THE RELATIONSHIP BETWEEN SIZE AND SHAPE OF SAND AND SILT USING FOURIER SHAPE ANALYSIS

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ABSTRACT

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By

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The development of a precise Fourier analysis technique to define grain shape has permitted a possible investigation into the possible relationship between detritial grain shape and size.

A polygenic sample of glacial-fluvial sand for study was chosen. The grains were mounted on slides and their projections traced and digitized. The Fourier series for closed shapes was determined for each grain. Each of the first twenty harmonic amplitudes was plotted against phi size and analyzed by simple inspection. Modified roughness coefficients were calculated to test the possibility that resolution of the grain into twenty harmonics has had a nebulous effect on detection of possible relationships.

The results indicate that other than very weak possible trends, there may be no relationship between size and shape in detritial glacial fluvial quartz. This lack of a relationship may be due to the fact that the sample

was from a complex environment and heterogenetic. Further study of detritus of known parent rock is required.

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INTRODUCTION

It is a generally accepted tenet of sedimentology that there is a relationship between detrital particles and shape. It has been hypothesized that grains in the sand range have been reported to possess higher sphericity and roundness than those in the silt range (Krumbein, 1941; Briggs, McCullock, Moser, 1962; Blatt, 1959; Wadell, 1935; Ingerson & Ranisch, 1942; Rowland, 1946; Sahu & Petro, 1970; Pettijohn, 1957; Waltz, 1972; Redmond, 1969). It has been speculated that the shape of sand size particles is a function of the initial shape of the grains in the parent rock with modifications of the shape through mechanical abrasion and chemical solution. They speculate that finer quartz particles in the silt, and finer sizes, were from abrasion of sand size particles and, thus, more angular.

However, up to this time, no quantitative test has been performed to test this hypothesis. With recent developments of precise definitions of shape (Ehrlich & Weinberg, 1970) a test of this hypothesis is of critical importance. If a strong size-shape relationship exists, then those who study shape variation must either sample at the same grain size (which is difficult and tedious) or one must determine the functional relationship between size and shape for each sample and compensate.

In addition to the importance of the size-shape relationship to the adjustment of shape analysis, the existance of such a relationship and the form of the relationship carries with it implications about grain provenances and transportation. That is to say, it is likely that the size-shape relationship might vary with sediments derived from different source terranes, or different means of transportation, or processes of deposition.

For the past four years shapes of detrital quartz grains have been analyzed using closed grain form analysis (Redmond, 1969; Waltz, 1972; Ehrlich & Weinberg, 1970; Kennedy, 1972). Most of these studies analyzed about one hundred grain shapes per sample and, because of the potential for confounding of the size-shape relationship, attempted to use, in a given study, grains of the same size. Redmond (1969) and Waltz (1972) examined the relationship between size and shape at the grain sizes of their studies and found no relationship to exist. However, small numbers of grains per sample may well have contributed to failure to see any relationship.

This investigative report is directed solely toward testing the relationship between size and shape of detrital quartz. For that reason, a single twelve hundred grain sample covering a range from silt to coarse sand was studied. The results of this investigation will affect sampling plans of all subsequent investigations of detrital quartz. It will evaluate the possibility of interaction between size and shape which might carry depositional and provenance information.

THE POTENTIAL NATURE OF THE RELATIONSHIP BETWEEN SIZE AND SHAPE

It is possible for size and shape to interact in an infinite number of ways. However, all such relationships can be classified into one of four categories.

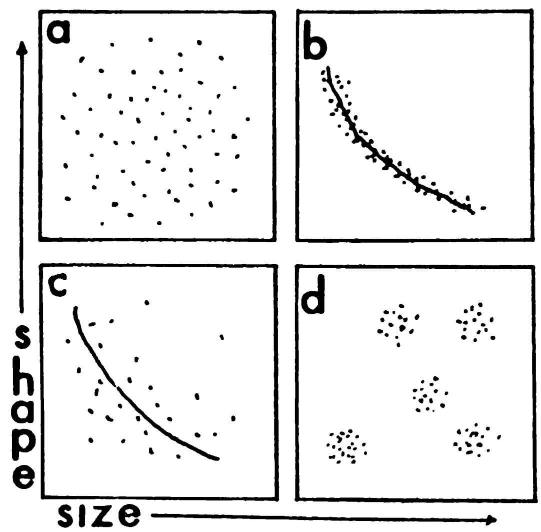

Figure 1.--Possible Size-Shape Interactions

The ordinate of the graph in Figure 1 represents any shape variable whatsoever (e.g., it may represent an amplitude of a harmonic or a modified roughness coefficient (Ehrlich and Weinberg, 1970) or an axial radius (Zingg 1935).

The abscissa may represent either linear or logrithmical size measurement. Of course, there may be no relationship (Figure 1-a) between size and shape, in which case, the relationship array is roughly, one which is circular in shape with equal point density. Shape and size may be related in such a way that the relationship may be clearly designated by any number of continuous mathematical functions (Figure 1-b). Such a relationship may exist with so much variation about the function that it is no longer useful (Figure 1-c). There indeed may be a strong relationship between size and shape that cannot be described by a continuous function (Figure 1-d). In such a case, the grains cluster nonrandomly about points in the shape-size plane. From this discussion, it may be seen that no one simple test between size and shape will be adequate. That is to say, for example, that Pearson's product-moment correlation coefficient would only detect a tight relationship in Figure 1-b but detect no relationship in the clustering in Figure 1-d. For this reason, it was decided that the preliminary analysis would be confined to visual inspection where size was graphed against grain size.

THE SAMPLE

The sample location chosen was one which would provide a sample of detritus containing grains from a great many source rocks and possessing as wide a depositional range and history as possible. Accordingly, a sample was taken from a pointbar in the Platte River near Honor, Michigan. The region has been glaciated four times, the most recent by the Michigan lobe of the Wisconsin glaciation. The site is on the leeward edge of the Lake Michigan sand dunes. Welsh (1971) showed that rivers tend to mix their detritial makeup with their surrounding environment in a complex way. Therefore, the sample will represent a wide range of parent rock and environmental shapes. A pointbar was chosen because of the size range of grains available was great and rich in quartz. No large body of water or impoundments exists immediately upstream to act as a sediment trap. Ease of access was also a factor.

The sample location is T26N, R14W, Sec. 16, NW1/4, NW1/4, NW1/4 of the Frankfort Quadrangle, Michigam, 200 feet upstream of the Henry Street bridge, 0.4 miles south of U.S. 31 in Honor, Michigan. A 3 liter metal container was driven vertically into the sediments in the center of a small pointbar located there, and collected in such a way that it represents the widest possible grain size.

The sample was dried. Large pebbles and debris were removed. The sample was split with a microsplitter to reduce the volume to less than 50cc. The sample was washed in a 30% H_2O_2 solution to remove organic detritus until the sample no longer greatly reacted with the H_2O_2 solution. The sample was then washed in 30% HCL to remove the carbonate fraction.

The cleansed sample was further split by a microsplitter until it was less than 1cc in volume. The sand grains were mounted on glass slides with cover slips to insure maximum area projection and orientation.

A Leitz "Prado" projector was used and calibrated with a stage micrometer. The grains were plotted on a radial graph with 48 intersecting equally spaced radial arms. The center of the graph was placed as near the center of gravity of the projected area as possible by visual estimate (See Figure 2). The intersections on the grains were then digitized on an automatic digitizer which transfers X, Y coordinates to Hollerith cards. This data was then processed by a computer for the standard Fourier series and modified roughness coefficients as described by Ehrlich and Weinberg (1970).

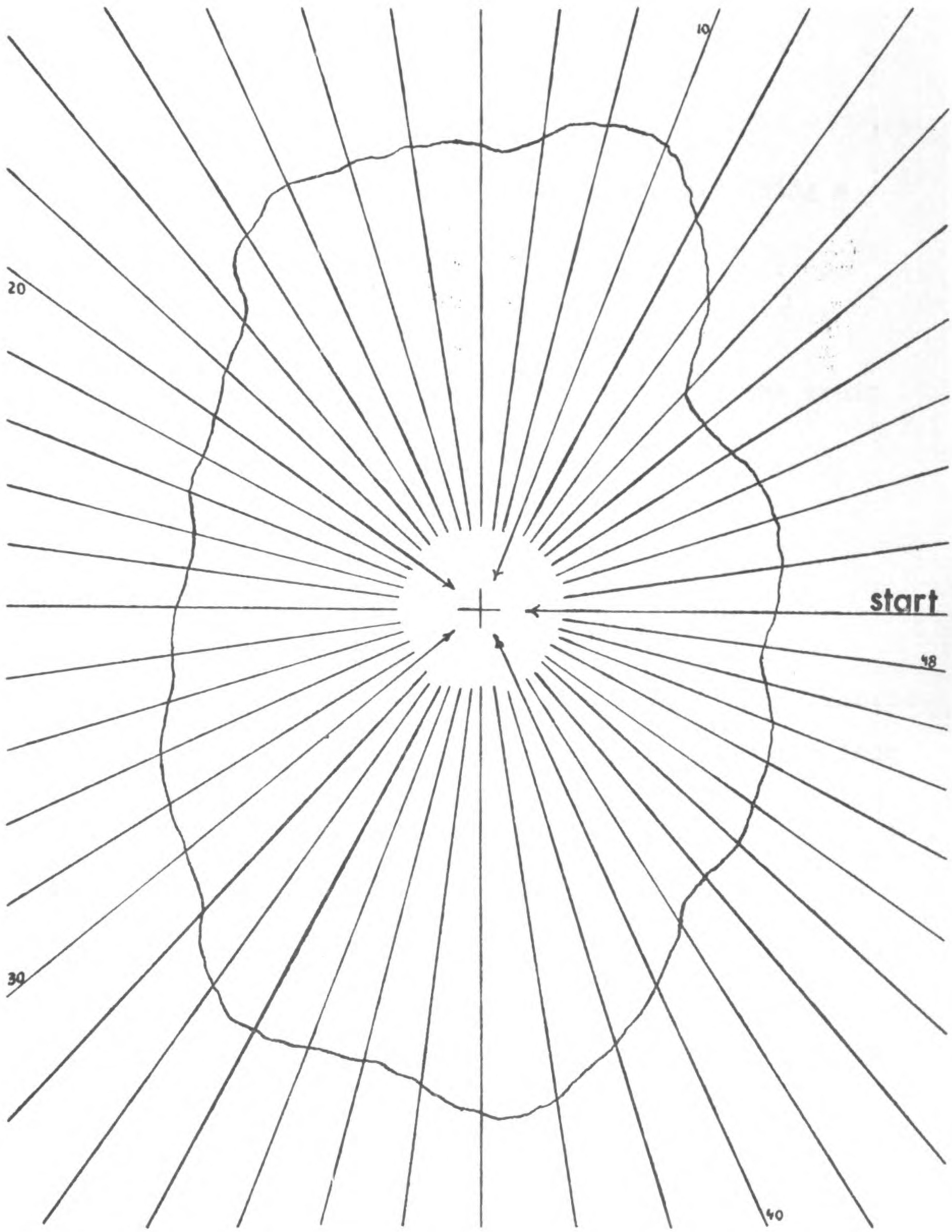

Figure 2.--Sample Radial Grain Plot

FOURIER SHAPE ANALYSIS

Mathematically, the shape of the grain using a series of Fourier terms is as follows:

$$R(\Theta) = R_o + \sum_{m=1}^{\infty} R_n \mathrm{Cos}(n\Theta_n - \phi_n)$$

where $R(\Theta)$ = the function defining the shape of the grain

R_o = average radius of the grain

R_n = harmonic amplitude

n = harmonic order

0_n = phase angle

Θ_n = polar angle.

For practical purposes, the shape of the maximum projection area, of the quartz grains in this study, was defined from the first twenty harmonic amplitudes. Size is defined as the radius of the circle with the same surface area as the maximum projection area of each grain.

The analysis starts by calculating from the perifphery points the center of gravity. The center of gravity is then used to convert the periphery coordinates to polar coordinates. These polar coordinates are then used to generate each harmonic. To eliminate harmonic amplitude variation due to size variation, each harmonic is then divided by the "zeroth" harmonic.

RESULTS

Each harmonic amplitude of the 1200 grains was plotted harmonic by harmonic for harmonics one through twenty (Figues 3 through 22). Thus shape was dissected into twenty orthogonal components and plotted against size. However, the possibility exists that shape thus divided may not represent the "shape" variation with grain size that has been reported. For that reason, additional plots of the modified roughness coefficient (MRC) used by Ehrlich and Weinberg (1970) were constructed. Since the MRC used in this analysis spans a selected range of harmonics, it can be expressed as:

$$P_{jk} = \sqrt{1/2\Sigma\ C_n^2}$$

Where C equals the Fourier coefficients. The roughness coefficient represents the squared deviations of the grain boundary from a circle of the same area, for a selected set of harmonics.

The three MRC's were calculated for each grain: one comprises harmonics one through five, another six through ten, and the third comprises the contributions of harmonics eleven through twenty.

The first MRC (harmonics 1-6) represent deviations from a circle of the "gross" shape (Figure 23). That is to say, the second harmonic represents how elongate the grain is; the third harmonic represents how triangular the grain is' the fourth harmonic represents how quadrate the grain is etc. The second MRC (harmonics 7-10) represents the contribution of the shape of intermediate excursions of the grain boundary, (Figure 24), e.g., the contributions of seven to ten semetrical "bumps". The third MRC (harmonics 11-20) represents the smallest excursions examined in this study (Figure 25.) This breakdown was done because it has been shown (Kennedy, 1972) that it is possible that the higher harmonics disproportionately carry more information than does the lower harmonics.

The three MRC's traverse the continuum of deviations from a circle. These coefficients thus more closely simulate the visual impression of grain shape than does a single harmonic.

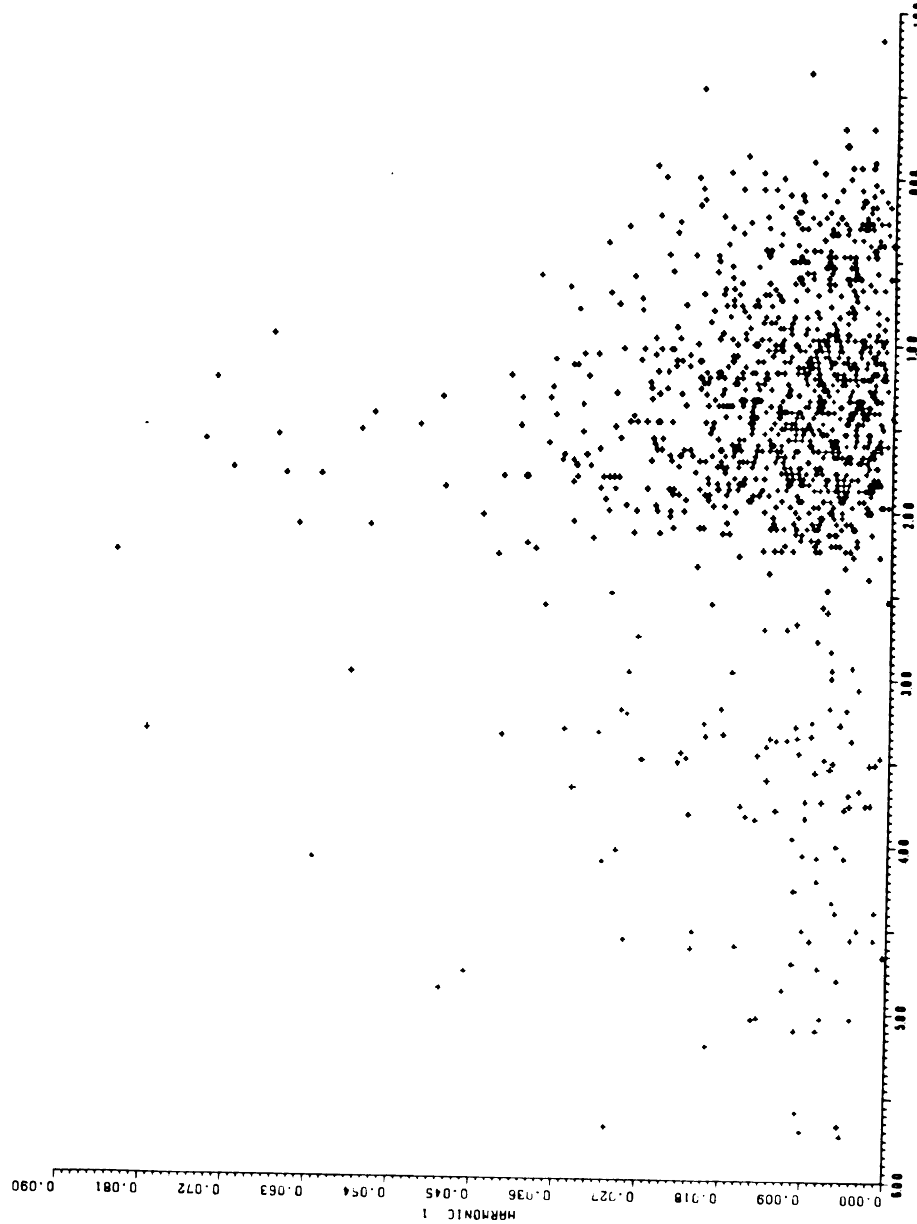

Figure 3.--Harmonic 1

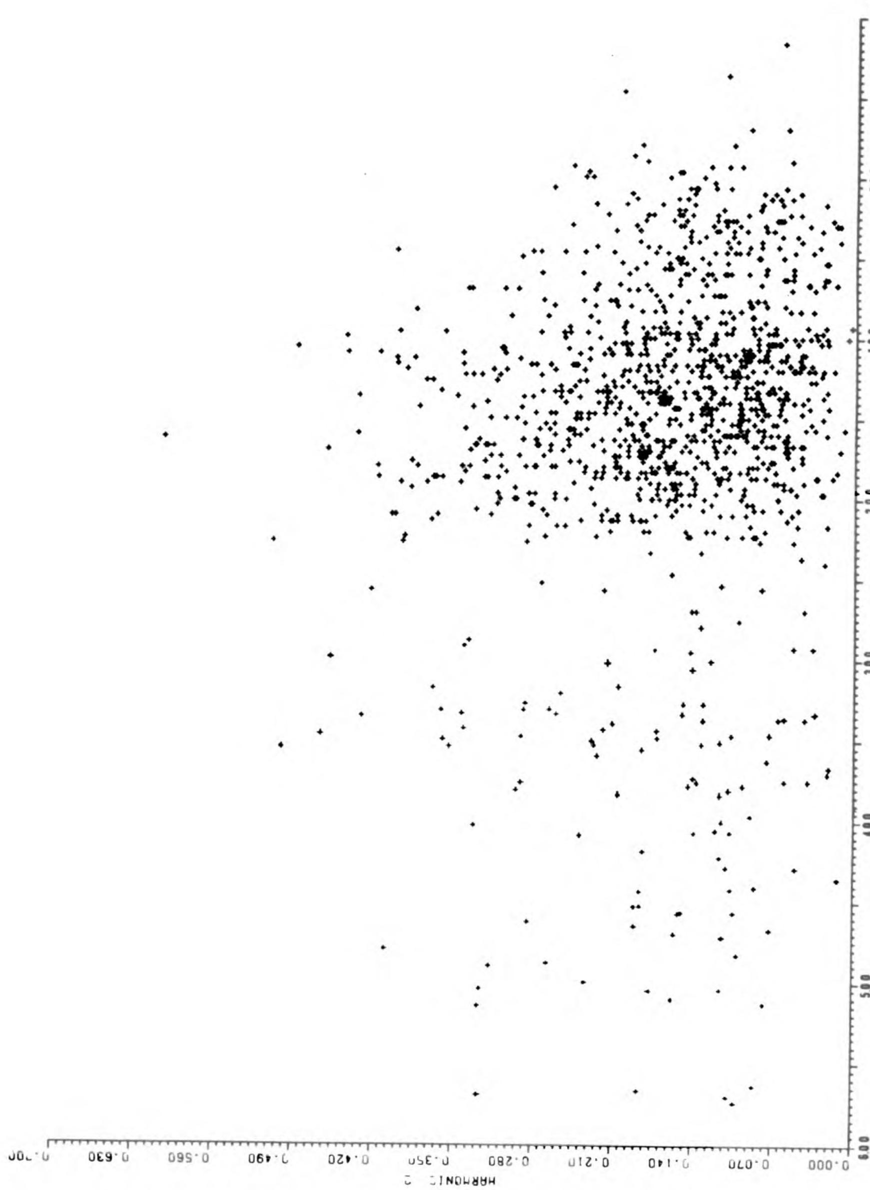

Figure 4.--Harmonic 2

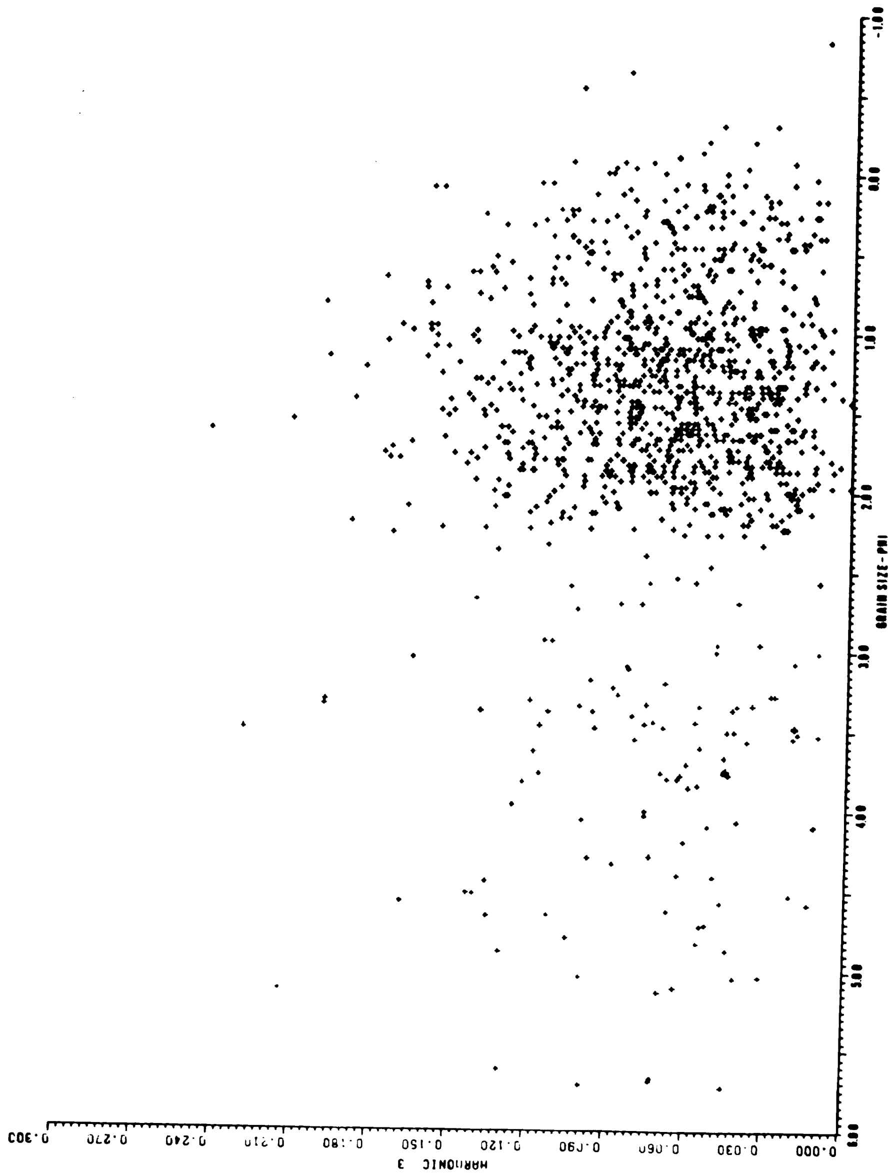

Figure 5.--Harmonic 3

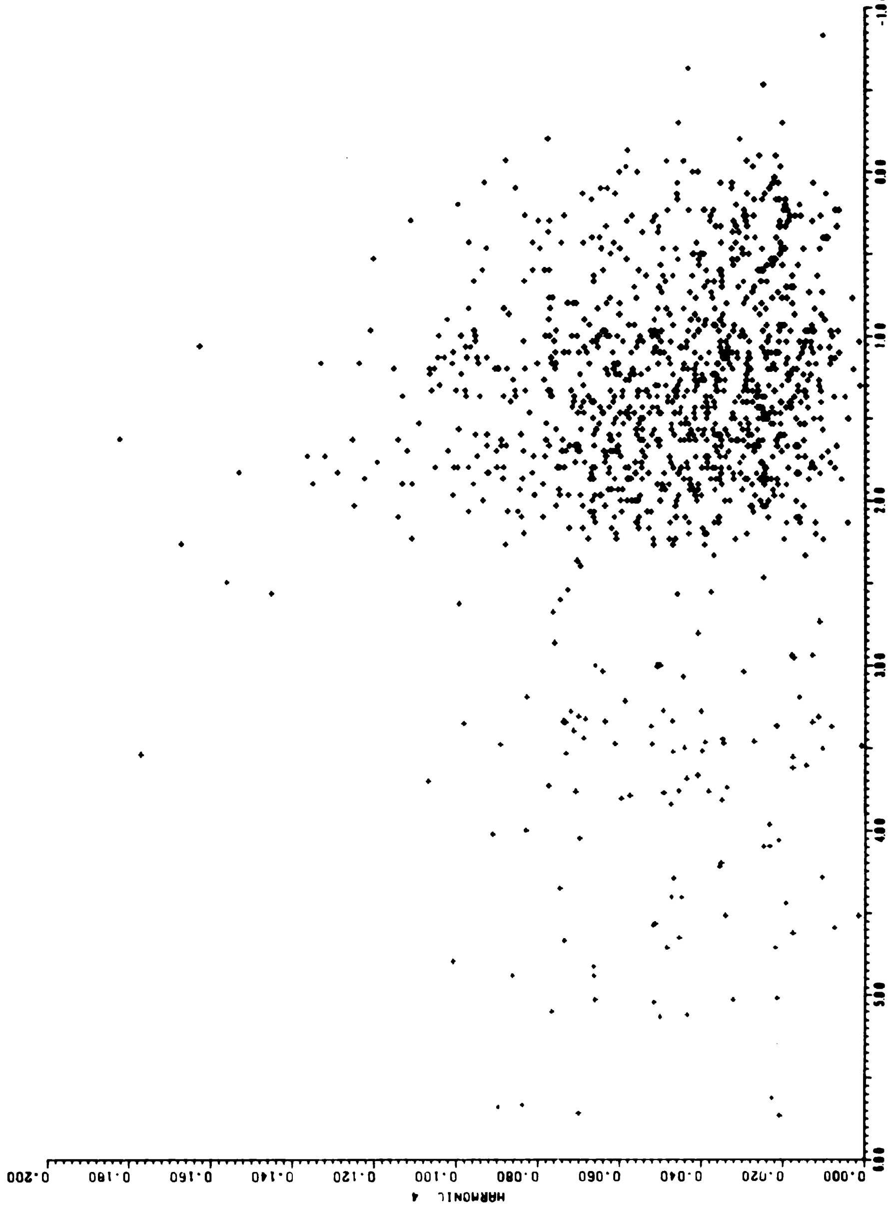

Figure 6.--Harmonic 4

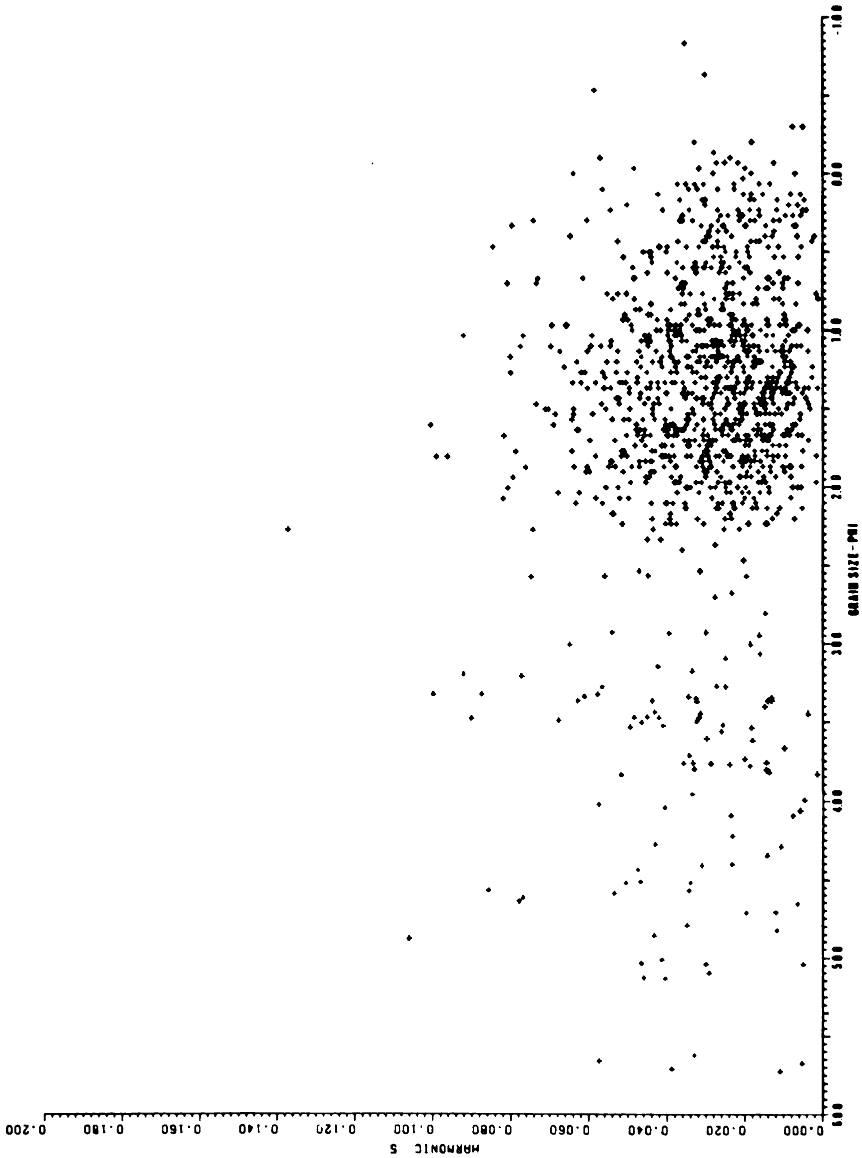

Figure 7.--Harmonic 5

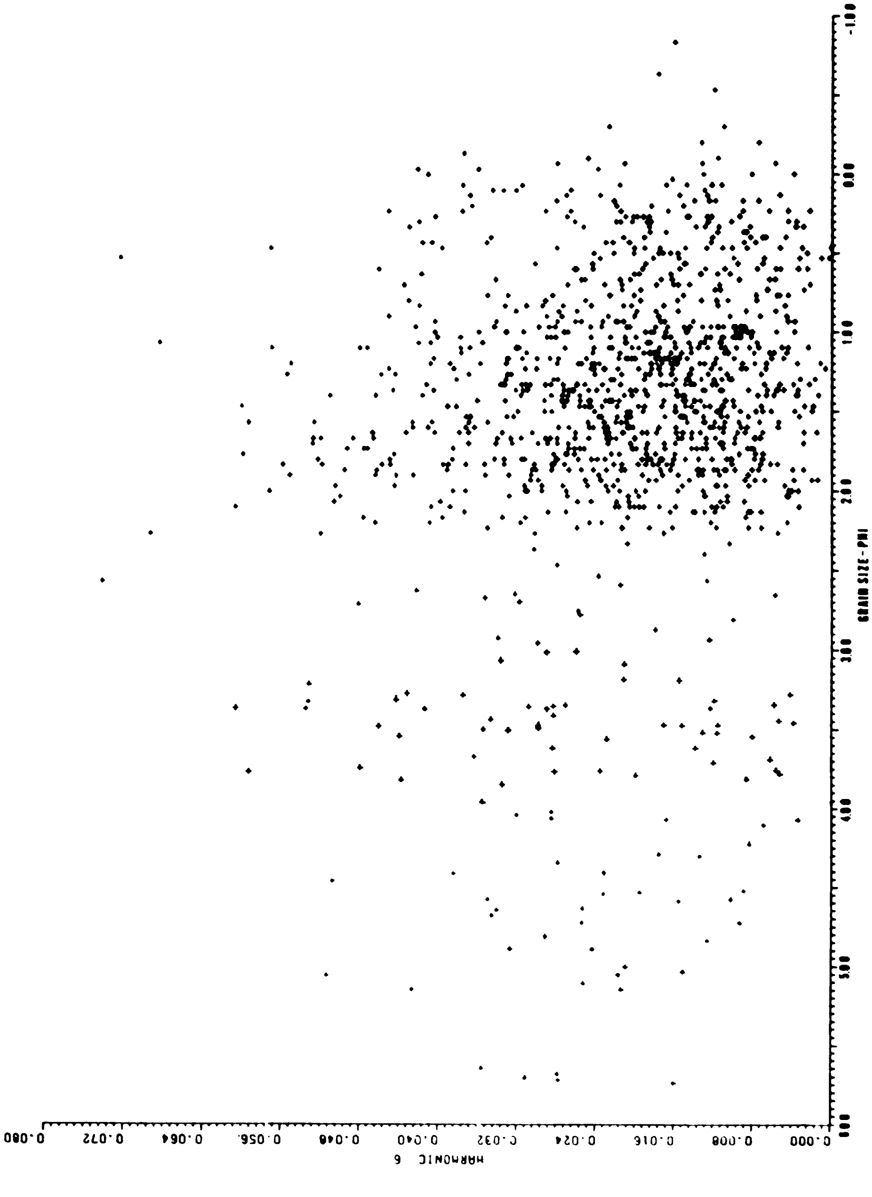

Figure 8.--Harmonic 6

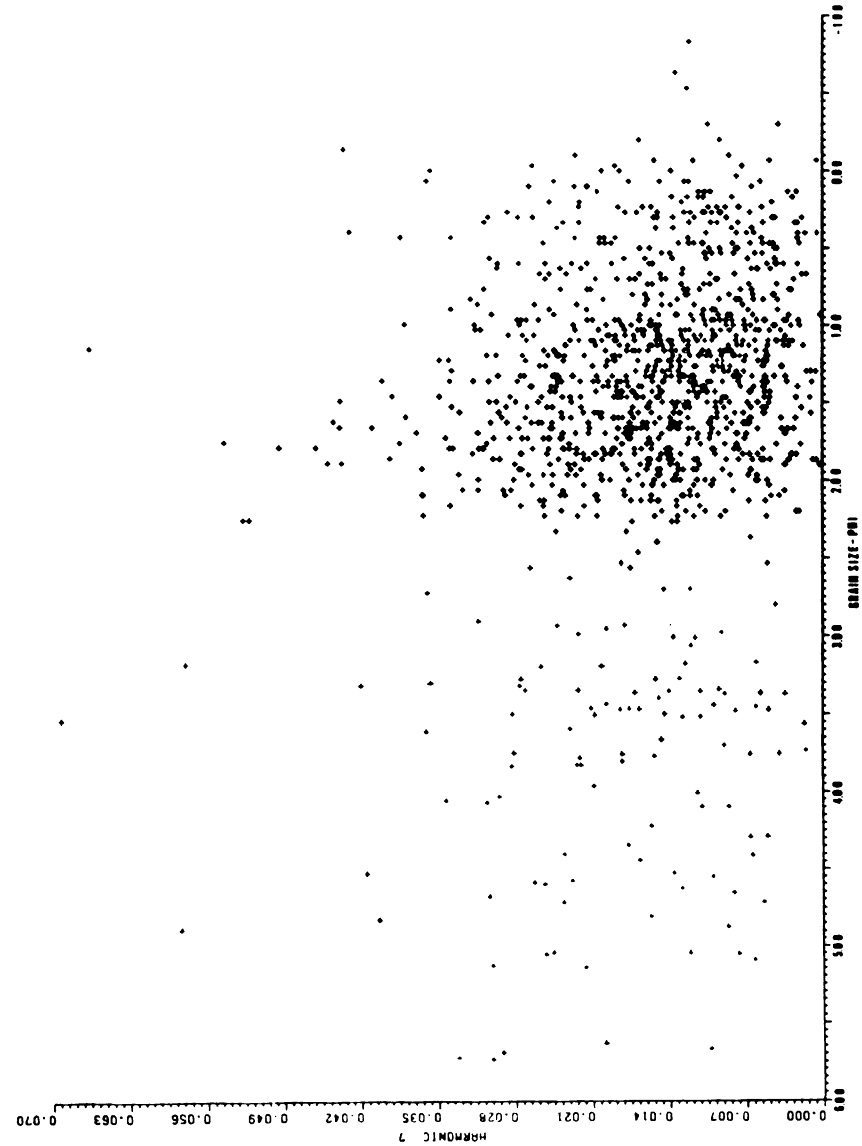

Figure 9.--Harmonic 7

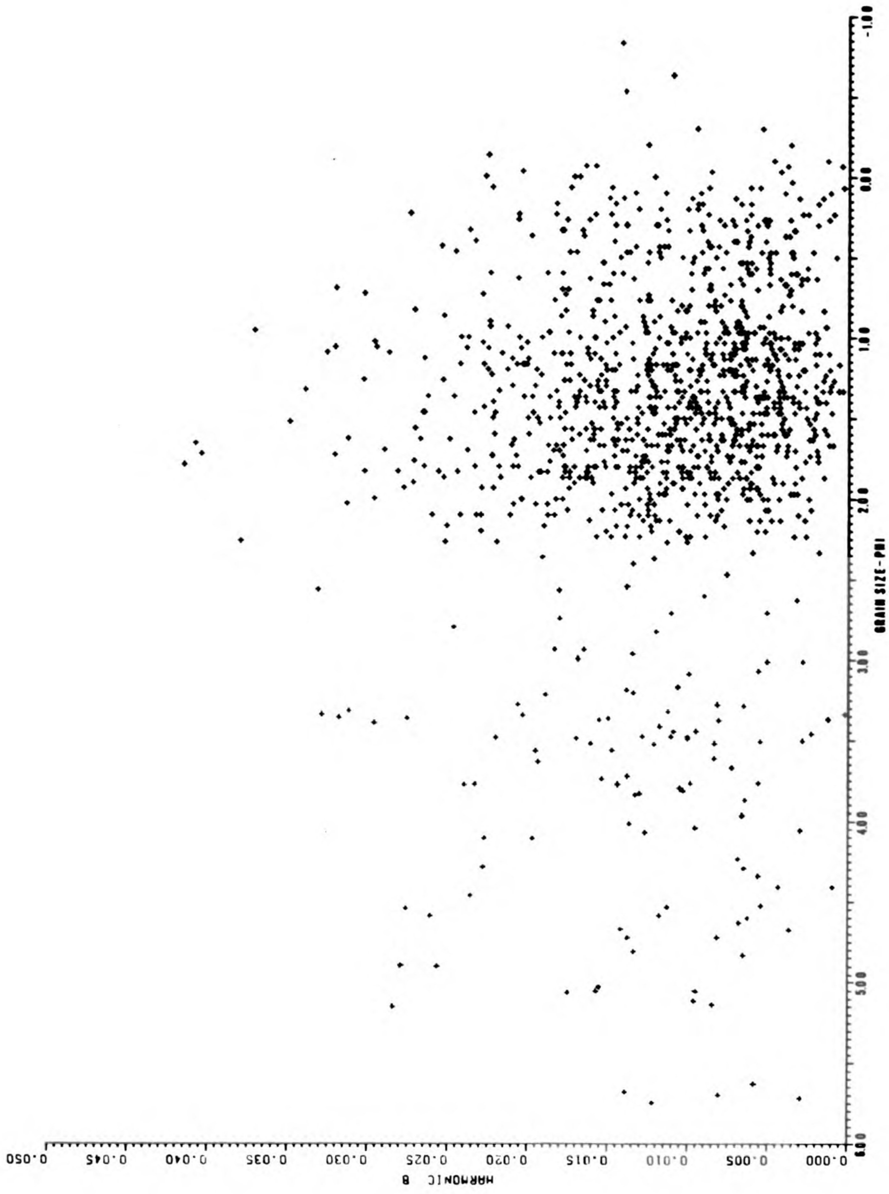

Figure 10.--Harmonic 8

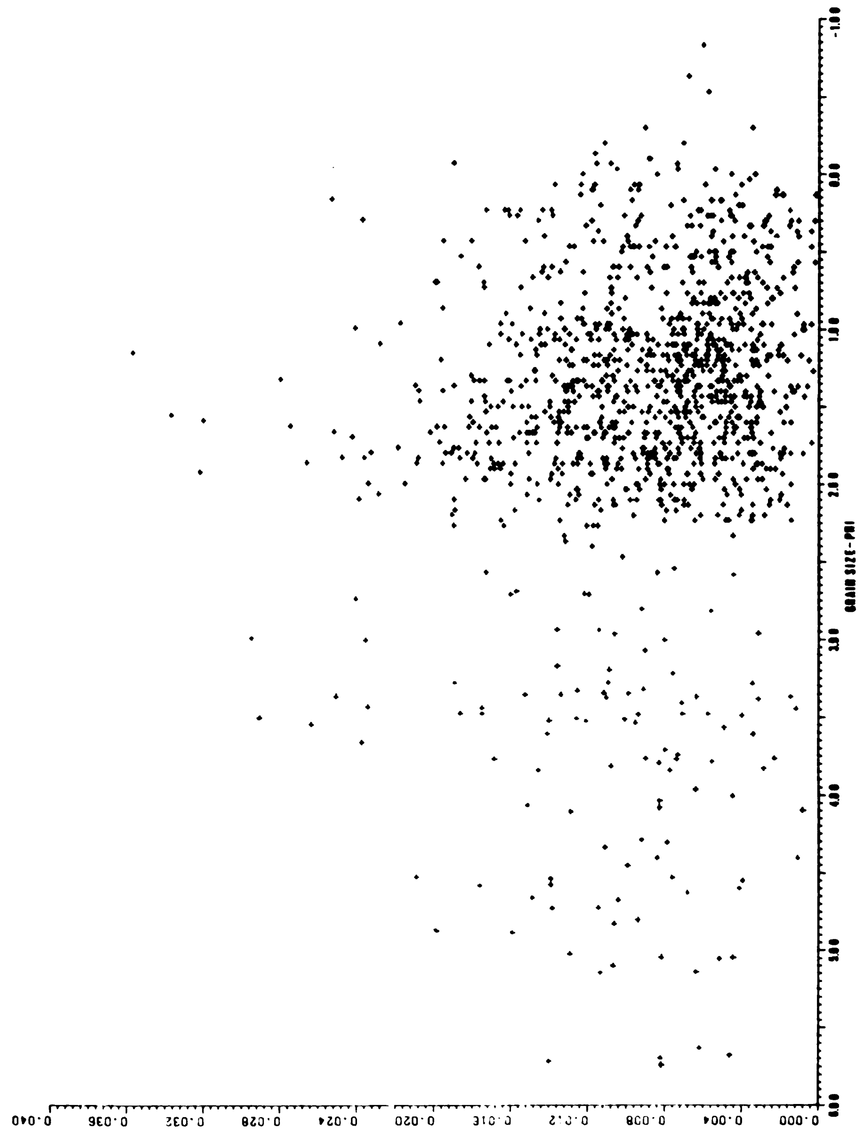

Figure 11.--Harmonic 9

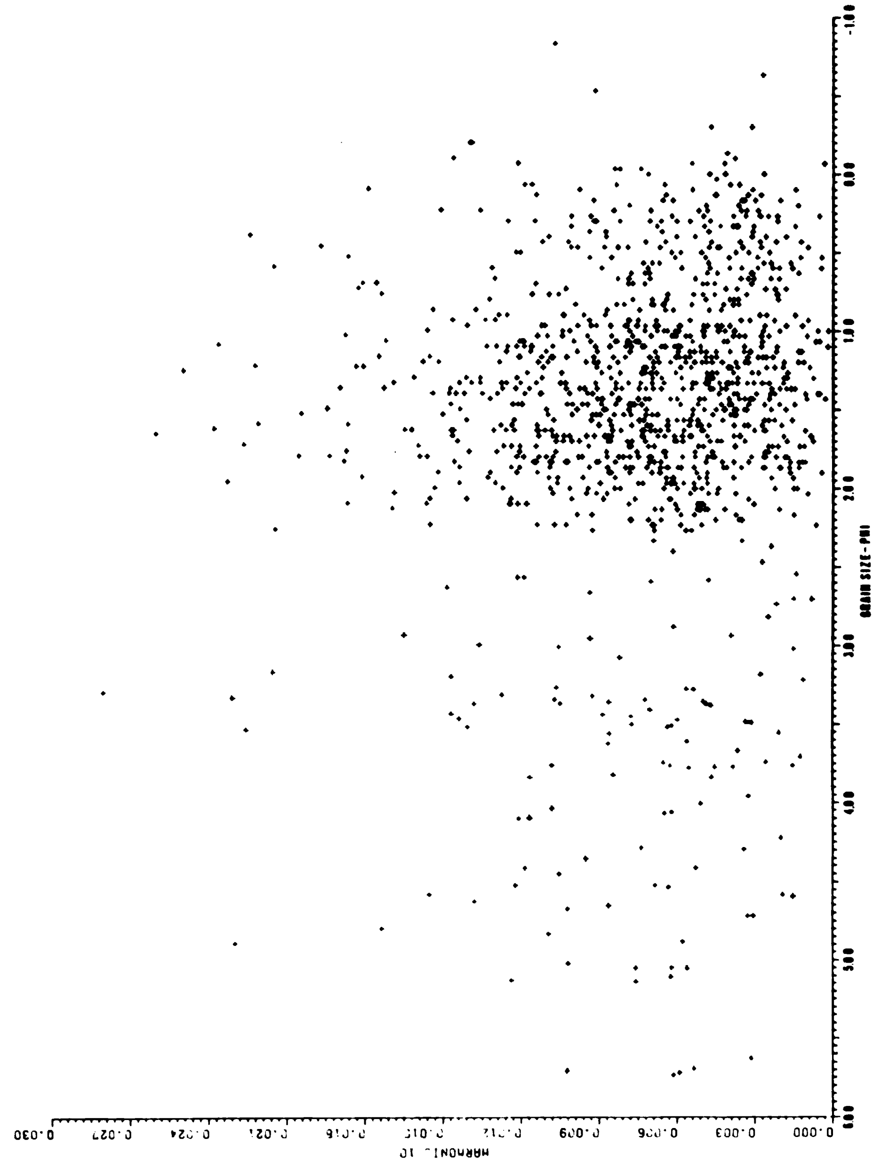

Figure 12.--Harmonic 10

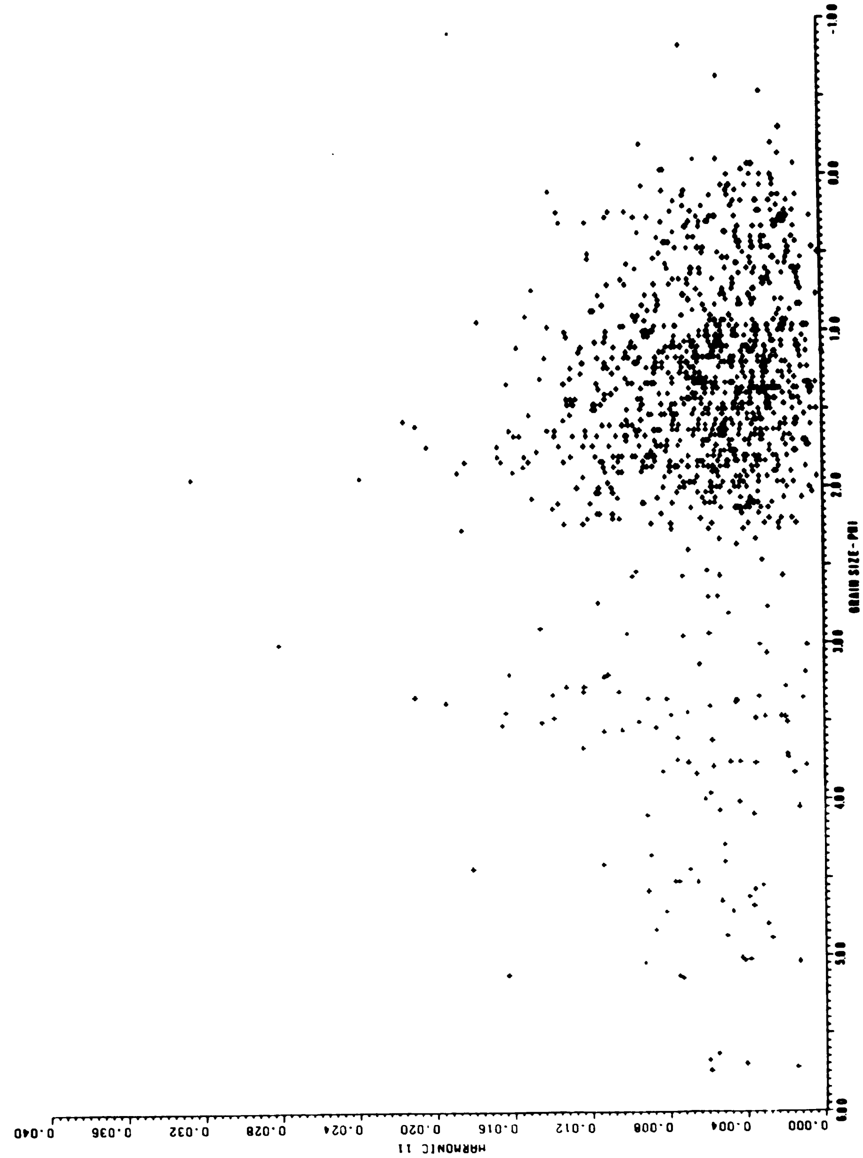

Figure 13.--Harmonic 11

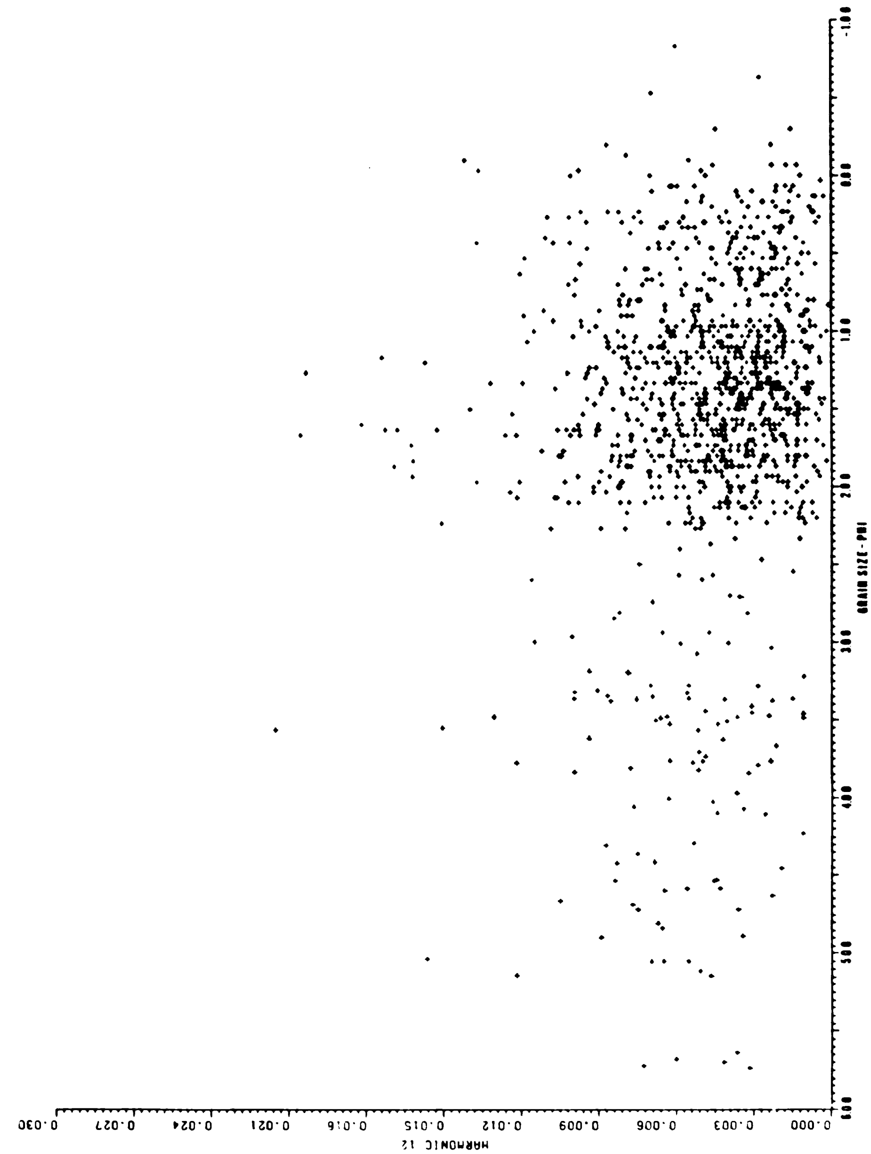

Figure 14.--Harmonic 12

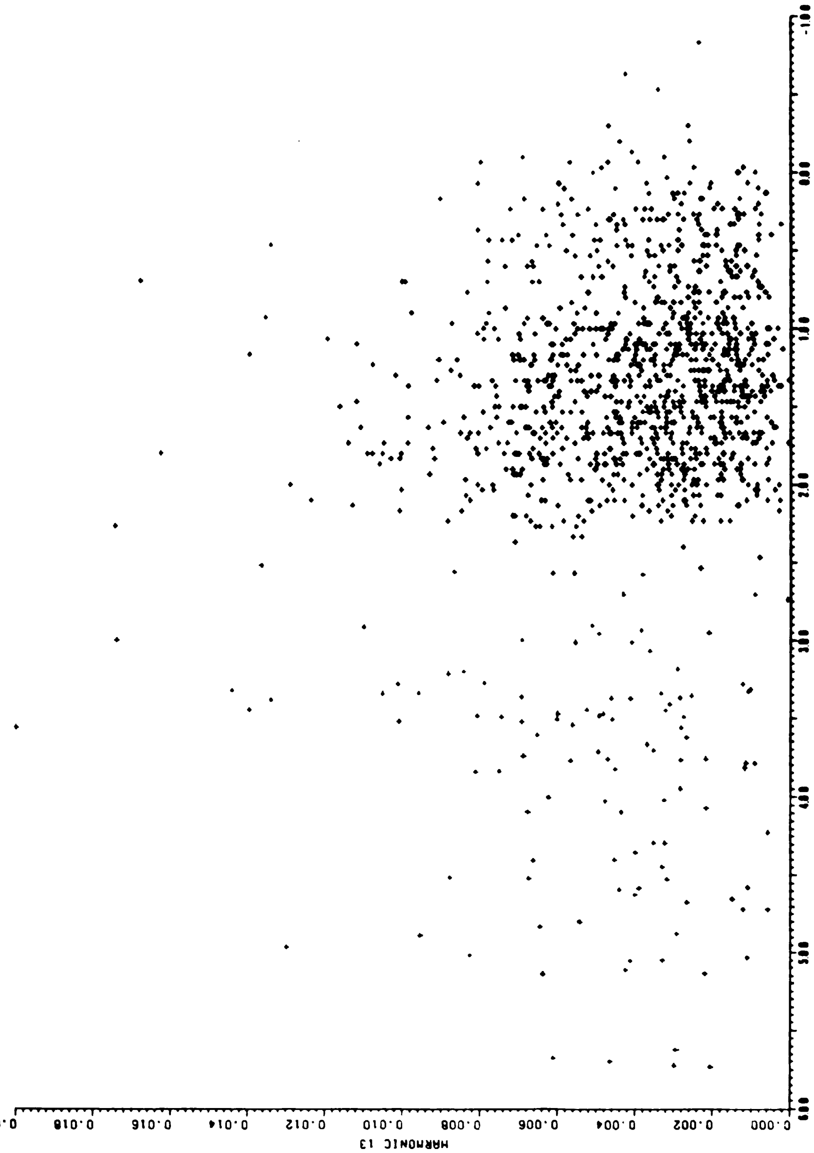

Figure 15.--Harmonic 13

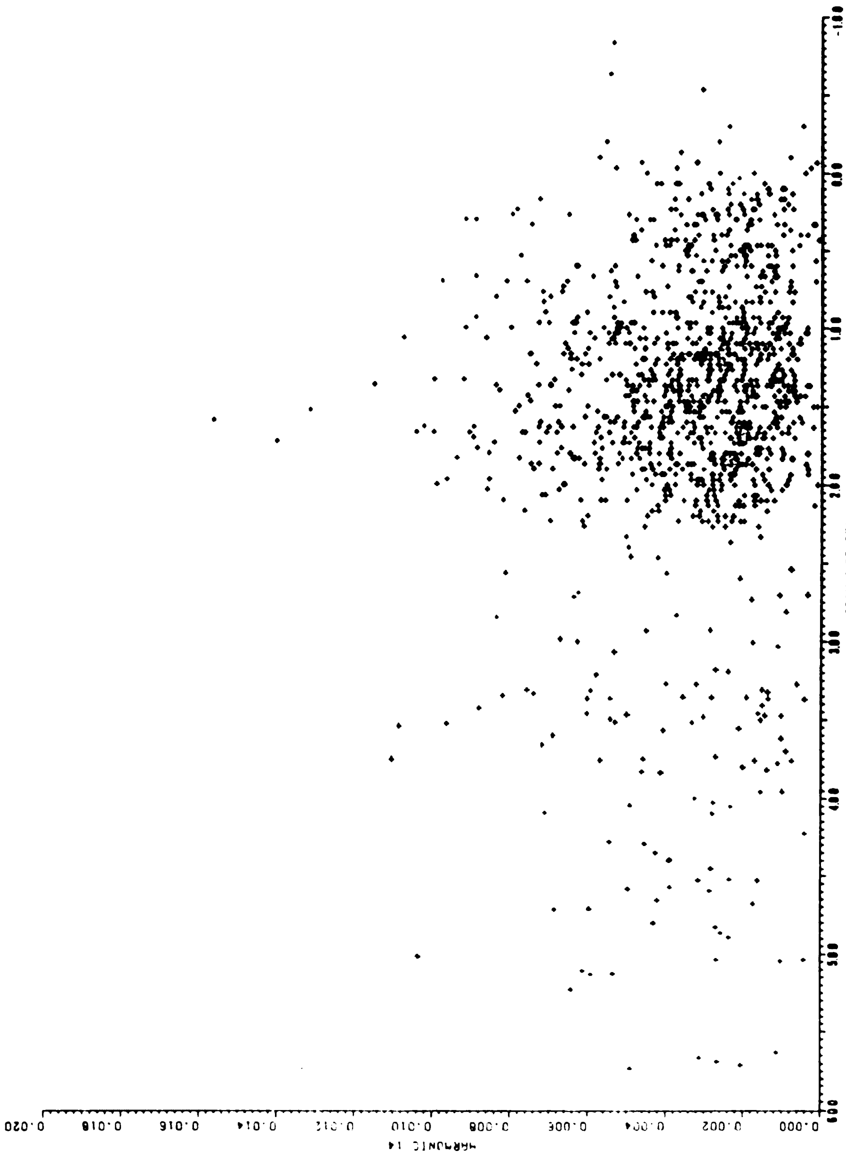

Figure 16.--Harmonic 14

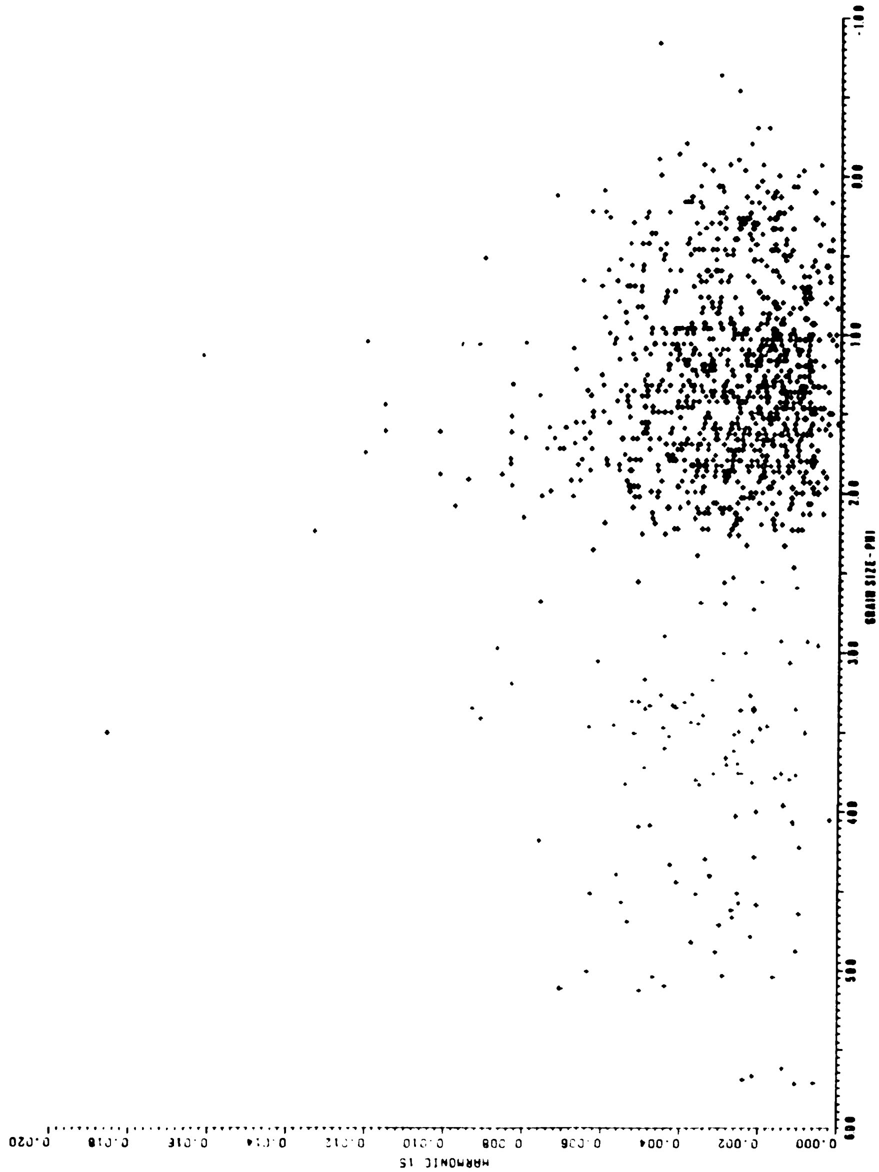

Figure 17.--Harmonic 15

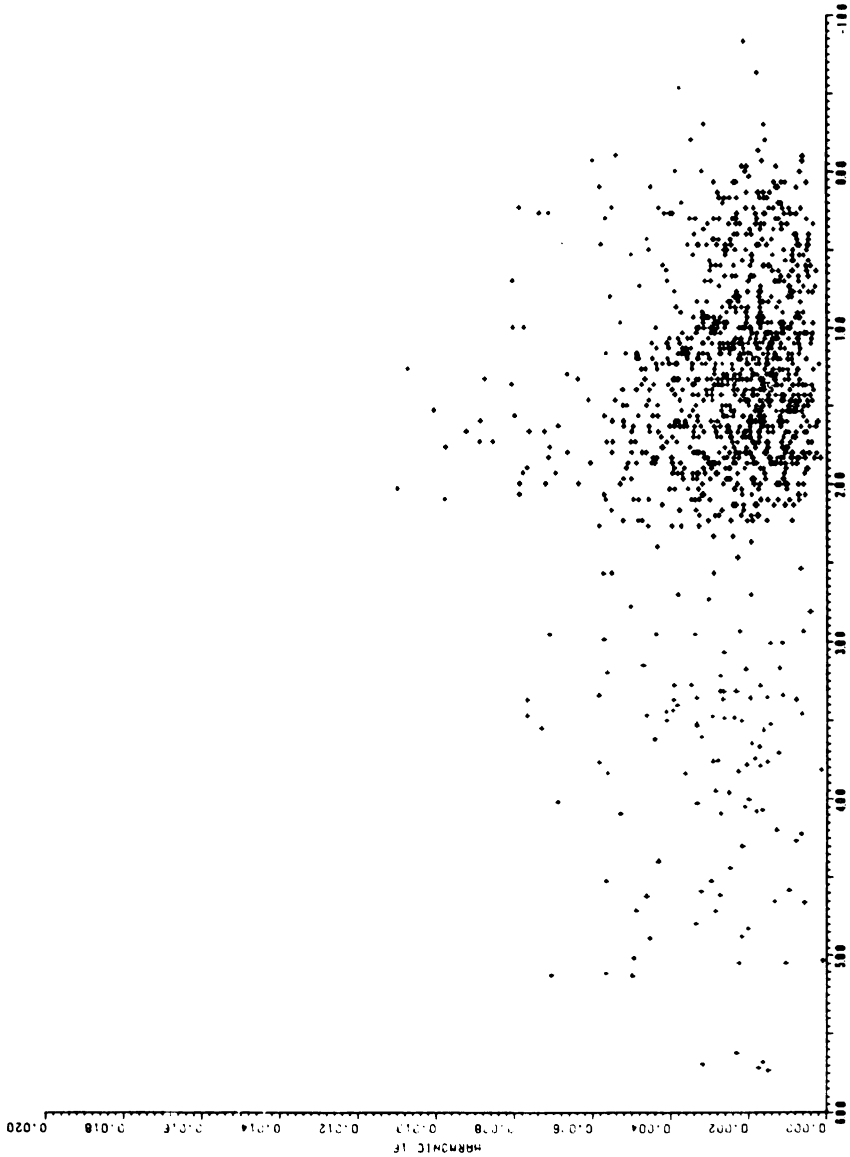

Figure 18.--Harmonic 16

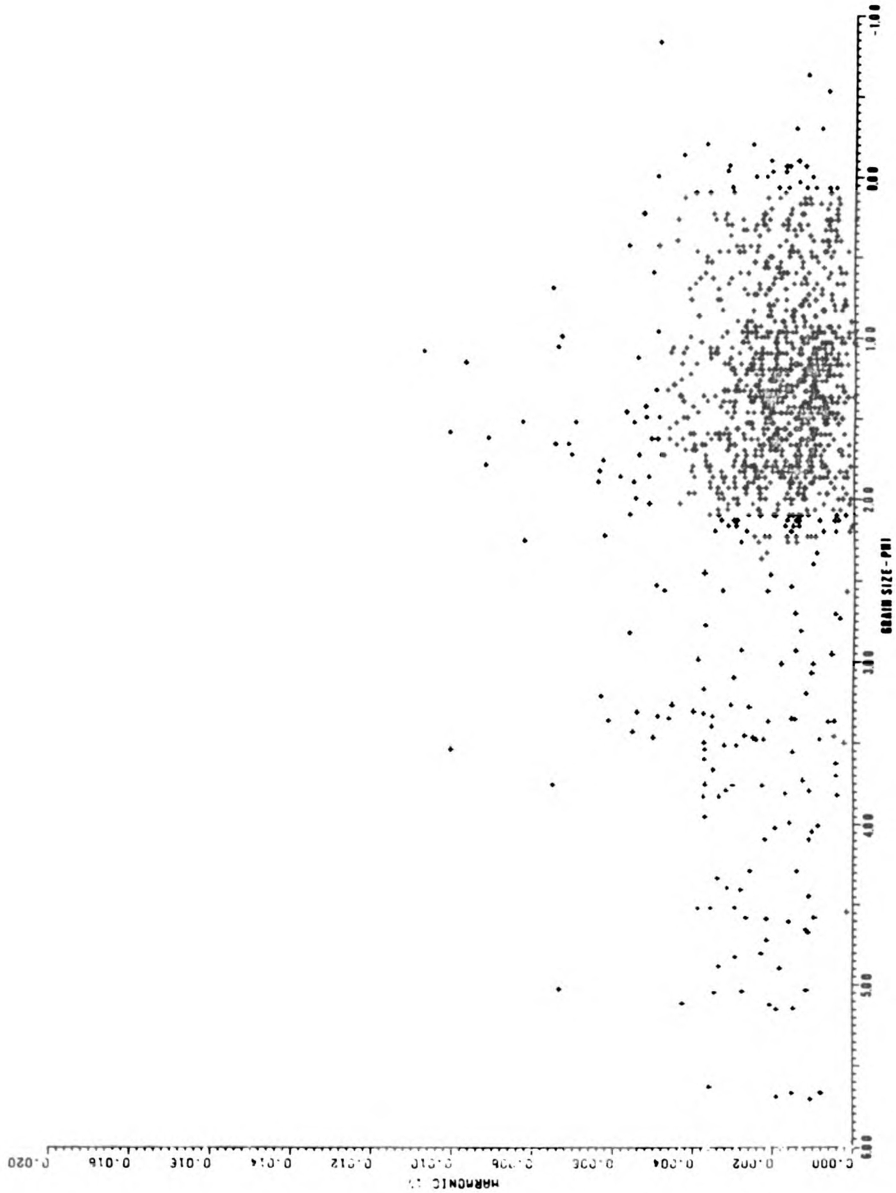

Figure 19.--Harmonic 17

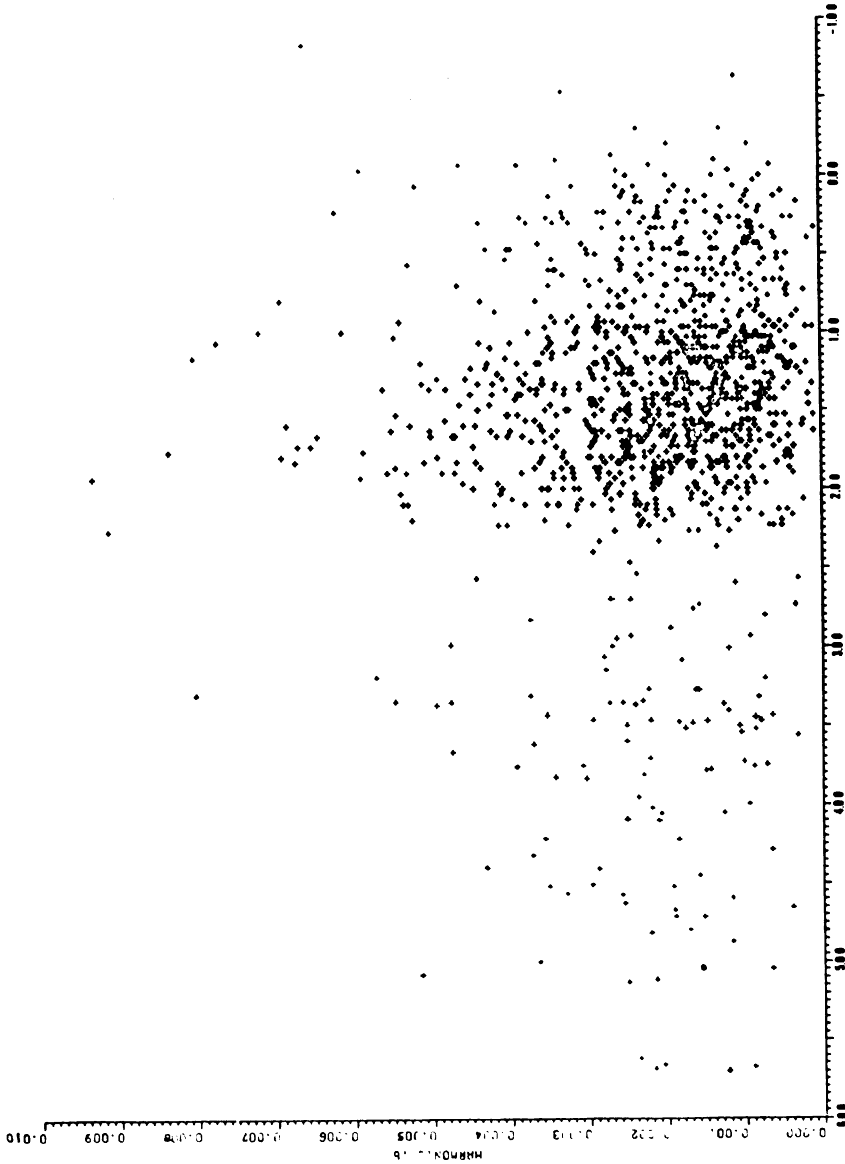

Figure 20.--Harmonic 18

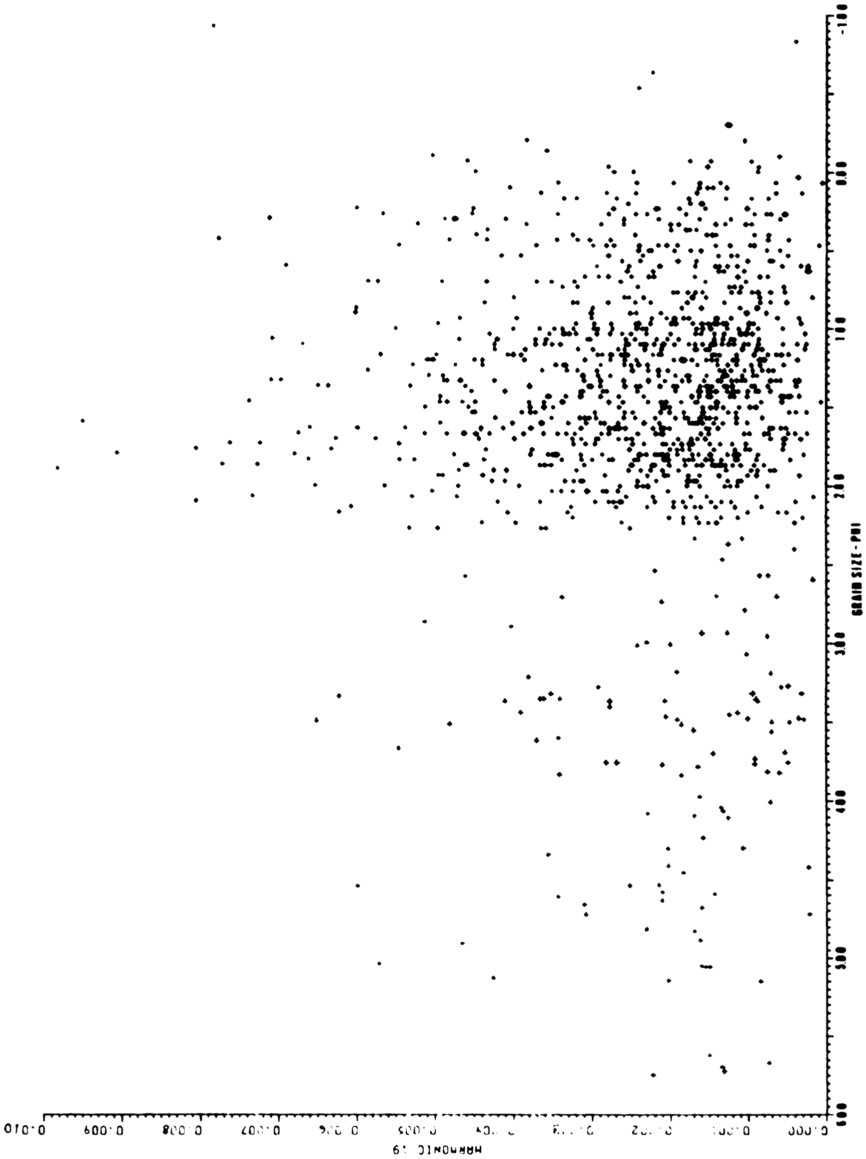

Figure 21.--Harmonic 19

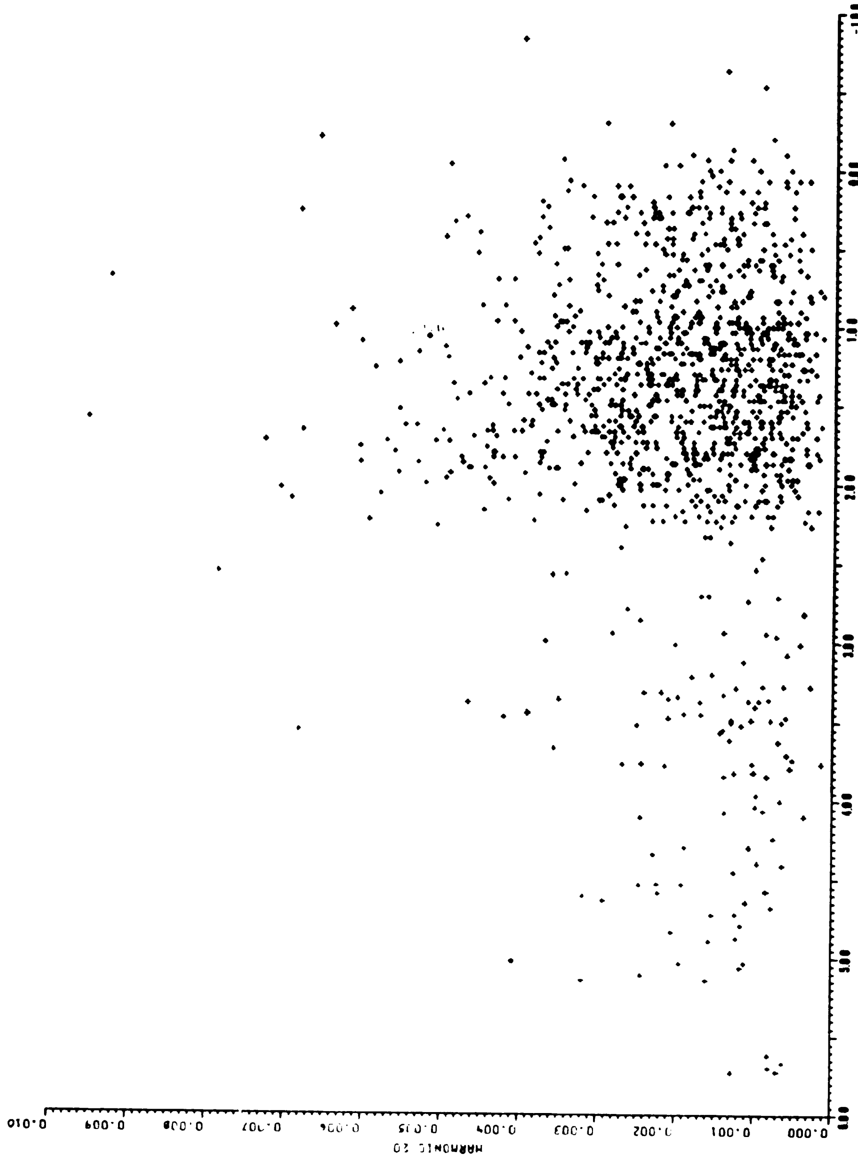

Figure 22.--Harmonic 20

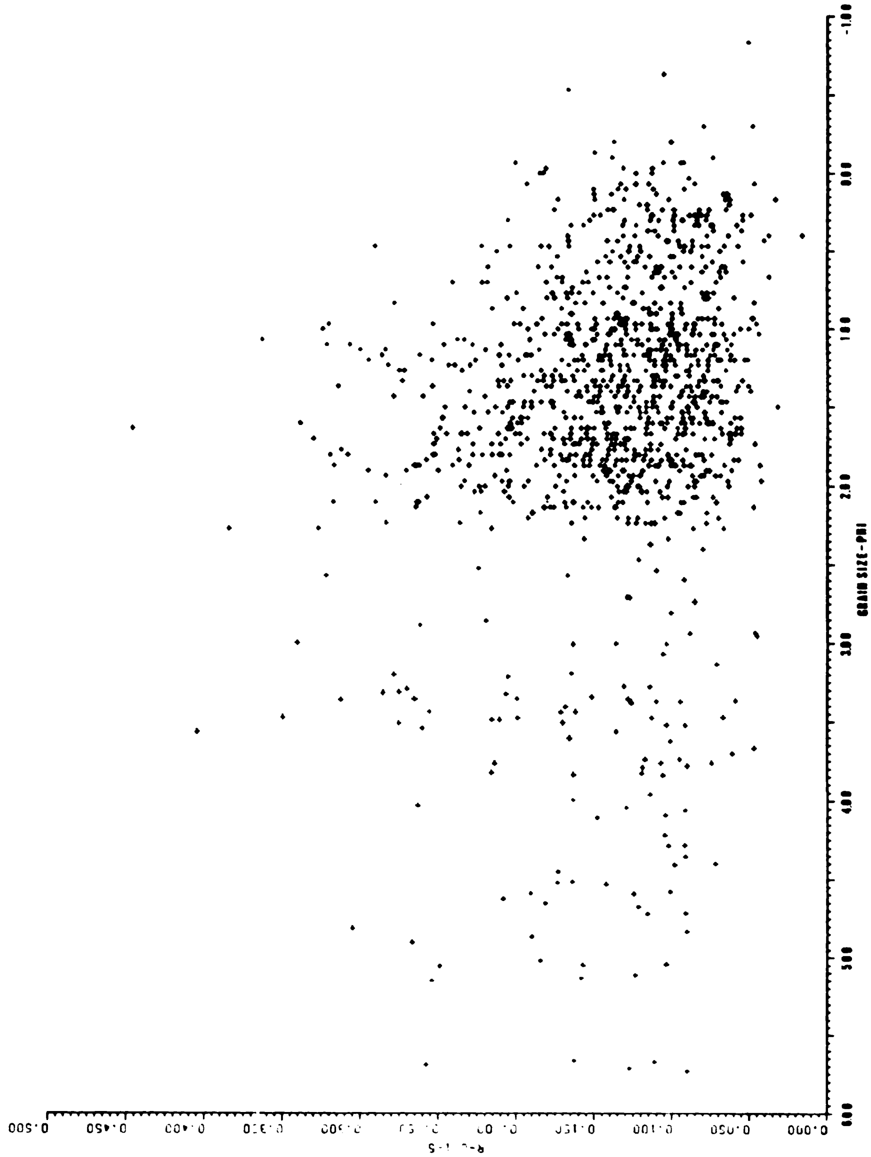

Figure 23.--Modified Roughness Coefficient 1-5

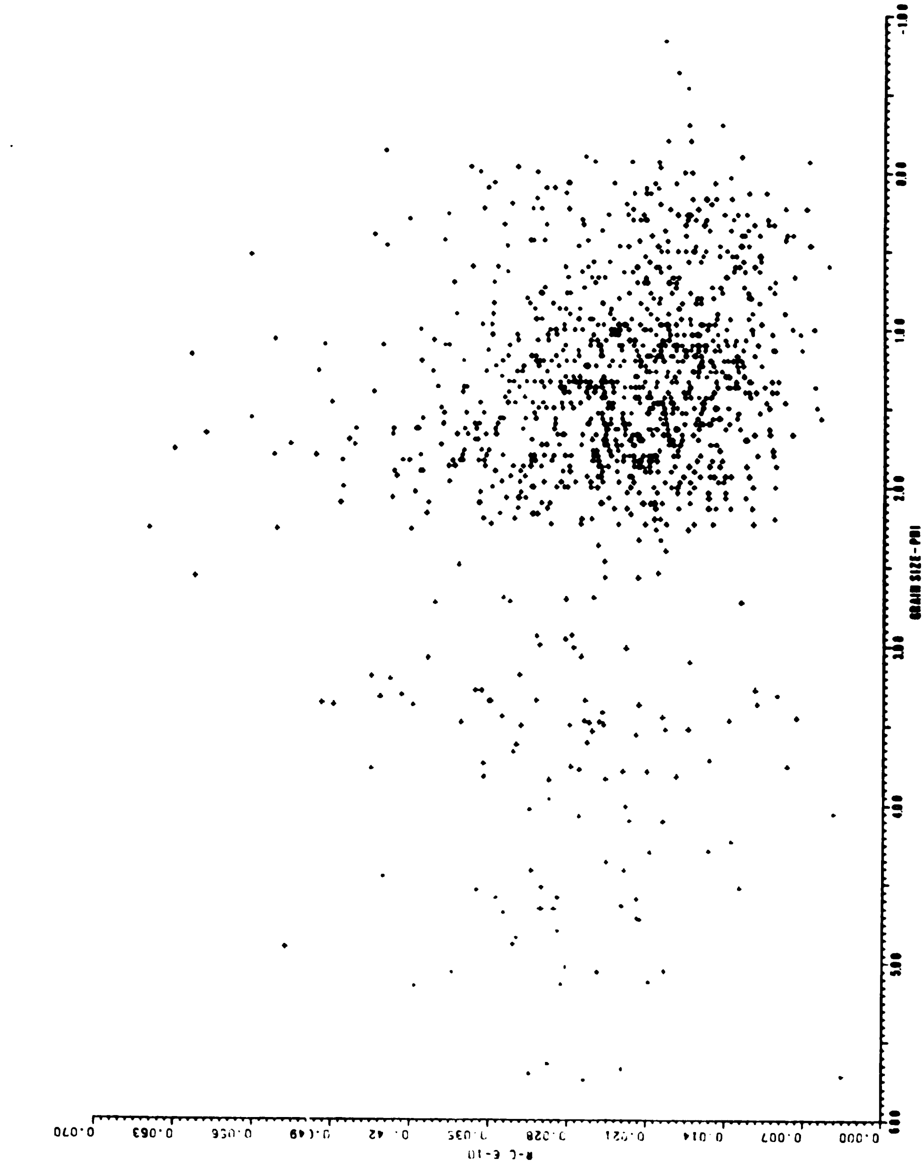

Figure 24.--Modified Roughness Coefficient 6-10

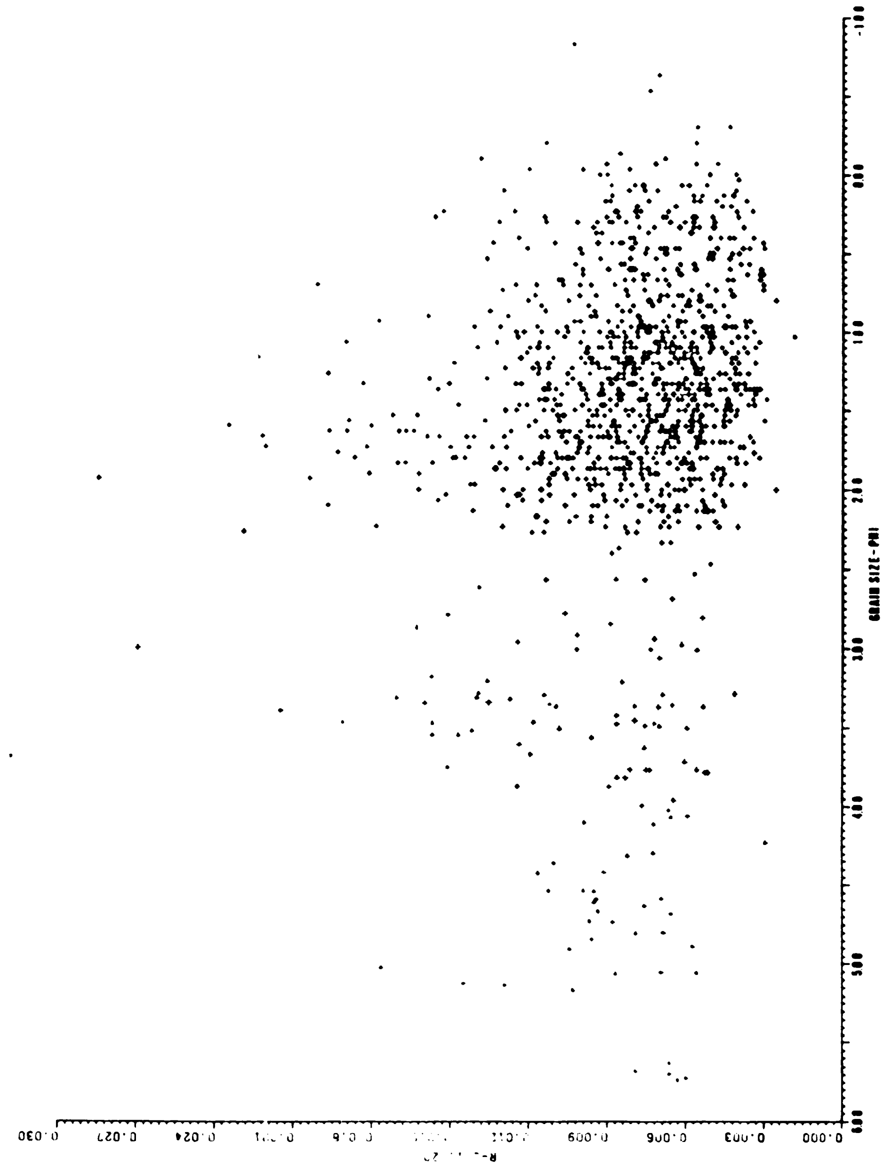

Figure 25.--Modified Roughness Coefficient 11-20

DISCUSSION

Simple inspection of the graphs representing the size and shape relationship reveals the absence of a functional relationship (Figure 1-b) between size and shape in the range of 6 phi to -1 phi. Neither do the arrays display patchy clustering as in Figure 1-d. However, observation of certain harmonics such as harmonics 6 and 7 show a slight lack of small grains of low amplitudes of smaller grains. This might imply that the smaller grains are not as angular as the larger grains. This possible trend may exist in the MRC 1-5 and the MRC 11-20. This trend is not strong and may not be statistically significant.

This data can be explained in only one of two ways. There may in fact be no relationship between shape and size, in which case, subsequent investigators can simplify their sampling plans.

On the other hand, the nature of the sample must be taken into account. The grains were derived from such a diverse variety of terranes and a wide enough spectrum of physical and chemical weathering that the data arrays may represent a series of continuous functions. This may be reflected in the weak trends seen in harmonics 6 and 7 and MRC's 1-5 and 11-20. In such an instance, it could result in the wide scatter observed in these plots.

The only way we can clarify this situation is to study the size and shape relationship of a series of samples derived from known sources, preferably soils resting on their parent rock material, or examine quartz grains such as those found in the St. Petersburg sandstone which has been subject to extreme weathering where provenance influence would be minimal.

However until such studies are preformed, the possibility exists that the relationship between size and shape, long expounded in sedimentology, may not exist.

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