phi-units.

A(iii) Analysis of the Grain Size Data

The prime objective of this petrographic analysis is to determine whether the properties, in this case quartz grain size, are different in ore-bearing and barren sediments. The experimental design summarized in table II-1 shows the arrangement of the experiment. There are two main effects which may contribute to variation in this data, namely the differences between ore-bearing and barren sediments and the differences between different operators performing the measurements. The third factor, the interaction of these two main effects, segregates the variation which occurs when operators are inconsistent from one sample set to another (see Griffiths and Rosenfeld, 1954).

Within each ore-bearing and barren set there are differences among samples and as each operator may measure each sample differently there is a sample-operator interaction. In the present design however, no sample of the ore-bearing set corresponds to one in the barren sets i.e. each set is supposedly a random selection of 25 from the infinite number which exists. Therefore there is no sample-set interaction. Similarly there are differences between microscopic fields within each sample and as each operator measured each field there is an interaction of operator and fields but no interaction between fields and samples.

Finally all unassigned sources of variation are segregated together into the effects which lead to differences among grains. It may be as well to emphasize that this experimental arrangement requires that the grains are random samples of the fields, the fields of the thin sections and the thin sections (samples) of the ore-bearing and barren sets respectively; non-randomness would defeat our objective.

The analysis of variance of "a" axes and "b" axes using this design is summarized in tables II-2 and II-3 respectively. Concerning the long "a" axis measurements it can be seen that the differences between means for each operator on each field is significantly greater than variation from error or unassigned sources. Evidently the operators used different sets of grains. The field means are also different and the differences are highly significant. Differences among operators from sample to sample are negligible but differences between sample means are very large and highly significant. Indeed differences between sample means are so large that all succeeding sources of variation are negligible compared with this source. Evidently 25 samples per set are insufficient.

Table II-2. Analysis of Variance of Long "a" Axes in Ore-bearing and Barren Samples of Salt Wash Sandstones.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F
Among Sets (k)	1	56,364.795	56,364.795	<1.0
Among Operators	2	1,718.332	859.166	<1.0
Operators Over Sets	2	1,611.324	805.662	<1.0
Among Samples	48	23,980,339.266	499,590.401	36.19***
Operators Over Samples	96	160,376.518	1,670.589	<1.0
Among Fields	450	6,212,279.904	13,805.066	5.44**
Operators Over Fields	900	2,282,710.226	2,536.345	1.115*
Error	13,500	30,696,626.900	2,273.824	--
Total	14,999	63,392,027.265	--	--

$C.T. = (\Sigma^{15,000} x)^2/15{,}000 = 1{,}142{,}283{,}987.735$

$\bar{X}_G = 2.7596$ $s_e = 0.4768$ $Cv\ \% = 17.27$

The data (X) for this analysis were coded (X^1) for use on the IBM computer as follows: $X^1 = 100X$.

* Significant at 5 per cent level
** Significant at 1 per cent level
***Significant at 0.1 per cent level

Table II-3. Analysis of Variance of Short "b" Axes in Ore-bearing and Barren Samples of Salt Wash Sandstones.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F
Among Sets	1	8,194.772	8,194.772	<1.0
Among Operators	2	464.069	232.035	<1.0
Operators Over Sets	2	6,759.254	3,379.627	<1.0
Among Samples	48	27,773,808.931	578,621.019	35.286***
Operators Over Samples	96	191,338.991	1,993.115	<1.0
Among Fields	450	7,379,091.770	16,937.982	4.763**
Operators Over Fields	900	3,098,354.520	3,442.616	1.464**
Error	13,500	31,745,996.000	2,351.555	--
Total	14,999	70,204,008.307	--	--

$C.T. = (\Sigma^{15,000} x)^2/15,000 = 1,696,096,112.693$

$\bar{\bar{X}}_G = 3.3626$ $s_e = 0.4849$ Cv % = 14.42

Data coded for analysis $X^1 = 100X$

* Significant at 5 per cent level
** Significant at 1 per cent level
***Significant at 0.1 per cent level

It is interesting to note that differences between operators and inconsistency of operators from set to set and sample to sample is negligible.

The analysis of the "b" axis measurements yields almost identical results (see table II-3).

It seems evident from the coefficient of variation (C_v o/o) based on the respective grand means ($\bar{\bar{X}}_a$) and error standard deviations (s_e) that the experimental control was good and the error variation arising from unassigned sources was reduced to a reasonable figure. The analysis failed because the sample means were so very different.

In order to elucidate whether the ore-bearing and barren sets were behaving differently the data was sub-divided into sets and an analysis of variance performed on each set for each axis. The results are summarized in tables II-4, 5, 6, and 7 respectively.

In general the results are similar for both axes and both ore-bearing and barren sediments as would be expected. One feature is different, the variation of operator from field to field is significant in ore-bearing samples for both "a" and "b" axis but not for the barren samples. Since operator variance plays a very small role in these analyses it would appear that the sets of grain vary more within each field in ore-bearing samples than in barren samples. This may well be due to finer lamination in the ore-bearing or as noted megascopically that the barren sandstones are more uniform or massive.

These analyses emphasize one of the outstanding difficulties in analyzing sediments, namely the problem of obtaining random samples from layered or stratified sedimentary populations where the layering is so fine that the strata cannot be easily identified. In every case where we have tried to sample such a population we have underestimated the sampling ratio and in particular the number of samples (Griffiths, 1955b).

The next step then is to examine by means of the components of variance the amount of variation attributable to each source and this is summarized in table II-8. On this basis we need about as many samples as grains if we are to reduce each source of variation to the same order of magnitude. It would therefore have been more correct to use 75 samples of 100 grains each and perhaps 2 sets of grains from each of 3 fields would have been adequate.

On the basis of these analyses it is impossible to detect any difference between ore-bearing and barren samples in terms of quartz grain size principally because 25 samples from each is insufficient and because the remainder of the sampling program is incorrectly balanced.

Table II-4. Analysis of Variance of Long "a" Axes of 25 Ore-bearing Samples of Salt Wash Sandstones.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F
Among Samples	24	12,164,542.074	506,855.92	41.035***
Among Operators	2	284.564	142.282	<1.0
Operators Over Samples	48	90,701.356	1,889.61	<1.0
Among Fields	225	2,779,130.183	12,351.69	2.963**
Operators Over Fields	450	1,876,159.947	4,169.24	1.826**
Among Grains (Error)	6750	15,416,114.300	2,283.87	--
Total	7499	32,326,932.424	--	--

C.T. = $(\Sigma^{7500} x)^2/7500$ = 563,146,174.576

$\bar{X}_G$ = 2.74028β s_e = 0.47708β Cv % = 17.44

Data coded for analysis X^1 = 100X obs

Table II-5. Analysis of Variance of Long "b" Axes of 25 Barren Samples of Salt Wash Sandstones.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F
Among Samples	24	11,815,797.192	492,324.88	32.266***
Among Operators	2	3,045.092	1,522.55	<1.0
Operators Over Samples	48	69,675.162	1,451.57	<1.0
Among Fields	225	3,433,149.720	15,258.44	6.740**
Operators Over Fields	450	406,550.280	903.45	<1.0
Among Grains (Error)	6750	15,280,512.600	2,263.78	--
Total	7400	31,008,730.046	--	--

C.T. = $(\sum^{7500} x)^2/7500$ = 579,194,177.954

$\bar{\bar{X}}_G$ = 2.7790 s_e = 0.4757 Cv % = 17.12

Data coded for analysis X^1 = 100X obs.

Table II-6. Analysis of Variance of Short "b" Axes of 25 Samples of Ore-bearing Salt Wash Sandstones.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F
Among Samples	24	13,589,047.336	566,210.305	33.924***
Among Operators	2	3,954.00	1,977.00	<1.0
Operators Over Samples	48	130,529.407	2,719.363	<1.0
Among Fields	225	3,755,376.513	16,690.562	2.840**
Operators Over Fields	450	2,644,849.627	5,877.444	2.553**
Among Grains (Error)	6750	15,540,369.700	2,302.277	--
Total	7499	35,664,126.583	--	--

$$C.T. = (\Sigma^{7500} x)^2/7500 = 844,324,001.417$$

$\bar{X}_G = 3.3552$ $s_e = 0.4798$ Cv % = 14.30

Data coded for analysis $X^1 = 100X$

Table II-7. Analysis of Variance of Short "b" Axes of 25 Samples of Barren Salt Wash Sandstones.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F
Among Samples	24	14,184,761.595	591,031.733	36.70***
Among Operators	2	3,299.324	1,649.662	<1.0
Operators Over Samples	48	60,779.583	1,266.241	<1.0
Among Fields	225	3,623,715.257	16,105.40	6.71***
Operators Over Fields	450	453,504.893	1,007.800	<1.0
Among Grains (Error)	6750	16,205,626.300	2,400.833	--
Total	7499	34,531,686.952	--	--

$$C.T. = (\sum^{7500} x)^2/7500 = 851,780,306.048$$

$\bar{X}_G = 3.3700$ $s_e = 0.4899$ $Cv\ \% = 14.53$

Table II-8. Variance Components for Each Source Based on Analysis of Variance of Tables II-4-7.

Source of Variation	Ore-bearing Samples a axis	Ratio	b axis	Ratio	Barren Samples a axis	Ratio	b axis	Ratio
Samples	1648.35	8.74	1831.73	5.12	1590.22	3.67	1916.42	4.20
Operators	0	--	0	--	0	--	0	--
Operators Over Samples	0	--	0	--	0	--	0	--
Fields	272.75	1.45	360.44	1.01	433.16	1.0	456.82	1.0
Operators Over Fields	188.54	1.00	357.52	1.00	0	--	0.	--
Grains (Error)	2283.87	12.11	2302.28	6.44	2263.78	5.23	2400.83	5.26

A(iv) The Problem of Non-Randomness of the Samples

On the basis of the above analysis it appears prudent to examine the frequency distributions of the measurements with somewhat greater care and attempt to determine the exact nature of the fault in the sampling plan.

We may first of all use the entire set of 15,000 measurements of each axis to set up confidence limits for the population means of "a" or "b" axes and see whether the sample means fall within these prescribed limits. The data summarized in table II-9 is relevant to this problem.

Table II-9 Means and variances for ore-bearing and barren sample sets of Salt Wash sandstones.

Axis	Samples		$\bar{x}_\phi$	s^2	s	n
a	all	50	2.7581	0.43784689	0.6617	15,000
	ore-bearing	25	2.7416	0.43283241	0.6579	7,500
	barren	25	2.7745	0.44235801	0.6657	7,500
b	all	50	3.3663	0.43720641	0.6879	15,000
	ore-bearing	25	3.3595	0.48024900	0.6930	7,500
	barren	25	3.3731	0.46621584	0.6828	7,500

Each sample comprises 300 measurements hence we may calculate the standard error of means based on 300 items selecting the 99 per cent confidence limits; one example, the a_ϕ measurements for all items, will suffice: -

$s^2\bar{x} = s^2/n = 0.43754689/300 = 0.0014594896$

whence $s/_{\bar{x}} = 0.0382$

and the 99 per cent value will be $ts_{\bar{x}} = 3.30 \times 0.0382 = 0.1261$ where "t" is Student's "t" with infinite degrees of freedom. The value for $s_{\bar{x}}$ and it's corresponding confidence limit is calculated for each of these six items in tables II-9, yielding the values in table II-10.

Table II-10 Standard errors of means and confidence limits for "a" and "b" axis of ore-bearing and barren sediments.

Axis	Item	Phi Units $s_{\bar{x}}$	$ts_{\bar{x}}$	99% confidence limits
a_ϕ	All samples	0.0382	0.1261	2.6320 - 2.8842
	25 ore-bearing	0.0380	0.1253	2.6163 - 2.8669
	25 barren	0.03840	0.1267	2.6478 - 2.9012
b_ϕ	All samples	0.0397	0.1311	3.2352 - 3.4974
	25 ore-bearing	0.0400	0.1320	3.2275 - 3.4915
	25 barren	0.0394	0.1301	3.2430 - 3.5032

A glance at tables II-11a, b and II-12a, b showing the mean for each sample, indicates that many sample means fall outside these limits. The results may be summarized graphically as in Fig. II-5; it can be seen that more sample means fall outside these limits than inside. The range in observed sample means is:

Axis	Item	Range in Sample Means ϕ Units
aϕ	Ore-bearing	1.918 - 3.653
	Barren	2.152 - 3.772
bϕ	Ore-bearing	2.781 - 4.330
	Barren	2.347 - 4.664

Now we may state that these confidence limits are based on certain assumptions namely that each set of samples are randomly selected from the same normal population; departures from normalcy are small as reflected by the "g" statistics. Presumably we have established that the population is the same in each case, namely either the "aϕ" or "bϕ" axes of ore-bearing and barren sediments respectively; we may test whether the variances for each subset are homogeneous e.g. for the aϕ axis.

$$F = \frac{\text{Barren } s^2}{\text{Ore-bearing } s^2} = \frac{0.44235801}{0.43283241} = 1.0220$$

In effect then if these two variances are from the same normal population we would expect an F value of 1.0387 more often than 5 times in 100. The observed F value is less than the 5 per cent value and hence the null hypothesis is not rejected and the variances for the aϕ axis of ore-bearing and barren sediments are homogeneous. The bϕ axes tested in the same way yield an F value of 1.0301 and a similar conclusion. Thus the variances of ore-bearing and barren samples for either aϕ or bϕ axes are similar and presumably since the kurtosis is non-significant in each case the uniformity of grain size, generally known as sorting, is the same in ore-bearing and barren sediments.

Returning now to our initial statement that for each axis the 25 samples of ore-bearing and barren sediments are random samples from the same normal population we have established the normalcy, and the sameness, hence the 25 samples are non-random samples in this case and Fig. II-5 shows that the departure from randomness is quite large, about 8 means from 25 occurring within the confidence limits. If samples are randomly drawn from the same normal population and 99 per cent confidence limits calculated we expect about 3 in 1000 outside these confidence limits. It seems obvious, therefore, that the large differences between sample means found in the analysis of variance are largely reflections of non-random sampling and to compare ore-bearing with barren samples we need many more samples than 25 per set.

Suppose we decided to re-sample and analyze additional samples we know the numbers and arrangement approximately from the components of variance table (table II-8) but are these samples of some special kind

Table II-11a. Summary Statistics for Size Distribution of Quartz Grains in 25 Samples of Ore-bearing Sediments.

Long "a" axis; phi units; N = 300

Sample No.	$\bar{X}$ ϕ	s ϕ	Cv %	Sk	K	g_1	g_2
6331-2	2.457	0.576	23.44	0.2843	0.8066	0.5716	0.8407
6334	1.918	0.563	29.35	0.0557	$\bar{0}$.4672	0.1120	$\bar{0}$.4548
6335-2	3.023	0.510	16.87	$\bar{0}$.0396	$\bar{0}$.5274	$\bar{0}$.0797	$\bar{0}$.5160
6336	2.346	0.574	24.47	0.1283	0.2338	0.2579	0.2582
6500	3.235	0.577	17.84	0.2081	0.2059	0.4183	0.2297
6502	2.853	0.512	17.95	0.1492	0.4497	0.2997	0.4575
65030	2.778	0.529	19.04	0.0273	$\bar{0}$.3347	0.0550	$\bar{0}$.3200
6506	2.847	0.551	19.35	0.0718	$\bar{0}$.5620	0.1445	$\bar{0}$.5512
6536-2	2.406	0.537	22.32	0.0423	$\bar{0}$.5592	0.0850	$\bar{0}$.5484
6537A	2.254	0.499	22.14	$\bar{0}$.1239	0.0195	0.2490	0.0418
6606	3.477	0.539	15.50	$\bar{0}$.1125	$\bar{0}$.1896	$\bar{0}$.2261	$\bar{0}$.1724
6607A	2.873	0.590	20.54	0.0602	0.2002	0.1211	0.2040
6608	2.810	0.488	17.37	0.0034	$\bar{0}$.2271	0.0069	$\bar{0}$.2106
6610	2.398	0.599	24.98	$\bar{0}$.2091	$\bar{0}$.1827	$\bar{0}$.4224	$\bar{0}$.1669
6620	2.339	0.642	27.45	$\bar{0}$.0120	$\bar{0}$.8257	$\bar{0}$.0252	$\bar{0}$.8193
6627-1	2.183	0.603	27.62	0.1795	$\bar{0}$.1685	0.3609	$\bar{0}$.1511
6636	2.576	0.416	16.15	0.5067	1.2772	1.0188	1.3200
6644	2.716	0.455	16.75	0.1565	0.7304	0.3146	0.7632
6646	3.653	0.432	11.83	0.0971	0.3445	0.1951	0.3708
6651	2.938	0.511	17.39	$\bar{0}$.1112	$\bar{0}$.2221	$\bar{0}$.2235	$\bar{0}$.2054
6657	3.058	0.374	12.23	$\bar{0}$.0885	$\bar{0}$.2128	$\bar{0}$.1780	$\bar{0}$.1960
6671	3.083	0.455	14.76	$\bar{0}$.0217	0.1790	$\bar{0}$.0436	0.2024
6675	2.517	0.342	13.59	0.2709	1.8069	0.4566	1.8568
6683	3.006	0.465	15.47	0.0587	$\bar{0}$.1539	0.1180	$\bar{0}$.1361
6638	2.797	0.542	19.38	0.2892	2.3720	0.5814	2.4327
25 Ore-bearing	2.7416	0.6579	24.00	$\bar{0}$.0034	0.0481	$\bar{0}$.0067	0.0489
50 samples	2.7581	0.6617	23.99	$\bar{0}$.0378	0.0072	$\bar{0}$.0757**	0.0074

Table II-11b. Summary Statistics for Size Distribution of Quartz Grains in 25 Samples of Barren Sediments.

Long "a" axis; phi units; N = 300

Sample No.	$\bar{X}$ ϕ	s ϕ	Cv %	Sk	K	g_1	g_2
6508	3.013	0.407	13.51	0.1022	0.3191	0.2055	0.3449
6510	3.363	0.449	13.35	0.2151	$\bar{0}$.3009	0.4324	$\bar{0}$.2856
6512	2.422	0.412	17.01	$\bar{0}$.0583	0.1572	$\bar{0}$.1171	0.1803
6513	2.222	0.847	38.12	0.0660	$\bar{0}$.3720	0.1502	$\bar{0}$.3579
6514	3.124	0.432	13.83	0.1927	$\bar{0}$.1541	0.3874	$\bar{0}$.1363
6515	2.765	0.550	19.89	0.1323	$\bar{0}$.1875	0.2659	$\bar{0}$.1703
6519	3.772	0.377	9.99	$\bar{0}$.1487	0.0188	$\bar{0}$.2989	0.0396
6520	2.966	0.532	17.94	$\bar{0}$.0944	0.3888	$\bar{0}$.1897	0.4156
6521	2.305	0.644	27.94	0.5258	2.3935	1.0571	2.4757
6522A	2.923	0.476	16.28	$\bar{0}$.1931	0.1104	$\bar{0}$.3882	0.1326
6523	2.888	0.683	23.65	$\bar{0}$.4444	0.7674	$\bar{0}$.8933	0.8008
6524	2.607	0.514	19.72	0.0734	$\bar{0}$.3890	0.1476	$\bar{0}$.3753
6525	2.576	0.477	18.52	0.3666	1.1864	0.7370	1.2270
6526	2.635	0.773	29.34	$\bar{0}$.1071	$\bar{1}$.0706	$\bar{0}$.2152	$\bar{1}$.0684
6527	2.042	0.456	22.33	0.2944	0.2545	0.5918	0.2792
6528	2.340	0.439	18.76	$\bar{0}$.0329	0.1249	$\bar{0}$.06607	0.1474
6529	3.306	0.439	13.28	0.1111	0.8354	0.2233	0.8699
6530	2.587	0.578	22.34	$\bar{0}$.2786	$\bar{0}$.5194	$\bar{0}$.5600	$\bar{0}$.5079
6531	3.106	0.411	13.23	$\bar{0}$.0378	$\bar{0}$.4354	$\bar{0}$.0761	$\bar{0}$.4224
6532	2.836	0.488	17.21	0.1692	0.2681	0.3402	0.2930
6534	2.152	0.627	29.14	0.1103	$\bar{0}$.5891	0.2218	$\bar{0}$.5787
6629	2.500	0.488	19.52	0.2016	$\bar{0}$.3963	0.4052	$\bar{0}$.3827
6630	2.827	0.448	15.85	0.1248	0.2036	0.2509	0.2274
6662	2.822	0.353	12.51	0.0479	0.0464	0.0963	0.0425
6667	3.267	0.454	13.90	0.3134	0.7603	0.6301	0.7988
25 barren samples	2.7745	0.6651	23.97	$\bar{0}$.0719	$\bar{0}$.0165	$\bar{0}$.1439**	$\bar{0}$.0154
50 samples	2.7581	0.6617	23.99	$\bar{0}$.0378	0.0072	$\bar{0}$.0757**	0.0074

Table II-12a. Summary Statistics for Size Distribution of Quartz Grains in 25 Samples of Ore-bearing Sediments.

Short "b" axis; phi units; N = 300

Sample No.	$\bar{X}$ ϕ	s ϕ	Cv %	Sk	K	g_1	g_2
6331-2	3.119	0.575	18.44	0.2406	0.3041	0.4836	0.3499
6334	2.347	0.538	22.94	0.0238	$\bar{0}$.6057	0.0478	$\bar{0}$.5956
6335-2	3.648	0.589	16.16	$\bar{0}$.0047	$\bar{0}$.3206	$\bar{0}$.0095	$\bar{0}$.3056
6336	2.928	0.614	20.97	0.2928	0.1534	0.4079	0.1762
6500	3.876	0.592	15.27	0.2966	$\bar{0}$.01700	0.5963	0.0031
6502	3.438	0.526	15.30	0.2620	0.5888	0.5270	0.6316
6503A	3.455	0.594	17.19	0.2262	0.3652	0.4547	0.3918
6506	3.473	0.536	15.43	0.1097	$\bar{0}$.5387	0.2206	$\bar{0}$.5275
6536-2	3.092	0.639	20.67	0.0915	0.0138	0.1841	0.0345
6537A	2.815	0.515	18.29	$\bar{0}$.0934	0.0768	$\bar{0}$.1867	0.0708
6606	4.144	0.532	12.84	$\bar{0}$.1705	$\bar{0}$.0760	$\bar{0}$.3426	$\bar{0}$.0569
6607A	3.500	0.669	19.12	0.0868	$\bar{0}$.4811	0.1745	$\bar{0}$.4690
6608	3.433	0.585	17.06	0.0224	$\bar{0}$.1712	0.0449	$\bar{0}$.1538
6610	2.944	0.620	21.05	$\bar{0}$.2777	$\bar{0}$.0514	$\bar{0}$.5582	0.0726
6620	2.959	0.680	22.98	0.1572	$\bar{0}$.3619	0.3159	$\bar{0}$.3478
6627-1	2.781	0.583	20.96	0.1579	-0.8995	0.3173	0.9352
6636	3.231	0.439	13.57	0.2481	0.3555	0.4988	0.3819
6638	3.379	0.510	15.09	$\bar{0}$.1240	0.9329	$\bar{0}$.2492	0.9691
6644	3.294	0.488	14.81	0.1160	0.5228	0.2331	0.5521
6646	4.330	0.453	10.46	0.1748	0.0478	0.3514	0.0690
6651	3.562	0.499	14.01	$\bar{0}$.1894	$\bar{0}$.4674	$\bar{0}$.0259	$\bar{0}$.4549
6657	3.739	0.420	11.23	0.2106	0.1666	0.4233	0.1899
6671	3.718	0.451	12.13	0.1513	0.9735	0.3011	0.9968
6675	3.125	0.421	13.47	0.1943	0.3325	0.3906	0.3585
6683	3.559	0.501	14.08	0.0379	$\bar{0}$.2526	0.0762	$\bar{0}$.2365
25 Ore-bearing	3.3595	0.6930	20.63	0.0205	$\bar{0}$.0197	0.0409	$\bar{0}$.0188
All 50	3.3663	0.6879	20.43	-0.0026	$\bar{0}$.0416	$\bar{0}$.0052	$\bar{0}$.0412

Table II-12b. Summary Statistics for Size Distributions of Quartz Grains in 25 Samples of Barren Sediments.

Short "b" axis; phi units; N = 300

Sample No.	$\bar{X}$ ϕ	s ϕ	Cv %	Sk	K	g_1	g_2
6508	3.631	0.462	12.72	0.1297	1.7069	0.2608	1.7562
6510	3.995	0.426	10.66	0.1212	$\bar{0}.3143$	0.2436	$\bar{0}.2993$
6512	2.9408	0.4364	14.84	$\bar{0}.0998$	1.5617	$\bar{0}.2007$	1.6086
6513	3.113	0.638	20.49	0.1790	0.9922	0.3598	1.0294
6514	3.7175	0.4158	11.18	0.1378	$\bar{0}.3379$	0.2771	$\bar{0}.3233$
6515	3.257	0.527	16.18	0.0349	$\bar{0}.1726$	0.0701	$\bar{0}.1551$
6519	4.664	0.464	9.95	$\bar{0}.1444$	2.9905	$\bar{0}.2909$	3.0617
6520	3.667	0.560	15.27	$\bar{0}.0340$	$\bar{0}.2443$	$\bar{0}.0684$	$\bar{0}.2281$
6521	2.827	0.615	21.75	0.4306	0.5450	0.8657	0.5746
6522A	3.509	0.491	13.99	$\bar{0}.0636$	$\bar{0}.0273$	$\bar{0}.1279$	$\bar{0}.0074$
6523	3.543	0.727	20.52	$\bar{0}.5050$	1.3321	$\bar{1}.0152$	1.3751
6524	3.210	0.513	15.98	0.1237	$\bar{0}.3475$	0.2486	$\bar{0}.3331$
6525	3.137	0.446	14.22	0.2788	0.9179	9.5604	0.9539
6526	3.161	0.7985	25.26	$\bar{0}.0676$	$\bar{0}.7971$	$\bar{0}.1359$	0.7902
6527	2.528	0.509	20.13	0.3014	1.3855	0.7868	1.4293
6528	2.922	0.496	16.97	0.1787	0.0756	0.3582	0.0973
6529	3.925	0.441	11.24	0.0117	1.0672	0.0235	1.1057
6530	3.164	0.567	17.92	$\bar{0}.1400$	$\bar{0}.4944$	$\bar{0}.2815$	$\bar{0}.4785$
6531	3.540	0.428	12.09	$\bar{0}.0607$	$\bar{0}.3569$	$\bar{0}.1220$	$\bar{0}.3426$
6532	3.398	0.487	14.33	0.1351	0.0815	0.2715	0.1032
6534	2.669	0.629	23.57	0.0480	$\bar{0}.7497$	0.0966	$\bar{0}.7421$
6629	3.1142	0.493	15.83	0.2487	1.0998	0.4999	1.1389
6630	3.377	0.460	13.62	$\bar{0}.0290$	1.1565	$\bar{0}.0582$	1.1965
6662	3.446	0.377	10.94	0.0271	1.2908	0.0545	1.3331
6667	3.950	0.495	12.53	0.3810	0.7587	0.7660	0.7920
25 Barren	3.3731	0.6828	20.24	$\bar{0}.0263$	$\bar{0}.0626$	$\bar{0}.0525$	$\bar{0}.0618$

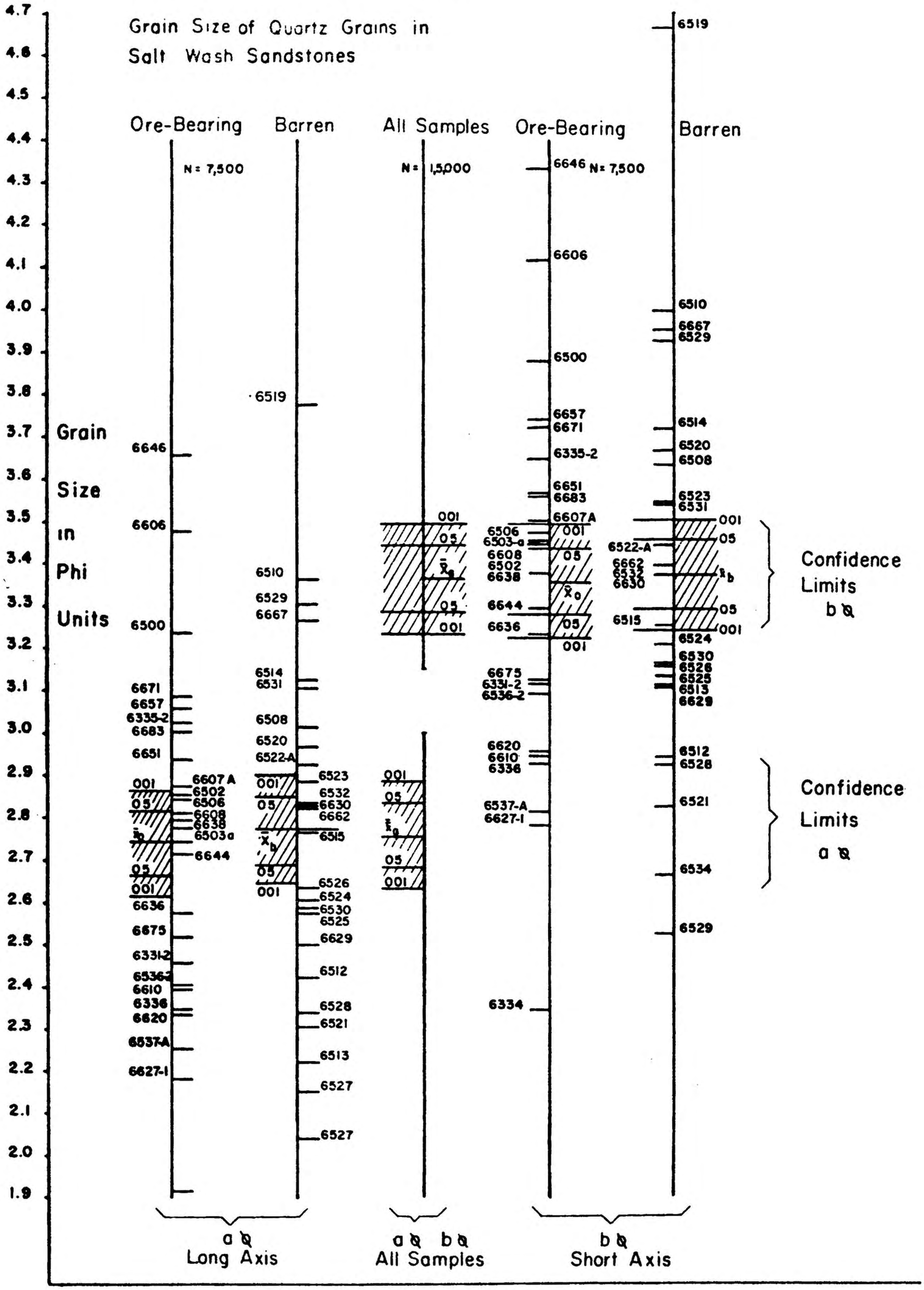


Fig II 5: CONFIDENCE LIMITS FOR SAMPLE MEANS e.g. coarse sands, very fine sands or just more samples? This question can be answered approximately by examining the frequency distributions for each set of ore-bearing and barren sediments and each axis. For example in Fig. II-2 the skewness of the distribution is towards the coarse side and we would have to fill in mostly on the coarse side and the extremely fine side to make the distribution symmetrical.

The grain size of quartz grains expressed as "a" axis in phi units for 25 samples of ore-bearing and 25 samples of barren Salt Wash sediments are exhibited in Fig. II-6 together with a normal distribution with the same mean and variance. The deficiencies and excesses of the observed over the expected are also indicated in the figure and they are not very large or systematically arranged. Evidently more samples but not necessarily any specific kind of samples are required to meet the specification of random samples from the same normal population.

The mean values for ore-bearing and barren samples are also inserted in the respective graphs and it can be seen that if the excesses and deficiencies in the sampling are corrected then differences between means will likely vanish. Hence we may, to a close approximation, deduce that there is no difference in mean grain size or sorting (standard deviation or variance) between ore-bearing and barren sediments. The same features appear to be true of the "a" and "b" axes (Fig. II-7).

A(v) Discussion of the Conclusions

The first difficulty which must be overcome for successful comparisons of size of quartz grains in Salt Wash sediments is the non-randomness of the samples. Evidently 25 samples per set is insufficient and from the frequency distributions we may deduce that no specific kind of sample is implied but merely more samples. The actual ratio of samples, fields and grains are given in table II-8 and it can be seen that we could successfully reduce the number of grains per sample and increase the number of samples. This is a guide to future work along these lines and will apply to any sediment texturally similar to the Salt Wash sandstones. The average grain size (long "a" axis) of the quartz grains for all grains in all samples is 2.7581 phi-units (148 microns), fine sand size on the Wentworth grade scale. Similarly the standard deviation is 0.6617 phi-units.

Very few sediments have been analyzed by means of thin section size measurement and a compilation of the data which has so far been collected is contained in Table II-13. Quartz grains from Salt Wash sandstones are finer grained than those in the Oriskany quartzite (Rosenfeld, 1953), coarser than those in the Berea graywacke and approximate to those in the Pocono graywacke (Emery, 1954). Uniformity of grain size may be estimated by comparing the standard deviations and kurtosis of size distributions; in these terms quartz grains in the Salt Wash sandstones are more uniform

Fig. II - 6

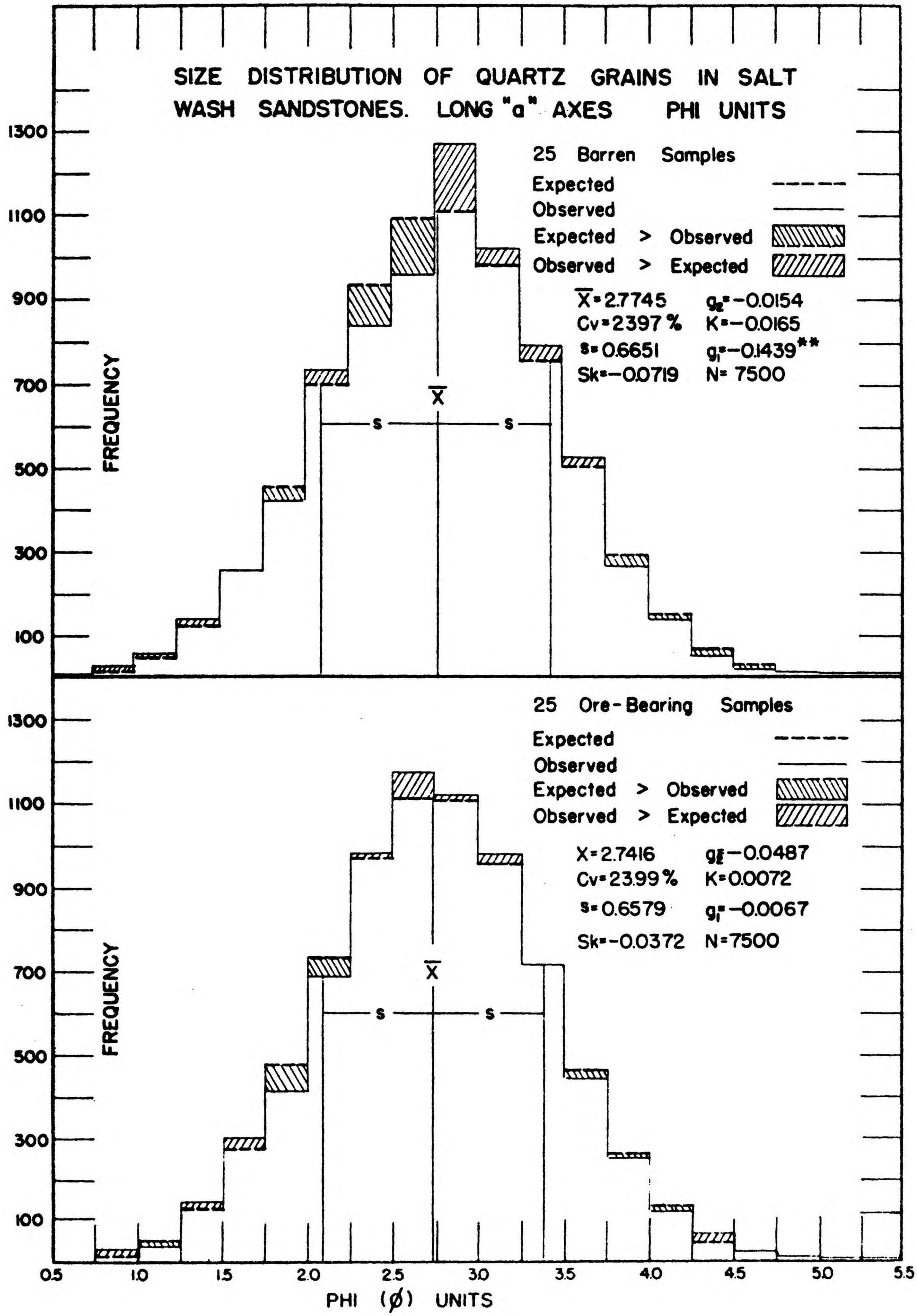

SIZE DISTRIBUTION OF QUARTZ GRAINS IN SALT WASH SANDSTONES. LONG "a" AXES PHI UNITS
25 Barren Samples
Expected
Observed
Expected > Observed
Observed > Expected
X̄=2.7745 g₂=-0.0154
Cv=23.97 % K=-0.0165
s=0.6651 g₁=-0.1439**
Sk=-0.0719 N=7500
25 Ore-Bearing Samples
Expected
Observed
Expected > Observed
Observed > Expected
X=2.7416 g₂=-0.0487
Cv=23.99 % K=0.0072
s=0.6579 g₁=-0.0067
Sk=-0.0372 N=7500
FREQUENCY
PHI (ϕ) UNITS

FIG. II - 7

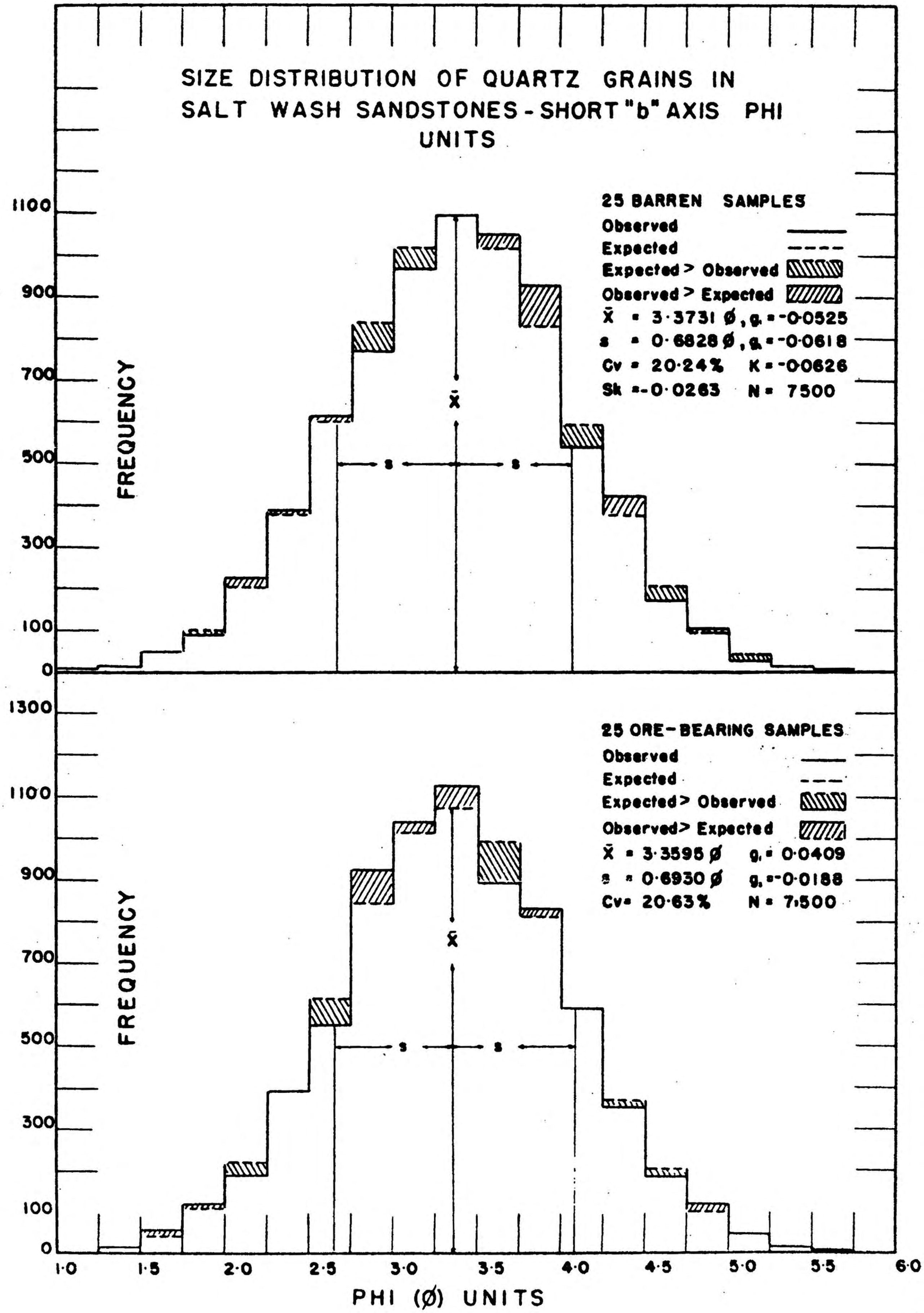

SIZE DISTRIBUTION OF QUARTZ GRAINS IN SALT WASH SANDSTONES - SHORT "b" AXIS PHI UNITS
25 BARREN SAMPLES
Observed
Expected
Expected > Observed
Observed > Expected
X̄ = 3·3731 Ø, g₁ = -0·0525
s = 0·6828 Ø, g₂ = -0·0618
Cv = 20·24% K = -0·0626
Sk = -0·0263 N = 7500
25 ORE-BEARING SAMPLES
Observed
Expected
Expected > Observed
Observed > Expected
X̄ = 3·3595 Ø g₁ = 0·0409
s = 0·6930 Ø g₂ = -0·0188
Cv = 20·63% N = 7,500
FREQUENCY
PHI (Ø) UNITS

Table II-13. Comparison of Population Estimates of Grain Size for Various Sediments.

Long "a" axis in phi units measured in thin section

Formation	Rock-type	$\bar{X}$ ∅	s ∅	Sk	K	g_1	g_2	Cv %	Samples	Grains
Pocono[1]	Low rank graywacke	2.87	1.07	0.0343	2.555	--	--	37.28	16	800
Berea[1]	Low rank graywacke	3.37	0.72	0.2006	3.700	--	--	21.36	16	800
Oriskany[2]	Quartzite	1.659	1.040	-0.0376**	0.6496**	--	--	62.68	87	9743
Salt Wash	Arkosic quartzite	2.7581	0.6617	-0.0378	0.0072	-0.0757**	0.0074	23.99	50	15000

[1]Emery, 1954; [2]Rosenfeld, 1953

**Significant at the 0.01 probability level than those in the Oriskany, Berea or Pocono sediments. The coefficient of variation is another expression of variability and it may be seen that the Salt Wash quartz grains most nearly approach those in the Berea on this basis and are less variable than those in the Pocono or Oriskany.

The quartz grain size of the Salt Wash and Oriskany are negatively skewed whereas those in the Pocono and Berea are positively skewed but skewness may be a reflection of sampling bias (Oriskany and Salt Wash) or technique error due to the difficulty of measuring small quartz grains (Berea and Pocono) and there may be no geological implications contained in these values.

More informative compilations must await compilation of extensive bodies of data on the quartz grains of various sediments.

Perhaps the most significant feature brought out by the analysis is the stratified arrangement of the grains. It is, of course, well known that sediments are stratified on a megascopic scale and that some sediments are laminated. In the case of the Salt Wash sandstones, however, the lenticular laminae are extremely fine, several laminae occurring in a single microscope field (See Fig. II, RME 3070). This accounts for the difficulty in sampling; it is necessary to select random samples from a very finely stratified population and there appears to be no objective basis for defining the ultimate strata. Otto has recommended sampling the sedimentation unit (Otto, 1938) and in the case of the Salt Wash sandstones this would require that each set of grains should be randomly selected from the same sedimentation unit. Unfortunately it is impractical to define the limits of the smallest strata which are the ultimate sedimentation units so that it is, at present, impossible to select random samples (grains) from a single sedimentation unit in this case.

Sedimentation processes generally accomplish the selective sorting of grains, in this case quartz grains, and the most efficient processes lead to finer and finer laminae within which the variation among the grains is small. The Salt Wash sandstones are an extreme case wherein the selective sorting has led to the production of very fine lenticular laminae. These sediments are, therefore, either very far from their source or have been reworked over a considerable period of time.

There is very little difference between the ore-bearing and barren sediments in terms of quartz grain size. Both the average grain size and sorting (estimated by the variance and kurtosis, g_2) are similar in both. Hence in a regional sense there is no difference in grain size between ore-bearing and barren sediments.

The only difference definitely established by the analysis is at the operator - field interaction level (see tables II-4 to 7). The operator-field interaction is significant in the ore-bearing and non-significant in the barren samples. Since operator difference is small in the entire sets of data then operators must have selected significantly different sets of grains in ore-bearing and not in barren sediments. Presumably this reflects the fact that there are bigger contrasts in grain size within one microscope field of a thin section in ore-bearing than barren sediments. This may be construed to mean that while the overall grain size is the same in both there are more local differences (in arrangement) of grain sizes in ore-bearing than barren sediments. Once again the petrographic analysis emphasizes that small local differences and not regional contrasts differentiate ore-bearing from barren sediments.

There is one other feature which is not brought out in the analysis because of the experimental design; thus suppose that at each ore deposit the ore-bearing sandstone is coarser than the surrounding barren sediment but absolute size is not important. This is a likely case because the Shinarump sandstones are generally much coarser than the Salt Wash sandstones while the Entrada at Placerville appears to be somewhat finer grained yet both contain ore and the ore-bearing sediments do appear on megascopic examination to differ in grain size from the barren sediment in each case. This feature would not emerge from the present experimental design and would necessitate a "paired sample" approach; at every ore-deposit a sample or set of samples should be taken and a corresponding sample or set taken from the neighboring barren sediments. Unfortunately, in practice, it would be very difficult to decide exactly what "neighboring" barren sediments means whether inches or feet away from the ore-bearing. Hence it appears likely that analysis of the well-cores from Bull Canyon Wells 155 A, B, and C would be the best means of resolving this problem.

B(i) Shape of Quartz Grains in Thin Sections of Salt Wash Sandstones

Shape measurement of quartz grains in sediments yields enigmatic results which are very difficult to interpret into factors of geological import. Recent studies of sphericity and roundness of loose quartz grains suggest that too little information has been compiled under suitable experimental control to establish with any degree of confidence the geological meaning of variations in shape (Rosenfeld and Griffiths, 1953; Curray and Griffiths, 1955). Measurement of roundness is particularly susceptible to errors in technique and measurement of both sphericity and roundness suffer from incorrect sampling procedures.

In the present investigation sphericity may be estimated in a two-dimensional sense (circularity) by measuring the long "a" and short "b" axes of quartz grains in thin sections and expressing the shape measure so obtained conventionally as a ratio of short "b" to long "a" axis i.e. $\psi_c = b/a$ where ψ_c is the shape measure. Experience with this ratio suggests that it would be prudent to examine the relationships between "a" and "b" axes rather than attempt to use the ratio (or product).

The b/a ratio is generally found by dividing "b" in millimeters (or microns) by the "a" axis expressed in the same scale. In studying the relationships between "a" and "b" however the scatter diagram reflects heteroscedasticity where the larger values of "a" and "b" show the greater variability. The frequency distributions of "a" and "b" axes in millimeters are highly skewed (e.g. Fig. II-2) and the heteroscedasticity is largely a reflection of this feature; it is customary to use a logarithmic scale to symmetrize the frequency distributions and similarly the log transformation removes the heteroscedasticity. Studies of the relationship between "a" and "b" axes are best performed with the variables expressed in phi units where following Krumbein (1936) $\xi = 2^{-\phi}$. The relationship is linear in phi units and the resulting equation may be transformed to the original scale when necessary.

B(ii) Relationship Between "a" and "b" Axes of Quartz Grains Measured in Thin Sections (Phi Units)

Both "a and "b" axes when measured in thin section yield apparent rather than true dimensions and the axial measurement may be represented as (P_{ts}) where:

$$P_{ts} = f\,(s, sh, o, p) \quad . . . . (1)$$

indicating that each measurement (P_{ts}) is a function of the four variables size (s), shape (sh), orientation (o) and packing (p) (see Griffiths, 1952a). The choice of dependent and independent variables for studies of inter-relationship between "a" and "b" axes is therefore arbitrary; in the present case the "a" axis is taken as the independent variable X and "b" the dependent variable Y.

As a first step we may plot the sample mean values of "a" and "b" axes as X and Y respectively in a scatter diagram (Fig. II-8). The relationship is linear and the correlation coefficient (r) is high. As a matter of convenience we may treat the two sets of samples, ore-bearing and barren, separately, and each set of 25 samples yields r = 0.9966 (ore-bearing) and r = 0.9953 (barren). The coefficients of determination (r^2) are close to 99 per cent implying that in the case of sample means about 99 per cent of the variation is common to both axes and only 1 per cent is independent. Evidently then in terms of sample means in phi units the "b" axis may be predicted very closely from the "a" axis. The linear regression equations are:-

For ore-bearing samples: $Y = 0.4685 + 1.0535X$; $Sy = 0.037$

For barren samples: $Y = 0.3403 + 1.0903X$; $Sy = 0.042$

Where Y is the length of the "b" axis in phi units estimated through the regression equation from the observed length of the "a" axis (X) in phi units. Sy is the standard error of estimate associated with the respective estimate Y. Apparently we can estimate "b" from "a" through their equations within about 0.04ϕ units.

B(iii) Consistency of the Association of "a" and "b" Axes of Quartz Grains in Phi Units

When each sample is taken individually and the correlation coefficient compiled on the basis of the 300 pairs of individual grain measurements the degree of association varies from r = 0.9352 - 0.4689 but tested for homogeneity (Tippett, 1952) they yield a chi-square value which is not significant and hence this entire range may be looked upon as variation due to accidents of sampling. The mean value and confidence limits based on this data are given in table II-14. The 99 per cent confidence interval embraces the entire range of sample r's.

Table II-14. Mean Value of r and Confidence Limits at the 95 and 99 Per Cent Probability Limits.

Mean r	Confidence Interval	Significance Level
0.7700	0.8937 - 0.5190	95 per cent
	0.9391 - 0.3095	99 per cent

If the association is consistent at all levels such as among grains, fields, and samples then we expect the degree of variability to be reduced as we take averages and the association measured by the correlation

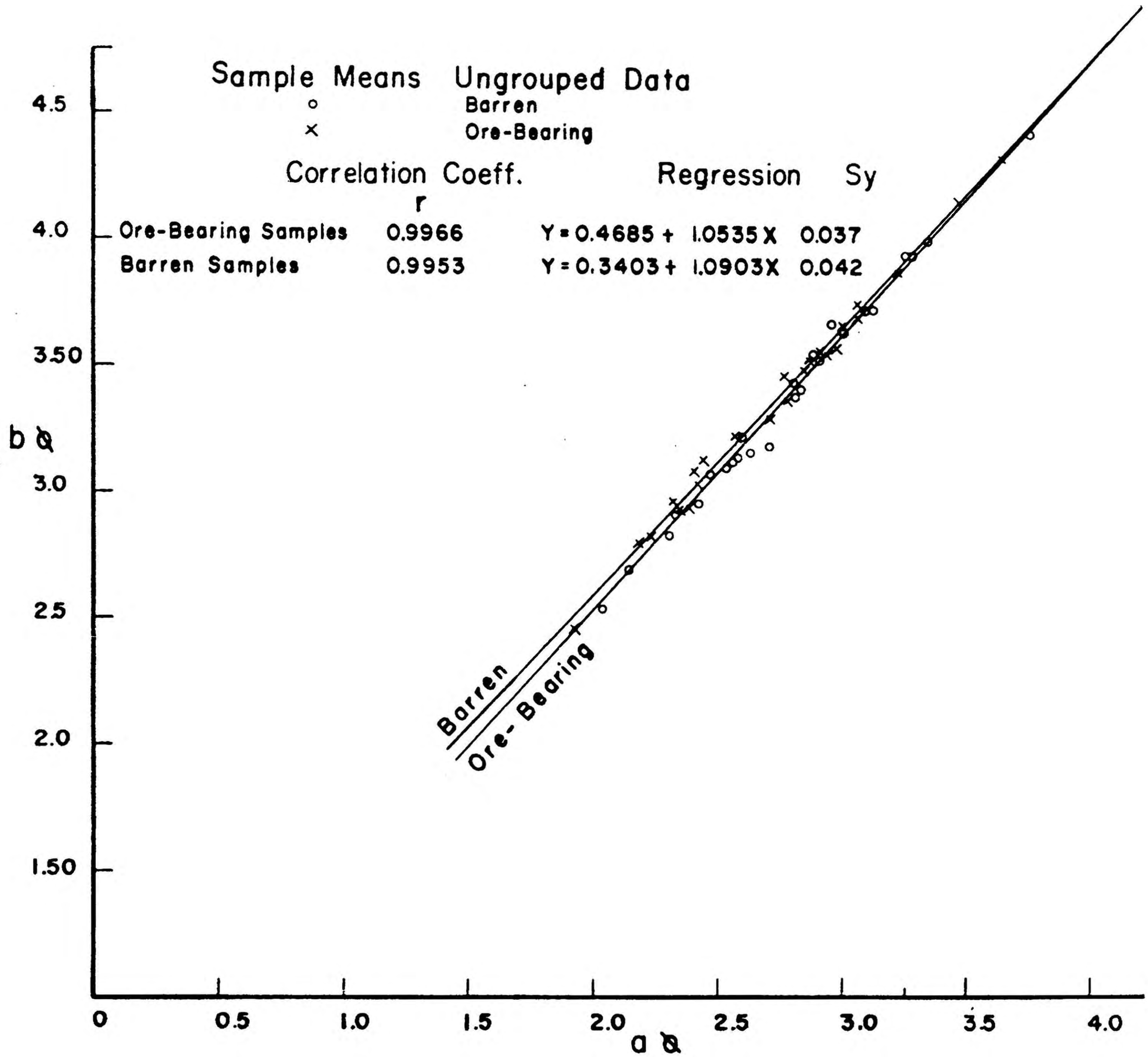


Fig II 8: ASSOCIATION BETWEEN LONG "a" AND SHORT "b" AXIS IN QUARTZ GRAINS - SALT WASH SANDSTONES coefficient should increase from the grain level, through fields to a maximum at the sample mean level. We may test this by means of the analysis of variance sums of squares and products yielding the results of table II-15.

Table II-15. Comparison of the Degree of Association Between "a" and "b" Axes in Phi Units at Grain, Field and Sample Mean Levels.

Levels	Correlation Ore-bearing	Coefficient Barren
Sample Means	0.9931	0.9937
Field Means	0.8049	0.8171
Grains	0.7697	0.5369
Total	0.7490	0.7325

The values are all positive and increase from grain to sample mean level; this suggests that the relationship is consistent throughout the set of data. There is some contrast at the grain level between ore-bearing and barren sediments.

We may then conclude that the "b" axis is linearly related to the "a" axis in phi units and that there is a close association. As the association is consistent throughout the sequence we may select the total variation to compute a representative regression equation based on the 15,000 items of data which yields:-

$$Y = 0.8619 + 0.9062X; \; S_y = 0.35\ \phi$$

B(iv) Relationship Between "a" and "b" Axes in Millimeter Units

Since the "a" and "b" axes are linearly related in phi units we may transform the equation by substitution to millimeter units to find the relationship between "a" and "b" axes in millimeters.

The diameter in millimeters (d) is related to the diameter in phi units as follows:-

$d = 2^{-\phi}$ where d = diameter in millimeters

or $\phi = -\log_2 d$; $\phi = \log_2 \frac{1}{d}$

Taking the general linear equation:-

$$Y_\phi = a + bX_\phi \quad \ldots\ldots\ldots\ldots \quad (1)$$

Then $\log_2 \frac{1}{2d} - a = b \log_2 \frac{1}{d_2}$

and $\frac{1}{d_1} = 2^{-a} \left(\frac{1}{d_2}\right)^b$

$$\frac{1}{d_1} = \frac{1}{2^a} \left(\frac{1}{d_2}\right)^b$$

$$d_1 \left(\frac{1}{d_2}\right)^b = 2^a \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

or substituting for the coefficients

$$d_1 \left(\frac{1}{d_2}\right) 0.9062 = 20.8619$$

then the ratio of "b" to "a" in millimeter units is approximately constant. If this relationship is correct then the estimate of shape $\psi_c = b/a$ in millimeter units is independent of size and is constant.

B(v) Comparison of Shapes of Quartz Grains in Different Sediments (Measured in Thin Section)

We may now compare the results of axial ratio (b/a) shape measurement of quartz grains in different sediments as in table II-16. The total range shown throughout the various sediments is:- b/a = 0.649 to 0.682 = 0.033 units. It seems very likely that shape as measured by axial ratio shows very little variation throughout the sediments quoted. The standard deviation also ranges over about 0.035 units among these sediments.

For the present therefore it seems likely that shape measurement of quartz grains in thin section yields so little variation that it is not possible to differentiate between different sediments and in the case of Salt Wash sandstones sample to sample variation is negligible (homogeneous "r" values).

B(vi) Discussion

We may conclude that for purposes of the present investigation variation in axial ratio is not likely to add to our information. The axial ratio shapes of quartz grains in ore-bearing and barren sediments does not differ.

It seems likely from the data of table II-16 that this is true of a wide range of sedimentary rocks. In phi units the "a" and "b" axes are linearly related, and in millimeter or micron units the ratio b/a is remarkably constant. There is a reasonably wide range among grains in any sediment but mean values among samples of the same sediment and among different sedimentary rocks are very similar.

It is not possible to decide the exact reason for this unusual relationship at present because the data do not represent all kinds of sediments but are more truly representative of sediments which have travelled far or at least suffered very considerably from selective sorting. Perhaps the sedimentary processes of selective sorting lead to concentrations of quartz grains of the same shape.

Perhaps, on the other hand, this similarity is some function of the measurement technique because both axes are apparent axes and variation in magnitude of both "a" and "b" are complex functions of four interacting variables. The constancy of axial ratio has been remarked upon in earlier investigations (Emery and Griffiths, 1952); until we learn much more about many different kinds of sediments it is not possible to decide the exact significance of these findings.

It is noteworthy that variation in sphericity measured in terms of the three axes, "a", "b" and "c" in loose quartz grains shows little difference in means among sedimentary rocks (Curray and Griffiths, 1955). Perhaps the shapes of quartz grains as represented by the ratios of their axes tend to be constant in all sediments. This could be either a product of environmental factors (e.g. by selective sorting) leading to segregation of quartz grains of similar shape or it could be a function of the structural attributes of quartz crystals which may control the ultimate quartz grain shape in sedimentary rocks; perhaps both these factors become cumulative in reducing the variation in shape of quartz grains in rocks.

Table II-16. Comparison of Axial Ratio of Quartz Grains in Various Sediments (Thin Section Measurement).

Sediment	Number of Samples	Number of Grains	Axial Ratio b/a Mean	Axial Ratio b/a Standard Deviation	Rock-type
Pocono[1]	16	800	0.6609	0.1739	Graywacke
Berea[1]	16	800	0.6691	0.1730	Graywacke
Bradford Sand					
5820[2]	1	1,250	0.6505	0.150	Quartzose Graywacke
P4-1 11[1] to bedding[3]	1	400	0.665	0.148	Quartzose Graywacke
11[1] to max perm	1	1,000	0.681	0.150	Quartzose Graywacke
+ 11[e] to min perm	1	1,000	0.682	0.144	Quartzose Graywacke
1 to max perm	1	1,000	0.655	0.149	Quartzose Graywacke
Oriskany[4]	87	9,981	0.677	0.142	Quartzite
Salt Wash	50	15,000	0.649	--	Arkosic Quartzite

[1]Emery, 1954; [2]Griffiths and Rosenfeld, 1953; [3]Griffiths and Rosenfeld, 1950; [4]Rosenfeld, 1953.

C Measurement of Grain Orientation

(i) Introduction

Mineral composition, grain size and grain shape are well known properties of sedimentary rocks and measurement of these properties has been reduced to standardized routines. To define a rock it is necessary to add to these three properties estimates of arrangement of the grains in a rock. At present arrangement is defined by two such measurements namely, grain orientation and packing. Any single grain is, at least in theory, uniquely defined when it is classified as to kind of mineral, and its size and shape are specified. A rock, on the other hand is composed of sets of grains, so that the mutual relationships or arrangement of the grains is also an important attribute (Griffiths, 1952a). Packing of grains in Salt Wash sandstones has been described in Part I of this report; it remains to specify grain orientation.

The arrangement of grains in sediments is a relatively new field of investigation but it has been shown that grain orientation is related to directional permeability patterns in oil sands (Griffiths, 1949, 1952b; Griffiths and Rosenfeld, 1950, 1953) and more recently that overall texture pattern, particularly uniform and disturbed textures, are important in determining the behavior of an oil reservoir during production (Griffiths and Shadle, 1955). Stokes (1953) has demonstrated that lineation of small-scale features may be useful in predicting trends in uranium-bearing sediments on the Colorado Plateau. Some of these small-scale features may well be reflections of changes in sedimentary texture or fabric. Again the presence of disturbed fabric, called rather loosely, slumping, has been recorded around the margins of many ore-bodies in the Salt Wash sandstones of the Colorado Plateau (Griffiths, et al, RME-3106, p. 10, pp. 67-78; RME-3097, p. 61; RME-3070, p. 81). It seems likely then that grain fabric and therefore grain orientation may be of some importance in localizing ore in the Salt Wash sandstones.

C(ii) Evolution of Measurement Procedures

Measurement of grain orientation in sandstones is a difficult problem which has not yet been satisfactorily solved. The concept of orientation is deceptively simple to formulate but while we may imagine that we have a clear concept of what we wish to measure, in practice, when we try to design a measurement technique, it is difficult to guarantee that the technique suffices to characterize our concept. Nearly all our technique - concept relationships suffer from these disadvantages; grain size is a typical example (Griffiths, 19[illegible]). To characterize the fabric of a sediment we must not disturb the fabric by our measurement technique hence we are, at least for the present, compelled to use thin sections. Here we see a two-dimensional image of the three-dimensional orientation we wish to characterize. Furthermore if we assume that quartz grains are three-dimensional ellipsoids which possess a longest (a), intermediate (b) and shortest (c) axis we cannot guarantee that we see any of these in thin section. We must be content then with the measurement of apparent long and apparent intermediate axes in the plane of thin section. A further limitation also arises; we cannot determine unequivocally one end of a quartz grain from the other. Hence our measurement of orientation becomes a measurement of inclination of the long axis of quartz grains in thin section wherein the long axis is an apparent long axis with no definable relationship to the true long axis and the angle of inclination, sometimes called azimuth, can range through 180 degrees.

In practice then we seek a unique definition of long axis (see measurement of grain size) and measure the inclination of this long axis to some fixed reference direction. In this sense we are not really interested in mean direction because the exact physical significance of such a measure based on the present operation is obscure; we are interested in perfection of orientation i.e. how many long axes parallel a single inclination direction. We may set up a model of randomness (= isotropicity) by defining a frequency distribution resulting from our measurements as possessing equal frequency in each inclination direction and this will form one end-member of our range - a rectangular frequency distribution. The other extreme would be represented by perfect orientation when the inclination of all grains are the same. We rarely approach perfection in the sediments that have been examined and, in practice, our other extreme becomes a unimodal symmetrical frequency distribution.

If we now characterize our family of frequency distributions as extending from rectangular through symmetrical unimodal frequency distributions in which more and more measured inclinations fall into the central classes, we will cover the bulk of the frequency distributions so far observed. On this basis the variance or standard deviation of the frequency distributions which fall within our definition will suffice as the test criterion estimating degree of perfection of orientation. In this approach we are assuming that the sets of grains measured are from the same homogeneous population and we are assuming the form of the distribution function of the population. Even these assumptions are not entirely sufficient, in theory or practice, to enable us to define our original concept of orientation but so far no acceptable alternative has been proposed.

C(iii) The Sampling Problem

If we accept the above assumptions about the form of the frequency distribution of the population it is necessary to obtain a random sample of measurements from this homogeneous population as a basis for analysis. The determination of a sampling program is another obstacle, largely because a suitable sampling pattern has yet to be clearly defined, and, because the simple assumption of a homogeneous population of orientations in a single thin section of a sedimentary rock is unlikely to be fulfilled in practice in most cases. Sedimentary rocks are composed of lenses (strata) and it is presumed that there is a fundamental lens or stratum called the sedimentation unit (Otto, 1938) representing a set of quartz grains which were deposited under constant, or at least a limited range of, conditions. This sedimentation unit is the homogeneous population which we must sample randomly. So far at least it has not been possible to define this unit in such a way that it can be randomly sampled; in the Salt Wash sandstones, for example, there are very many such units in a single thin section and, at the magnification we must use to perform the measurements of grain size, shape, orientation and packing, it is difficult to decide the limits of this fundamental stratum, the sedimentation unit. It is important to realize what this implies in terms of measurement of orientation, and it should also be realized that the same features apply in a similar manner to our measurements of grain size, shape, and packing.

Let us consider a few simplified models as a basis for comparison. We will assume in each case that we possess 5 thin sections of some population (= uniform sedimentary rock); in the first case the orientation of the grains is perfect, then each thin section represents a random sample of this homogeneous population. We measure the inclinations of sets of 10 grains in traverses arranged randomly across the thin section. Each grain is a random sample of a traverse, each traverse a random sample of a thin section, each thin section of the entire population. Now to make the model approach reality we will assume that not all the grains are inclined in parallel but there is some small range of inclinations (otherwise the variance s^2 would be zero throughout the analysis).

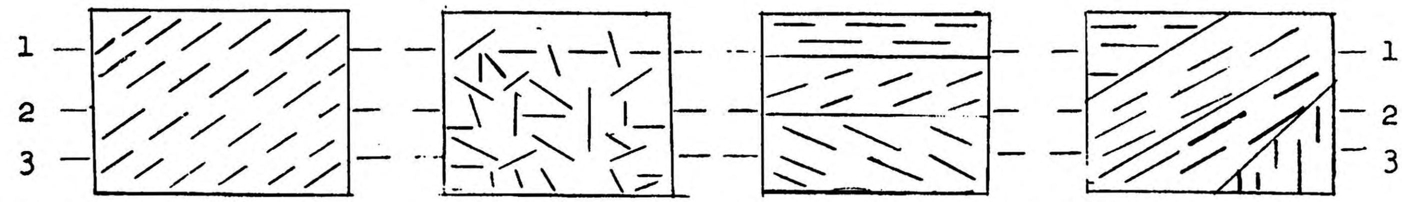
Then each set of grains comprising a traverse would yield some small amount of variation in inclination, i.e. variance among grains within a traverse is small and this would be true over all traverses. Now because we have assumed a near perfect orientation, homogeneous throughout the population sampled, then each set of grains would yield a mean and each of these traverse means is a close estimate of the population mean hence variation among traverse means is small to very samll. Thin section means representing the average of similar traverse means would be even more alike and hence thin section means would also yield a very small variation or variance (see case A, Fig. II-9).

Now let us consider a homogeneous population which possesses random orientation (case B, Fig. II-9). Here variance arising from variation in inclination among grains is very large; on the other hand traverse means would hardly differ and thin section means would be even more nearly alike. Therefore the essential difference between perfect and random orientation is at the grains level of variation and only at the grains level.

Case C is more representative of the usual sediment and if we increased the number of lenses (layers in Case C, Fig. II-9) we would have a close analogy. It will be realized that here we have a number of homogeneous subpopulations (sedimentation units) and we wish to obtain random samples of these subpopulations. We have contrived to

Fig. II-9. Sampling Idealized Models of Orientation Distributions of Quartz Grains in Thin Sections of Sediments.

Traverse — Thin Section A — Thin Section B — Thin Section C — Thin Section D



No. of Items	Source of Variation	Degrees of Freedom	Relative Magnitude of Mean Squares (or Variances) A	B	C	D
5	Among thin sections	4	Very small	Very small	Small	Very Small
10	Among across within thin sections	45	Very small	Very small	Large	Very large
10	Among grain within traverses	450	Very small	Very large	Very small	Large
500	Total	499	Very small	Very large	Very large	Very large

arrange the traverses so that each lies within a homogeneous subpopulation (lens or sedimentation unit). In this case (C) variation among grains within each traverse is small, variation among traverse means within each thin section large; if there were a large number of layers, say 10 or more, each containing one traverse, then thin section means would tend to be similar. In this case then, the comparison of traverse and grain variances holds the clue to the fabric.

Finally in case D we meet our real problem; suppose it is not possible to confine each of our traverses to single layers (or subpopulations = sedimentary units) or, in other words, that we have no means of defining our subpopulations sufficiently well to enable us to be certain that each traverse is a random sample of a homogeneous unit. Then we have: Variance among grains within a traverse, probably large; variations among traverse means, very large, if only a few layers differing in mean orientation are sampled by each traverse; variation among traverse means small, if large numbers of layers are sampled by each traverse. Variation among thin section means small to very small.

It will be observed that "total variance" can be a very misleading estimator of degree of perfection of orientation; in some extreme examples it cannot even be used to determine presence or absence of preferred orientation.

It must be obvious from these four simplified models that the problem of differentiation of fabrics of different sedimentary populations contains a difficult and important sampling problem. It may be of interest to geologists to imagine that the thin section is enlarged to represent an outcrop, and each item magnified on the same same scale. The same sampling problem exists on this scale, and, unless the sampling pattern is clear, the results of dip measurement (equivalent to our grain orientation) are likely to be very confusing; the regional structure pattern is a function of the availability of observation sites (i.e. outcrops, drill cores, etc.). It is to be hoped that the model used by the geologist in deciding his sampling pattern, and its contained assumptions of negligible degree of variation at all levels below the outcrop, is correct or our structures are likely to need revision. In addition, of course, no attempt is made on the field scale to random sample a sedimentary unit. Perhaps, by accident, the lack of randomness in the selection of sites for dip measurement is offset by the failure of the remaining assumptions in the model - this would be something more than a lucky coincidence I presume! It is perhaps of some comfort that no one has attempted to evaluate, let alone offer a solution to, this problem either on a field or thin section scale.

C(iv) Statistical Analysis of the Results

If we may now assume that our measurements are satisfactory then we proceed to analyze the results. The first step in the reduction of the

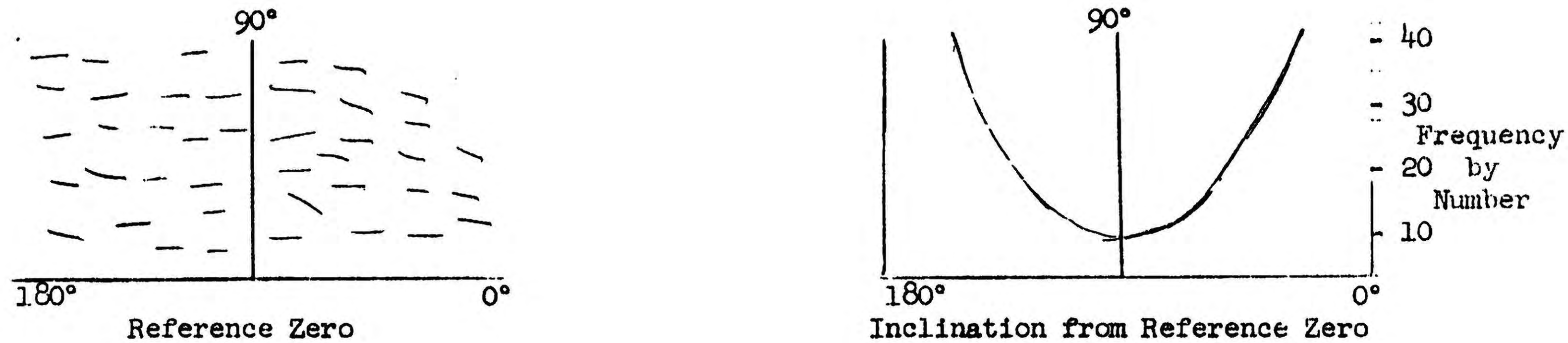


Figure II-10A. Orientation of Quartz Grains Yielding U-shaped Frequency Distribution.

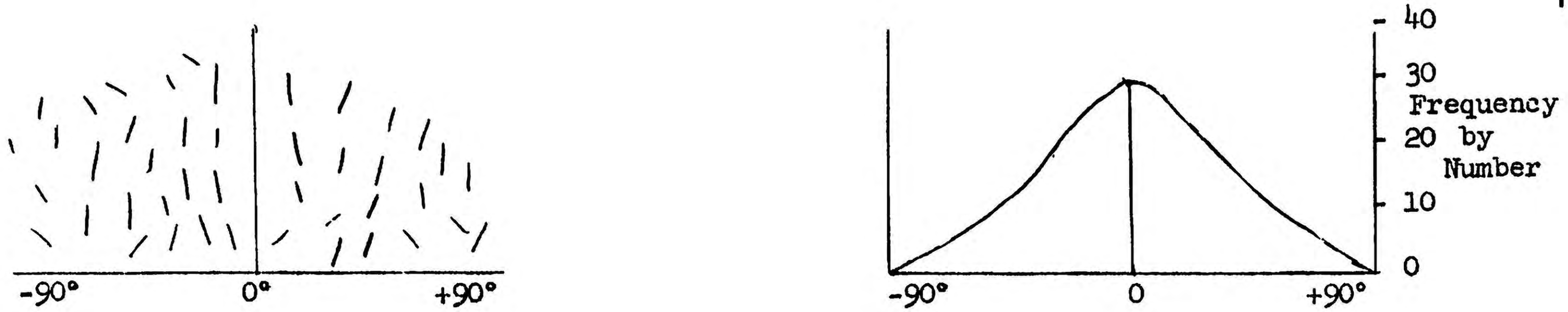


Figure II-10B. Orientation of Quartz Grains Yielding Unimodal Symmetrical Frequency Distribution by Change of Reference Zero Through 90° from Fig. II-10A.

data is to express the measurements in a frequency distribution or histogram. In the present instance with 300 grain measurements per thin section 10 degree class intervals are used over the 180 degree range. The form of the histogram will depend on the reference line chosen as a basis for the inclination measurement (Jizba, 1953) and we generally attempt to avoid this issue by selecting some lineation in the thin section as a base line. If the lineation is a suitable base, in a physical sense, and it is taken as zero (equivalent to 180 degrees on this scale) then a perfect orientation will be U-shaped (Fig. II-10A) most of the grains lying at small angles to the zero reference plane in two quadrants. We endeavor to offset this by arranging our reference line perpendicular at zero degrees and measure grain inclinations as deviations ranging from 0 to 90 degrees on either side of zero and labelling one quadrant negative relative to the other (Fig. II-10b). Hence our scale extends from -90 degrees through zero to +90 degrees.

In many cases no lineation can be selected (e.g. in massive or uniform sediments or in cases of current bedding when more than one reference line exists) and the frequency histogram may be symmetrical, skewed, polymodal or U-shaped. When the resulting frequency histogram is not symmetrical a minimum variance origin may be determined by Chayes technique (Chayes, 1954) or the mean may be obtained from Tukey's Isotropicity test (Tukey, 1954, see also Appendix pp. 71-81 . Assuming a unimodal frequency histogram can be established then the variance may be tested for significance by comparison with the isotropic random orientation model (Griffiths and Rosenfeld, 1953). A number of other tests have been suggested and some are considered later such as Tukey's Isotropicity test, and Gini's G (See Appendix pp. 76.

It is, of course, obvious that ultimately we must resort to analysis of variance comparisons of grain, traverse, and thin section sources of variation if we are to interpret the physical meaning of perfection of orientation. How we are to do this is, however, not clear because it is necessary to use minimum variance if we are to apply analysis at all and just which level we should use for this computation is not obvious. The mean around which the variance should be calculated may differ in each layer and to use the entire set of measurements as a homogeneous population is then incorrect. It seems likely that the sampling problem will have to be solved to proceed further with the measurement of orientation.

Investigation of quartz grain orientation of the Salt Wash sediments was approached on a pragmatic basis and the total variance, despite its drawbacks, is used in the subsequent analyses. In each of the 50 samples the total variance is the minimum variance calculated by the Chayes technique (Chayes, 1954) from each set of 300 measurements for each sample. In addition as a guide for future work a number of examples are given in detail as an appendix together with various tests of these data as a basis for comparison. For the present, at least, we cannot do better than hope that the perfection of orientation expressed as the minimum variance will suffice for an estimate of grain orientation in these sediments (see also Hutta, J. J., 1956).

C(v) Procedure for Measurement of Quartz Grain Orientation in Salt Wash Sandstones

The technique used to measure the inclination of apparent long axes of quartz grains in Salt Wash sediments follows that of our earlier experiments (Griffiths, 1949, 1952b; Griffiths and Rosenfeld, 1950, 1953).

The sampling program is the same as that used for the measurement of quartz grain size; three operators measured the inclination of 10 randomly selected quartz grains from 10 fields of each thin section leading to 300 grain inclinations per thin section.

The data were expressed in frequency distributions as histograms (for examples see figs. II-15, 16, 17, Appendix 1); each set of data was submitted to minimum variance computation (Chayes, 1954) and Tukey's Isotropicity Test (Tukey, 1954) and Gini's Mean Squared Difference (G) was calculated following Tukey's proposals (Tukey, op. cit.). These statistics along with descriptive remarks on the frequency distributions are summarized in Table II-17. Analysis of variance of each set necessitates correcting each of the 15,000 measurements to its own minimum variance mean and then computing the usual sums of squares etc. This has not yet been accomplished. Hence for comparison with other petrographic data the minimum variance is used as a measure of perfection of orientation of each of the 50 samples.

C(vi) Orientation of Quartz Grains in 50 Samples of Salt Wash Sandstones

The range in perfection of orientation expressed in terms of the standard deviation (s°) extends from about 20 degrees (Emery and Griffiths, 1954, p. 76, table 4) to over 50 degrees (Griffiths and Rosenfeld, 1953); in the present samples standard deviation of quartz grains inclination varies from 37.64 degrees to 52.77 degrees.

It has been shown that in a sample with random orientation (rectangular frequency distribution) the theoretical value of s is 52 degrees. However the level of confidence of any measure used in practice is a function of the number of measurements (N) and in this investigation an N = 300 requires a standard deviation less than 46 degrees to be significant at the 5 per cent probability level (Griffiths, 1952b, p. 53, Griffiths and Rosenfeld, 1953, p. 212.).

The range in standard deviation and the number of samples with values exceeding the minimum level for 5 per cent significance are illustrated in Fig. II-11.

Fig. II - 11 Perfection of Orientation estimated by Chaye's Minimum Variance for 50 Samples of Salt Wash Sandstones

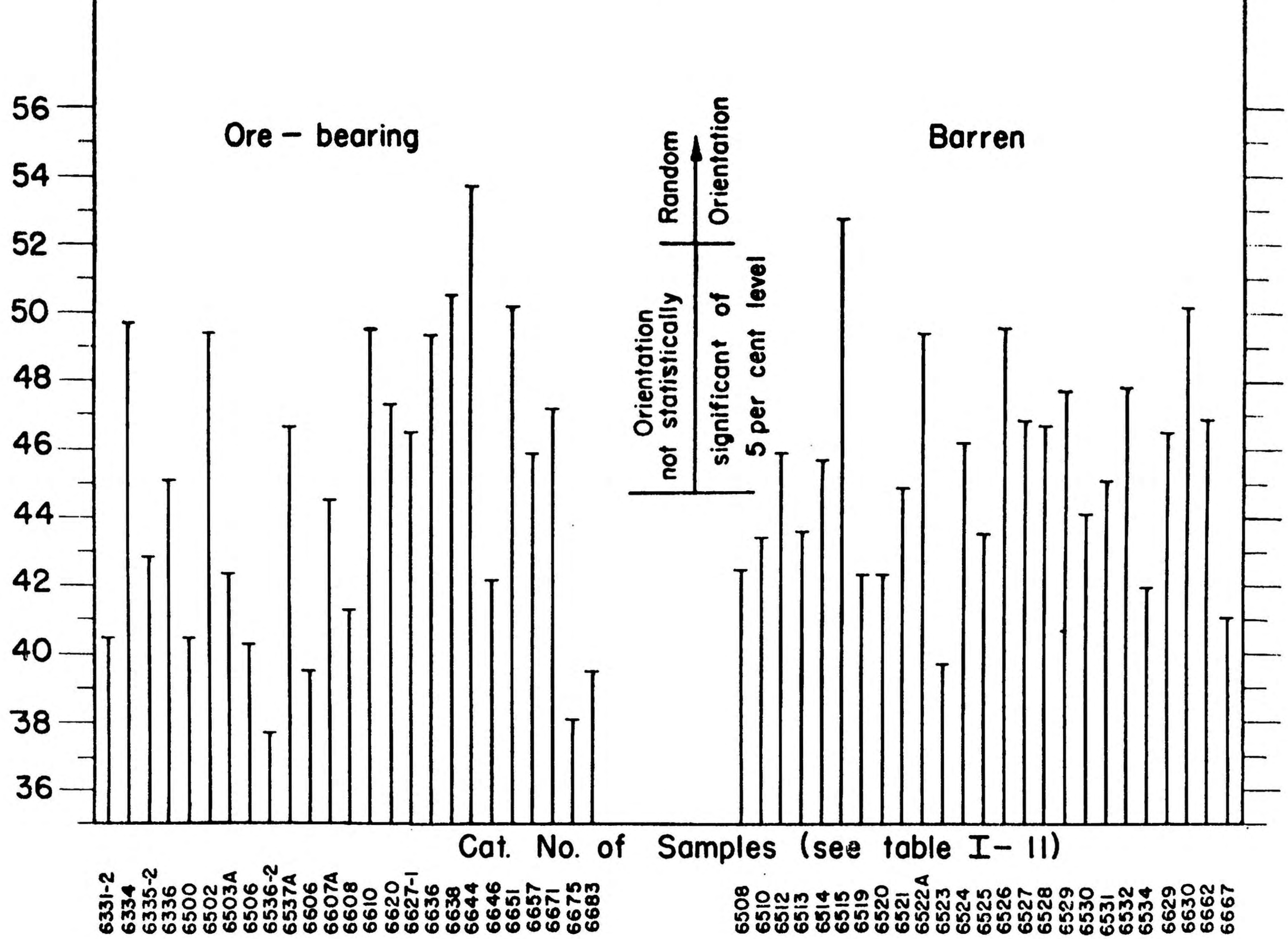


Fig. II- 12 Relationship Between Perfection of Quartz Grain Orientation & Proportion of Quartz & Feldspar in 50 Samples of Salt Wash Sandstones

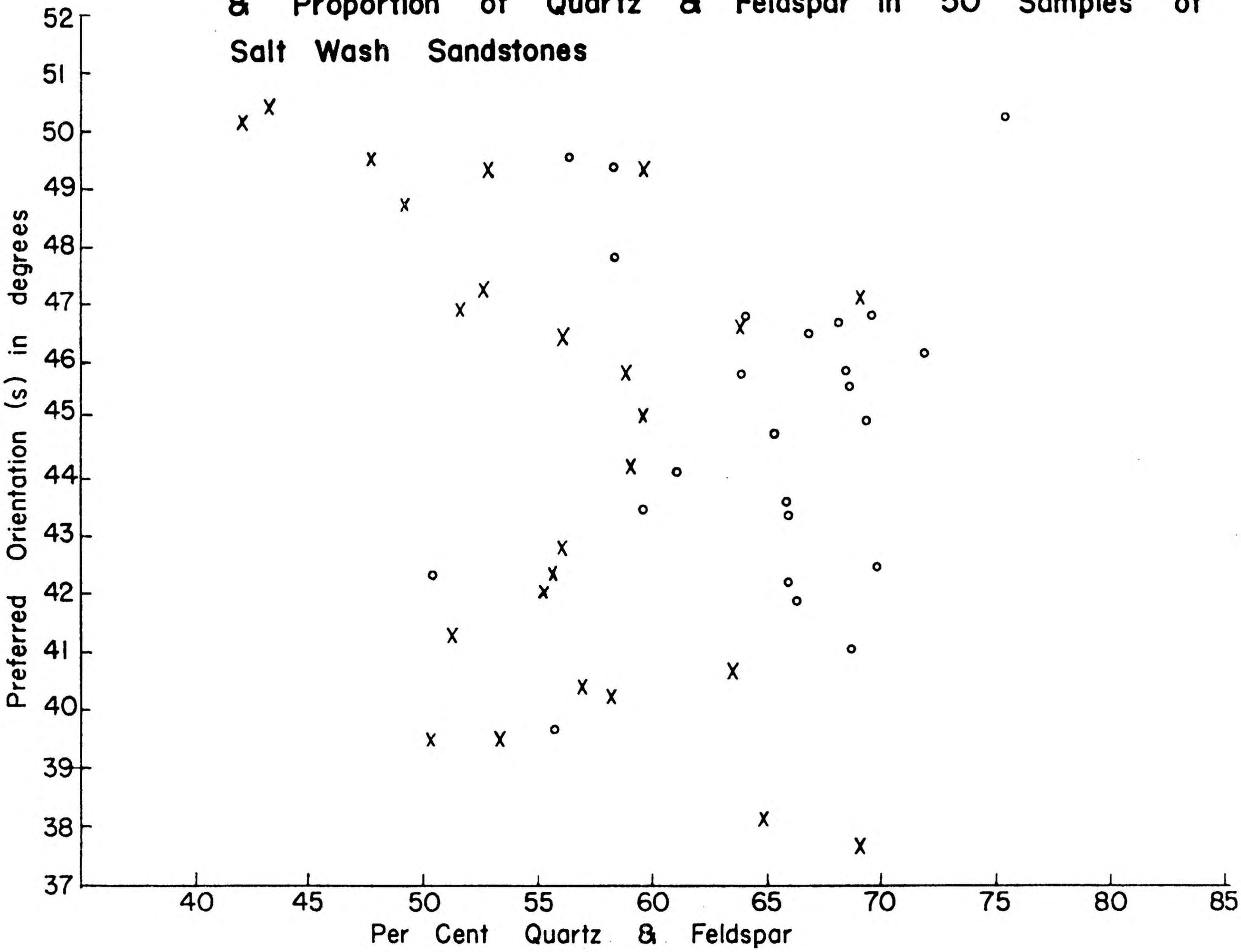


Fig II - 13 Mean Grain Size ($\overline{X}\phi$) versus Preferred Orientation (s) in degrees

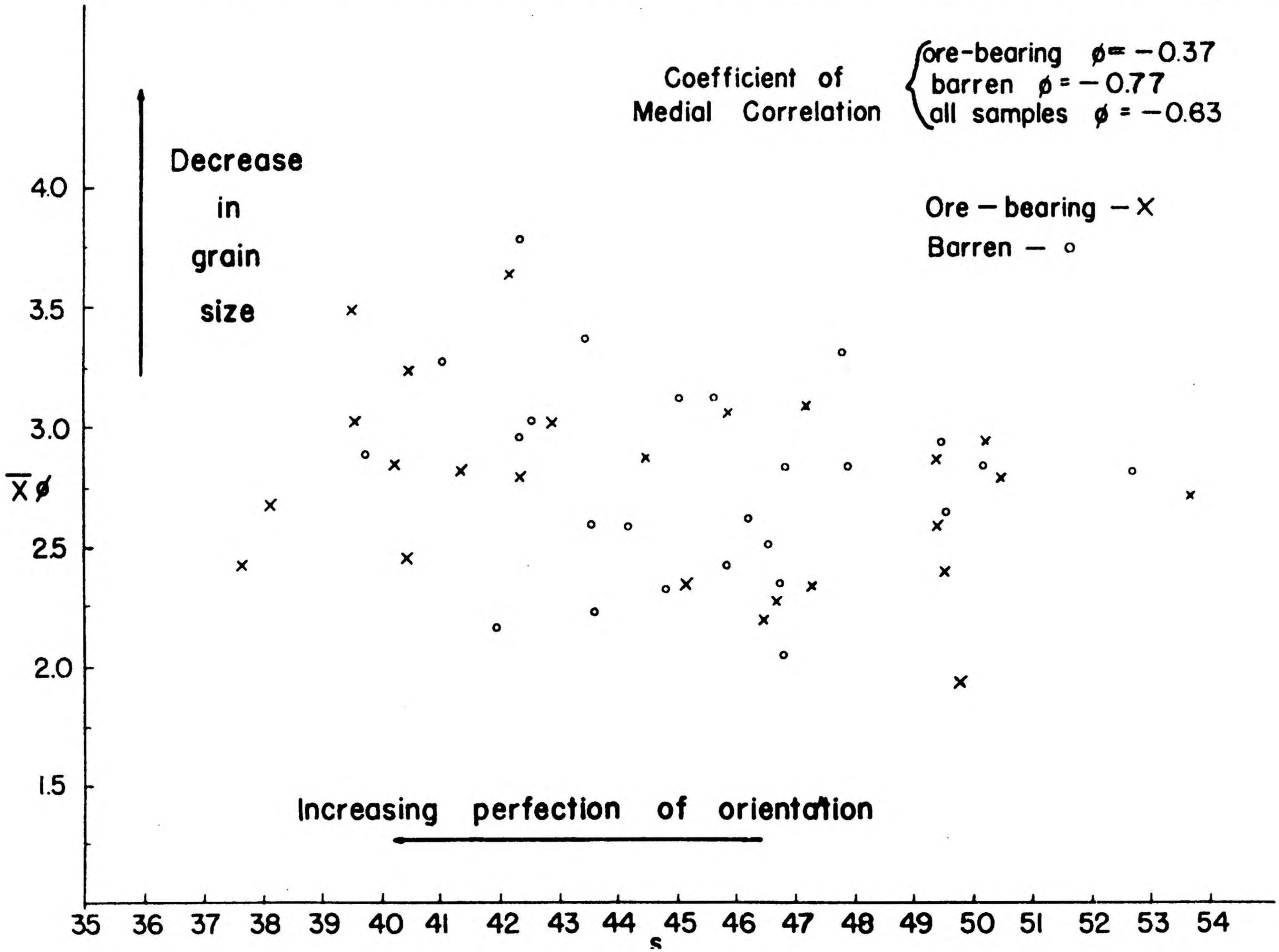


Fig. II - 14 Perfection of Orientation (s) versus Grain/Grain Contacts (Packing) in Per Cent

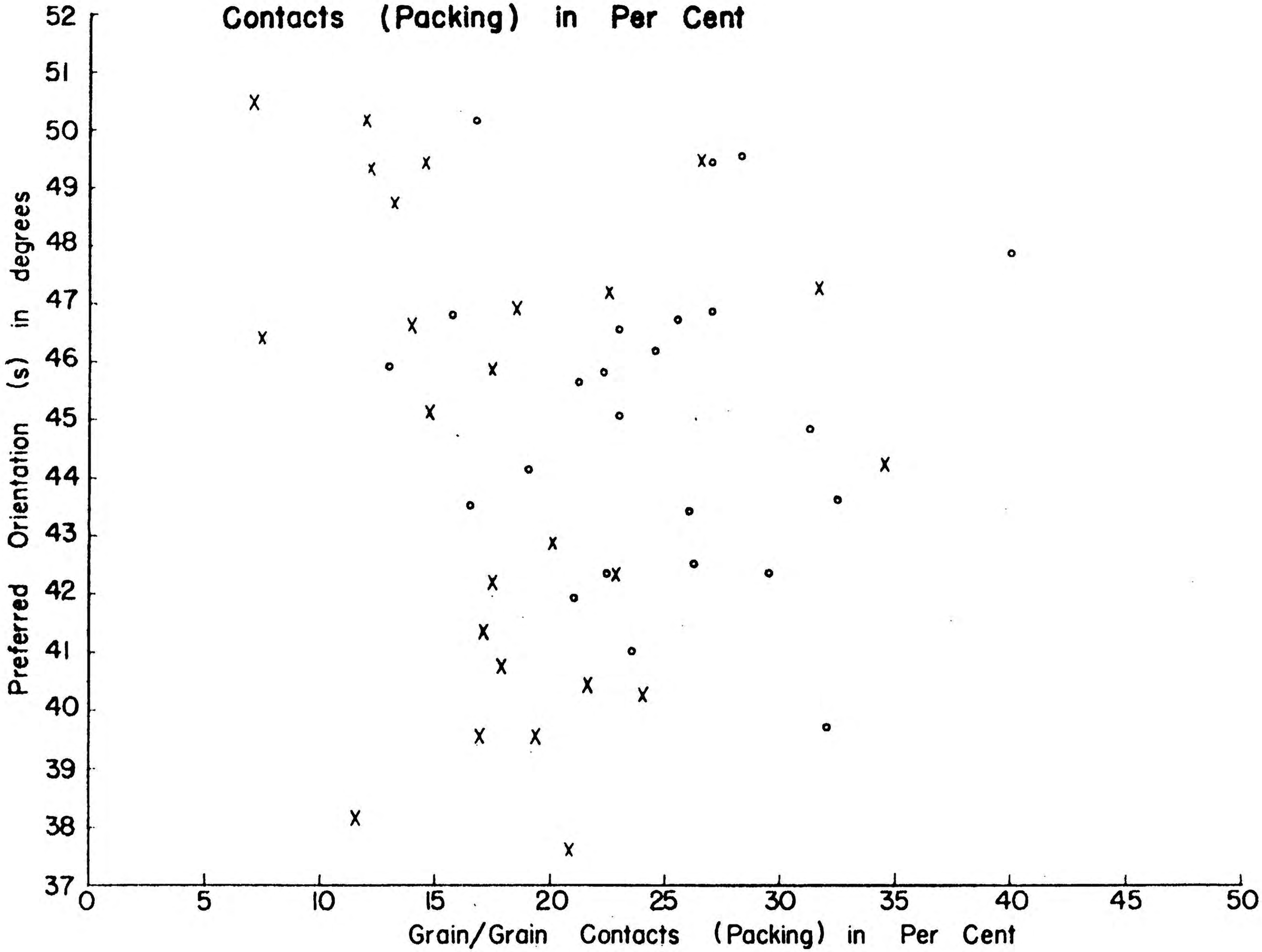


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Fig. II-15 - FREQUENCY HISTOGRAMS OF QUARTZ GRAIN ORIENTATION IN SOME ORE-BEARING SALT WASH SANDSTONES

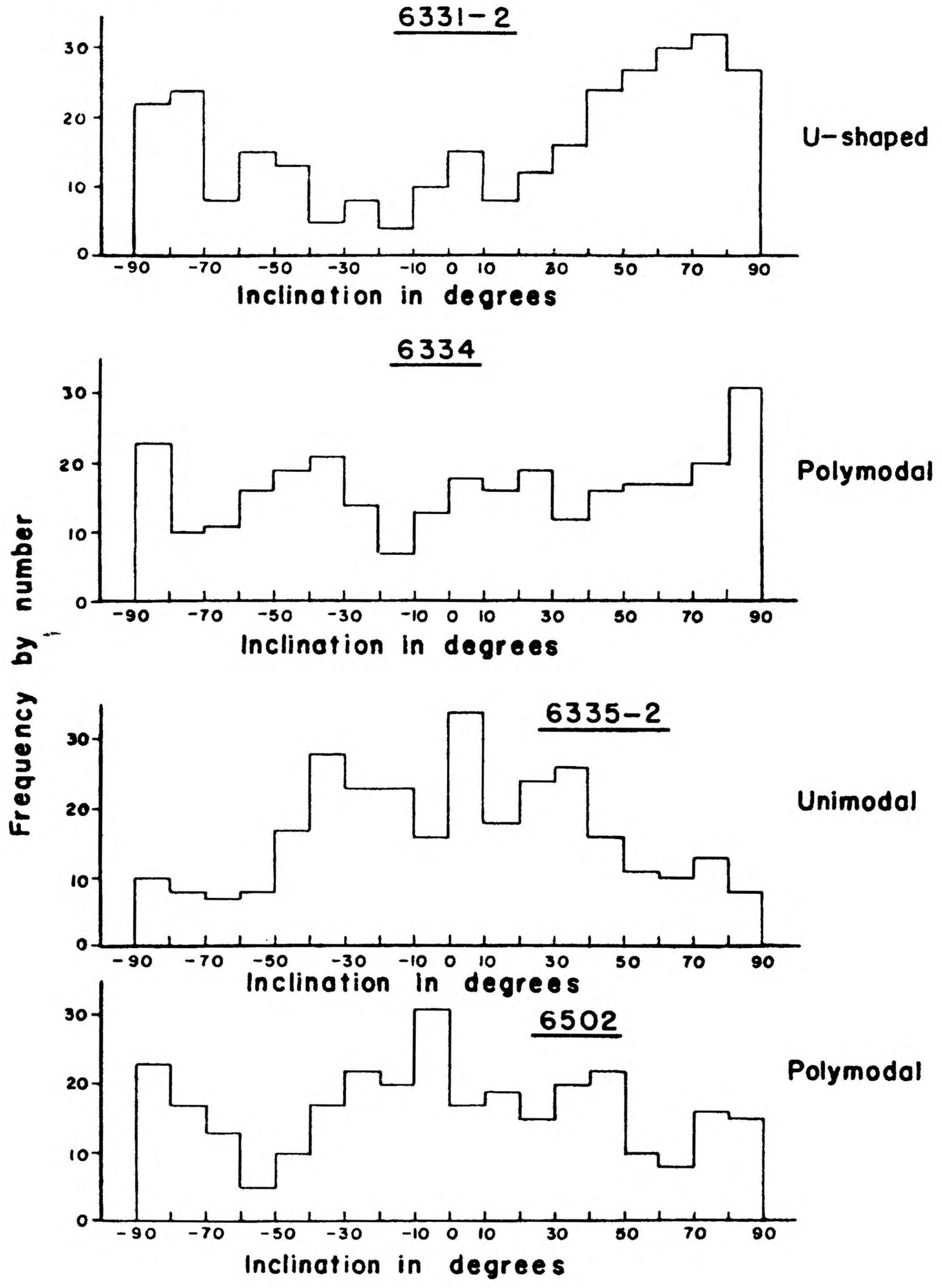

Fig. II-16 - FREQUENCY HISTOGRAMS OF QUARTZ GRAIN ORIENTATION IN SOME ORE-BEARING SALT WASH SANDSTONES

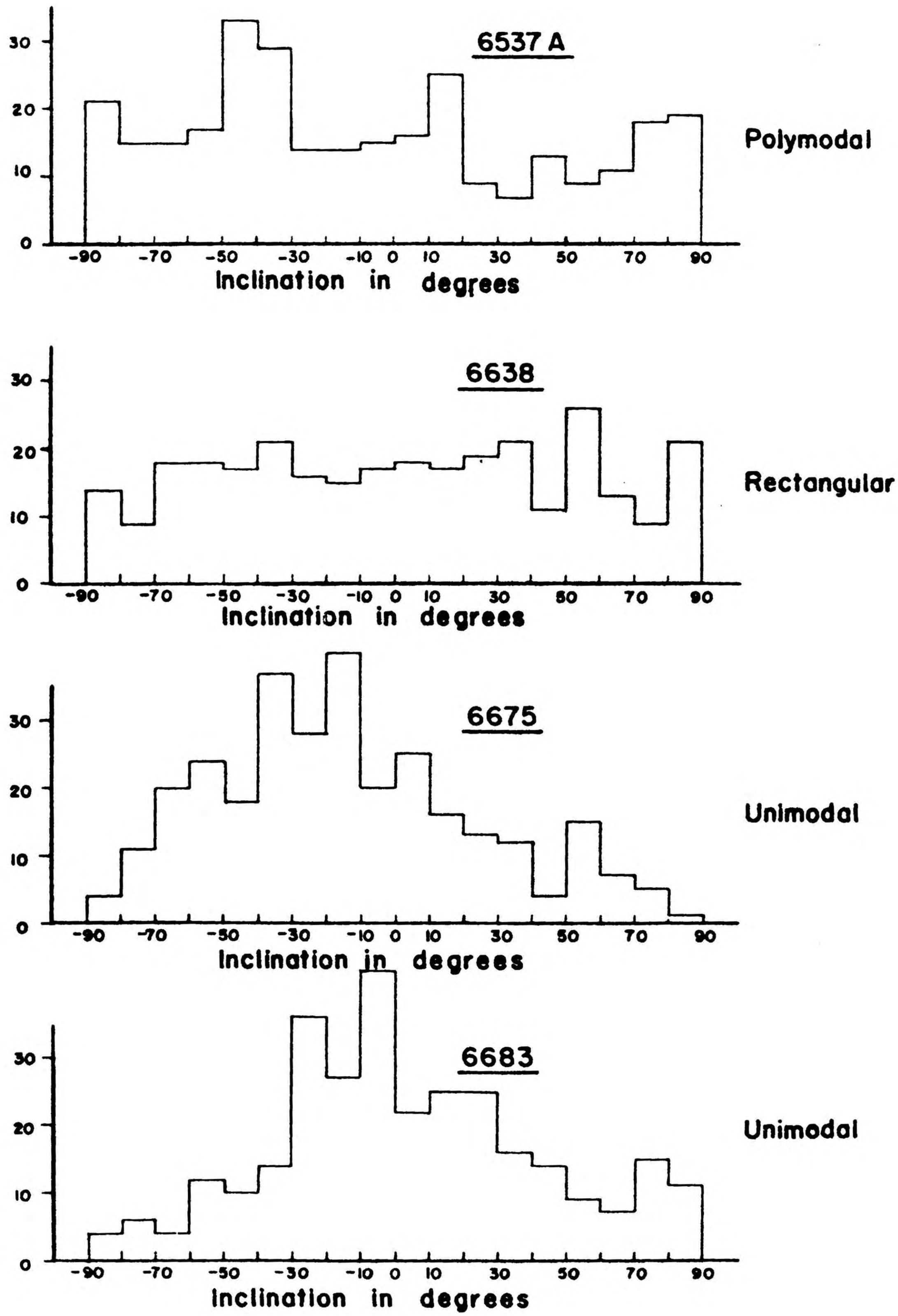

Fig. II-17 - FREQUENCY HISTOGRAMS OF QUARTZ GRAIN ORIENTATION IN SOME BARREN SALT WASH SANDSTONES

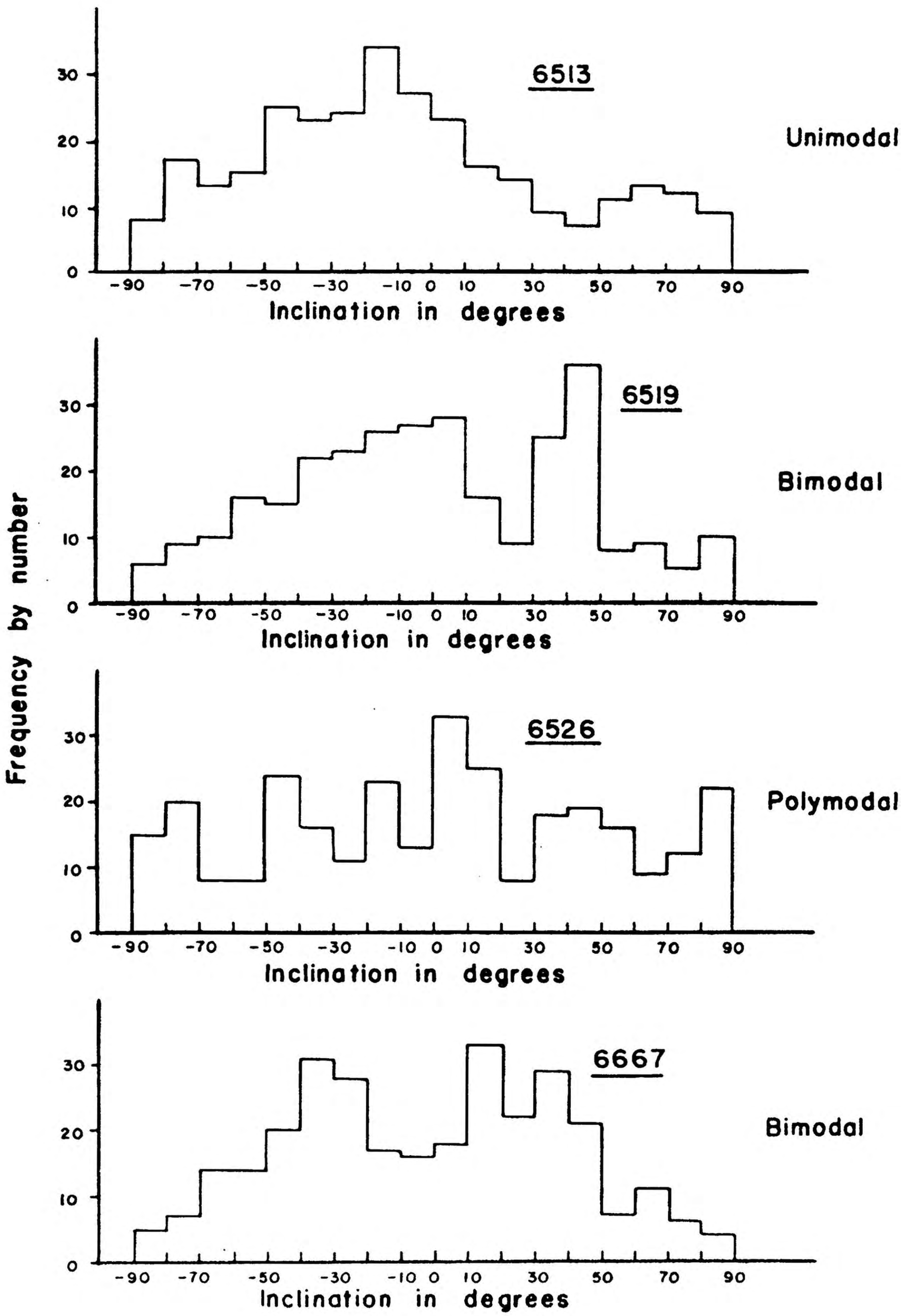

Table II-17. Summary Comparison of Some Measures of Orientation in Salt Wash Sandstones.

$P < 0.001 \quad \chi^2 = 13.815$

Sample No.	Visual Estimates Curve Description	Visual Estimates $\bar{X}$	Tukey $\bar{X}$	Tukey X^2	Isotropicity P	Minimum Variance $\bar{X}$	Minimum Variance s^2	(Chayes) s	Gini's G
6331-2	U-shape	70 to 80	-86.4	31.625	<<0.001	+76.33	1657.83	40.71	0.951
6334	U-shape (Polymodal)	80 to 90	-83.3	3.683	<20>10	78.3	2372.78	48.71	0.997
6335-2	Unimodal	0 to 10	+13.8	46.750	<<0.001	+ 2.37	1836.07	42.85	0.925
6336	Unimodal, skew(?)	10 to 20	+24.9	24.546	<<0.001	+22.43	2038.42	45.14	0.962
6500	Unimodal, skew(?)	-40 to -30	-37.0	29.112	<<0.001	-41.73	1634.00	40.42	0.955
6502	Polymodal	-10 to 0	+25.9	13.341	<01>001	-12.7	2440.17	49.39	0.981
6503A	U-shape	80 to 90	+87.2	31.331	<<0.001	+72.07	1794.73	42.36	0.951
6506	U-shape	80 to 90	-83.9	55.093	<<0.001	+81.67	1621.55	40.27	0.912
6536-2	U-shape	-90 to -80	-79.5	103.758	<<0.001	-80.83	1416.97	37.64	0.830
6537A	Polymodal - rect.	-40 to -30	-51.2	5.086	<10>5	-36.37	2176.31	46.65	0.995
6606	U-shape	80 to 90	-77.8	88.709	<<0.001	+87.5	1560.75	39.50	0.855
6607A	U-shape	-90 to -80	-76.9	29.924	<<0.001	+80.93	1977.43	44.23	0.953
6608	U-shape	80 to 90	-74.1	66.888	<<0.001	-84.60	1709.17	41.34	0.892
6610	Unimodal - rect.	20 to 30	+24.2	12.394	<01>001	+28.17	2450.30	49.50	0.983
6620	U-shape - rect.	70 to 80	-87.9	9.133	<02>01	+88.67	2236.88	47.29	0.988
6627-1	Unimodal, skew	20 to 30	+22.5	30.065	<0.001	+16.07	2159.29	46.46	0.970
6636	Rectangular	80 to 90	-88.3	2.468	530>20	+90.97	2438.06	49.38	0.999
6638	Rectangular	50 to 60	-32.4	0.208	>90	-16.17	2547.65	50.47	1.003
6644	Unimodal - skew	30 to 40	+28.1	14.094	<0.001	+24.37	2201.63	46.92	0.980
6646	U-shape	80 to 90	+84.1	35.045	<<0.001	+82.57	1778.48	42.17	0.945
6651	Rectangular	-30 to -20	+23.2	3.692	<20>10	-33.43	2518.53	50.18	0.997
6657	Unimodal	0 to 10	+11.8	21.706	<<0.001	- 0.33	2104.89	45.88	0.967
6671	U-shape - polymodal	60 to 70	-83.6	9.422	<01 001	+63.07	2226.25	47.19	0.988
6675	Unimodal, skew	-20 to -10	-12.6	50.219	<<0.001	-17.8	1452.83	38.12	0.920
6683	Unimodal, skew	-10 to 0	+ 9.3	81.50	<<0.001	+ 3.8	1563.23	[illegible]	0.868
6508	U-shape - polymodal	-80 to -70	-64.0	45.539	<<0.001	-64.4	1811.26	42.56	0.927
6510	Unimodal (?)	-20 to -10	+12.7	40.46	<<0.001	- 7.77	1884.68	43.41	0.936
6512	Unimodal	-30 to -20	- 6.7	22.49	<<0.001	-32.57	2105.75	45.88	0.966
6513	Unimodal	-20 to -10	-12.7	25.132	<<0.001	-20.43	1901.47	43.61	0.962
6514	Unimodal (?)	20 to 30	+ 7.9	20.187	<<0.001	+13.83	2086.97	45.68	0.970
6515	Rect. - polymodal	-10 to -	- 4.8	1.458	<50>30	- 1.93	2784.59	52.77	1.001
6519	Unimodal - Bimodal	0 to 10	+17.9	50.801	<<0.001	+ 0.30	1796.24	42.38	0.919
6520	U-shape	-70 to -60	-66.1	68.419	<<0.001	-76.63	1793.66	42.35	0.889
6521	Unimodal, skew	-20 to -10	+ 0.4	24.284	<0.001	-13.9	2009.79	44.83	0.963
6522A	Polymodal - rect.	0 to 10	+26.9	3.580	<20>10	+13.63	2441.80	49.41	0.997
6523	Unimodal skews	20 to 30	+24.2	107.282	<<0.001	+ 3.97	1579.26	39.74	0.825
6524	Unimodal	0 to 10	+12.2	22.765	<0.001	- 4.90	2134.32	46.20	0.965
6525	Unimodal	10 to 20	+18.8	41.016	<<0.001	+11.73	1894.67	43.53	0.935
6526	Polymodal - rect.	0 to 10	+19.6	6.767	<05>02	+10.33	2457.56	49.58	0.992
6527	Unimodal	10 to 20	+20.6	23.224	<<0.001	+11.67	2191.55	46.81	0.965
6528	Unimodal, skew	10 to 20	+21.1	35.231	<<0.001	+20.3	2182.91	46.72	0.945
6529	Polymodal	10 to 20	+ 8.9	16.706	<0.001	+ 7.93	2113.39	45.97	0.976
6530	Unimodal, skew	20 to 30	+32.2	15.031	<0.001	+34.87	1948.64	44.14	0.978
6531	Unimodal, skew	10 to 20	+11.2	24.516	<<0.001	+ 1.33	2031.89	45.08	0.963
6532	Polymodal	-10 to 0	+16.6	10.152	<01>001	+ 5.00	2290.67	47.86	0.986
6534	Unimodal, skew	0 to 10	- 6.5	50.628	<<0.001	+ 0.40	1762.17	41.98	0.919
6629	Polymodal	-20 to -10	-16.6	10.717	<01>001	-21.67	2168.89	46.57	0.985
6630	Polymodal	0 to 10	+ 8.6	2.103	<50>30	- 1.57	2519.21	50.19	0.9998
6662	Unimodal	-10 to 0	+19.9	22.219	<001	- 6.00	2197.67	46.88	0.966
6667	Bimodal	-10 to 0	+15.4	49.942	<<001	- 2.17	1684.97	41.05	0.920

A qualitative comparison of ore-bearing and barren samples by means of Fig. II-11 suggests that the same range in perfection of orientation is present in both ore-bearing and barren samples. This is confirmed by comparison of the frequency by number in two degree classes illustrated in table II-18. There is apparently little difference in degree of preferred orientation among ore-bearing and barren sandstones. There appears to be a few more samples with high degree of preferred orientation ($s < 42$ degrees) in ore-bearing than barren samples but this difference may be more apparent than real because of the few samples (25 in each group).

An approximate interpretation of the physical implications of the frequency distributions and their accompanying minimum variance standard deviations may be summarized as follows:-

U-shape frequency distributions arise from incorrect selection of the reference plane and after computing the minimum variance they yield a high degree of preferred orientation ($s < 45$ degrees) and approximately symmetrical unimodal frequency distributions. It may be inferred that these samples approach a homogeneous population with well-defined preferred orientation.

Rectangular frequency distributions possess minimum variance standard deviations of greater than 50 degrees and presumably imply random orientation of the grains. These samples may comprise slumped sediments in which original preferred orientation has been destroyed by disturbance of the sedimentary fabric shortly after deposition. Unfortunately this kind of a standard deviation would arise from incorrect sampling of a thin section composed of several 'strata' differing in direction of orientation but possessing high degrees of preferred orientation within each 'stratum' (see Fig. II-9D, p. 50).

Polymodal frequency distributions possess minimum variance standard deviations between those for U-shape and rectangular; presumably these distributions indicate more than one population ('stratum') each of which is differently oriented and each may possess a high degree of preferred orientation. Here again incorrect sampling may have inflated the standard deviation.

Finally unimodal distributions are, like U-shape distributions, indicative of homogeneously oriented populations and generally possess minimum variance standard deviation of less than 45 degrees. Skew unimodal are generally made symmetrical by minimum variance computation; again incorrect choice of reference plane is usually responsible for for the skewness.

It must be emphasized that without insurance of correct sampling and analysis of variance comparisons the interpretation of the total variance may be very misleading (see Griffiths and Rosenfeld, 1953).

Table II-18. Frequency Distribution of Preferred Orientation of Quartz Grains in Salt Wash Sandstones.

Class Limits	Ore-bearing Frequency	Ore-bearing Cumulative Frequency	Barren Frequency	Barren Cumulative Frequency	All Sands Frequency	All Sands Cumulative Frequency
36-38	1	1	-	-	1	1
38-40	3	4	1	1	4	5
40-42	4	8	2	3	6	11
42-44	3	11	6	9	9	20
44-46	3	14	5	14	8	28
46-48	4	18	7	21	11	39
48-50	4	22	2	23	6	45
50+	3	25	2	25	5	50
Total	25	25	25	25	50	50

C(vii) Interrelationships Between Quartz Grain Orientation and Other Petrographic Properties

The next step in the analysis of these data is to attempt to discover any inter-relationship among pairs of petrographic properties and to establish where possible that such inter-relationships are not the same in ore-bearing and barren sandstones. Inter-relationships of this kind may be assumed linear as a first approximation and the coefficient of medial correlation may be used as an indicator of degree of association between pairs of properties (Quenouille, 1952, p. 44). With $N = 25$ the coefficient of medial correlation must exceed $\pm$ 0.483 to be significant at the 5 per cent level and with $N = 50$ this coefficient must exceed $\pm$ 0.317 to be significant at the 5 per cent level (Quenouille, 1952, table V, p. 228).

Associations between grain orientation and various other petrographic properties expressed as coefficients of medial correlation are summarized in table II-19; the coefficients for ore-bearing, barren and the combined samples are included in the table.

C(viia) Quartz Grain Orientation and Mineral Composition of Salt Wash Sandstones

Three items of general importance in terms of mineral composition are compared with quartz grain orientation, namely the grains, matrix and cement components (see RME-3023, pp. 39-40 for explanation of these terms). The combined proportion of quartz and feldspar is used as an estimate of the volume of grains in these samples and its relationship to perfection of quartz grain orientation is expressed graphically in Fig. II-12.

There appears to be a trend of increasing quartz and feldspar content with increasing value of the standard deviation or alternately as quartz and feldspar content increases the perfection of orientation decreases. A number of ore-bearing samples tend to show a trend in the opposite direction i.e. as quartz and feldspar content decreases so does the perfection of orientation. These samples are probably slumped sediments.

For equal quartz and feldspar content the barren samples are generally less well oriented (possess a larger standard deviation) than the ore-bearing; this may be indirect confirmation of a difference in textural arrangement between ore-bearing (generally bedded) and barren (generally massive) sandstones observed in the field (RME-3070, p. 52 ff. -3106, p. 67 ff.). The coefficients of medial correlation are all non-significant and small and to establish any trend would require a very large number of samples.

Table II-19. Relationship Between Grain Orientation and Other Properties of Some Salt Wash Sandstones.

Perfection of Quartz Grain Orientation (s) versus	Coefficient of Medial Correlation: 25 Ore-bearing Samples	25 Barren Samples	50 Combined Samples
Quartz and Feldspar Per Cent	-0.17	+0.09	-0.04
Clay Pebbles and Matrix Per Cent	+0.04	-0.13	-0.12
Silica Cement Per Cent	-0.58*	-0.01	-0.10
Carbonate Cement Per Cent	+0.08	+0.04	+0.04
Silica and Carbonate Per Cent	-0.22	-0.04	0.00
Grain Size (a axis) $\bar{X}$ ϕ	-0.37	-0.27	-0.63*
Sorting (Size) s ϕ	-0.18	-0.27	-0.20
Grain/Grain Packing Per Cent	-0.36	+0.04	+0.08

*Significant at 5 per cent probability level.

The combined volume of clay pebbles and matrix used as an estimator of matrix material shows no relationship to quartz grain orientation (Table II-19). Similarly estimation of the volume of combined cements (silica and carbonate) show no obvious relationship to preferred grain orientation (Table II-19). In the case of silica alone, however, the ore-bearing samples yield a significant value of the coefficient of medial correlation (ϕ_c = -0.58; table II-19); the association is inverse, increasing silica cement accompanying decreasing standard deviation. This implies that the better oriented ore-bearing samples possess higher proportion of silica cement. There are of course many exceptions. The barren samples show no such relationship and a combination of two such different trends for the 50 samples is meaningless.

Carbonate cement taken alone shows no relationship to preferred orientation of the quartz grains.

C(viib) Quartz Grain Orientation and Other Textural Properties of Salt Wash Sandstones

Grain size expressed as the sample mean in phi units is inversely correlated with perfection of quartz grain orientation (Fig. II-13) i.e. as the phi mean increases the standard deviation of inclination decreases. This implies that as the grain size decreases perfection of orientation increases. Both ore-bearing and barren samples yield negative values of the coefficient of medial correlation (Table II-19) but they are not significant. Since, however, they are apparently homogeneous they may be combined and they then yield a coefficient which is significant at the 5 per cent level (ϕ_c = -0.63, table II-19).

Size-sorting expressed as the standard deviation in phi units shows a very poor relationship of the same kind as mean grain size but here the scatter is so large that the combined set of samples fails to yield a significant coefficient. The relationship suggests that sediments with poorer sorting yield higher perfection of orientation.

Grain to grain contacts are used as an estimate of packing and when these values are plotted against degree of preferred orientation once again the ore-bearing samples appear to behave differently from the barren samples (Fig. II-14).

In the ore-bearing samples the relationship is inverse, lower number of grain to grain contacts accompany increasing values of standard deviation in degrees. In other words in ore-bearing samples as the number of grain to grain contacts increases the degree of preferred orientation also improves. Barren samples show no such relationship and the association measured by the coefficient of medial correlation is near zero (Table II-19). Similarly the combined samples yield no relationship (ϕ_c = +0.08). Here again for equal packing index values the barren samples are (on the whole) less well oriented than the ore-bearing samples.

C(viii) Discussion

Grain orientation in ore-bearing and barren sediments effectively extends over similar ranges; however, when grain orientation is related to other petrographic properties it appears that the relationships among samples of ore-bearing sediments are different from those in barren samples.

This feature serves to emphasize that differences between ore-bearing and barren sediments in terms of any petrographic property are small and that such differences are best evaluated by studying simultaneous variation in a number of properties. The local inter-relationships within small volumes of sediments appears more important than any large scale regional factor.

Appendix I Examples of Grain Orientation Measurement in Salt Wash Sandstones

Twelve examples of grain orientation measurement in Salt Wash sandstones are summarized in Table II-20 and Figs. II-15, 16, 17. Eight of these samples are ore-bearing and four are barren sandstones.

The frequency histograms are reasonably representative of the results obtained in plotting the raw data as described under section C(iv), p. 51. U-shaped frequency histograms represent well oriented samples with reference lines at the extremes of the range. It is necessary to compute the minimum variance origin for these distributions to characterize the orientation. Unimodal distributions, when they are symmetrical around zero inclination yield the minimum variance directly; when assymetric (sample no. 6675 for example) it is necessary to compute the minimum variance.

Polymodal distributions are treated in the same manner and a minimum variance computed but here there is some question whether the minimum variance is representative. Polymodal distributions may be a function of incorrect sampling and may reflect the presence of uniform sub-populations in the thin section.

Rectangular distributions imply absence of orientation i.e. randomness or isotropic fabric. The exact physical meaning of a random fabric is not obvious but may in some cases rise from disturbance of the original depositional fabric.

The computed minimum variance and test for isotropicity are summarized in Table II-17.

Table II-20. Frequency Distributions of Quartz Grain Inclinations from 12 Selected Samples of Salt Wash Sandstones.

	Ore-bearing								Barren			
Class Limits	6331-2	6334	63352	6502	6537A	6638	6675	6683	6513	6519	6526	6667
-90 to -80	22	23	10	23	21	14	4	4	8	6	15	5
-80 to -70	24	10	8	17	15	9	11	6	17	9	20	7
-70 to -60	8	11	7	13	15	18	20	4	13	10	8	14
-60 to -50	15	16	8	5	17	18	24	12	15	16	8	14
-50 to -40	13	19	17	10	33	17	18	10	25	15	24	20
-40 to -30	5	21	28	17	29	21	37	14	23	22	16	31
-30 to -20	8	14	23	22	14	16	28	36	24	23	11	28
-20 to -10	4	7	23	20	14	15	40	27	34	26	23	16
-10 to 0	10	13	16	31	15	17	20	43	27	27	13	15
0 to 10	15	18	34	17	16	18	25	22	23	28	33	17
10 to 20	8	16	18	19	25	17	16	25	16	16	25	33
20 to 30	12	19	24	15	9	19	13	25	14	9	8	22
30 to 40	16	12	26	20	7	21	12	16	9	25	18	29
40 to 50	24	16	16	22	13	11	4	14	7	36	19	21
50 to 60	27	17	11	10	9	26	15	9	11	8	16	7
60 to 70	30	17	10	8	11	13	7	7	13	9	9	11
70 to 80	32	20	13	16	18	9	5	15	12	5	12	6
80 to 90	27	31	8	15	19	21	1	11	9	10	22	4
Total	300	300	300	300	300	300	300	300	300	300	300	300

Appendix II Tukey's Isotropicity Test

Because of the difficulty of deciding how to test the orientation fabric of sediments by the usual tests (Fairbairn, 1942; Griffiths and Rosenfeld, 1950, 1953), Tukey proposed a special test for isotropicity. The isotropic model, a rectangular frequency distribution, is chosen as base and in place of computing the entire set of departures from randomness and then using the total chi-square Tukey proposes the use of only the two degrees of freedom which form the main contribution to the chi-square.

The procedure comprises a change of scale to polar co-ordinates and the routine is easiest to carry out by means of a tabular arrangement (Table II-21, a, b, c, d). The factors

$$C = \frac{\Sigma\ x \cos 2\theta}{(\Sigma \cos^2 2\theta)^{1/2}} \quad \text{and } S = \frac{\Sigma\ x \sin 2\theta}{(\Sigma \sin^2 2\theta)^{1/2}}$$

are the basis for the test of isotropicity.

For a fixed number of measurements per thin section it is convenient to arrange the computation tabularly; column 1 of Table II-21 a-d contains the class limits, column 2 the observed frequency (obs), column 3 the expected frequency for the isotropic case (exp = 300/18 = 16.67 in the present example). Column 4 lists the deviation of observed from the expected (O-E). In column 5 the deviation is reduced to standard measure; x = (O-E/ E). Column 6 lists the angular value of each class; columns 7 and 8 the corresponding values in polar co-ordinates. The denominators of the C and S factors may be calculated once for all for a fixed class interval; in the Salt Wash investigation they are $(\Sigma \cos^2 2\theta)^{\frac{1}{2}} = 2.993$ and $(\Sigma \sin^2 2\theta)^{\frac{1}{2}} = 2.992$. The relevant sums ($\Sigma\ x \cos 2\theta$ and $\Sigma\ x \sin 2\theta$) are accumulated on an automatic calculator and the factors C and S derived.

Tukey then proposes that $C^2 + S^2$ be treated as chi-square with 2 degrees of freedom and the results of the test are expressed as a probability value (P). The actual values of chi-square for this test are:-

Probability Level	P_{05}	P_{01}	P_{001}
Chi-square (d.f. = 2)	5.991	9.210	13.815

and the observed sum of squares $(C^2 + S^2)$ must exceed these values to reflect a significant departure from random orientation.

Tukey further points out that a mean may be obtained from these values and this computation is included in the examples Tables II-21 a-d. It comprises calculating tan 2θ = S/C and obtaining the signum of sin 2θ = signum S. These two values determine the angle which represents the mean inclination for the sample.

Four examples of such procedure taken from the samples in Appendix I are included by way of illustration. The results of the tests for all 50 samples are summarized in Table II-17.

Table II-21a. Tukey's Isotropicity Test for Sample No. 6331-2 in the Salt Wash Sandstones.

$\sqrt{E} = 4.0824$; $1/\sqrt{E} = 0.2450$ Remarks: Ore-bearing, U-shaped

Class Limits	Obs.	N = 300 Exp.	O-E	x (O-E)/$\sqrt{E}$	Θ	Cos 2Θ	Sin 2Θ
-90 to -80	22	16.67	5.33	+1.306	0	1.00	0.00
-80 to -70	24	16.67	7.33	+1.796	10	0.94	0.34
-70 to -60	8	16.67	- 8.67	-2.124	20	0.76	0.64
-60 to -50	15	16.67	- 1.67	-0.409	30	0.50	0.87
-50 to -40	13	16.67	- 3.67	-0.899	40	0.17	0.98
-40 to -30	5	16.67	-11.67	-2.859	50	-0.17	0.98
-30 to -20	8	16.67	- 8.67	-2.124	60	-0.50	0.87
-20 to -10	4	16.67	-12.67	-3.104	70	-0.76	0.64
-10 to 0	10	16.67	- 6.67	-1.634	80	-0.94	0.34
0 to 10	15	16.67	- 1.67	-0.409	90	-1.00	0.00
10 to 20	8	16.67	- 8.67	-2.124	100	-0.94	-0.34
20 to 30	12	16.67	- 4.67	-1.144	110	-0.76	-0.64
30 to 40	16	16.67	- 0.67	-0.164	120	-0.50	-0.87
40 to 50	24	16.67	7.33	+1.796	130	-0.17	-0.98
50 to 60	27	16.67	10.33	+2.531	140	0.17	0.98
60 to 70	30	16.67	13.33	+3.266	150	0.50	0.86
70 to 80	32	16.67	15.33	+3.756	160	0.76	0.64
80 to 90	27	16.67	10.33	+2.531	170	0.94	0.34
Total	300	300	-	-	-	-	-

$\Sigma \cos^2 2\theta = 8.9604$ $\Sigma \sin^2 2\theta = 8.9527$ $\Sigma x \cos 2\theta = +16.8144$

$\sqrt{\cos^2 2\theta} = 2.993$ $\sqrt{\sin^2 2\theta} = 2.992$ $\Sigma x \sin 2\theta = -0.7890$

$$C = \frac{\Sigma x \cos 2\theta}{(\Sigma \cos^2\theta)1/2} = \frac{16.8144}{2.993} = 5.6179$$

$C^2 + S^2 = 31.630 = \chi^2$ (20.f)

P $\ll$ 0.001

$$S = \frac{\Sigma x \sin 2\theta}{(\Sigma \sin^2\theta)1/2} = \frac{-0.7890}{2.992} = -0.2637$$

$\tan 2\theta_o = S/C = -0.0469$

sgn $\sin 2\theta_o$ = sgn S = -ve

and therefore $2\theta_o = 357.3\theta = 178.7$

(330-360)

$\bar{X} = -85 + 178.7 = 93.7$

Table II-21b. Tukey's Isotropicity Test for Sample No. 6335-2 in the Salt Wash Sandstones.

$\sqrt{E} = 4.0824$; $1/\sqrt{E} = 0.2450$ Remarks: Ore-bearing, unimodal

Class Limits	Obs.	N = 300 Exp.	O-E	x (O-E)/$\sqrt{E}$	Θ	Cos 2Θ	Sin 2Θ
-90 to -80	10	16.67	- 6.67	-1.634	0	1.00	0.00
-80 to -70	8	16.67	- 8.67	-2.124	10	0.94	0.34
-70 to -60	7	16.67	- 9.67	-2.369	20	0.76	0.64
-60 to -50	8	16.67	- 8.67	-2.124	30	0.50	0.87
-50 to -40	17	16.67	+ 0.33	+0.081	40	0.17	0.98
-40 to -30	28	16.67	+11.33	+2.776	50	-0.17	0.98
-30 to -20	23	16.67	+ 6.33	+1.551	60	-0.50	0.87
-20 to -10	23	16.67	+ 6.33	+1.551	70	-0.76	0.64
-10 to 0	16	16.67	- 0.67	-0.164	80	-0.94	0.34
0 to 10	34	16.67	+17.33	+4.246	90	-1.00	0.00
10 to 20	18	16.67	+ 1.33	+0.326	100	-0.94	-0.34
20 to 30	24	16.67	+ 7.33	+1.796	110	-0.76	-0.64
30 to 40	26	16.67	+ 9.33	+2.286	120	-0.50	-0.87
40 to 50	16	16.67	- 0.67	-0.164	130	-0.17	-0.98
50 to 60	11	16.67	- 5.67	-1.389	140	0.17	0.98
60 to 70	10	16.67	- 6.67	-1.634	150	0.50	0.86
70 to 80	13	16.67	- 3.67	-0.899	160	0.76	0.64
80 to 90	8	16.67	- 8.67	-2.124	170	0.94	0.34
Total	300	300	-	-	-	-	-

$\Sigma \cos^2 2\theta = 8.9604$ $\Sigma \sin^2 2\theta = 8.9527$ $\Sigma x \cos 2\theta = -19.5167$

$\sqrt{\cos^2 2\theta} = 2.993$ $\sqrt{\sin^2 2\theta} = 2.992$ $\Sigma x \sin 2\theta = -6.15245$

$$C = \frac{\Sigma x \cos 2\theta}{(\Sigma \cos^2\theta)1/2} = -6.5208$$

$$C^2 + S^2 = 46.7492 = \chi^2 \text{ (2d.f)}$$

$$P \ll 0.001$$

$$S = \frac{\Sigma x \sin 2\theta}{(\Sigma \sin^2\theta)1/2} = -2.0563$$

$\tan 2\theta_0 = S/C = 0.3153$
sgn $\sin 2\theta_0$ = sgn S = -ve
and therefore $2\theta_0 = 197.5\theta = 98.8^\circ$

$\bar{X} = -85 + 98.8 = 13.8^\circ$

Table II-21. Tukey's Isotropicity Test for Sample No. 6537A in the Salt Wash Sandstones.

$\sqrt{E} = 4.0824$; $1/\sqrt{E} = 0.2450$ Remarks: Ore-bearing, polymodal

Class Limits	Obs.	N = 300 Exp.	O-E	x $(O-E)/\sqrt{E}$	θ	Cos 2θ	Sin 2θ
-90 to -80	21	16.67	+ 4.33	+1.061	0	1.00	0.00
-80 to -70	15	16.67	- 1.67	-0.409	10	0.94	0.34
-70 to -60	15	16.67	- 1.67	-0.409	20	0.76	0.64
-60 to -50	17	16.67	+ 0.33	+0.081	30	0.50	0.87
-50 to -40	33	16.67	+16.33	+4.001	40	0.17	0.98
-40 to -30	29	16.67	+12.33	+3.021	50	-0.17	0.98
-30 to -20	14	16.67	- 2.67	-0.654	60	-0.50	0.87
-20 to -10	14	16.67	- 2.67	-0.654	70	-0.76	0.64
-10 to 0	15	16.67	- 1.67	-0.409	80	-0.94	0.34
0 to 10	16	16.67	- 0.67	-0.164	90	-1.00	0.00
10 to 20	25	16.67	+ 8.33	+2.041	100	-0.94	-0.34
20 to 30	9	16.67	- 7.67	-1.879	110	-0.76	-0.64
30 to 40	7	16.67	- 9.67	-2.369	120	-0.50	-0.87
40 to 50	13	16.67	- 3.67	-0.899	130	-0.17	-0.98
50 to 60	9	16.67	- 7.67	-1.879	140	0.17	0.98
60 to 70	11	16.67	- 5.67	-1.389	150	0.50	0.86
70 to 80	18	16.67	+ 1.33	+0.326	160	0.76	0.64
80 to 90	19	16.67	+ 2.33	+0.571	170	0.94	0.34
Total	300	300	-	-	-	-	-

$\Sigma \cos^2 2\theta = 8.9604$ $\Sigma \sin^2 2\theta = 8.9527$ $\Sigma x \cos 2\theta = 2.562700$

$\sqrt{\Sigma \cos^2 2\theta} = 2.993$ $\sqrt{\sin^2 2\theta} = 2.992$ $\Sigma x \sin 2\theta = 6.2421$

$$C = \frac{\Sigma x \cos 2\theta}{(\Sigma \cos^2 \theta)^{1/2}} = \frac{2.5627}{2.993} = 0.8562$$

$$S = \frac{\Sigma x \sin 2\theta}{(\Sigma \sin^2 2\theta)^{1/2}} = \frac{6.2421}{2.992} = 2.0863$$

$C^2 + S^2 = 5.0857 = X^2$ (d.f.)[1]

$P > 0.05$

$\tan 2\theta° = S/C = 2.4367$

sgn Sin 2θ = sgn S = +

and therefore $2\theta_o = 67.7\theta = 33.85$

$\bar{X} = -85 + 33.85 = -51.15$

[1] d.f. = degrees of freedom

Table II-21d. Tukey's Isotropicity Test for Sample No. 6513 in the Salt Wash Sandstones.

$\sqrt{E}$ = 4.0824; $1/\sqrt{E}$ = 0.2450 Remarks: Barren; unimodal

Class Limits	Obs.	N = 300 Exp.	0-E	x $(0-E)/\sqrt{E}$	θ	Cos 2θ	Sin 2θ
-90 to -80	8	16.67	- 8.67	-2.124	0	1.00	0.00
-80 to -70	17	16.67	+ 0.33	+0.081	10	0.94	0.34
-70 to -60	13	16.67	- 3.67	-0.899	20	0.76	0.64
-60 to -50	15	16.67	- 1.67	-0.409	30	0.50	0.87
-50 to -40	25	16.67	+ 8.33	+2.041	40	0.17	0.98
-40 to -30	23	16.67	+ 6.33	+1.551	50	-0.17	0.98
-30 to -20	24	16.67	+ 7.33	+1.796	60	-0.50	0.87
-20 to -10	34	16.67	+17.33	+4.246	70	-0.76	0.64
-10 to 0	27	16.67	+10.33	+2.531	80	-0.94	0.34
0 to 10	23	16.67	+ 6.33	+1.551	90	-1.00	0.00
10 to 20	16	16.67	- 0.67	-0.164	100	-0.94	-0.34
20 to 30	14	16.67	- 2.67	-0.654	110	-0.76	-0.64
30 to 40	9	16.67	- 7.67	-1.879	120	-0.50	-0.87
40 to 50	7	16.67	- 9.67	-2.369	130	-0.17	-0.98
50 to 60	11	16.67	- 5.67	-1.389	140	0.17	0.98
60 to 70	13	16.67	- 3.67	-0.899	150	0.50	0.86
70 to 80	12	16.67	- 4.67	-1.144	160	0.76	0.64
80 to 90	9	16.67	- 7.67	-1.879	170	0.94	0.34
Total	300	300	-	-	-	-	-

$\Sigma \cos^2 2\theta = 8.9604$ $\Sigma \sin^2 2\theta = 8.9527$ $\Sigma x \cos 2\theta = 12.2353$

$\sqrt{\cos^2 2\theta} = 2.993 = -4.0880$ $\sqrt{\sin^2 2\theta} = 2.992$ $\Sigma x \sin 2\theta = +8.6823$

$$C = \frac{\Sigma x \cos 2\theta}{(\Sigma \sin^2\theta)^{1/2}} = +2.9018$$

$$c^2 + s^2 = 25.132 = \chi^2 \text{ (2d.f.)}$$

$P \ll 0.001$

$$S = \frac{\Sigma x \sin 2\theta}{(\Sigma \sin^2\theta)^{1/2}}$$

$\tan 2\theta_o = S/C = -0.7098$

sgn $\sin 2\theta_o = +$

and therefore $2\theta_o = -35.40 = -17.7$

$\bar{X} = -85 - 17.7 = -102.7 + 90$

Appendix III Gini's Mean Squared Difference

In following the development of measures of orientation Tukey further proposes a number of approaches to the estimation of measures of concentration of orientation which are vitally necessary to the study and comparison of grain orientations in sediments. One such factor is Gini's mean squared difference (G).

The computation of G when the expected value for the frequency of orientation is constant becomes (Tukey, op. cit., p. 5):-

$$G = \frac{n}{n-1} - \frac{\exp}{n(n-1)} (\Sigma \text{ Cos}^2 2\theta)^{1/2} \quad (\Sigma \text{ Sin}^2 2\theta)^{1/2} \; (C^2 + S^2)$$

All the factors in this equation will remain the same throughout the present investigation except for $C^2 + S^2 = X^2$. Hence this computation may be reduced to a very simple operation:-

$$G = \frac{300}{299} - \frac{16.67}{89700} (2.993)(2.992)(C^2 + S^2)$$

$$= 1.0033 - (0.001666)(C^2 + S^2)$$

By way of example if we take the value of $(C^2 + S^2)$ for sample no. 6331-2 we have:-

$$G = 1.0033 - 0.001666 \times 31.63 = 0.950649$$

The value of G for each of the 50 samples is summarized in Table II-17.

As a matter of interest we may now compare the value of Gini's mean squared difference (G) with the computed minimum variance (after Chayes, op. cit.) as in Fig. II-18. Ignoring the extreme deviations[1] there appears to be a relatively simple relationship between the minimum variance and Gini's G.

It may be noted that on the basis of the minimum variance standard deviation (s) more samples would be considered not to possess a significant orientation than by using Gini's G, otherwise the results of both are very similar.

[1] These may be due to miscalculation although careful checking failed to find any obvious errors.

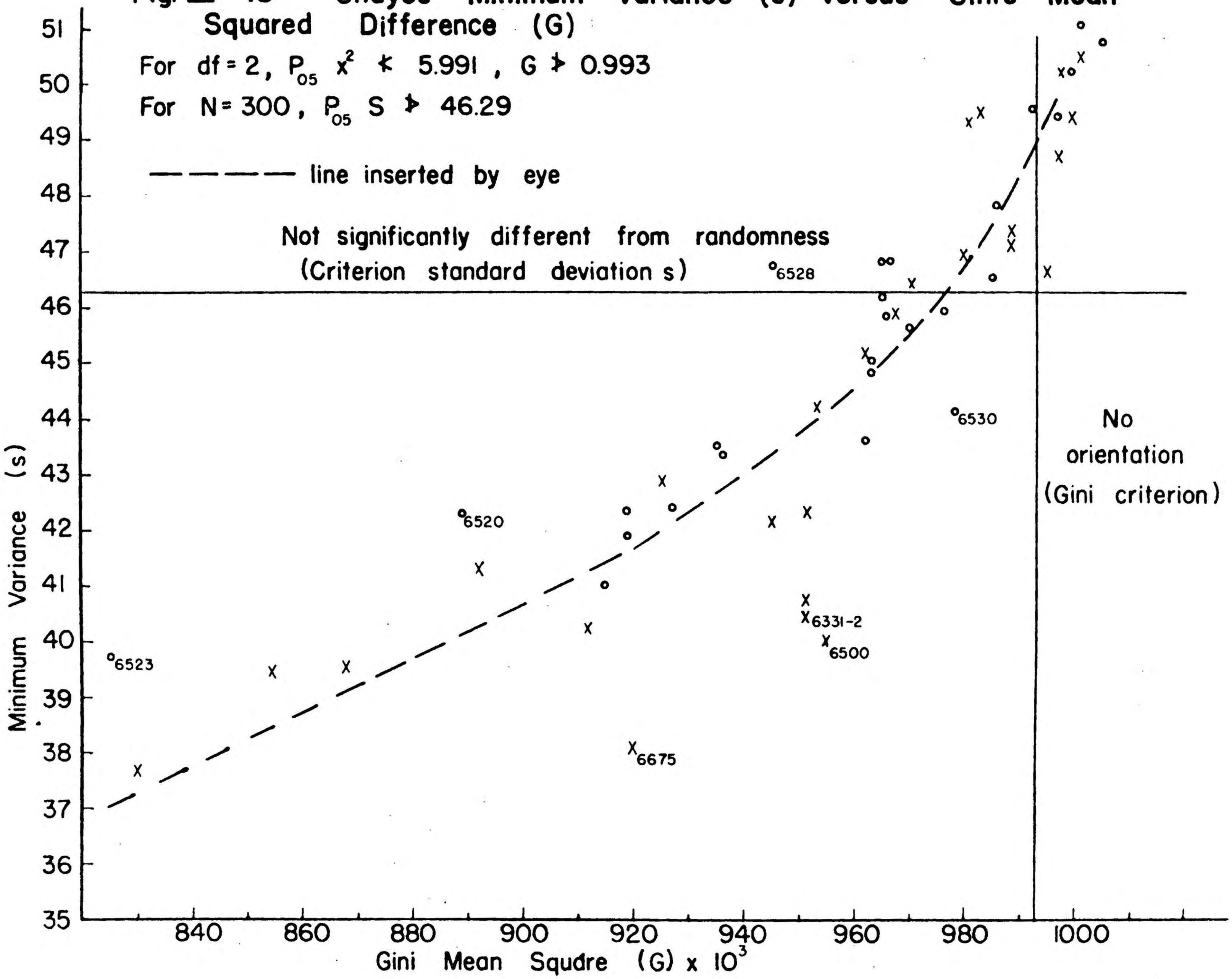

Fig. II – 18 Chaye's Minimum Variance (s) versus Gini's Mean Squared Difference (G)

Appendix IV Chayes Minimum Variance Computation

The procedure for locating the minimum variance origin has been described in detail by Chayes (1954) and three examples of the computation are included to indicate the routine.

One feature of note appears to be that whereas Chayes states that the minimum variance origin is represented by the maximum negative value of the variance indicator (I_V) we find in Salt Wash investigation that the maximum positive variance indicator (I_v) yields the minimum variance value. Presumably this may be connected with our different class limits and negative scale.

Table II-22a. Minimum Variance Origin for Sample No. 6331-2.

N = 300 R = 180

Lower Class Limit	Freq. F	Cum. S(F)	Cum. S(F)(Xa)	$\bar{X}a$	$(\bar{X}a-\bar{X}_1)$	Na/N Ka	(1-Ka)	R/2(1-Ka)	$(\bar{X}a-\bar{X}_1)$ +R/2(1-Ka)	Ka(10)
-80	22	22	-1760	-80.0	-98.9	0.07	0.93	83.7	-15.2	1.064-
-70	24	46	-3440	74.8	-93.7	0.15	0.85	76.5	-17.2	2.580-
-60	8	54	-3920	72.6	-91.5	0.18	0.82	73.8	-17.7	3.186-
-50	15	69	-4670	67.7	-86.6	0.23	0.77	69.3	-17.3	3.979-
-40	13	82	-5190	63.2	-82.1	0.27	0.73	65.7	-16.4	4.428-
-30	5	87	-5340	61.4	-80.3	0.29	0.71	63.9	-16.4	4.756-
-20	8	95	-5500	57.9	-76.8	0.32	0.68	61.2	-15.6	4.992-
-10	4	99	-5540	55.9	-74.8	0.33	0.67	60.3	-14.5	4.785-
- 0	10	109	-5540	50.8	-69.7	0.36	0.64	57.6	-12.1	4.356-
10	15	124	-5390	43.5	-62.4	0.41	0.59	53.1	- 9.3	3.813-
20	8	132	-5230	39.6	-58.5	0.44	0.56	50.4	- 8.1	3.564-
30	12	144	-4870	33.8	-52.7	0.48	0.52	46.8	- 5.9	2.832-
40	16	160	-4230	26.4	-45.3	0.53	0.47	42.3	- 3.0	1.590-
50	24	184	-3030	16.5	-35.4	0.61	0.39	35.1	- 0.3	0.183-
60	27	211	-1410	6.7	-25.6	0.70	0.30	27.0	+ 1.4	0.980+
70	30	241	+ 690	+ 2.9	-16.0	0.80	0.20	18.0	+ 2.0	1.600+
80	32	273	+3250	11.9	- 7.0	0.91	0.09	8.1	+ 1.1	1.001+
90	27	300	+5680	18.9	0.00	1.00	0.00	0.00	0.00	0.00

Minimum variance origin is max. negative value of $I_v = K_a[(\bar{X}_a-\bar{X}_1) + 90(1-K_a)]$ = -4.992 (-30 to -20 class)

Maximum variance origin is max. positive value of $I_v = K_a[(\bar{X}_a-X_1) + 90(1-K_a)]$ = +1.600 (60 to 70 class)

Table II-22b. Minimum Variance Origin for Sample No. 6675.

N = 300 R = 180

Lower Class Limit	Freq. F	Cum. S(F)	Cum. S(F)(Xa)	$\bar{X}a$	$(\bar{X}a-\bar{X}_1)$	Na/N Ka	(1-Ka)	R/2(1-Ka)	$(\bar{X}a-\bar{X}_1)$ +R/2(1-Ka)	Ka(10)
-80	4	4	- 320	-80.0	-70.8	0.01	0.99	89.1	+18.3	0.183+
-70	11	15	-1090	-72.7	-63.5	0.05	0.95	85.5	+22.0	1.100+
-60	20	35	-2290	-65.4	-56.2	0.12	0.88	79.2	+23.0	2.760+
-50	24	59	-3490	-59.2	-50.0	0.20	0.80	72.0	+22.0	4.400+
-40	18	77	-4210	-54.7	-45.5	0.26	0.74	66.6	+21.1	5.486+
-30	37	114	-5320	-46.7	-37.5	0.38	0.62	55.8	+18.3	6.454+
-20	28	142	-5380	-41.4	-32.2	0.47	0.53	47.7	+15.5	7.285+
-10	40	182	-6280	-34.5	-23.3	0.61	0.39	35.1	+11.8	7.198+
- 0	20	202	-6280	-31.1	-21.9	0.67	0.33	29.7	+ 7.8	5.226+
10	25	227	-6030	-26.6	-17.4	0.76	0.24	21.6	+ 4.2	3.192+
20	16	243	-5710	-23.5	-14.3	0.81	0.19	17.1	+ 2.8	2.268+
30	13	256	-5320	-20.8	-11.6	0.85	0.15	13.5	+ 1.9	1.615+
40	12	268	-4840	-18.1	- 8.9	0.89	0.11	9.9	+ 1.0	0.890+
50	4	272	-4640	-17.1	- 7.9	0.91	0.09	8.1	+ 0.2	0.182+
60	15	287	-3746	-13.0	- 3.8	0.96	0.04	3.6	- 0.2	0.192-
70	7	294	-3250	-11.1	- 1.9	0.98	0.02	1.8	- 0.1	0.098-
80	5	299	-2850	- 9.5	- 0.3	0.996	0.004	0.4	+ 0.1	0.010-
90	1	300	-2760	- 9.2	0.00	1.00	0.00	0.00	0.00	0.00

Minimum variance origin is max. negative value of $I_v = K_a\left[(\bar{X}_a-\bar{X}_1) + 90(1-K_a)\right] =$
-0.279 (50 to 60 class)

Maximum variance origin is max. positive value of $I_v = K_a\left[(\bar{X}_a-\bar{X}_1) + 90(1-K_a)\right] =$
+1.653 (-30 to -20 class)

Table II-22c. Minimum Variance Origin for Sample No. 6526.

N = 300 R = 180

Lower Class Limit	Freq. F	Cum. S(F)	Cum. S(F)(Xa)	$\bar{X}a$	$(\bar{X}a-\bar{X}_1)$	Na/N Ka	(1-Ka)	R/2(1-Ka)	$(\bar{X}a-\bar{X}_1)$ +R/2(1-Ka)	Ka(10)
-80	15	15	-1200	-80.0	-86.3	0.05	0.95	85.5	-0.80	-0.04
-70	20	35	-2600	-74.3	-80.6	0.12	0.88	79.2	-1.40	-0.168
-60	8	43	-3080	-71.6	-77.9	0.14	0.86	77.4	-0.50	-0.07
-50	8	51	-3480	-68.2	-74.5	0.17	0.83	74.7	+0.20	+0.034
-40	24	75	-4440	-59.2	-65.5	0.25	0.75	67.5	+2.00	+0.50
-30	16	91	-4920	-54.1	-60.4	0.30	0.70	63.0	+2.60	+0.78
-20	11	102	-5140	-50.4	-56.7	0.34	0.66	59.4	+2.70	+0.918
-10	23	125	-5370	-43.0	-49.3	0.42	0.58	52.2	+2.9	+1.218
- 0	13	138	-5370	-38.9	-45.2	0.46	0.54	48.6	+3.4	+1.564
10	33	171	-5040	-29.5	-35.8	0.57	0.43	38.7	+2.9	+1.653
20	25	196	-4540	-23.2	-29.5	0.65	0.35	31.5	+2.0	+1.300
30	8	204	-4300	-21.1	-27.4	0.68	0.32	28.8	+1.4	+0.952
40	18	222	-3580	-16.1	-22.4	0.74	0.26	23.4	+1.0	+0.740
50	19	241	-2630	-10.9	-17.2	0.80	0.20	18.0	+0.8	+0.640
60	16	257	-1670	- 6.5	-12.8	0.86	0.14	12.6	-0.2	-0.172
70	9	266	-1040	- 3.9	-10.2	0.89	0.11	9.9	-0.3	-0.267
80	12	278	- 80	- 0.3	- 6.6	0.93	0.07	6.3	-0.3	-0.279
90	22	300	+1900	6.3	0.00	1.00	0.00	0.00	0.00	0.00

Minimum variance origin is max. negative value of $I_v = K_a\left[(\bar{X}_a-\bar{X}_1) + 90(1-K_a)\right] =$ -0.279 (70 to 80 class)

Maximum variance origin is max. positive value of $I_v = K_a\left[(\bar{X}_a-\bar{X}_1) + 90(1-K_a)\right] =$ +1.653 (0 to 10 class)

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