SHOOFLY CHAPTER
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HARDNESS TESTING OF PREHISTORIC CERAMICS

AN EXAMPLE FROM SHOOFLY VILLAGE, ARIZONA

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INTRODUCTION

An indentation device, the Rockwell Superficial-Hardness Tester (Figure 1), is assessed as a means of precisely quantifying hardness in prehistoric ceramics. In this project, the apparatus is used to determine hardness measures of a sample of plain ware sherds from Shoofly Village, a prehistoric site located near Payson, Arizona. Results indicate that the method is useable on heterogeneous materials such as prehistoric ceramics and that results may be used in statistical comparisons to other ceramic attributes.

Moh's Hardness Scale has generally been used to quantify hardness in prehistoric ceramics. This scratch test is relatively easy and inexpensive to use, however Shepard (1956:115, Table 4) stated that the results obtained from Moh's Hardness Scale result in only a rough approximation due to lack of standardization of the point shape and pressure of application. During the thirty years Shepard's manual has been in use, no other test has been come into common useage to replace Moh's Hardness Scale.

While ceramic hardness measured by Moh's Hardness Scale has commonly been a part of describing different ceramic wares, a more precise measurement allows testing questions of vessel and paste strength through different physical attributes. Ceramic strength is a result of the material

selection, manufacturing, and firing process. The products have been further modified through use and depositional processes.

Identification of physical attributes is particularly important in the analysis of ceramic plain wares, since stylistic analysis may be limited to vessel form. Although a variety of physical property measures and tests are available, these differ in precision, quantification, and replicability. Since ceramics are complex materials, a number of analytic techniques need to be employed, each reflecting a different physical property aspect.

An emphasis on technological questions in the ceramic analysis can aid in identifying the decision making process which went into the selection of clay and temper, the manufacturing technique, firing technique and conditions, as well as suitability for different uses. The application of a precise means for measuring hardness is one method of standardizing and quantifying physical property tests.

METHOD

PROBLEM STATEMENT

The previous failure in use of indentation hardness testing may be due to lack of exploration of the full range of applications of the different apparatuses and associated scales of measurement. Shepard (1956:116) stated that prehistoric pottery is not well suited to fine hardness testing as with an indentation device. The heterogeneity and

porosity of the material as well as surface irregularities will affect the penetration of the point and accuracy of the results. However, her experiments were with the Knoop indenter which is quite microscopic in size compared to those indenters used in this study.

An advantage of microhardness testers is that the scale is even, in contrast to Moh's Hardness Scale which has uneven increments between numbers. The purpose of this study is to test the applicability of microhardness testing to prehistoric ceramics and to assess its utility in terms of the nature of the material and relationship to other variables (thickness, slip and smudge treatment, vessel form).

TESTING APPARATUS

A method of determining "differential-depth" measurements to record hardness is used in this study. Two apparatuses are used: a Rockwell Hardness Tester and a Rockwell Superficial-Hardness tester. The principle of operation is the same for both, although the weights involved differ. The method (Kehl 1949:229) was developed for testing hardness in metals. It measures depth increments of a diamond-cone penetrator which is forced into the metal by a primary and secondary load. The test controls mechanical errors such as backlash, slight imperfections of the test surface, and varying contact between the test surface and the penetrator.

The principle of operation is illustrated in Figure 2

(Kehl 1949:237,Fig. 117). The explanations of each step in the test are excerpts in part from Kehl (1949:236,238):

1) The test specimen is placed on a suitable anvil at the upper end of the elevating screw. An anvil slightly greater than .5 cm in diameter was used in this study to reduce the affects of curvature of the potsherds. The dial pointers are idle and neither minor nor major load is applied.

2) The elevating screw is rotated with the capstan wheel to bring the test specimen surface in contact with the penetrator. The minor load (3 kg) is slowly applied. The small dial is in the "set" position. The bezel of the dial is rotated so that the large pointer is in the "set" position. The minor load has forced the indenter into a depth corresponding with A - B.

3) The major load of 15 kg (3 kg plus 12 kg) is applied by release of a handle on the side of the apparatus. The load is applied at a definite rate (by a oil-dashpot arrangement). This application forces the indenter to an additional depth of B - C.

4) The major load (12 kg) is withdrawn which allows the impression to recover elastically to D - C. The gage now reads B - D which is the Rockwell Hardness number. The setting of the dial at the beginning and the reading of the final hardness number are conducted under identical stress conditions; stress conditions under the minor (3 kg) load. This standardizes the final hardness numbers since the conditions are the same from one test to the next (the major

load may be varied without changing the final reading conditions).

5) The platform is lowered and the test piece removed. The next test piece is inserted and the dials again reset.

The Rockwell Hardness tester can be used to apply loads of 60, 100, and 150 kg. The dial face has 100 equal division marks and each division represents one point on the Rockwell Hardness scales and a corresponding vertical indenter motion of 0.002 mm (Kehl 1949:235). Hardness readings are influenced by the hardness at the penetration point and also the hardness of the material at least 10 times this depth below the impression (1949:239).

The Rockwell Superficial-Hardness tester (Kehl 1949:240-241) is designed for light testing, using loads of 15, 30, or 45 kg. The dial has 100 divisions with each representing one point of the hardness scale and a corresponding vertical indenter motion of 0.001 mm. The dial is more sensitive to small indenter movements because of the shallow impression.

Both the Rockwell and Rockwell Superficial-Hardness testers were used in the study. Five different indenters were used: a "C" Brale diamond-cone, 1/16" ball, 1/8" ball, 1/4" ball, and 1/2" ball.

TESTING CONDITIONS

To begin a set of "scrap sherds" are used with the hardness testers to determine which loads and which machine

will work without breaking the ceramics. Accurate readings can not be obtained if the specimen breaks during the test (the penetrator continues through the break with nothing to stop it or the dial spinning).

All readings are taken on the sherd exteriors with the interior of the sherd resting on the anvil. Use of the Rockwell tester is eliminated since all loads (60, 100, and 150 kg) applied with both the Brale and ball indenters usually results in breakage of the sherds. Use of the Rockwell-Superficial Hardness tester at a major load of 15 kg is successful in obtaining readings and not breaking the test pieces.

Once the machine and load level are established, a pilot study is conducted on a set of scrap sherds to compare the effects of the different indenters. The results are used to reduce the number of indenters to the two most useful (the Brale and the 1/8" ball) and these are used to gather hardness readings on the ceramic sample from the Shoofly site.

For both the pilot study and the Shoofly study, a sampling pattern of nine points (a 3 x 3 point grid at .5 cm intervals) is marked on each sherd using a fine tipped felt pen and a transparent plastic template. Since the prehistoric ceramics are composed of differing particles of clays, temper, inclusions, and pores, a sample of several intervals on the ceramic surface is more likely to adequately reflect the hardness of the sherd than a single reading which would be adequate on a highly homogenous material. The

sampling point number of nine is chosen arbitrarily as is the pattern. The points are positioned far enough apart so that each test point is independent of the affects of other points. The 3 x 3 point grid fits most sherds, however a few narrow sherds were tested with two rows of points. The .5 cm interval between points was maintained where ever possible.

PILOT STUDY

TESTING

Four large plain ware scrap sherds are chosen for the pilot study. The goal is to repeat the nine point pattern on each sherd for each of the five indenters. For each indenter the grid is shifted slightly from the position of the previous one so that the indentation points do not overlap. The sherds chosen are large enough (roughly 4 x 4 cm) to accommodate this many test positions. For each reading the dial reading and the number of revolutions of the dial are recorded. The sherds vary in hardness to the degree that some readings involve less than one full turn of the dial, some involve one full turn, and others involve two full turns.

DATA DEFINITIONS

The readings gathered from the pilot study are entered as inline data in an SPSSX run called #PILOT1 which is stored as a PDS (Figure 3). Data definitions include 21 variables which breakdown as follows: V1 sample number; V2 kg major

load; V3 (A) indenter size (B=Brale, C=1/16" ball, D=1/8" ball, E=1/4" ball, and F=1/2" ball); the remaining variables are paired sets of readings (V4) followed by number of turns (V5). There are five lines of data for each sample piece; one line for each indenter and nine point set.

The raw data (readings and number of turns) are transformed through COMPUTE statements into hardness (H1 - H9) and depth of indentation with the minor load (D1 - D9) for each of the nine points per set. The formulas are as follows:

Hardness = (-100 * n of turns) + reading + 100

Depth = (n of turns * .1) + ((100 - reading) * .001)

(Note: one full revolution of the dial equals 100; each of the 100 marks or readings on the dial is equal to .001 mm vertical motion of the indenter).

Other COMPUTE statements are used to calculate new variables which will be the sum, mean, standard deviation, and variance for each nine point set of hardness numbers and depth measurements. The computed variables first letter stands for Rockwell, the second letter stands for either Hardness or for Depth, and the remaining name is for the statistic calculated. (RHMEAN - Rockwell Hardness Mean and RDVAR - Rockwell Depth Variance). A LIST VARIABLES was then done for all the compute statements.

RESULTS

Dr. Coghlan (Engineering Research Center - ASU) entered the hardness means for the four sherds and five indenter nine point sets into a Super Calc program and plotted the Brale measurements on the X-axis and a 200 point scale of hardness on the Y-axis of a scatterplot (Figure 4). A second scatter plot was done which scaled all five indenter hardness means against the 1/8" ball range. From examining these plots and the variable list, we determined that the Brale and 1/8" indenters were the most useful.

The results from the 1/16" ball are erratic, there is a slight problem with the indenter causing the sherd to tilt and impact the shoulder of the indenter mount when the major load is applied. This the most probable cause of the erratic readings. The 1/4" and 1/2" ball indenters are not useful because they "average" out the variability in the sherd because of their larger surface area resulting in a flat plot. The large diameter indenters are not sensitive enough to effectively contrast the hardness of different sherds.

SHOOFLY STUDY

TESTING

The testing procedure for the Shoofly sample is the same as described for the Pilot study. A sample of 77 sherds were

tested with nine point grids for the Brale and the 1/8" indenter. The sherd sample had been chosen by Gabriel as a stratified random sample of the Shoofly ceramic collection. Sherds were chosen to be representative of different parts of the site, different kinds of vessels, and vessels with differing surface treatment (smudged, slipped).

DATA DEFINITION

Two files are initially composed for the Shoofly study, both are PDS. One file (#SAMPLE) (Figure 5) contains identifiers for the sample sherds (V1,V2) and several alpha-numeric variables which serve as locational identifiers (V3 - V7). Presence or absence of slipped or smudged surface are noted in V8 and V9. Thickness measurements are recorded in V10, and vessel form (bowl or jar) is noted in V11. The variable definitions and labels are written into the SPSSX runstream and the data slightly modified for more compact presentation and storage (slashes and extra spaces between variable columns were deleted).

The second file (#SHOFLY) (Figure 6) contains the data from the Rockwell readings. Organization of the file and function of the various compute statements is the same as the PILOT study. The variable names are modified to letter codes so that the only two overlapping variables between #SAMPLE and #SHOFLY are V1 and V2, the sherd identifier numbers. Each line of the inline data contains V1 and V2 followed by the nine sets of readings and number of turns for the Brale

indenter, followed by the nine sets for the 1/8" indenter. One line represents one sherd and all its readings.

The variable codes are as follows: for the inline data V1 and V2 are the sherd identifiers; these are followed by sets of readings and numbers of turns (BR1 - BR9 are the Brale Readings and BT1 - BT9 are the Brale Turns; followed by the readings and turns for each nine sets with the D=1/8" ball). Summary variables are computed for each sherd for the Brale and the 1/8" ball sets (RHB and RHD sum, mean, standard deviation, and variance). The LIST VARIABLES command is used to print out the computed variable values. A FREQUENCIES command for histograms or barcharts is added to the end of the run.

The next step is to set up a Wylbur sequential file called ROCKWELL to store the combined data sets. A runstream is written in SPSSX which uses the MATCH FILES command Key command lines are highlighted in blue in Figure 7. In the runstream #SHOFLY is temporarily saved as a sequential file and then #SAMPLE is merged from the active file. The final definition of the RECORDS for the new file at the end of the run combines the #SHOFLY Record 1 (78 columns), #SAMPLE Record 2 plus some of the computed variables (75 columns), and the remainder of the computed variables in Record 3 (26 variables). The definition of the computed variable column widths and decimal places is obtained from the LIST VARIABLES tables on the #SHOFLY printout. The merge files runstream is saved as a PDS called #ROCKWL (Figure 7) so that modifications can be made if necessary, and so that a list

off of the RECORDS can be printed for reference and copied into the DATA LIST part of other SPSSX jobs which will access the sequential data file formed by the merged files.

To form the sequential data file, the runstream saved as #ROCKWL is called into active and run as a job. This automatically forms a sequential data file called ROCKWELL (Figure 8). This sequential file is accessed for all successive runstreams.

RESULTS

Several procedures are run on the data accessing the sequential file ROCKWELL, which contains the combined data set. These are individually described below and results presented either in the text or referenced as appendices.

The major variables from the data set are summarized by using the REPORT command with the nobreaks option. The runstream for this is given in Figure 9 and the resulting table in Figure 10.

SCATTERGRAMS are the next procedure. Six scatterplots with statistics were produced using a runstream which accessed the ROCKWELL file (Figure 11). The statistics used in the scattergrams are those of linear regression and correlation. The results of the analysis are discussed for each scatterplot.

1) Comparison of hardness between the Brale and 1/8" indenter data (RHBMEAN AND RHDMEAN)(Figure 11). The correlation coefficient is close to 1.0 indicating a strong

linear relationship between the two variables. The coefficient of determination is high, 73% of the variation in scores is explained by the linear relationship indicating a high degree of predictability between variables. The slope (B) is positive indicating that as one variable increases, so does the other. These results are expected since the Brale and 1/8" indenter should be measuring the same thing at slightly different magnitudes. The results indicate a strong linear relationship between the readings of the two indenters.

2) Comparison of depth measurements between the Brale and 1/8" indenter (RDBMEAN AND RDDMEAN) (Figure 13). This scatterplot statistics for r, r2, and B are very similar to those from the preceding scatterplot. The individual points cluster very closely. These results indicate a strong linear relationship between the two variables. The scatter and statistics are close to the preceding one since both sets are derived from different calculations (one for hardness and one for depth) based on the same data. The hardness calculations amplify the spread of points on the plot.

3) Comparison of hardness and depth calculations for the Brale indenter (RHBMEAN and RDBMEAN) (Figure 14). This scatterplot shows a near perfect correlation between the two variables which should be expected since both computations are done from the same raw data. Both the r and B statistic are negative indicating that as hardness increases the depth of the indentation decreases. The r2 statistic indicates that 97% of the variation can be explained by the linear

relationship between the variables.

4) Comparison of hardness and depth calculations for the 1/8" indenter (RHDMEAN AND RDDMEAN) (Figure 15). The results of this linear regression analysis are very similar to those for the Brale. There is again a near perfect negative correlation in the r and B statistic, indicating that as hardness increases the depth of the indenter decreases. The linear relation (r2) explains 99% of the variation between the two variables. The 1/8" indenter tends to more tightly cluster the readings than the Brale.

5) Comparison of hardness with the Brale indenter to thickness of the pottery (RHBMEAN and V10) (Figure 16). There is virtually no linear relationship between the hardness of the pottery and the thickness. This indicates that the thickness of the pottery is controlled for by the testing method and does not affect the results. It also indicates that thickness and hardness are not dependent variables. The r and B statistics are both positive but very close to 0.0 and the coefficient of determination indicates that only .072% of the variation is accounted for by linear relationship between the two variables.

6) Comparison of hardness with the 1/8" indenter and thickness of the pottery (RHDMEAN and V10) (Figure 17). The results of this linear regression analysis are similar to those of the preceding scattergram. The numbers for all three statistics (r, r2, B) are slightly higher than in the prior plot. For the 1/8" indenter the linear relationship accounts for only .21% of the variation, an insignificant amount.

Thickness and hardness are not dependent variables.

ANALYSIS OF VARIANCE is the next step and two procedures were used depending whether two means (T-TESTS) or multiple means (ONEWAY) were compared. These procedures involved testing hardness and depth calculations against distributional and vessel descriptive variables.

In completing the ONEWAY analysis of multiple means it is necessary to recode V6 and V7 (alphanumerics) into AREA and PLT (proposed locus type), new variables which are numerics since the procedure requires numeric grouping variables (Figure 18). The ONEWAY analysis of variance tests the following hypotheses:

Ho (null): MEAN1 = MEAN2 = MEAN3, etc.

H1 (alternate): Differences exist between at least some of the means.

If the F-Ratio is near 0.0 then Ho is accepted; if the F-Ratio is near 1.0 then Ho is rejected and H1 is accepted. The F Probability indicates the probablility that if all the means were equal the same F-Ratio would result. Four ONEWAY analysis of variance were put into the runstream. The RANGES=SCHEFFE/OPTIONS 6 subcommand was used on all four. If Ho is accepted a statement results which indicates there is no significant difference in means. If H1 is accepted, the subcommand will result in a table which indicates which means are different. This is quite useful in interpreting the

statistic. Results are shown the appendix. Each test is discussed below.

1) Comparison of hardness with the Brale indenter and proposed locus type (RHBMEAN and PLT). The F-Ratio is low and and the F Probability is 98% that the means are equal. The multiple range test (Scheffe procedure) indicates that no two groups are significantly different at the 0.050 level of significance. This indicates that for proposed locus type, the within group variance is greater than the between group variance. Therefore, distribution of ceramic hardness is not dependent on proposed locus type.

2) Comparison of hardness with the 1/8" indenter and proposed locus type (RHBMEAN and PLT). The F-Ratio is still low (.22) and the probability that the means are equal is 92%. The results of the multiple range test are the same as above.

3) Comparison of hardness with the Brale indenter and site area (RHBMEAN and AREA). These results indicate slightly more contrast than the comparisons by proposed locus type. The F-Ratio is higher (.50) and the F Probability that the means are equal is 80%. The multiple range test indicates that no two groups are significantly different at the 0.050 level of significance. There is slightly more between group variance by areas within the site than by proposed locus type, but the within group variance is still greater than the between group variance.

4) Comparison of hardness with the 1/8" indenter and site area (RHDMEAN and AREA). These results are somewhat

different from the preceding set. The F-Ratio is 1.35 with only 24% probability that the means are equal. The between group variance is greater than the within groups variance when considering the mean squares. However, the multiple range test negates this interpretation, stating that the ranges are the same as for the prior test and that no two groups are significantly different at the 0.050 level of significance.

T-TEST procedures were run to test whether there is a significant difference in means between groups based on SLIP, SMUDGE, and FORM. Results are presented in the appendix. The results are ambiguous between the Brale and the 1/8" indenter, and will need slightly different tests performed to clarify the results.

BMDP - discriminant analysis is used to discriminate between the hardness, depth, and thickness measurements. CLUSTAN is used as a grouping technique for these three variables. The runstreams and printouts are included in the appendix. Interpretation of these results hinges on clarification of the T-TEST results between the Brale and the 1/8" indenter. The continuation of this study in the next few months will address these issues.

CONCLUSIONS

This study has assessed the application of Rockwell Superfical-Hardness testing methods to prehistoric ceramics. The method is found to work successfully. A precisely

quantified measurement of hardness is produced from the test. The Brale diamond-cone indenter produces the most accurate results since it has the deepest penetration into the ceramic. The 1/8" indenter has the next most accurate results but produces a more compact, or flat profile of variability.

The results indicate that the Brale and 1/8" ball readings and computations closely parallel each other, that one is highly predictable from the other. There is a strong positive correlation between the two sets of readings, as one increases so does the other. There is a near perfect negative correlation between the hardness and depth computations, as hardness increases the depth decreases. This is true for readings from both indenters.

The results are independent of the thickness of the pottery. The testing method is controlled for thickness and there is not a strong correlation between thickness and hardness. It is likely that other variables such as firing temperature, quantity and size of temper, vessel diameter, etc., may correlate more closely with hardness than the variables compared in this study.

Some of the statistical tests are ambiguous, with the Brale results and 1/8" results seemingly in contradiction. This may be a question of scale, with the one indenter amplifying or muting the variation expressed in the other. Consequently where one set would indicate acceptance of a null hypothesis, the other would indicate its rejection. The clarification of these issues is a primary goal in the continuation of this project.

Strategies to consider in future work with these data will include:

1) Clarification of the ambiguities between Brale and 1/8" readings on some of the statistical tests. This may require use of alternative testing procedures which better fit the nature of the data (different tests of variance).

2) Inclusion of additional data on vessel diameter, tempering material, size and quantity, firing temperature, warpage, etc.

3) Rescaling of the results and recoding of hardness and/or depth as grouping variables based on variations in distributions from the histograms of means and standard deviations.

4) Continued use of the sequential file ROCKWELL, with additional runstreams that will allow copying certain variables into other files and allow additions of other variables to the existing file.

In summary, this project is a step toward more precise quantification of hardness for prehistoric ceramics. The method is shown to be of utility in that accurate measurements can be obtained which through a series of transformations are presented as measures of hardness and depth of indention. Future work is focused on clarifying some of the ambiguities between the two indenters, and further assessing the dependence or independence of hardness with other stylistic, locational, and physical property variables.

REFERENCES CITED

Kehl, George L.

1949 *The principles of metallographic laboratory practice.* McGraw-Hill Book Company, New York. (Third Edition).

Shepard, Anna O.

1956 Ceramics for the archaeologist. *Publication* 609, Carnegie Institution of Washington, Washington, DC.

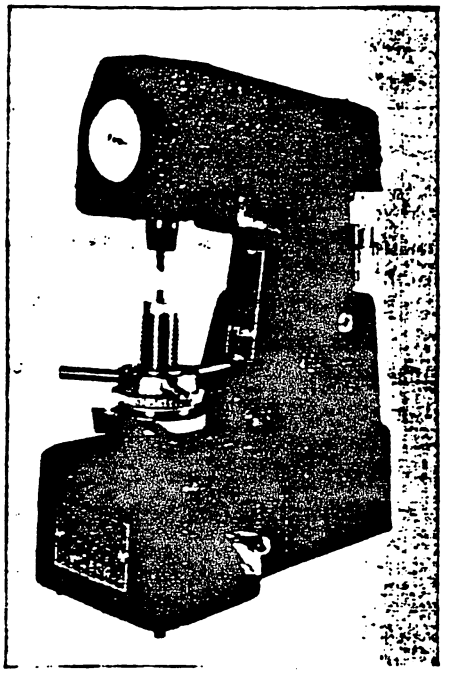


Figure 1. Illustration of Rockwell Superficial-Hardness tester (from Kehl 1949:241, Figure 118).

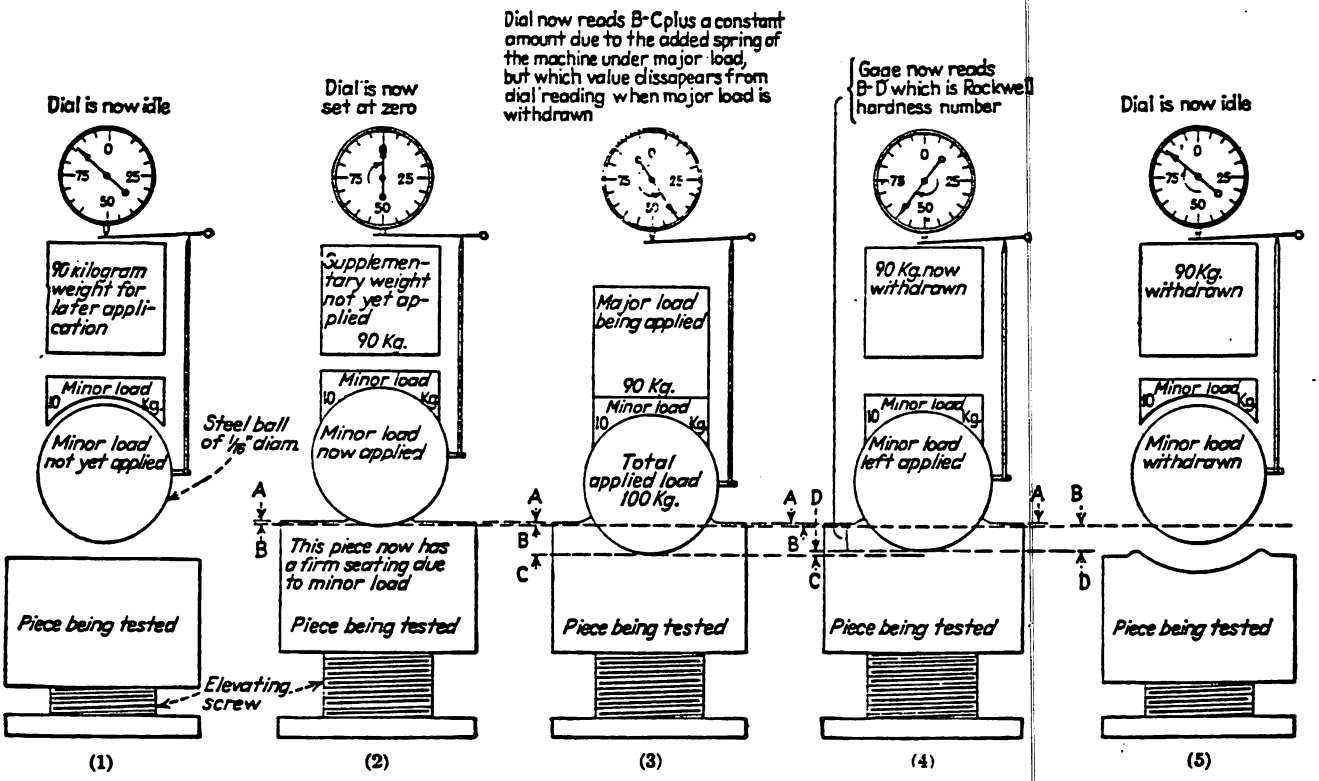


Figure 2. Schematic illustration of Rockwell Hardness Tester principle of operation (from Kehl 1949:237, Figure 117). For Rockwell Superficial-Hardness Tester as used in this study substitute 3 kg for minor load and 12 kg for major load - total of 15 kg.

```
//     JOB
//     EXEC SPSSX
DATA LIST FILE=INLINE FIXED/
 V1 1-2 V2 3-4 V3 5(A) V4 6-8 V5 9 V6 10-12 V7 13 V8 14-16
 V9 17 V10 18-20 V11 21 V12 22-24 V13 25 V14 26-28 V15 29
 V16 30-32 V17 33 V18 34-36 V19 37 V20 38-40 V21 41
LIST VARIABLES=ALL
BEGIN DATA
0115501100921027104600811007006610791098 1
0115C0360044005200430041103700170040004 10
0115D045005100260051004700510046103810371
0115E0390063002100710061005200640061004 50
0115F0540037007000560002002700590058005 80
0215A0100067106410021010010631063109310791
0215C0331025101410341011109710321015101 51
0215D0620025104210391064105100541052005 60
0215E0370034004900430060005700690061005 60
0215F0690037005700690009006100620060006 80
0215G0090072100311000011000210100971079 1
0315C0361029102310291029110371030106110 211
0315D0911051105910461054104910531095100 31
0315E0360051105300550071106600461057106 10
0315F0630073007100730069005600790067004 90
0415C0761074100310611091104010691015003 51
0415D0231010109910691091077101310741082 1
0415E0271070003900431048000500510055004 10
0415F0610045006500560048005200630043004 11
0415G0700260062005300730053006600550060 0
END DATA
COMPUTE H1=(-100 * V5 ) + V4  + 100
COMPUTE H2=(-100 * V7 ) + V6  + 100
COMPUTE H3=(-100 * V9 ) + V8  + 100
COMPUTE H4=(-100 * V11) + V10 + 100
COMPUTE H5=(-100 * V13) + V12 + 100
COMPUTE H6=(-100 * V15) + V14 + 100
COMPUTE H7=(-100 * V17) + V16 + 100
COMPUTE H8=(-100 * V19) + V18 + 100
COMPUTE H9=(-100 * V21) + V20 + 100
COMPUTE D1=(V5  * .1) + ((100 - V4 ) * .001)
COMPUTE D2=(V7  * .1) + ((100 - V6 ) * .001)
COMPUTE D3=(V9  * .1) + ((100 - V8 ) * .001)
COMPUTE D4=(V11 * .1) + ((100 - V10) * .001)
COMPUTE D5=(V13 * .1) + ((100 - V12) * .001)
COMPUTE D6=(V15 * .1) + ((100 - V14) * .001)
COMPUTE D7=(V17 * .1) + ((100 - V16) * .001)
COMPUTE D8=(V19 * .1) + ((100 - V18) * .001)
COMPUTE D9=(V21 * .1) + ((100 - V20) * .001)
SORT CASES BY V1 V3
COMPUTE RHSUM=SUM (H1 TO H9)
COMPUTE RHMEAN=MEAN (H1 TO H9)
COMPUTE RHSDDV=SD (H1 TO H9)
COMPUTE RHVAR=VARIANCE (H1 TO H9)
COMPUTE RDSUM=SUM (D1 TO D9)
COMPUTE RDMEAN=MEAN (D1 TO D9)
COMPUTE RDSDDV=SD (D1 TO D9)
COMPUTE RDVAR=VARIANCE (D1 TO D9)
LIST VARIABLES=V1 V3 RHSUM RHMEAN RHSDDV RHVAR
LIST VARIABLES=V1 V3 RDSUM RDMEAN RDSDDV RDVAR
LIST VARIABLES=V1 V3 H1 H2 H3 H4 H5 H6 H7 H8 H9
LIST VARIABLES=V1 V3 D1 D2 D3 D4 D5 D6 D7 D8 D9
//
```

Figure 3. Runstream list off of #PILOT1 file.

Hardness Data for Pottery Sherds (Simon.cal)
Hardness

No	Braile	1/16	1/8	1/4	1/2
1	98.56	127.89	110.22	158.56	155.67
2	78.44	30.67	93.89	156.22	163.33
3	105	36.78	62.89	113.78	166.89
4	69.11	56.67	123.44	141.56	162

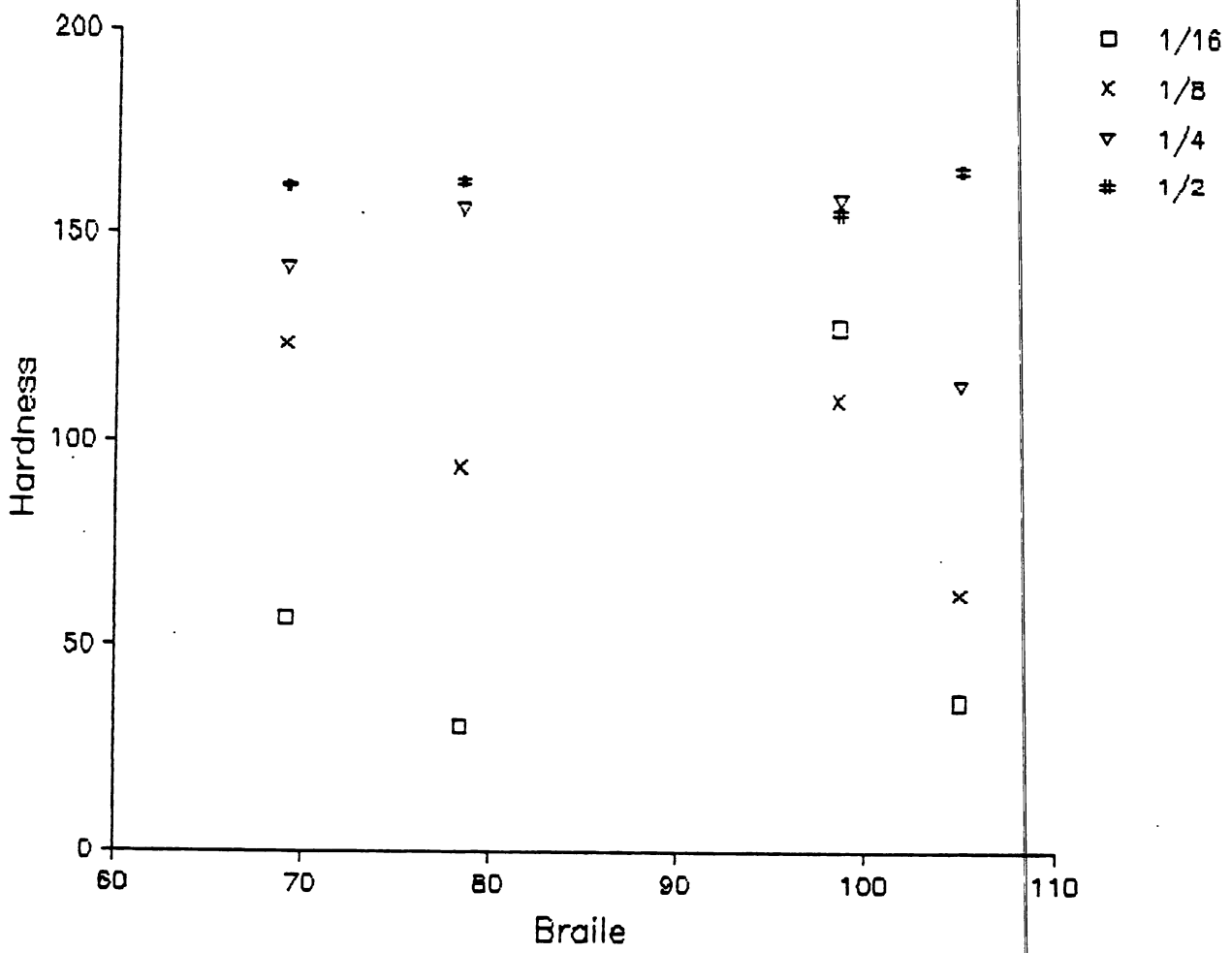


Figure 4. Super Calc plots of hardness scaling and indenter results for PILOT study.

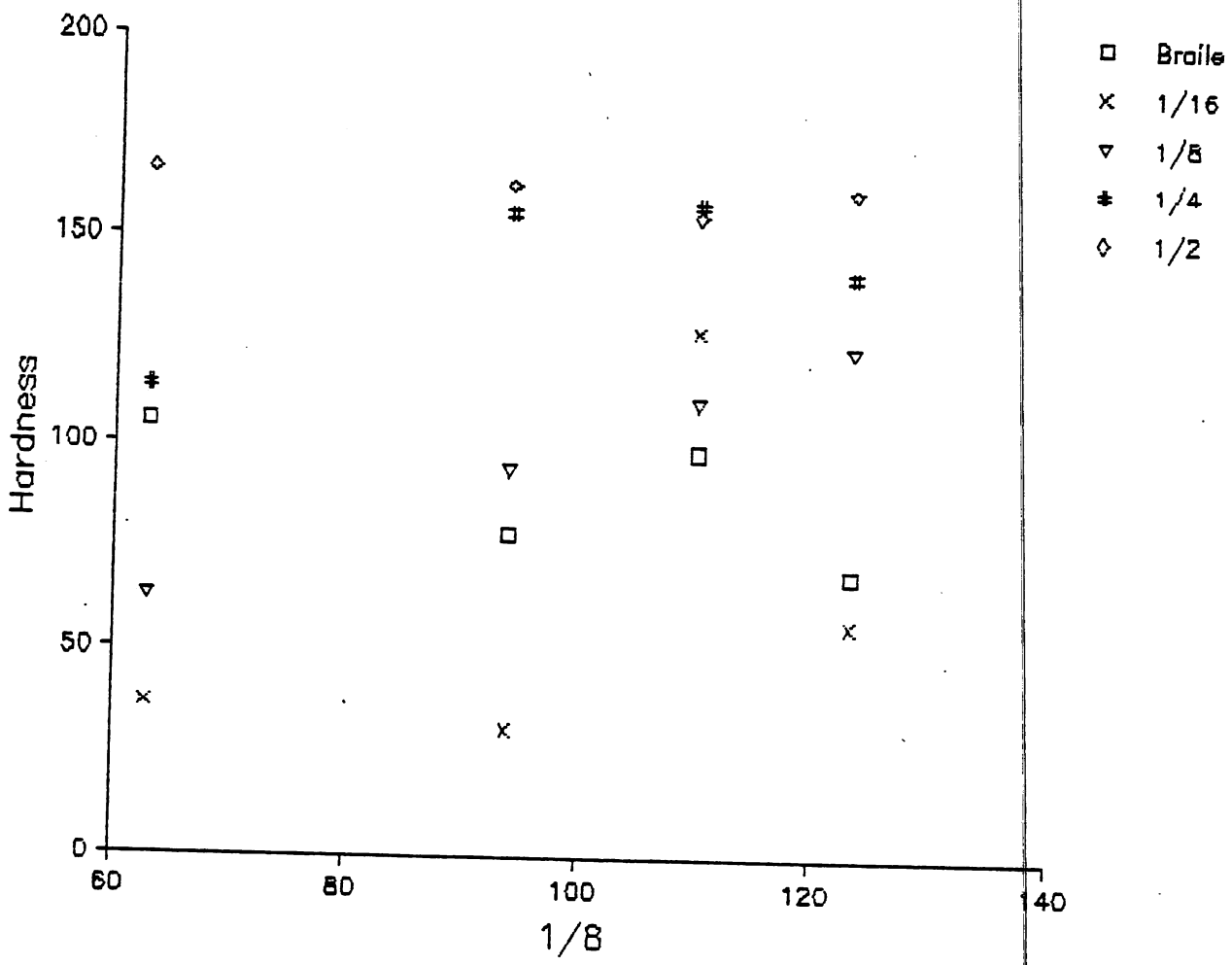


Figure 4. (Continued).

```
//      JOB
//      EXEC SPSSX
//REPORT DD DSN=WYL.AG.AWS.ROCKWELL,DISP=SHR
DATA LIST FILE=REPORT RECORDS=3
 /1 V1 1-4 V2 5-6
 /2 V6 15 (A) V7 16-18 (A) V8 19 (A) V9 20 (A) V11 24 (A)
 V10 21-23 RHBMEAN 32-37 RHDMEAN 57-62
 /3 RDBMEAN 5-7  RDDMEAN 18-20
LIST FORMAT=NUMBERED
SET LENGTH=NONE
LIST VARIABLES=V1 V2 RHBMEAN RHDMEAN RDBMEAN RDDMEAN
                V6 V7 V8 V9 V11
SORT CASES BY V1 V2
REPORT FORMAT=LIST TSPACE(2) MARGINS(1,80) BRKSPACE(-1)
  /LTITLE 'SHOOFLY VILLAGE CERAMIC SAMPLE
          'TEST CASE FOR PLAIN WARES'
  /RTITLE 'SUMMARY OF KEY VARIABLES'
          'ROCKWELL HARDNESS TESTER'
  /VARIABLES=V1 'LOCATION' ( 8) (OFFSET(1))
             V2 'NUMBER' (6) (OFFSET(1))
             V8 'SLIP' (4) (OFFSET(1))
             V9 'SMUDGE' (6) (OFFSET(2))
             V11 'VESSEL' (6) (OFFSET(1))
             V10 'THICKNESS' ( 9) (OFFSET(1))
             RHBMEAN 'RHBMEAN' (7) (OFFSET(1))
             RDBMEAN 'RDBMEAN' (7) (OFFSET(1))
             RHDMEAN 'RHDMEAN' (7) (OFFSET(1))
             RDDMEAN 'RDDMEAN' (7) (OFFSET(1))
  /BREAK=(NOBREAK)
  /SUMMARY=MEAN (RHBMEAN(2) RDBMEAN(2) RHDMEAN(2) RDDMEAN(2))'MEAN'
  /SUMMARY=STDDEV (RHBMEAN(2) RDBMEAN(2) RHDMEAN(2) RDDMEAN(2))
          'STANDARD' 'DEVIATION'
  /LFOOTNOTE='ASM 591 PROJECT'
  /RFOOTNOTE='SPRING SEMESTER 1985'
//
```

Figure 9. Runstream list off of #REPORT.

SMOOFLY VILLAGE CERAMIC SAMPLE
TEST CASE FOR PLAIN WARES

SUMMARY OF KEY VARIABLES
ROCKWELL HARDNESS TESTER

LOCATION	NUMBER	SLIP	SMUDGE	VESSEL	THICKNESS	RMBMEAN	RDBMEAN	RHOMEAN	RDOMEAN
160	1	1	1	B	55	-14.22	.21	-17.00	.22
193	5	0	1	J	70	86.11	.11	137.33	.06
215	2	1	0	B	45	34.44	.17	89.56	.11
272	6	1	1	J	60	72.22	.13	132.44	.07
278	1	1	1	B	45	68.78	.13	137.78	.06
278	3	0	0	J	65	89.00	.11	139.00	.06
288	1	0	1	B	45	33.44	.17	93.56	.11
299	7	0	0	B	40	55.78	.14	121.11	.08
301	4	0	1	B	50	89.44	.11	149.33	.05
355	1	0	1	J	100	72.44	.13	133.33	.06
1008	3	1	0	B	55	64.89	.14	120.89	.08
1227	2	0	0	B	70	81.33	.14	120.56	.08
1229	1	0	1	B	50	40.67	.16	95.44	.10
1248	1	1	1	B	60	59.00	.14	117.89	.08
1303	3	1	0	J	60	92.56	.11	140.78	.05
1303	5	1	0	B	55	73.11	.13	129.67	.07
1303	8	0	1	J	50	71.44	.13	130.33	.07
1336	2	1	1	B	50	74.44	.13	142.56	.06
1344	2	1	1	J	75	32.22	.17	87.78	.11
1351	2	1	1	B	45	85.78	.11	137.78	.06
1383	4	0	0	J	65	49.89	.15	119.22	.08
1384	1	1	0	B	45	75.11	.12	133.00	.06
1384	3	1	1	B	50	64.44	.14	131.67	.07
1417	1	1	1	J	45	53.11	.14	89.56	.11
1417	3	0	1	J	80	57.44	.14	121.44	.08
1434	4	0	1	B	50	53.56	.15	129.89	.07
1434	6	0	0	B	60	73.78	.13	138.89	.06
1443	12	1	1	B	55	41.67	.16	83.67	.11
1443	14	1	0	J	65	35.11	.16	41.22	.16
1443	20	1	1	B	60	45.78	.15	99.00	.10
1443	23	1	0	J	50	83.33	.12	150.11	.05
1443	31	0	0	J	60	34.33	.17	86.56	.11
1455	30	0	1	B	50	72.44	.13	131.89	.07
1465	1	0	0	B	65	62.22	.14	135.22	.06
2100	2	1	0	J	55	63.33	.14	132.22	.07
2174	5	0	0	J	80	73.89	.13	141.56	.06
2180	4	0	1	J	60	72.11	.13	129.00	.07
2191	1	0	0	J	60	53.44	.15	126.00	.07
2191	15	1	1	B	60	40.44	.16	110.89	.09
2215	4	1	1	J	50	80.56	.12	137.56	.06
2230	5	1	1	B	50	47.00	.15	112.89	.09
2230	12	1	1	B	45	65.78	.13	126.11	.07
2241	4	0	0	J	90	44.00	.16	118.00	.08
2245	3	1	0	B	55	92.44	.11	141.22	.06
2249	12	1	1	B	50	64.11	.14	154.00	.05
2249	17	0	0	B	65	70.67	.13	132.11	.07
2268	4	0	0	J	60	31.22	.17	90.33	.11
2282	5	0	1	B	60	43.89	.16	103.11	.09
2287	2	1	0	J	60	98.56	.10	156.11	.04
2290	1	1	0	B	90	91.67	.11	136.44	.06
2290	8	1	0	B	65	85.78	.11	165.22	.03
2319	1	0	0	J	85	94.00	.11	139.56	.06
2321	7	0	0	J	80	51.33	.15	125.67	.07
2336	8	0	0	J	60	55.44	.14	115.22	.08
2336	16	0	0	B	70	88.89	.11	145.67	.05
2336	27	0	0	J	70	64.33	.14	129.44	.07
2341	2	0	0	J	100	88.00	.11	142.22	.06
2346	4	0	1	J	60	55.00	.14	131.11	.07
2353	4	0	0	J	70	43.44	.15	117.67	.08
2356	7	0	0	B	90	43.56	.16	111.11	.09
2356	14	0	0	J	100	46.78	.15	114.67	.09
2356	20	0	0	B	65	80.56	.12	133.78	.07
2356	26	0	1	J	80	31.00	.17	92.11	.11
2356	27	1	0	B	50	53.44	.15	111.33	.09
2356	30	0	1	B	65	54.44	.15	121.78	.08
3110	2	1	1	J	60	79.89	.12	142.00	.06
3131	1	0	1	B	70	97.67	.10	150.22	.05
3137	3	1	0	B	50	42.89	.16	99.11	.10
3144	1	1	1	J	55	58.00	.14	105.78	.09
3182	3	1	1	B	70	59.67	.14	126.11	.07
3182	6	1	0	B	65	36.89	.16	104.56	.10
3230	2	1	1	B	50	72.56	.13	137.44	.06
3250	1	1	1	J	60	76.33	.12	141.00	.06
3269	6	1	0	B	45	56.89	.14	140.89	.06
3300	4	1	0	J	55	92.89	.11	147.44	.05
3300	5	0	0	J	75	26.44	.17	103.78	.10
3374	8	1	0	B	35	62.00	.14	122.00	.08
MEAN						62.16	.14	122.28	.08
DEVIATION						20.84	.02	26.30	.03

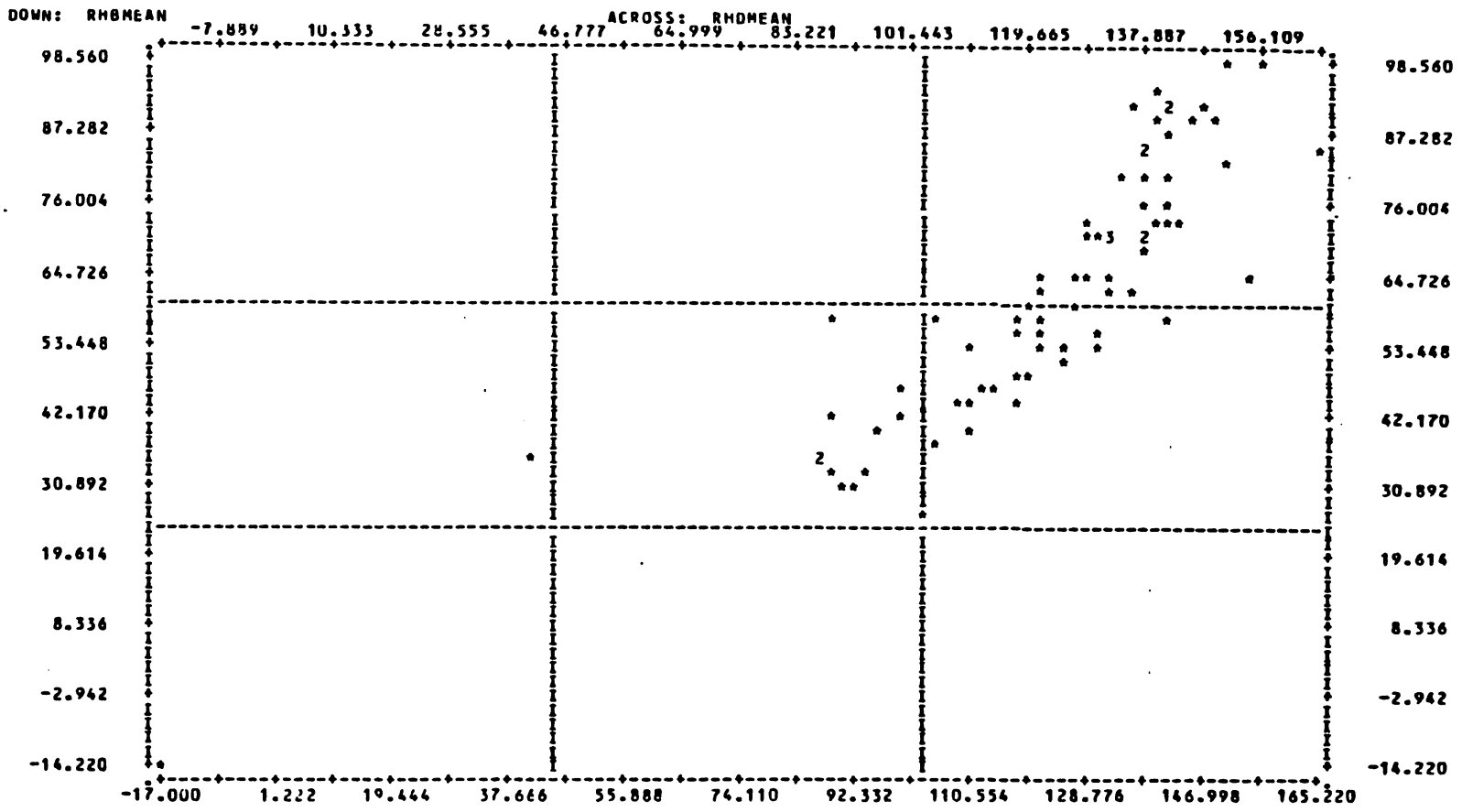
ASM 591 PROJECT

SPRING SEMESTER 1985

Figure 10. REPORT Table.

```
//      JOB
//      EXEC SPSSX
//STRGRM DD DSN=WYL.AG.AWS.ROCKWELL,DISP=SHR
DATA LIST FILE=STRGRM RECORDS=3
 /1 V1 1-4  V2 5-6
 /2 V10 21-23 RHBMEAN 32-37 (2) RHDMEAN 57-62 (2)
 /3 RDBMEAN 5-7 (2)  RDDMEAN 18-20 (2)
SET LENGTH=NONE
LIST VARIABLES=V1 V2 RHBMEAN RHDMEAN RDBMEAN RDDMEAN V10
SCATTERGRAM RHBMEAN WITH RHDMEAN
OPTIONS 6
STATISTICS ALL
SCATTERGRAM RDBMEAN WITH RDDMEAN
OPTIONS 6
STATISTICS ALL
SCATTERGRAM RHBMEAN WITH RDBMEAN
OPTIONS 6
STATISTICS ALL
SCATTERGRAM RHDMEAN WITH RDDMEAN
OPTIONS 6
STATISTICS ALL
SCATTERGRAM RHBMEAN WITH V10
OPTIONS 6
STATISTICS ALL
SCATTERGRAM RHDMEAN WITH V10
OPTIONS 6
STATISTICS ALL
//
```

Figure 11. Runstream list off of #SCATTERGRAM.

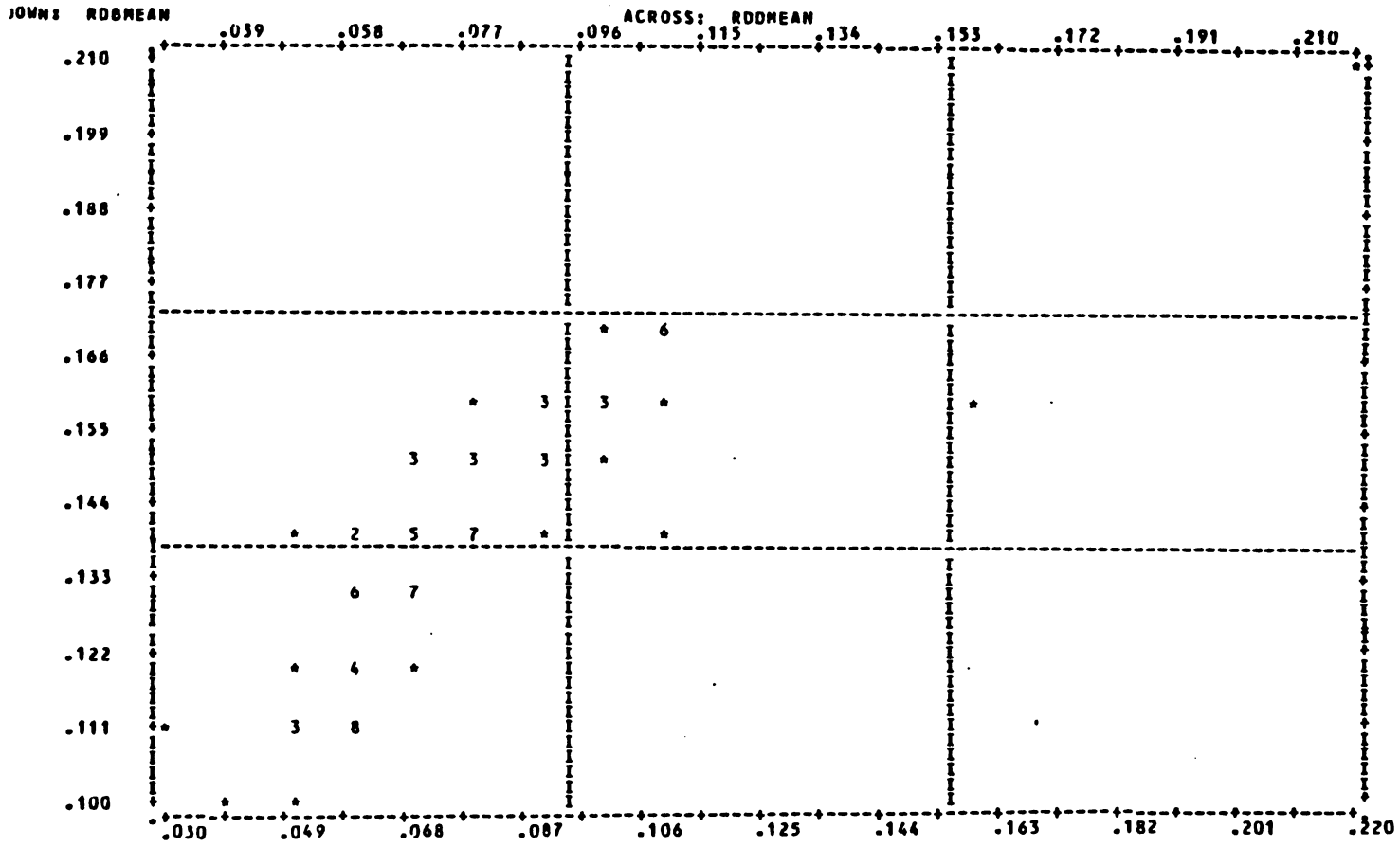



```
30 APR 85    SPSS-X RELEASE 2.0  FOR IBM OS
14:37:33     ARIZONA STATE UNIVERSITY        IBM 3081          MVS/SP

STATISTICS..
  CORRELATION (R)-          .85927     R SQUARED      -        .73834     SIGNIFICANCE   -        .00000
  STD ERR OF EST -        10.73350     INTERCEPT (A)  -     -21.13290     SLOPE (B)      -        .68114
  PLOTTED VALUES -          77         EXCLUDED VALUES-        0        MISSING VALUES -        0

                    '********' IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
```

Figure 12. Scattergram of comparison between hardness with the Brale (RHBMEAN) and 1/8" (RHDMEAN) indenters.



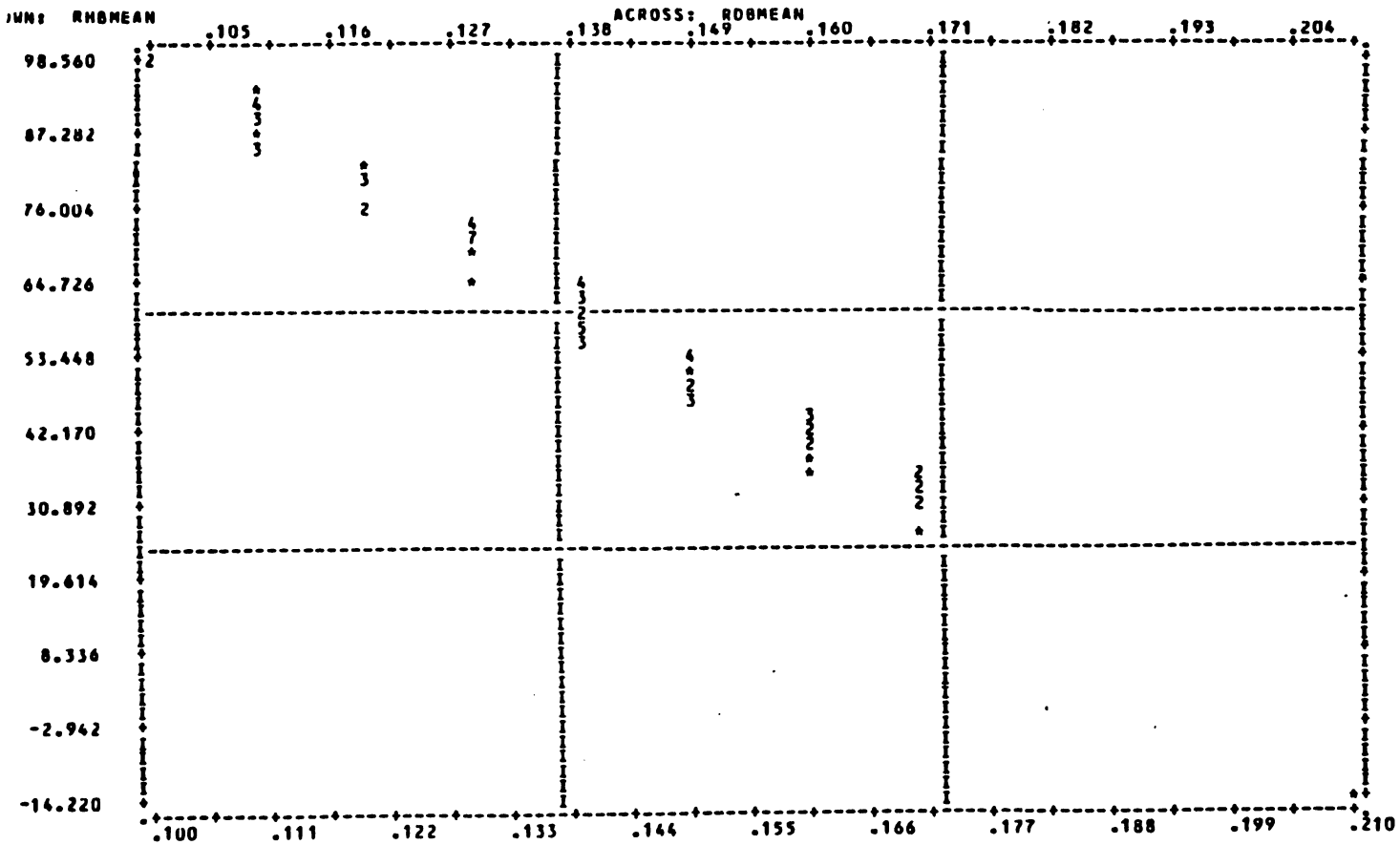
30 APR 85 SPSS-X RELEASE 2.0 FOR IBM OS
14:37:41 ARIZONA STATE UNIVERSITY IBM 3081 MVS/SP

STATISTICS:

CORRELATION (R) -	.83937	R SQUARED -	.70538	SIGNIFICANCE -	.00000
STD ERR OF EST -	.01143	INTERCEPT (A) -	.08750	SLOPE (B) -	.65642
PLOTTED VALUES -	77	EXCLUDED VALUES-	0	MISSING VALUES -	0

"********" IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.

Figure 13. Scattergram of comparison between depth with the Brale (RDBMEAN) and 1/8" (RDDMEAN) indenters.



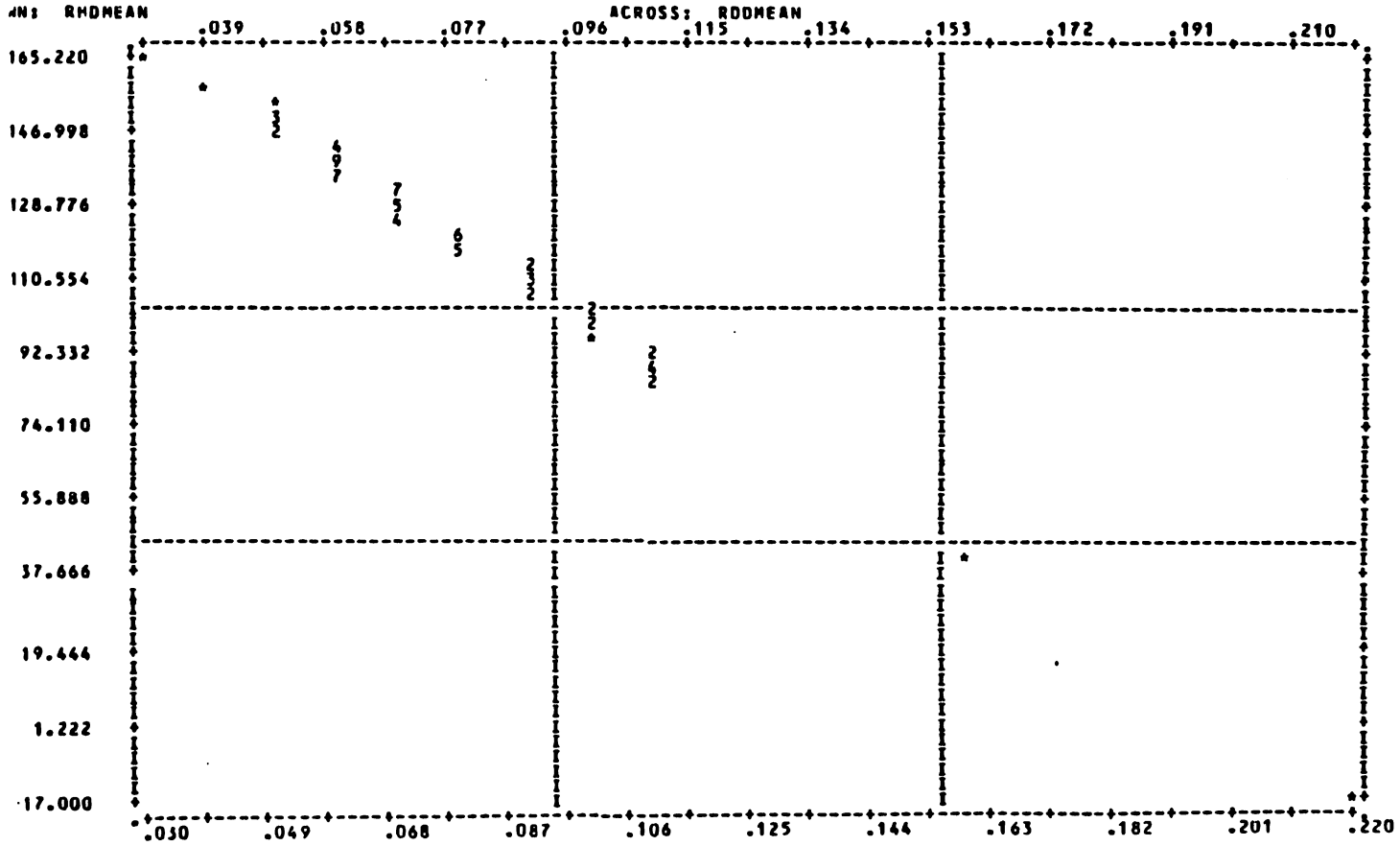
J APR 85 SPSS-X RELEASE 2.0 FOR IBM OS
4:37:48 ARIZONA STATE UNIVERSITY IBM 3081 MVS/SP

TATISTICS..

CORRELATION (R)-	-.98931	R SQUARED -	.97873	SIGNIFICANCE -	.00000
STD ERR OF EST -	3.05996	INTERCEPT (A) -	198.46085	SLOPE (B) -	-985.46340
PLOTTED VALUES -	77	EXCLUDED VALUES-	0	MISSING VALUES -	0

'********' IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.

Figure 14. Scattergram of comparison for the Brale indenter between hardness (RHBMEAN) and depth (RDBMEAN).

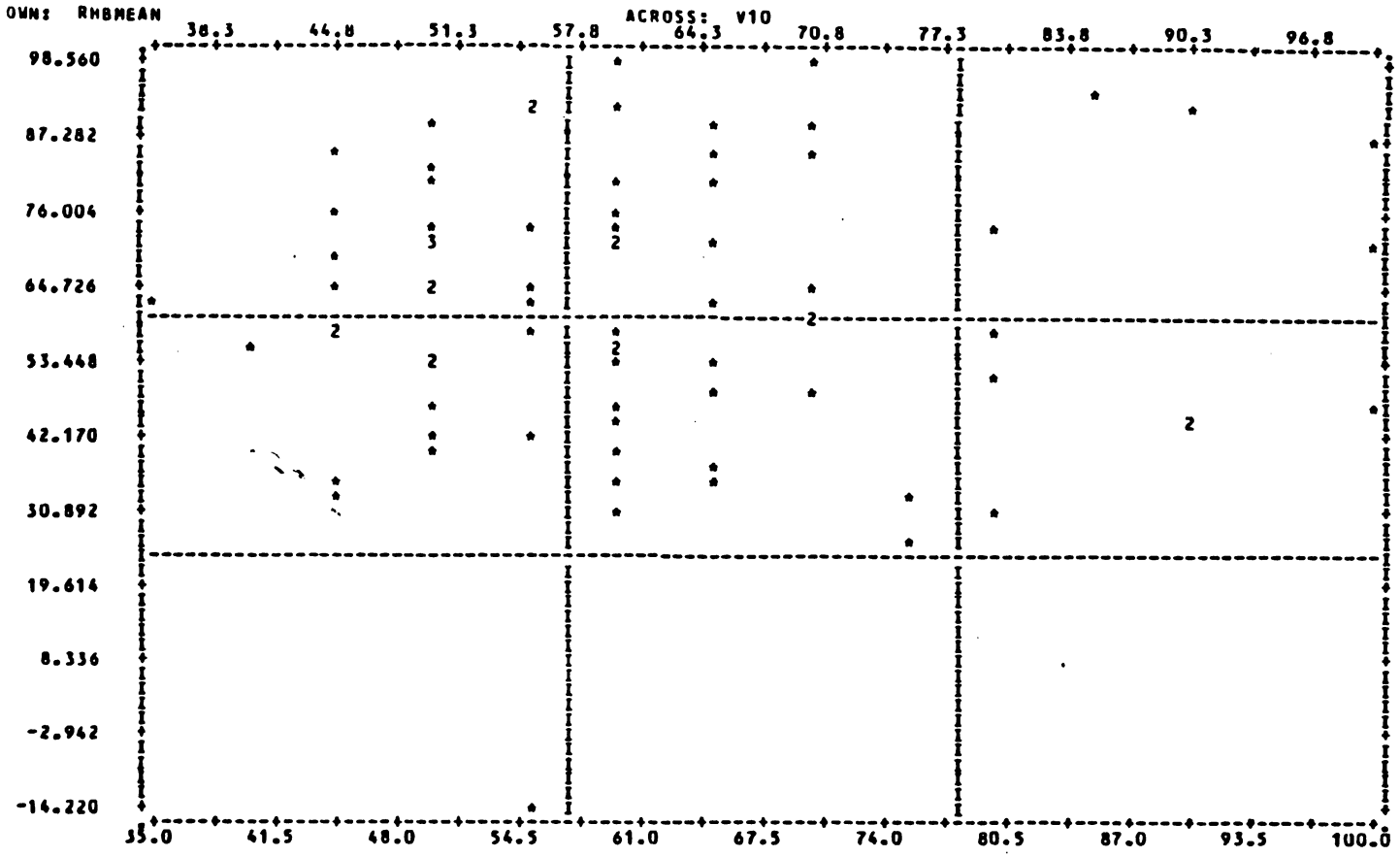



```
APR 85    SPSS-X RELEASE 2.0  FOR IBM OS
:37:55    ARIZONA STATE UNIVERSITY        IBM 3081'        MVS/SP

ATISTICS..
:ORRELATION (R)-          -.99575     R SQUARED        -        .99151     SIGNIFICANCE   -        .00000
:TD ERR OF EST -          2.43893     INTERCEPT (A)    -     197.98155     SLOPE (B)      -    -977.96639
'LOTTED VALUES -         77           EXCLUDED VALUES-          0         MISSING VALUES -          0

                    '********' IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
```

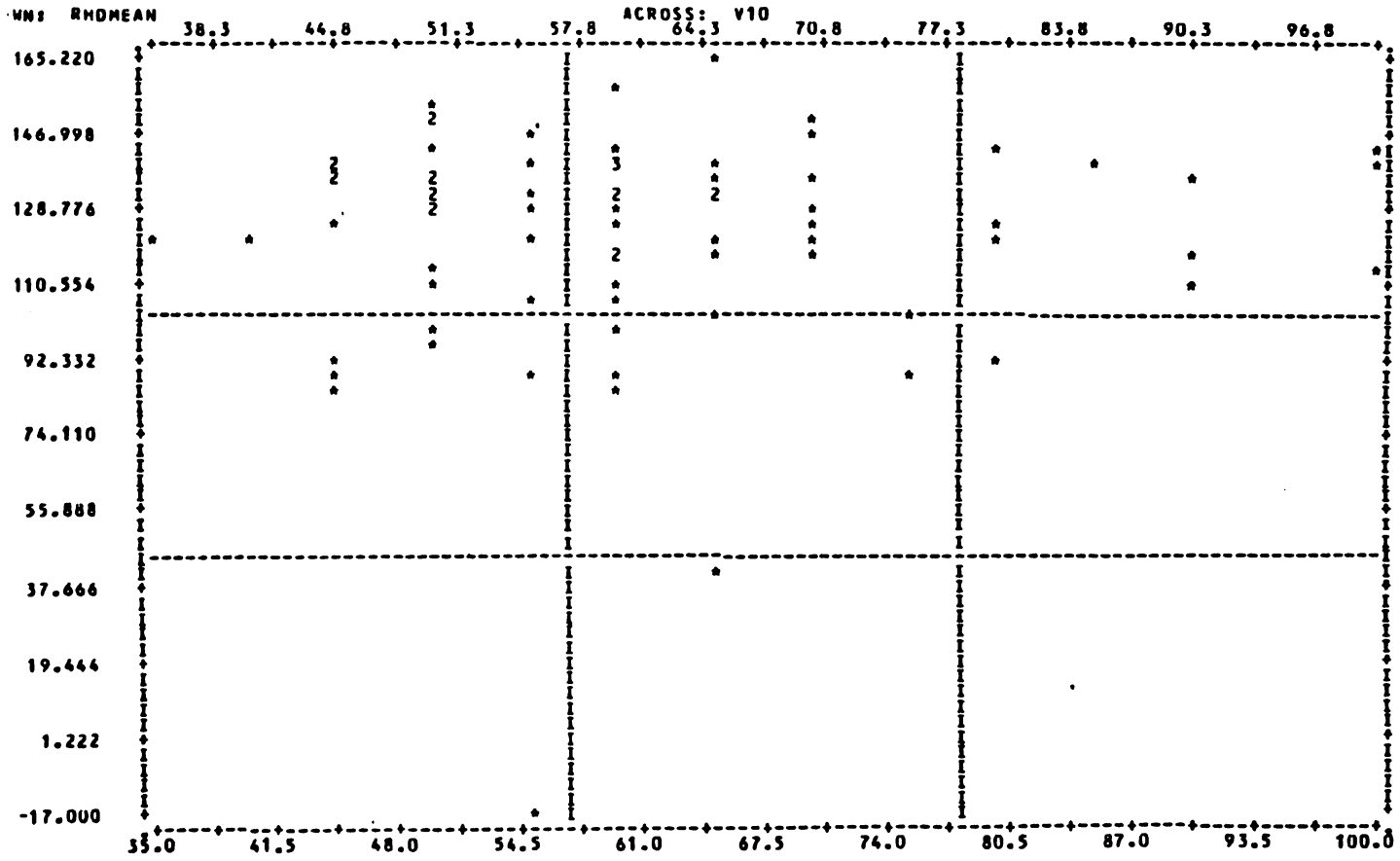
Figure 15. Scattergram of comparison for the 1/8" indenter between hardness (RHDMEAN) and depth (RDBMEAN).




```
) APR 85    SPSS-X RELEASE 2.0  FOR IBM OS
.:38:00     ARIZONA STATE UNIVERSITY        IBM 3081        MVS/SP

'ATISTICS..
 CORRELATION (R)-          .02679     R SQUARED       -          .00072     SIGNIFICANCE    -          .81707
 STD ERR OF EST -        20.97571     INTERCEPT (A)   -        59.74326     SLOPE (B)       -          .03930
 PLOTTED VALUES -          77         EXCLUDED VALUES-           0        MISSING VALUES -           0
```

Figure 16. Scattergram of comparison between Brale hardness (RHBMEAN) and thickness of pottery (V10).



APR 85 SPSS-X RELEASE 2.0 FOR IBM OS
:38:08 ARIZONA STATE UNIVERSITY IBM 3081 MVS/SP

STATISTICS...					
CORRELATION (R) =	.04631	R SQUARED =	.00214	SIGNIFICANCE =	.68921
STD ERR OF EST =	26.44229	INTERCEPT (A) =	117.01595	SLOPE (B) =	.08568
PLOTTED VALUES =	77	EXCLUDED VALUES =	0	MISSING VALUES =	0

"********" IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.

Figure 17. Scattergram of comparison between 1/8" hardness (RHDMEAN) and thickness of pottery (V10).

```
1.      //      JOB
2.      //      EXEC SPSSX
3.      //ONEWAY DD DSN=WYL.AG.AWS.ROCKWELL,DISP=SHR
4.      DATA LIST FILE=ONEWAY RECORDS=3
5.       /1 V1 1-4 V2 5-5
6.       /2 V5 15 (A) V7 16-18 (A) V8 19 (A) V9 20 (A) V11 24 (A)
7.       V10 21-23 RHBMEAN 32-37 (2) RHDMEAN 57-62 (2)
8.       /3 RDBMEAN 5-7 (2)  RDDMEAN 18-20 (2)
9.      SET LENGTH=NONE
10.     LIST VARIABLES=V1 V2 RHBMEAN RHDMEAN RDBMEAN RDDMEAN
11.                    V5 V7 V8 V9 V11
12.     RECODE V6('1'=1)('2'=2)('3'=3)('4'=4)('5'=5)('6'=6)('7'=7)INTO AREA
13.     RECODE V7('CRR'=001)('TSR'=002)('RRM'=003)('RPL'=004)('PAR'=005)INTO PLT
14.     RECODE V8('0'=1)('1'=2)('9'=3) INTO SLIP
15.     RECODE V9('0'=1)('1'=2)('9'=3) INTO SMUDGE
16.     RECODE V11('3'=1)('J'=2)INTO FORM
17.     ONEWAY RHBMEAN BY PLT(001,005)/RANGES=SCHEFFE/
18.     OPTIONS 6
19.     STATISTICS ALL
20.     ONEWAY RHDMEAN BY PLT(001,005)/RANGES=SCHEFFE/
21.     OPTIONS 6
22.     STATISTICS ALL
23.     ONEWAY RHBMEAN BY AREA(1,7)/RANGES=SCHEFFE/
24.     OPTIONS 6
25.     STATISTICS ALL
26.     ONEWAY RHDMEAN BY AREA(1,7)/RANGES=SCHEFFE/
27.     OPTIONS 6
28.     STATISTICS ALL
29.     //
```

Figure 18. Runstream list off of #ONEWAY file.

```
//      JOB
//      EXEC SPSSX
//      DD DSN=WYL.AG.AWS.ROCKWELL,DISP=SHR
DATA LIST FILE=' ... ' RECORDS=3
 /1 V1 1-4 V2 5-6
 /2 V6 15 (A) V7 16-18 (A) V8 19 (A) V9 20 (A) V11 24 (A)
 V10 21-23 RHBMEAN 32-37 (2) RHDMEAN 57-62 (2)
 /3 RDBMEAN 5-7 (2)  RDDMEAN 18-20 (2)
SET LENGTH=NONE
LIST VARIABLES=V1 V2 RHBMEAN RHDMEAN RDBMEAN RDDMEAN
                V6 V7 V8 V9 V11
RECODE V6('1'=1)('2'=2)('3'=3)('4'=4)('5'=5)('6'=6)('7'=7)INTO AREA
RECODE V7('CRR'=001)('ISR'=002)('RRM'=003)('RRL'=004)('PAR'=005)INTO PLT
RECODE V8('0'=1)('1'=2)('9'=3) INTO SLIP
RECODE V9('0'=1)('1'=2)('9'=3) INTO SMUDGE
RECODE V11('0'=1)('J'=2)INTO FORM
T-TEST GROUPS=SLIP(1,2)/VARIABLES=RHBMEAN RHDMEAN
OPTION 1 4
T-TEST GROUPS=SMUDGE(1,2)/VARIABLES=RHBMEAN RHDMEAN
OPTION 1 4
T-TEST GROUPS=FORM(1,2)/VARIABLES=RHBMEAN RHDMEAN
OPTION 1 4
//
```

Figure 19. Runstream list off of #T-TEST.

```
1.      //
2.      //
3.      //
4.      //
5.      FILE
6.      SHOOFLY CERAMIC ANALYSIS (V10, RHBSDDV, RHDSDDV)
7.        77
8.
9.      CORREL
10.
11.     MILLER-COMM
12.
13.     TREE
14.
15.     RESULT
16.     X X                                    XXX
17.     STOP
18.     //
```

Figure 20. Runstream list off of #CLUS using variables V10, RHBSDDV, RHDSDDV.

```
1.      //
2.      //     EXLC CLUSTER
3.      //
4.      //
5.      FILE
6.      SHOOFLY CERAMIC CLUSTER ANALYSIS
7.        77
8.
9.      CORREL
10.
11.     MILLER-COMM
12.
13.     TREE
14.
15.     RESULT
16.     X X                                    XXX
17.     STOP
18.     //
```

Figure 21. Runstream list off of #CLUS using variables V10, RHBMEAN, RHDMEAN.

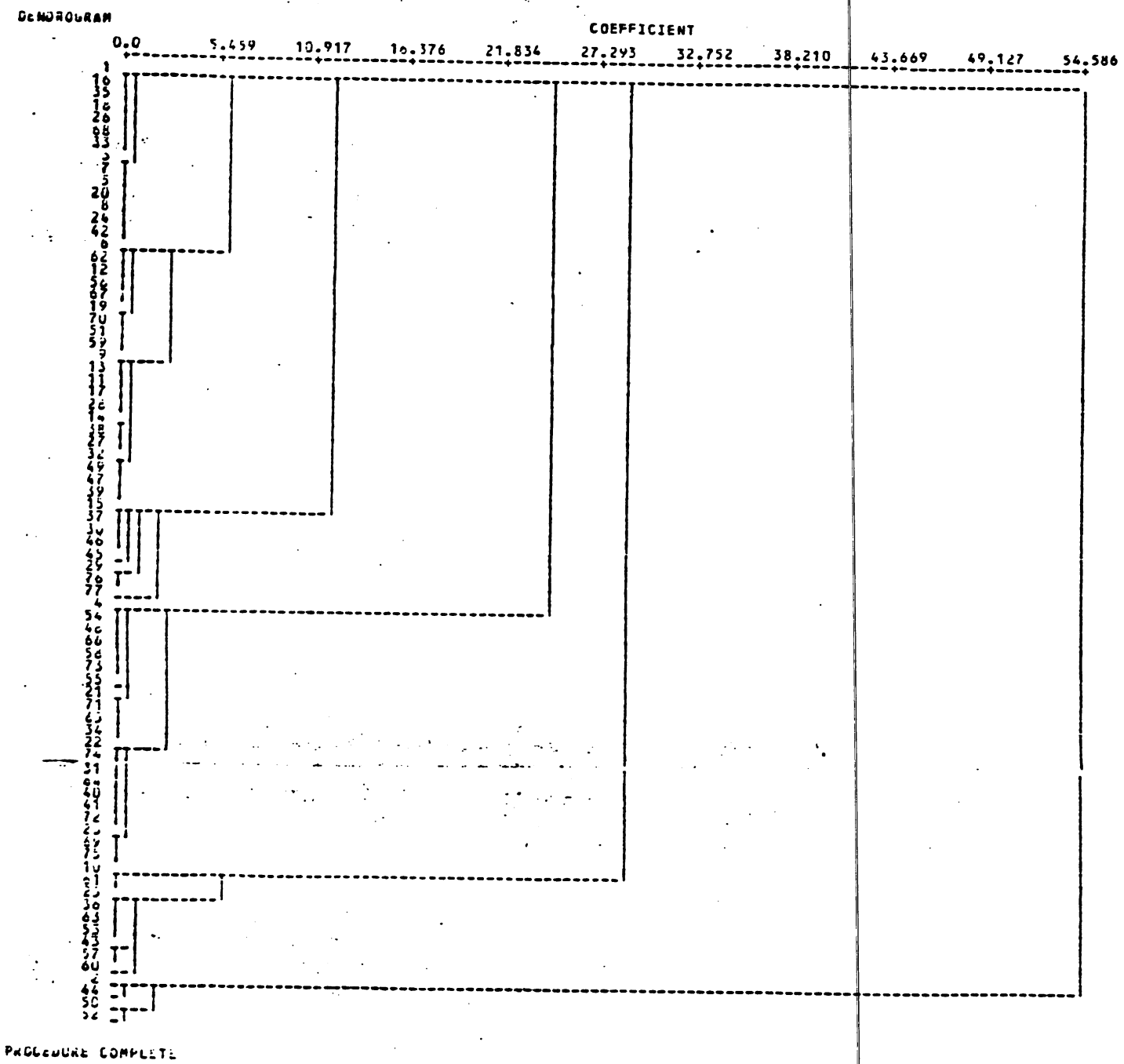


Figure 22. Dendrogram produced using #CLUS and variables V10, RHBSDDV, RHDSDDV.

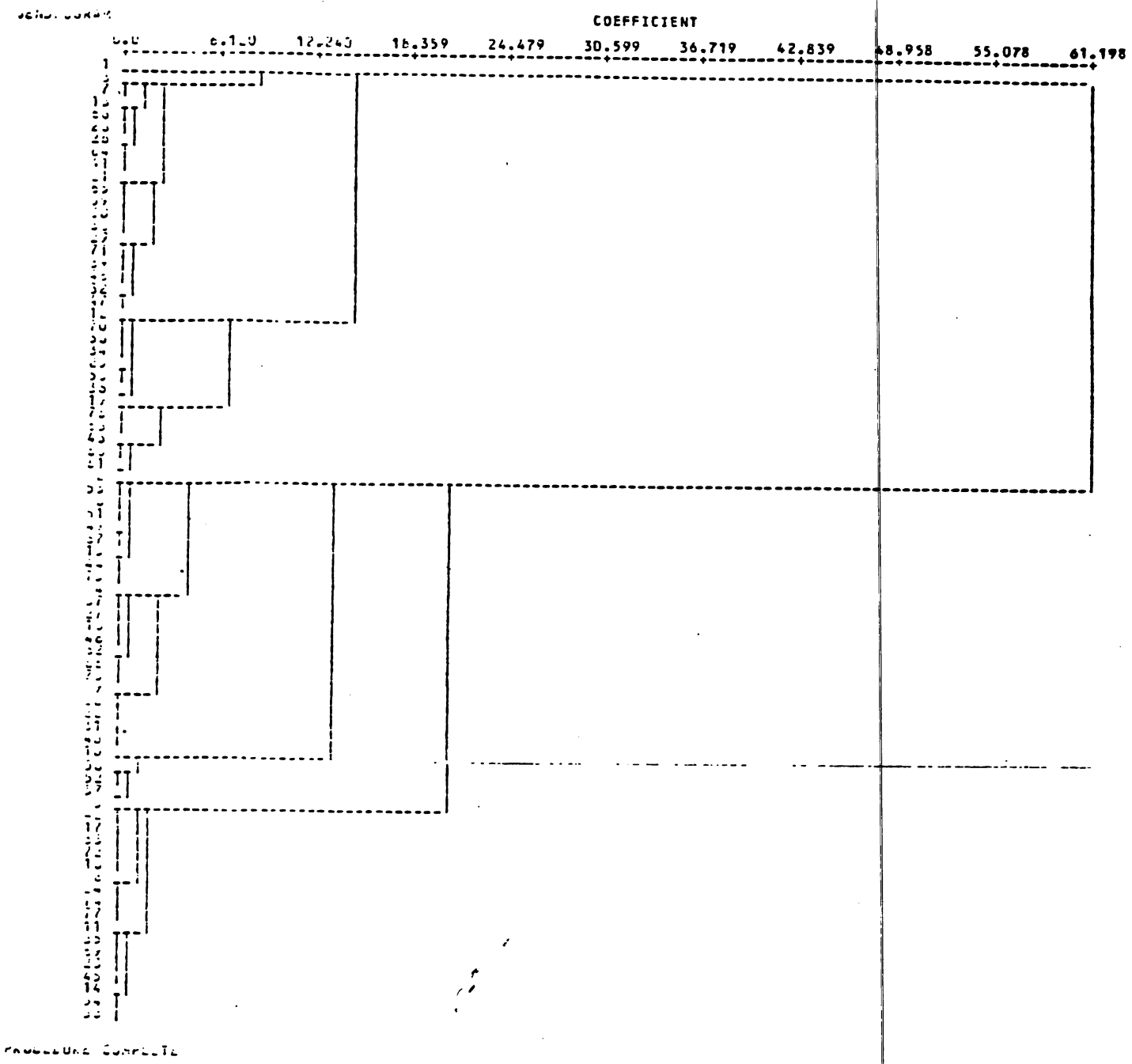


Figure 23. Dendrogram produced using #CLUS and variables V10, RHBMEAN, RHDMEAN.

```
//      JOB
//      EXEC BIMED,PROG=BMDP7M
//FT15F001 DD DSN=WYL.AG.AWS.ROCKWELL,DISP=SHR
//SYSIN DD *
/PROBLEM
  TITLE IS 'DISCRIMINANT ANALYSIS-SHOOFLY SAMPLE'.
/INPUT
  VARIABLES ARE 3.
  FORMAT IS '(78X/20X,F3.0,8X,F6.2,/4X,F3.2)'.
  CASES ARE 77.
  UNIT IS 15.
/VARIABLES NAMES ARE 'V10','RHBMEAN','RDBMEAN'.
  BLANKS ARE MISSING.
  GROUPS ARE 1.
/GROUP
  CUTPOINT (1)=050.
  NAMES (1) ARE 'THIN','THICK'.
/PRINT
  CLASSIFICATION IS 1 TO 2.
/PLOT
  CANONICAL.
/DISCRIM
  JACKNIFE.
/END
//
```

Figure 24. Runstream list off of #DISCRIM using BMDP.