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STORAGE, RETRIEVAL AND STATISTICAL ANALYSIS OF INDIANA SHALE DATA

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PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

Interim Report

STORAGE, RETRIEVAL AND STATISTICAL ANALYSIS
OF INDIANA SHALE DATA

TO: J. F. McLaughlin, Director
Joint Highway Research Project

July 6, 1977

Project: C-36-5L

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

File: 6-6-12

Attached is an Interim Report on the HPR-1(14) Part II Research Study titled "Design and Construction Guidelines for Shale Embankments". The Report is titled "Storage, Retrieval and Statistical Analysis of Indiana Shale Data". It has been authored by Mr. Dirk J. A. van Zyl, Graduate Instructor on our staff, under the direction of C. W. Lovell, and L. E. Wood of our staff and W. J. Sisiliano, Soils Engineer of the ISHC.

The attached report gives a concise but complete summary of the shales data generated by the ISHC and Purdue University. The storage and retrieval system should be of assistance in the future for any further statistical analyses, as well as in obtaining details of available data. The statistical analyses reported in this report can be used by geotechnical engineers in Indiana for a variety of applications and could also form a basis for further research on the use of shales in embankments.

The Report is submitted as partial fulfillment of the objectives of the Study. Copies of the Report will also be submitted to ISHC and FHWA for their review, comment and similar acceptance.

Respectfully submitted,

Harold L. Michael

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Interim Report

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16. Abstract

This report gives a complete summary of the test data on shales generated by ISHC and Purdue University. Details are given for a very simple storage and retrieval system which is adequate for the small amount of data (163 sets) available at the present time.

Results are presented from the different statistical analyses that were performed. These results include histograms, bivariate correlation coefficients and regression equations. Reasonably good bivariate correlations exist between the different indices describing the slaking resistance of shales. These correlations are however improved by using quadratic equations. Various regression equations are proposed for determining CBR from various parameters, usually a combination of five.

It became clear during the investigation that it is important to have as many complete data sets as possible for future analyses. The standardization of testing methods is also of utmost importance in order to increase the potential of the data bank.

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Table of Contents

		Page
	List of Tables	v
	List of Figures	vii
	Highlight Summary	ix
1.	Introduction	1
2.	Geology of Indiana Shales	3
	2.1 Shales of Ordovician Age	5
	2.2 Shales of Silurian Age	5
	2.3 Shales of Devonian Age	7
	2.4 Shales of Mississippian Age	8
	2.5 Shales of Pennsylvanian Age	10
3.	Physiography of Indiana	10
	3.1 Dearborn Upland	13
	3.2 Muscatatuck Regional Slope	14
	3.3 Scottsburg Lowland	14
	3.4 Norman Upland	15
	3.5 Mitchell Plain	17
	3.6 Crawford Upland	17
	3.7 Sullivan Lowland	18
	3.8 Bluffton Plain	19
	3.9 Rensselaer Plateau	20
	3.10 DeKalb Lowland	21
	3.11 Lake George Upland	22
4.	Tests Performed on Shale Samples	23
5.	Storage of Data	23
6.	Retrieval of Data	40
7.	Statistical Analysis of Data	45
	7.1 Frequency Analysis	45
	7.2 Bivariate Correlation Analysis	56
	7.3 Multiple Regression Analysis	81
8.	Conclusions	96
9.	Recommendations	97
10.	List of References	98

Table of Contents (Continued)

Page

Appendix A - Description of Testing Methods Used by ISHC

A-1: Method of test for determining loss-on-ignition . . A-1

A-2: Method of test for determining the slake durability index of shale A-3

A-3: Method of test for determining the slaking index of shale A-7

A-4: Method of test for determining fissility number . . A-10

A-5: Method of test for determining modified soundness A-11

Appendix B - Data segregated according to geological formations B-1

Appendix C - Program for printing data on data cards C-1

List of Tables

Table		Page
1	Data Sets in Storage System According to Geological Description	11
2	AASHTO Designator Numbers for Standard Tests Used by ISHC	25
3	Coding of Four Card Series	29
4	Data Points Available in the Different Data Sets	31
5	Laboratory Numbers of Shale Samples Utilized by Researchers at Purdue	39
6	Discrepancies Between Values Given in Report by Chapman (1975)and Those Provided by ISHC	41
7	Detail of Cards for Sorting Data on CDC of Purdue University Computer Center by Utilizing the SORT/MERGE System	43
8	Statistics Available from CODEBOOK	47
9	Statistics Obtained by CODEBOOK	49
10	Statistics Available from SCATTERGRAM	57
11	Values of Coefficient of Correlation and the Number of Data Sets with Reported Values for Both Parameters	60
12	Bivariate Correlations with $r \geq 0.7$	61
13	Combinations of Parameters Analyzed After Dividing the Data According to Geological Differences	79
14	Significant Correlations of Analyses After Dividing the Data According to Geological Differences	80
15	Regression Models to Predict CBR1 and CBR2 Based on High One-to-One Correlation	86
16	Model to Predict CBR1, Set Up for 24 Data Sets and Tested for 15 Different Sets	88

List of Tables (Continued)

Table Page

17 Regression Models to Predict CBR1 and CBR2 from Simple-To-Perform Tests 93

18 Results of Regression on Second Order Equations for Durability Parameters 95

List of Figures

Figure		Page
1	Bedrock Geology of Indiana	4
2	Bedrock Physiographic Units of Indiana	12
3	Standard Form Used by ISHC for Reporting Laboratory Test Data on Shales	24
4	Details on Determining the Textural Classification of Shale Samples	26
5	Identification of Data Included in This Study	28
6	Typical Print-out of a Data Set	42
7	Histograms for Grouped Data	51
8	Slaking Index Cycle 5 versus Slaking Index Cycle 1	62
9	Slake Durability Index 500 Rev. Dry versus Slaking Index Cycle 5	63
10	Slake Durability Index 200 Rev. Soaked versus Slaking Index Cycle 5	64
11	Slake Durability Index 500 Rev. Soaked versus Slaking Index Cycle 5	65
12	Slake Durability Index 500 Rev. Soaked versus Slake Durability Index 500 Rev. Dry	66
13	Slake Durability Index 500 Rev. Soaked versus Slake Durability Index 200 Rev. Soaked	67
14	Natural Moisture Content versus Modified Soundness	68
15	Maximum Wet Density versus Modified Soundness	69
16	Liquid Limit versus Plasticity Index	70
17	Natural Dry Density versus Natural Wet Density	71
18	Maximum Dry Density versus Maximum Wet Density	72
19	After Soaking CBR versus As Compacted CBR	73

List of Figures (Continued)

Figure		Page
20	Example of Trend Between Two Parameters with Low Correlation	74
	a) Plasticity Index versus Slake Durability Index 500 Rev. Dry	74
	b) Optimum Moisture versus Slake Durability Index 500 Rev. Soaked	75
	c) Optimum Moisture versus Slake Durability Index 200 Rev. Dry	76
	d) Lineal Shrinkage versus Slake Durability Index 200 Rev. Dry	77
21	Slake Durability Index 500 Rev. Dry versus Slaking Index Cycle 1 for Different Geological Formations	82
22	Goodness of Fit of Regression Model for Data Used to Set up the Model (24 Data sets)	90
23	Goodness of Fit of Regression Model for Data Used to Verify the Model (15 Sets of Data)	91
A-1	Classification of Shales	A-13

Highlight Summary

This report gives a complete summary of the test data on Shales generated by ISHC and Purdue University. Details are given for a very simple storage and retrieval system which is adequate for the small amount of data (163 sets) available at the present time.

Results are presented from the different statistical analyses that were performed. These results include histograms, bivariate correlation coefficients and regression equations. Reasonably good bivariate correlations exist between the different indices describing the slaking resistance of shales. These correlations are however improved by using quadratic equations. Various regression equations are proposed for determining CBR from various parameters, usually a combination of five.

It became clear during the investigation that it is important to have as many complete data sets as possible for future analyses. The standardization of testing methods is also of utmost importance in order to increase the potential of the data bank.

Laboratory Test Results on Indiana Shales: Storage, Retrieval and Statistical Analyses

1. Introduction

Large amounts of soil test data are being generated in every state during the testing of material for new highway facilities. Centerline samples and samples of proposed material sources are subjected to series of 'standard' material tests. The test data usually find their way to the archives or the waste paper basket after completion of the design and construction of a facility. The usefulness of these generated data was not realized until recently and a number of states are now in the process of introducing storage and retrieval systems (Crawford et al., 1972; Spradling, 1976). Such a system is easily handled by a computer, especially when a large number of data sets are available. For a storage and retrieval system to be as complete as possible it is necessary to include data generated by everybody involved in material testing, e.g., state highway materials laboratories, consulting engineers and research organizations.

It is very important that a storage and retrieval system be centralized so that potential users can obtain the data in which they might be interested. The availability of such a data bank should be brought to the attention of potential users.

The type of storage and retrieval system to be used depends on the amount of data available. Any system should be flexible enough so that changes can be made at a later stage with the least amount of effort. Any storage and retrieval system should therefore be seen as a dynamic system because it will be changed from time to time to fit the needs of the users and to make its administration easier and more economical. These qualities can be best incorporated in a computerized system.

The statistical analysis of stored data can lead to a number of very useful results. Experience usually indicates some 'typical properties and behavior' of certain types of material. Statistical analyses can prove or disprove such notions. Statistical analyses will also indicate the typical range of values to be expected for different parameters of the different members in the system as well as the distribution of these parameters. This can play a very important role in assessing the suitability of a certain sample before elaborate laboratory testing is undertaken. Statistical analyses should be updated (regularly) as more data become available. They are therefore dynamic and the results can be stated with greater confidence with increase in the size of the available data bank. The results are just as good and complete as the data available at the time of the analyses. An additional benefit is the development of new ideas for more productive research based on empirical relationships and correlation of soil properties (Spradling, 1976).

Correlations between different parameters can be developed by using stored data. Regression models can be established to predict the parameters which are difficult to measure by using a set of simple parameters. These models should be evaluated as new data become available to test their reliability.

This particular study was conducted to set up a storage and retrieval system for the test data generated on Indiana shales. This system was set up separately from a comprehensive storage and retrieval system being introduced presently by the Indiana State Highway Commission. The purpose of this system was to be of help to the Indiana State Highway Commission in providing them with information on shales while they are setting up their own storage and retrieval system. This system will also be an aid in the development of research projects on shales at Purdue University. It is hoped that useful practical results will also be obtained from the statistical analyses done during the course of this study.

Certain descriptors had to be used in order to locate the different data sets. In the system described in this report, laboratory number, geographic (counties), geological (system, series, stage) and physiographic (bedrock units) descriptors are used. Retrieval should be done in the most useful way, e.g., based on alphabetical order for certain parameters and numerical order for others. This type of ordering will help to increase the usefulness of the system.

The sources of data for the system described in this report are the testing done by the Indiana State Highway Commission on shales as well as the data given in the three theses dealing with shales submitted to Purdue University (Deo, 1972; Chapman, 1975; Bailey, 1976).

This report describes the information stored and the retrieval of the data. The results of various statistical analyses are also presented. Finally, recommendations are made for future research.

2. Geology of Indiana Shales

The information of this section was taken from the thesis by Deo (1972). Another useful reference in this respect is that by Harrison and Murray (1964). A geological map of Indiana is given in Figure 1.

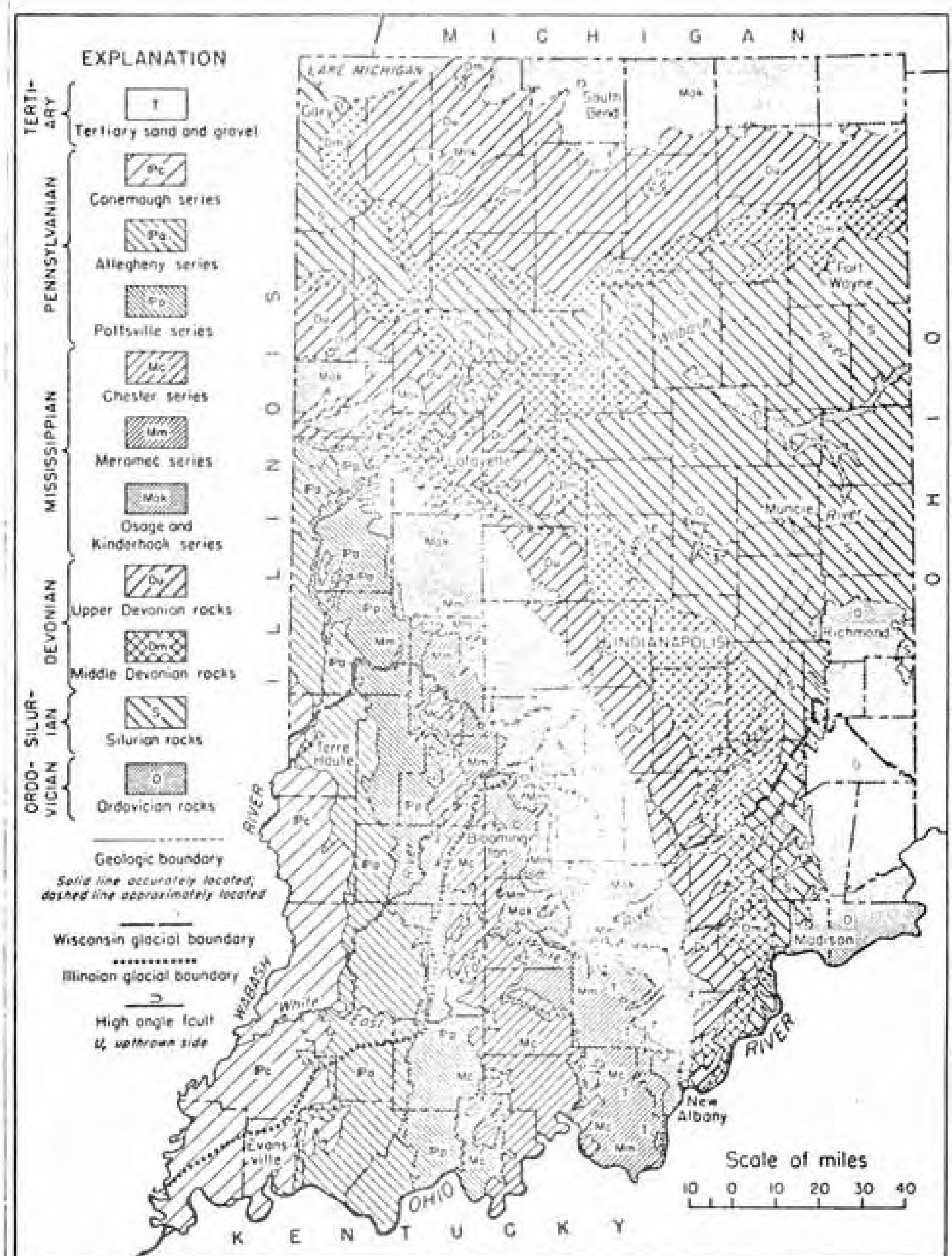

Figure 1. Bedrock geology of Indiana (after Wayne, 1956).

In many parts of Indiana, shales are either exposed at the earth's surface or underlie it at shallow depths that are within the range of engineering considerations. Only shales of the Palezoic Era are present in Indiana and hence the montmorillonitic clays related to more recent rocks, volcanic activity, and weathering in arid regions are not represented.

2.1 Shales of Ordovician Age

The oldest geologic system of rocks in Indiana that contain shale of engineering significance is the Ordovician. These rocks are exposed in the southeastern part of the state. One such rock unit of importance, the "Dillsboro Formation", lies within the Ordovician.

a) Shale of Dillsboro Formation. This formation consists of alternating beds of shale and limestone; at some locations more than five hundred beds of alternating shale and limestone can be observed. The thickness of shale beds varies between one inch and two feet.

The Dillsboro Formation lies above the Kope Formation and directly below the Saluda Formation. Limestone in the Dillsboro is argillaceous and shales are calcareous. Common clay minerals present are illite, kaolinite and chlorite.

Generally the shales are highly fissile, and with repeated wetting and drying, they weather into low strength clay. The shale has few open joints, but the limestone is well jointed. The beds of shale and limestone are essentially horizontal.

2.2 Shales of Silurian Age

The Silurian System is represented in Indiana by a succession of limestones and dolomites. Silurian rocks are exposed at the surface in the southeastern part of the state. North of the Illinoian glacial boundary, glacial drift of varying thickness covers the bedrock surface. In some locations, such as certain creeks and river beds, the glacial drift has been removed by erosion and the bedrock is exposed. Despite the predominance of carbonate rocks in the Silurian, there are two formations with prominent shale lithologies, the "Waldron" and the "Mississinewa".

a) Waldron Shale. This formation overlies the Laurel Limestone and is overlain in turn by the Louisville Limestone. It ranges from 5 to 12 feet in thickness. In a few places the Waldron is entirely missing, and the Louisville Limestone rests uncomformably on the Laurel Limestone.

Waldron Shale contains the clay minerals kaolinite, illite and chlorite; the non-clay fraction consists of quartz, dolomite and calcite. The color of Waldron Shale varies from green to gray. In some places it is massive and soft, but in others, is fissile and hard. It is fine grained and much of the quartz, calcite and dolomite are nearly as fine grained as the clay minerals.

b) Mississinewa Shale. This formation overlies the Louisville Limestone and is overlain in turn by the Liston Creek Limestone. In places along the Mississinewa River it is more than 50 feet thick.

Shale in the Mississinewa is mineralogically similar to Waldron Shale, except that the former commonly lacks kaolinite. In many places Mississinewa rocks are primarily dolomite rather than shale, as the dolomite beds consistently comprise more than 50 percent of the sequence.

Mississinewa Shale is gray to blue on fresh surfaces and light brown when weathered. The shale is massive and bedding is not apparent. It is dominantly fine grained, but in some places silt or sand give the unit a silty or sandy appearance.

2.3 Shales of Devonian Age

Similar to the Silurian, the Devonian System is also represented in Indiana by a succession of limestones and dolomites. They are exposed at the surface in southeastern Indiana, but are otherwise covered by glacial drift of varying thickness. There is only one shale formation, the "New Albany", contained in the Devonian sequence.

a) New Albany Shale. This shale is partially Devonian and Mississipian in age, since the unit extends above and below the boundary of these two geologic systems. The North Vernon Limestone underlies the New Albany Shale and the Rockford Limestone of Mississippian age overlies it.

New Albany Shale varies in thickness from 80 to 150 feet along its outcrop. Illite, kaolinite and chlorite are common clay minerals. Quartz is the most abundant non-clay mineral and is associated with feldspar, calcite, dolomite and phosphate minerals. Pyrite is commonly present as coarse to fine crystals in the form of nodules or concretions.

New Albany Shale is dark gray, dark olive green, or black, and weathers to light gray, brown or maroon after a few years of exposure. It is found in almost all known locations as thinly bedded to fissile, fine grained shale. Some of its quartz and pyrite grains are large enough to fall within the sand size.

2.4 Shales of Mississippian Age

Mississippian rocks in Indiana are exposed in a band that trends in a northwest-southeast direction across the approximate center of the state. The oldest rocks (Kinderhook) are at the eastern edge of this band, and the youngest rocks (Chester) are at the western edge. Much of the band of Mississippian rocks is buried by glacial drift.

Rocks of the Mississippian System are assigned to four series in Indiana: Kinderhook, Osage, Meramec, and Chester. The only shale of the Kinderhook Series occurs in the top portion of the New Albany Shale, which has been discussed under the Devonian System. Rocks of the Osage Series consist of shales and limestones. Meramec rocks are mostly limestones and dolomites and contain practically no shale. Rocks of the Chester Series are composed of limestones, sandstones and shales.

a) Osage Shales. Rocks of the Osage Series are assigned to the Borden Group and are popularly known as "Borden rocks". The shales of this group occur in two formations, the New Providence Shale, which is the oldest formation of the Borden Group and the Locust Point Formation, which lies directly above the New Providence. These two have a similar lithology and are difficult to distinguish.

Rocks of the Borden Group lie in a narrow band about 12 to 15 miles wide trending from New Albany, on the Ohio River, to Lafayette. From the Illinoian glacial boundary northward, glacial drift of varying thickness covers the Borden Shales, but they are locally exposed in places. The Borden Group overlies either the Rockford Limestone or the New Albany Shale because of a prominent unconformity which cuts across those geologic units.

Borden Shales contain illite, kaolinite, chlorite, quartz and feldspar. The non-clay particles in Borden Shales are commonly silt size. The color ranges from blue gray to brown. In most places these shales are massive to blocky on fresh surfaces, but on weathered surfaces they display definite partings and break out in small pieces. The shales vary from soft to very hard.

b) Chester Shales. The rocks of the Chester Series consist of shales, sandstones and limestones. This series is more variable in mineralogy, thickness, and physical properties, both laterally and vertically, than the shale units previously described.

Chester rocks crop out in a band west of the Borden rocks. The outcrop belt extends from the Ohio River to a point midway between Indianapolis and Terre Haute.

The Bethel Formation is stratigraphically the lowest formation of the Chester Series which contains shale. The Bethel consists of dark gray shales and argillaceous sandstones, 5 to 30 feet thick. Most of the Bethel Shales are soft, and their grain size ranges from coarse to fine.

All shales of the Chester Series are variable in physical properties and mineralogy, particularly in the lateral direction. In many locations the shale grades laterally into sandstone or limestone in less than a mile, and in other places in a matter of tens of feet. The dominant clay minerals are illite, kaolinite and occasionally montmorillonite. Quartz is the main non-clay mineral. Feldspar and calcite may be present in small quantities.

2.5 Shales of Pennsylvanian Age

Rocks of the Pennsylvanian System lie west of the Mississippian outcrop, in a belt extending from the Ohio River northward to Lafayette, and then westward to the Indiana-Illinois state boundary. North of the Illinoian glacial boundary, glacial drift of varying thickness covers most Pennsylvanian rocks.

Pennsylvanian formations are stratigraphically complex because of common changes from one rock type to another over relatively short distances. In addition, rocks of a specific lithologic type are similar mineralogically from one Pennsylvanian formation to another, making it difficult to distinguish between the formations using lithology alone.

Two types of shales are found in Pennsylvanian rocks in Indiana: 1) dark-gray to black, fine grained thinly bedded shale; and 2) light-gray silty thick bedded shale.

Pennsylvanian shales have less quartz and feldspar than the shales previously discussed. The common clay minerals are illite, kaolinite and chlorite. They also contain traces of iron.

A summary of the available data sets based on the geological descriptors is given in Table 1.

3. Physiography of Indiana

It was decided to use the bedrock physiography as modified by Wayne (1956) as the basis for the physiographic description. Figure 2 shows these bedrock physiographic units.

TABLE 1

DATA SETS IN STORAGE SYSTEM ACCORDING TO GEOLOGICAL DESCRIPTION

Geological System	Geological Stage		No. of Data Sets
Pennsylvanian	Shelburn Formation		3
	Dugger Formation		2
	Petersburg Formation		2
	Brazil Formation		1
	Mansfield Formation		23
		Total	31
Mississippian	Core Limestone		2
	Palestine Sandstone		17
	Watersburg Sandstone		5
	Tar Springs Formation		15
	Glen Dean Limestone		3
	Hardinsburg Formation		20
	Haney Limestone		3
	Big Clifty Formation		3
	Elwren Formation		1
	Sample Formation		4
	Bethel Formation		3
	Borden Group		16
	Locust Point Formation		4
	New Providence Shale		4
	New Albany Shale		5
		Total	105
Devonian	Antrim Shale		1
	New Albany Shale		6
		Total	7
Ordovician	Whitewater Formation		2
	Dillsboro Formation		6
	Kope Formation		12
		Total	20

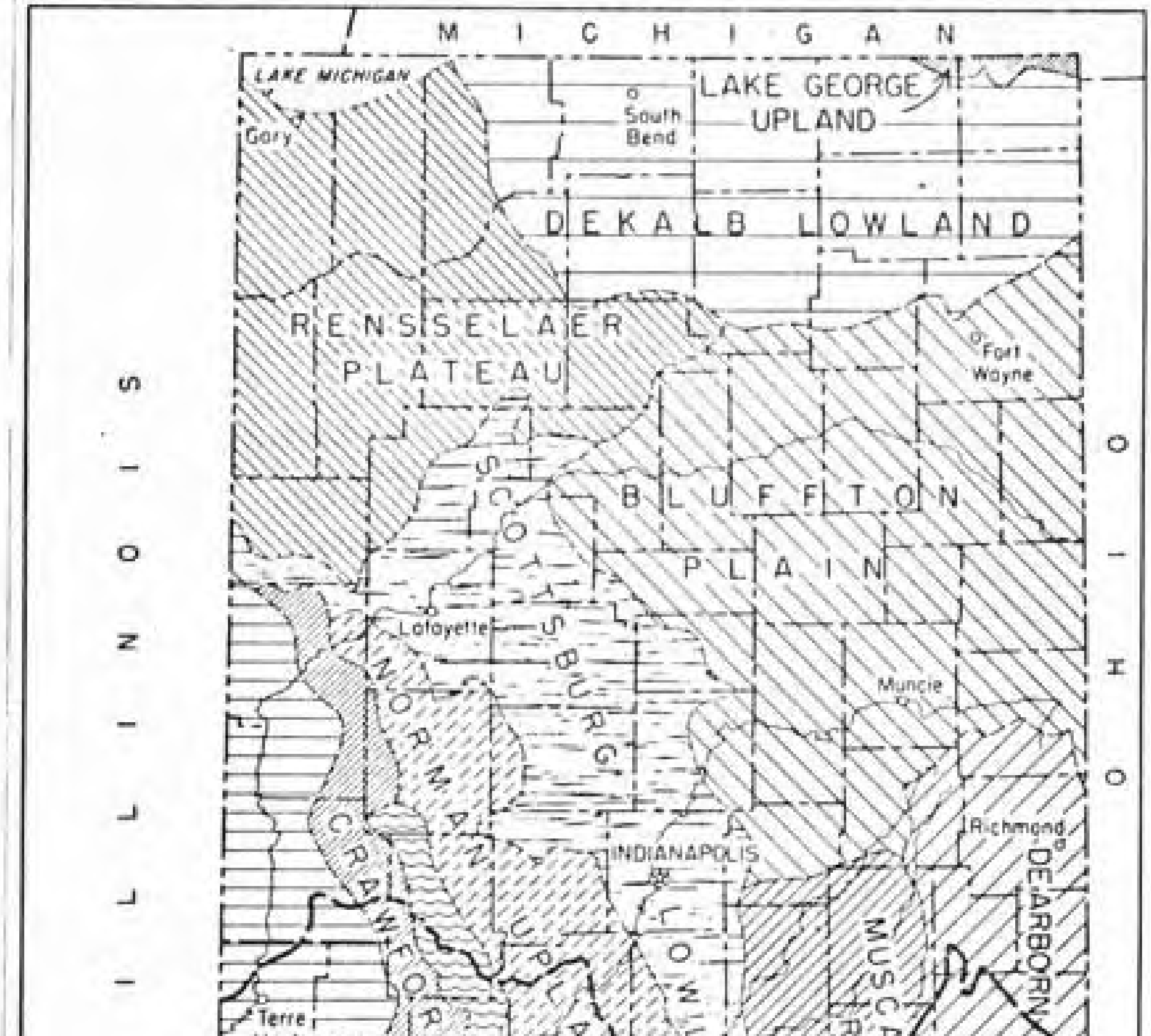

Figure 2. Bedrock Physiographic Units of Indiana (after Wayne, 1956)

In Indiana the bedrock physiographic units are regional features that were formed by differential rates of erosion on gently dipping Paleozoic shales, limestones, and sandstones. These physiographic units must have been in existence before the Pleistocene epoch, for the units are well defined even in northern Indiana, where they were protected from extensive dissection during the Pleistocene by a mantle of glacial drift (Wayne, 1956).

The well-differentiated physiographic units of central and northern Indiana which had been formed during the interval that followed late Tertiary peneplation and preceded glaciation were covered by glacial deposits and preserved from further modification (Wayne, 1956).

The description of the different units which follows is taken from Wayne (1956).

3.1 Dearborn Upland

The Dearborn upland, which lies within the area covered by ice during Illinoian glaciation,is characterized by smooth, steep slopes and long, flat-topped fingers of upland between deeply intrenched valleys. Most of the valley bottoms are narrow. The upland, ranging from 950 to 1,000 feet in altitude, is a glacially modified remnant of the Lexington peneplain.

Buried valleys that have been traced are deeply incised below a fairly flat upland whose slope coincides with the gentle dip of the rocks. Glacial deposits thicken from less than 50 feet in Franklin, Union, and Fayette Counties to more than 200 feet over the north and west margins of this upland.

3.2 Muscatatuck Regional Slope

The back slope of the escarpment formed by the resistant Silurian limestones of southern Indiana is a gently westward-dipping structural plain called the Muscatatuck Regional Slope. It is covered with thin Illinoian drift in Indiana and can be recognized for a short distance north of the Wisconsin glacial boundary.

North of the Wisconsin boundary the Muscatatuck Regional Slope retains its characteristics as far as the bedrock structure has a distinct westerly dip. In Rush and Henry Counties, Middle Silurian limestones increase in thickness from about 50 feet to more than 200 feet, and the regional dip ranges from about 30 feet per mile to the southwest to almost the vanishing point over the broad top of the north end of the Cincinnati Arch. The northern boundary of the Muscatatuck Regional Slope has been placed along the upper reaches of a large bedrock valley in southern Hancock County and across Henry County.

A northward-trending belt of fairly rugged morainic topography lies over the Laughery escarpment in Randolph, Henry, and Rush Counties. The high bedrock surface along this escarpment probably contributed to the formation of a re-entrant between ice lobes in this area. Drift is thin and outcrops of the underlying bedrock are abundant along the eastside of the regional slope, but glacial deposits increase to about 200 feet in thickness toward the west edge of the slope.

3.3 Scottsburg Lowland

The Muscatatuck regional slope grades westward into a narrow lowland formed on Devonian and lower Mississippian shales. Most of this region, the Scottsburg Lowland, is between 600 and 700 feet in altitude, and relief is slight. Thin Illinoian drift blankets this region. The Knobstone escarpment rises abruptly above the west edge of the lowland to form its boundary.

Glacial deposits, which thicken north of Johnson County, entirely obscure this lowland. Because the glacial deposits over this physiographic unit are thick, in places exceeding 400 feet, not many water wells reach bedrock. Therefore only a few of the larger drainage lines have been identified across the buried lowland.

Although prior to the Pleistocene Epoch the Scottsburg Lowland in Indiana was crossed by five large rivers,none of these followed it for any great distance. The Lowland is primarily the result of more rapid erosion on shales than on limestones and sandstones which underlie adjacent uplands. Much of this Lowland probably was formed in late Tertiary and early Pleistocene time, although degradation continued in the southern part throughout most of the Pleistocene.

The present topography over this preglacial Lowland includes some of the flattest parts of the Tipton Till Plain. The few moraines are weakly developed, and postglacial dissection has been slight, Drift is so thick that the underlying shales are exposed only along the Wabash Valley near Delphi, where postglacial erosion has uncovered the New Albany (black) Shale.

3.4 Norman Upland

The Knobstone escarpment, by far the most prominent topographic feature of southern Indiana, rises 400 to 600 feet above lowland east of it and reaches an altitude of 1,000 feet between the Ohio and

Muscatatuck Rivers. This escarpment forms the east edge of the Norman Upland, a physiographical unit that is on the dip slope of a cuesta produced by resistant sandstones and siltstones of the upper part of the Borden (lower Mississippian) series. The western boundary of the Upland is gradational and is drawn where sinkholes of the karst plain to the west become predominant over valleys that have been eroded by running water.

The Norman Upland is a remnant of the late Tertiary Lexington peneplain. Its altitude exceeds 1,000 feet in the south but decreases gradually northward to 650 ft in Warren County. The upland is maturely dissected in the unglaciated part of southern Indiana. Dissection of this upland also undoubtedly continues northward, but many of the smaller buried ravines probably never will be located partly because the locations of these buried ravines are unknown and partly because the buried part of the Norman Upland has been less dissected than that south of the glacial boundary.

The width of the Norman Upland broadens northwestward from less than 1 mile at the Ohio River to about 40 miles north of East White River and then narrows again farther north. Glacial drift is less than 50 feet thick over much of the Upland, and outcrops are fairly common. Drift thickens to more than 200 feet,however, over the intrenched bedrock valleys in Hendricks and Montgomery Counties.

A complex group of moraines deposited during a readvance of Wisconsin ice constitutes much of the present surface topography above the Norman Upland in Fountain, Montgomery, and Hendricks Counties. Although the buried Knobstone escarpment has no recognizable surface expression so far north, the higher bedrock must have influenced the deposition of these moraines.

3.5 Mitchell Plain

The Mitchell Plain is a karst terrain that was formed upon the middle Mississippian limestones in southern Indiana. A few miles north of the Wisconsin boundary these limestones are covered by an overlap of lower Pennsylvanian clastics. A few karst features can be seen through thin drift in Putnam County and the buried Mitchell Plain exists as far north as southwestern Montgomery County, where solution-widened bedding planes and fractures are reported occasionally by well drillers. No other karst features, however, have been recognized beneath the drift, which ranges from the vanishing point to 150 feet in thickness.

3.6 Crawford Upland

The most rugged topography of southern Indiana is found in the Crawford Upland, a physiographic unit that is separated from the Mitchell Plain to the east by the rugged Chester escarpment. Trenchlike, flat-bottomed valleys, rock benches, and local structural plains typify its land forms. Caverns and karst valleys are common, and remnants of the Lexington peneplain are recognizable at some places. The western boundary of the Crawford Upland is located where the angular topography formed on alternating massive sandstones, shales, and limestones of the Chester (upper Mississippian) series grade into rounded land forms that are a result of erosion on Pennsylvanian shales and coals.

North of the Wisconsion drift margin the upland widens somewhat to include the region of gorgelike valleys cut into the Mansfield sandstone in Parke, Vermillion, Fountain, and Warren Counties. Relief features characteristic of the Crawford upland continue as far north as the bluff overlooking the Teays Valley. Part of the preglacial divide between the Teays and Wabash drainage basins was in northern Parke County,and Sugar Creek now is trenching part of this former upland.

During part of the Wisconsin glaciation, the north end of the Crawford Upland lay between ice lobes in central Indiana and east-central Illinois. Although it is the location of many rugged morainic features, drift is thin over most of this preglacial upland, and many present streams have cut valleys in bedrock. Thick drift is limited largely to buried valleys.

3.7 Sullivan Lowland

Prior to glaciation a topography of subdued land forms which had moderate relief along the major valleys was formed upon the Pennsylvanian strata of central Illinois and southern Indiana, where weak shales permitted valley widening to a greater extent than was possible in areas of more resistant rock. Most of the bedrock slopes are gentle, smooth inclines, unlike the angular topography of the Crawford Upland, and, except near the bedrock strata of major valleys such as the Wabash, deep stream courses are uncommon. Because the bedrock surface in Sullivan County, Ind., seems to exemplify the characteristics of this unit, the name "Sullivan Lowland" was used for it by Wayne (1956).

Little of the Sullivan Lowland lies north of the Wisconsin boundary in Indiana. It is restricted to southern Parke County, Vermillion County, and the west edge of Warren County, where it seems to merge with the Knobstone escarpment along the south bluff of the Teays Valley near the state line.

3.8 Bluffton Plain

A nearly flat limestone upland that slopes gently to the north constitutes the bedrock surface in east-central Indiana. It is bounded by a large preglacial valley from northern Allen County to near Logansport, in Cass County. On the west it grades into the Scottsburg Lowland and on the south lies next to the Muscatatuck Regional Slope and the Dearborn Upland. The boundary between this upland plain and the Muscatatuck Regional Slope is a transitional one in Hancock and Henry Counties. It has been drawn across a narrow divide between the Whitewater Bedrock and Wabash Bedrock drainage basin in southwestern Henry County and then follows the course of a bedrock valley westward across Hancock County. Because the flat, plainlike character of this upland is well developed in Wells County and drift is thin enough near Bluffton to expose the underlying dolomites, the name "Bluffton Plain" was proposed for this region.

This plain is about 900 feet above sea level in Randolph and Jay Counties. Its altitude decreases to 750 feet near Teays Valley in Blackford and Grant Counties and to 650 to 700 feet in Wabash County. North of Teays Valley it never rises much above 750 feet in altitude but slopes into a lowland to the north. The plain was formed upon the thick sequence of Silurian limestones and dolomites of northern Indiana, and its slope corresponds closely to the regional dip on the north end of the Cincinnati Arch.

Karst phenomena were at least moderately well formed upon the limestone plain prior to its burial. Discoveries of caverns have been reported by water well drillers in Adams, Wells, and adjacent counties near Teays Valley and some of its deeply incised tributaries. Some of these cavernous openings in the dolomite are partly filled with red silt and clay; others are open and yield large quantities of ground water. Small dolines may be observed in some of the reefs exposed near Lagro, in Wabash County.

3.9 Rensselaer Plateau

The northeastward-sloping upland of northern Illinois seems to extend into Indiana. It was named the "Rensselaer Plateau," because the features of this unit are well displayed in the bedrock topography of Jasper County, Ind., in the vicinity of Rensselaer. This unit is largely a dip slope that was formed upon Middle Silurian dolomites and limestones, but Devonian and Mississippian limestones also underlie it.

To the south, the Rensselaer Plateau ends at Teays Valley, and its northeastern boundary is placed along a large valley in LaPorte and Marshall Counties.

Although glacial deposits are less than 50 feet thick over a large area in the Kankakee Valley, no bedrock outcrops are known. Drift thickens to nearly 300 feet in the large valley at the northeastern boundary of the region. Much of the bedrock surface has so little relief that thickening of drift along the Valparaiso moraine showed up readily.

3.10 <u>DeKalb Lowland</u>

The bedrock physiography of most of the northern two tiers of counties in Indiana is a broad lowland formed upon Upper Devonian and Lower Mississippian shales. Altitudes range from 400 feet in valleys beneath the drift in DeKalb and LaPorte Counties to nearly 700 feet in St. Joseph and Elkhart Counties. Rocks underlying this Lowland dip gently northward toward the Michigan Basin. The term "DeKalb Lowland" was proposed for this physiographic upland. It was named from DeKalb County, where the Lowland is well formed and where some of the thickest glacial deposits in Indiana are found.

Because of the great thickness of drift and the abundance of buried gravel beds, few wells drilled over this Lowland reach bedrock. A notable exception is along the St. Joseph Valley, where several test holes in the industrial areas of South Bend, Mishawaka, and Elkhart have reached bedrock.

The topography of the DeKalb Lowland should have only moderate relief except along intrenched valleys like the topography of the Scottsburg Lowland of central and southern Indiana, which is formed upon rock similar in lithology and structure.

The minimum and maximum thicknesses of glacial drift recorded in this region, namely, 28 feet in Mishawaka and 525 feet just west of Elkhart, are within a few miles of each other. Drift less than 100 feet thick is exceptional, and most of the region is covered with 200 to 350 feet of Pleistocene deposits. Some of the greatest local surface relief on glacial deposits in Indiana is over the DeKalb Lowland.

3.11 Lake George Upland

The upper part of the lower Mississippian shales and sandstones at the south margin of the Michigan Basin produced an abrupt escarpment which crosses the northeast corner of Indiana. The Coldwater Formation of early Mississippian age seems to contain the resistant beds that form the crest of this scarp. The name "Lake George Upland" was proposed for the physiographic unit bounded on the south by the escarpment and extending northward on the dip slope. Lake George in Steuben County, Ind., and Branch County, Mich., is within a group of moraines that overlies this upland. The bedrock surface beneath Lake George is 750 to 800 feet in altitude and is buried beneath 200 to 250 feet of drift.

Altitudes in the northern part of Steuben County show that the upland is between 750 and 900 feet above sea level and stands as much as 400 feet above the DeKalb Lowland south of it. Glacial drift thins abruptly over the scarp from more than 500 feet to 150 to 200 feet. Surface altitudes exceed 1,200 feet in this part of Indiana, and some of the steepest morainic topography of the state is found here.

4. Tests Performed on Shale Samples.

A number of tests are performed on shale samples submitted to the laboratory. These tests must comply with standard testing methods in order to use the data in any statistical analysis. The main contributor of data to the present system is the Indiana State Highway Commission. Results of their testing are reported on a standard form, a reduced copy of which is shown in Figure 3. The different testing methods used by ISHC will be discussed in this section.

The General Physical Description (see Figure 3) of the material is based on the reporter's subjective opinion and will not be discussed any further.

A number of the tests are performed according to AASHTO standard procedures. The designator numbers of these tests are given in Table 2. The tests not covered in this table are: pH, loss of ignition, soil textural classification and all the tests for shale classification. The soil pH is determined by means of an electrical pH - meter in a 1:1 soil-water suspension. The method is described in Part II of ASTM D 2976 (1972). The textural classification is done according to Figure 4.

Tests to determine the loss-on-ignition, slake durability index, slaking index, fissility number, modified soundness and classification of shale are described in Appendix A.

5. Storage of Data.

Laboratory test data on shales is reported by the Indiana State Highway Commission on a standard form, a copy of which is shown in Figure 3. For the purpose of this study it was decided not to include all the data on Figure 3. The data of importance to this study are the description of the sample and the laboratory testing results. It was therefore decided to include only those data indicated by a bar on Figure

TD-445 (4-74)
1M 4-74
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INDIANA STATE HIGHWAY COMMISSION
DIVISION OF MATERIALS AND TESTS

Purchase Order No. ____________

CONTRACT No. ____________ PROJECT No. ____________ ROAD No. ____________

REPORT ON SAMPLE OF SHALE

Laboratory Number: County:
Quad/Date ¼ ¼ ¼S T R 2nd PM
Date Sampled: Date Received: Submitted by:
Station: Offset: Depth: Elevation: Sample marked:
Source of material: Proposed use:

GEOLOGICAL DESCRIPTION

System: Series: Stage (Formation):

TEST RESULTS

GENERAL PHYSICAL DESCRIPTION

Color: Hardness: Soft ☐ Medium ☐ Hard ☐ Fissility: Massive ☐ Flaggy ☐ Flaky ☐

SHALE CLASSIFICATION

Soil like ☐ Intermediate 2 ☐ 1 ☐ Rock like ☐
Slaking Index:
Cycle No: (1) (5)

Slake Durability Index	200 Rev.	500 Rev.
Dry		
Soaked		

Fissility Number:
Modified Soundness Test: % Loss

SOIL CLASSIFICATION

Textural:
AASHTO:
Plastic Limit: %
Liquid Limit: %
Plasticity Index: %
% Sand: Silt: Clay: Colloids:

PHYSICAL PROPERTIES

Natural Wet Density: lbs/cuft.
Natural Dry Density: lbs/cuft.
Natural Moisture: percent
Specific Gravity:
Ph:
Shrinkage Limit: %
Lineal Shrinkage: %
Loss on Ignition: %

MOISTURE DENSITY RELATIONS

(Note: Minus ☐ No. 4 ☐ ¾ inch material)

Maximum Wet Density: lbs/cuft.
Maximum Dry Density: lbs/cuft.
Optimum Moisture: percent

CALIFORNIA BEARING RATIO

As Compacted CBR Value: %
After Soaking CBR Value: %
Average % Swell: %
(CBR value at 95% of Maximum Dry Density)

REMARKS: ____________

Figure 3. Standard Form Used by ISHC for Reporting Laboratory Test Data on Shales

Table 2

AASHTO Designator Numbers for Standard Tests Used by ISHC

	Title of Test	Designation
1.	Dry Preparation of Disturbed Soil and Soil Aggregate Samples for Test	T87-72
2.	Wet Preparation of Disturbed Soil Samples for Test	T186-49
3.	Particle Size Analysis of Soils	T88-72
4.	Determining the Liquid Limit of Soils	T89-68
5.	Determining the Plastic Limit and Plasticity Index of Soils	T90-70
6.	Determining the Shrinkage Factors of Soils	T92-68
7.	Moisture-Density Relations of Soils Using a 5.5 lb. Rammer and a 12-in. Drop (methods B & D)	T99-74
8.	Specific Gravity of Soils	T100-74
9.	The California Bearing Ratio	T193-72
10.	Density of Soil-in-Place by Block, Chunk or Core Sampling	T233-70
11.	Classification of Soil and Soil-Aggregate Mixtures for Highway Construction Purposes	M145-73

INDIANA STATE HIGHWAY COMMISSION
DIVISION OF MATERIALS & TESTS
SOILS DEPARTMENT

Revised
1-13-76

Grain Size Classification of Soils

Definitions

Gravel	- 3" to #10 Sieve
Coarse Sand	- #10 to #40 Sieve
Fine Sand	- #40 to #200 Sieve (0.074 mm.)
Silt	- 0.074 to 0.005 mm.
Clay	- smaller than 0.005 mm.

A. Soils having 0 to 19% retained on #10 sieve
(Chart below may be used)

Classification	% Sand & Gravel	% Silt	% Clay
Sand	80-100	0- 20	0- 20
Sandy Loam	50- 80	0- 50	0- 20
Loam	30- 50	30- 50	0- 20
Silty Loam	0- 50	50- 80	0- 20
Silt	0- 20	80-100	0- 20
Sandy Clay Loam	50- 80	0- 30	20- 30
Clay Loam	20- 50	20- 50	20- 30
Silty Clay Loam	0- 30	50- 80	20- 30
Sandy Clay	50- 70	0- 20	30- 50
Silty Clay	0- 20	50- 70	30- 50
Clay	0- 50	0- 50	30-100

B. Soils having 20% or more retained on #10 sieve & more than 20% passing #200 sieve (Silt & Clay)

Classify in accordance with par. A, followed by term describing relative amount of gravel according to following:

20% to 35% gravel - "With some gravel"
36% to 50% gravel - "and gravel"

Examples: Clay Loam with some gravel
Sandy Loam and gravel

C. Soils having 20% or more retained on #10 sieve less than 20% passing #200 sieve

Classification	% Gravel	% Sand	% Silt	% Clay
Gravel	85-100	0-15	0-15	0-15
Sandy Gravel	40- 85	15-40	0-20	0-20
Gravelly Sand	20- 40	40-80	0-20	0-20
Sand and Gravel	20- 40	20-40	0-20	0-20

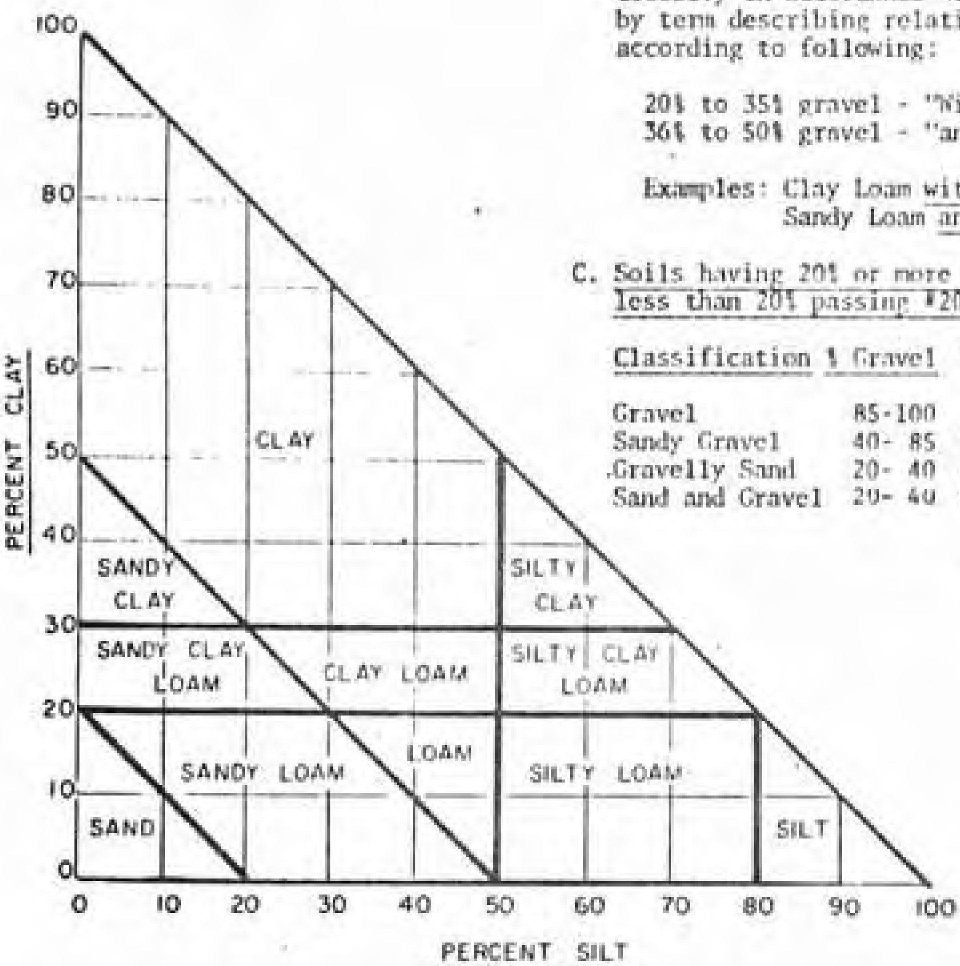

Figure 4. Details on Determining the Textural Classification of Shale Samples

5. The original data sheets should be consulted if any other data are required.

The data had to be coded for computer purposes. A four card series is used to put all the data of Figure 5 into storage. The format of the coding is given in Table 3.

In order to assess which data points are available in each data set, Table 4 was compiled. The crosses indicate the data points available. The descriptor used in this table to identify the samples is the laboratory number, which is given here in ascending order. The data broken down into the different geological units are given in Appendix B.

Because of the small number (163) of data sets presently available, a number of parameters are given as words, e.g., all the data on card 1 and the two classifications on card 3 (see Table 3). The alternative was to use numbers as codes for these parameters with 'word-files', in order to get a print-out with the correct descriptions on it. This alternative is not justified at this stage. The data sets can, however, be changed easily if this feature is necessary in the future.

The data sets can also be enlarged in the future, i.e., more than four cards can be used for each data set. This will only be justified if more data on other parameters became available for a large number of data sets.

The data stored in the present system are based on that provided by Indiana State Highway Commission as well as the results of studies on shales at Purdue University. Table 5 gives the laboratory numbers of the samples used by Deo (1972), Chapman (1975), and Bailey (1976).

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1M 4-74
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INDIANA STATE HIGHWAY COMMISSION
DIVISION OF MATERIALS AND TESTS

Purchase Order No. ____________

CONTRACT No. ____________ PROJECT No. ____________ ROAD No. ____________

REPORT ON SAMPLE OF SHALE

Laboratory Number: [redacted] County: [redacted]
Quad/Date: ¼ ¼ S T R 2nd PM
Date Sampled: Date Received: Submitted by:
Station: Offset: Depth: Elevation: Sample marked:
Source of material: Proposed use:

GEOLOGICAL DESCRIPTION

System: [redacted] Series: [redacted] Stage (Formation): [redacted]

TEST RESULTS

GENERAL PHYSICAL DESCRIPTION

Color: Hardness: Soft ☐ Medium ☐ Hard ☐ Fissility: Massive ☐ Flaggy ☐ Flaky ☐

SHALE CLASSIFICATION

Soil like ☐ Intermediate 2 ☐ 1 ☐ Rock like ☐
Slaking Index
Cycle No (1) [redacted] (5) [redacted]

Slake Durability Index	200 Rev.	500 Rev.
Dry	[redacted]	[redacted]
Soaked	[redacted]	[redacted]

Fissility Number: [redacted]
Modified Soundness Test: [redacted] % Loss

SOIL CLASSIFICATION

Textural: [redacted]
AASHTO: [redacted]
Plastic Limit: [redacted] %
Liquid Limit: [redacted] %
Plasticity Index: [redacted] %
% Sand: [redacted] Silt: [redacted] Clay: [redacted] Colloids: [redacted]

PHYSICAL PROPERTIES

Natural Wet Density: [redacted] lbs/cuft
Natural Dry Density: [redacted] lbs/cuft
Natural Moisture: [redacted] percent
Specific Gravity: [redacted]
Ph: [redacted]
Shrinkage Limit: [redacted] %
Lineal Shrinkage: [redacted] %
Loss on Ignition: [redacted] %

MOISTURE DENSITY RELATIONS

(Note: Minus [redacted] No. 4 [redacted] ¾ inch material)

Maximum Wet Density: [redacted] lbs/cuft
Maximum Dry Density: [redacted] lbs/cuft
Optimum Moisture: [redacted] percent

CALIFORNIA BEARING RATIO

As Compacted CBR Value: [redacted] %
After Soaking CBR Value: [redacted] %
Average % Swell: [redacted] %
(CBR value at 95% of Maximum Dry Density)

REMARKS: ____________

Figure 5. Identification of Data Included in This Study

Table 3

Coding of Four Card Series

Parameter	Symbols (for program and tables and figures)	Format	Columns
Card 1			
Laboratory number	NO	I10	1 - 10
County	CO	A10	11 - 20
Geological system	GSY1,GSY2	A10A5	21 - 35
Geological series	GSE1,GSE2	A10A5	36 - 50
Geological stage	GST1,GST2	A10A5	51 - 65
Physiographic unit	PHU1,PHU2	A10A5	66 - 80
Card 2			
Laboratory number	NO	I10	1 - 10
Slaking index cycle 1	SDI1	F5.1	11 - 15
Slaking index cycle 5	SDI2	F5.1	16 - 20
Slake durability index 200 rev. dry	SD2D	F5.1	21 - 25
Slake durability index 500 rev. dry	SD5D	F5.1	26 - 30
Slake durability index 200 rev. soaked	SD2S	F5.1	31 - 35
Slake durability index 500 rev. soaked	SD5S	F5.1	36 - 40
Fissility number	FN	F5.1	41 - 45
Modified soundness	MS	F5.1	46 - 50
Card 3			
Laboratory number	NO	I10	1 - 10
Textural classification	TEX1,TEX2	A10A5	11 - 25
AASHTO classification	ASH	A10	26 - 35
Plastic limit	PL	F5.1	36 - 40
Liquid limit	QL	F5.1	41 - 45
Plasticity index	PI	F5.1	46 - 50
Percent sand	PSA	I5	51 - 55
Persent silt	PSI	I5	56 - 60
Percent clay	PCL	I5	61 - 65
Percent colloids	PCOL	I5	66 - 70

Table 3 (Continued)

Parameter	Symbols (for program and tables and figures)	Format	Columns
Card 4			
Laboratory number	NO	I10	1 - 10
Natural wet density	WD	F5.1	11 - 15
Natural dry density	DD	F5.1	16 - 20
Natural moisture content	AMC	F5.1	21 - 35
Specific gravity	SG	F5.1	26 - 30
pH	PH	F5.1	31 - 35
Shrinkage limit	SL	F5.1	36 - 40
Lineal shrinkage	SH	F5.1	41 - 45
Loss-on-Ignition	XY	F5.1	46 - 50
Moisture density*	MD	I1	51
Optimum moisture	PM	F5.1	52 - 55
Maximum wet density	WD1	F5.1	56 - 60
Maximum dry density	DD1	F5.1	61 - 65
As Compacted CBR	CBR1	F5.1	66 - 70
After Soaking CBR	CBR2	F5.1	71 - 75
Average % Swell	AS	F5.1	76 - 80

*Coding for moisture density:

1 - Test done on minus No. 4 material
2 - Test done on minus 3/4 inch material
3 - When there is a special note on the laboratory report which should be referred to
4 - Nothing indicated on test report

TABLE 4

Data Points Available in the Different Data Sets

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
1				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
2				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
3				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
4				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
5				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
6				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
7				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
8				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
9				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
10				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
11				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
12				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
13				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
14				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
15				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
73-51703			X	X	X	X			X	X	X	X	X	X	X	X	X	X	X					X	X	X			
74-50505									X	X	X	X	X	X	X			X	X	X				X	X	X			
74-50506									X	X	X	X	X	X	X			X	X	X				X	X	X			
74-50560	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
74-54475	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54600	X	X		X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54601	X	X		X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

TABLE 4 (Continued)

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
74-54611	X	X		X		X										X	X	X						X	X	X			
74-54621	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54622	X	X	X	X	X	X			X	X	X	X	X	X	X			X	X	X	X	X	X						
74-54664	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54665	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54666	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54684	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54716	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54766	X	X		X		X																							
74-54767	X	X		X		X																							
74-54768	X	X		X		X																							
74-54832	X	X				X			X	X	X	X	X	X	X				X	X	X	X	X						
74-54834	X	X				X			X	X	X	X	X	X	X				X	X	X	X	X						
74-54836	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54878	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54879	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54905	X	X							X	X	X	X	X	X	X			X	X	X	X	X							
74-54956	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54957	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54958	X	X		X		X	X											X											
74-54959	X	X	X	X	X	X										X	X	X											
74-54960	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						

TABLE 4 (Continued)

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
74-54963	X	X	X	X	X	X										X	X	X											
74-54964	X	X		X		X										X	X	X											
74-54965	X	X	X	X	X	X										X	X	X											
74-54966	X	X		X		X										X	X	X											
74-54967	X	X	X	X	X	X										X	X	X											
74-54968	X	X	X	X	X	X										X	X	X											
74-54969	X	X	X	X	X	X										X	X	X											
74-54970	X	X	X	X	X	X										X	X	X											
74-54971	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54972	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54973	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54974						X										X	X	X											
74-54975	X	X				X										X	X	X											
74-54976									X	X	X	X	X	X	X			X	X	X			X						
74-54977																		X					X						
74-54978																		X					X						
74-54979	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54980																		X					X						
74-54981	X	X				X										X	X	X					X						
74-54982	X	X		X		X										X	X	X					X						
74-54983	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X							
74-54984	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						

TABLE 4 (Continued)

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
74-54985	X	X	X	X	X	X										X	X	X											
74-54986	X	X	X	X	X	X										X	X	X											
74-54987	X	X		X		X												X											
74-54988	X	X		X		X												X											
74-54989	X	X	X	X	X	X												X											
74-54990	X	X	X	X	X	X												X											
74-54991	X	X	X	X	X	X												X											
74-54992	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54993	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54994	X	X	X	X	X	X												X											
74-54995	X	X	X	X	X	X												X											
74-55053	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-55054	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-55055	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55018	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55019	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55020	X	X				X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55021	X	X				X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55022	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55023									X	X	X	X	X	X	X				X	X	X	X	X						
75-55024	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55025						X																							

TABLE 4 (Continued)

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
75-55026	X	X				X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55027	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55028	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55029	X	X	X	X	X	X	X		-							X	X	X											
75-55038	X	X																X											
75-55040	X	X	X	X	X	X	X									X	X	X					X						
75-55041	X	X	X	X	X	X	X									X	X	X					X						
75-55042	X	X	X	X	X	X	X									X	X	X					X						
75-55043	X	X	X	X	X	X	X									X	X	X					X						
75-55044	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55193	X	X																X											
75-55205	X	X																X											
75-55223	X	X																X											
75-55224	X	X																X											
75-55230	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55231	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55232	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55246	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55247	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55252	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55265	X	X																X											
75-55291	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

TABLE 4 (Continued)

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SC	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
75-55302	X	X																X											
75-55303	X	X																X											
75-55304	X	X																X											
75-55305	X	X																X											
75-55306	X	X																X											
75-55307	X	X																X											
75-55308	X	X																X											
75-55315	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
75-55316	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
75-55440	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
75-55486	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55487	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55505	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55564	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55567	X	X		X		X										X	X	X											
75-55568	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55569	X	X				X										X	X	X											
75-55570	X	X		X		X										X	X	X											
75-55571	X	X				X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55572	X	X		X		X										X	X	X											
75-55583	X	X		X		X	X											X											
75-55584	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						

TABLE 4 (Continued)

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
75-55653	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55678	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55715	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55716	X	X				X										X	X	X											
75-55717									X	X	X	X	X	X	X				X	X	X	X	X						
75-55718	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55731	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55767	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55792	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
76-55014	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
76-55055									X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X
76-55126						X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
76-55127						X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
76-55128						X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
76-55129						X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
76-55130						X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
76-55135	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
76-55250	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
76-55251	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
76-55252	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
76-55451	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
76-55452	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

TABLE 4 (Continued)

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
76-55453	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
76-55454	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
76-55483	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
76-55484	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
76-55529	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
76-55530	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
76-55554	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
76-55723	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
76-55758	X	X	X	X	X	X			X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X

TABLE 5

Laboratory Numbers of Shale Samples Utilized by Researchers at Purdue

1. Deo (1972)
   Samples 1 to 15

2. Chapman (1975)

Number in report	ISHC Laboratory No.
1	73-51703
2	74-54621
3	74-54684
4	74-54716
5	75-55018
6	75-55315

3. Bailey (1976)

1	74-54878
2	74-54684
3	75-55653
4	74-54716
5	74-54836
6	75-55044
7	74-54767
8	73-51703
9	74-54973
10	74-54972
11	75-55564
12	75-55316
13	75-55315
14	75-55731
15	75-55505
16	74-54621
17	75-55718
18	75-55486
19	75-55487
20	75-55018
21	75-55291
22	76-55014

There are some discrepancies between the values of the parameters as given in the report by Chapman (1975) and the values given by ISHC on their results sheet. The different values are given in Table 6. In order to limit the variables contributing to differences in test parameter values it is necessary to use data from as few different sources as possible. With this in mind it was decided to use the values supplied by ISHC.

6. Retrieval of Data

There are basically three purposes for the retrieval of data:

a) To get print-outs of all the data available.

b) To get print-outs based on some descriptor in some order, e.g., geological stage in alphabetical order. The printed data sets belonging to a certain geological stage can then be separated for study.

c) To use certain sets of data for statistical manipulation.

The program for printing out all the data sets in the order which they are on the data cards is given in Appendix C. This program was written for the CDC system of the Purdue University Computer Center and might need changes in order to use it on any other system. A typical print-out of a data set is given in Figure 6.

The sorting of the data is accomplished by using the SORT/MERGE package on the CDC system. Sorting can be done in an ascending or descending order based on any parameter. Before the sorting can be done, each data set must be changed to a string of 320 characters in the computer, and after sorting it is broken up again into 4 groups of 80 characters each. Printing can now take place by using the program given in Appendix C. Detail of this is given in Table 7. Detail of the sorting is also given in this table.

TABLE 6

Discrepancies Between Values Given in Report by Chapman (1975) and Those Provided by ISHC

Laboratory Number	Slake Durability Index: 200 Dry		200 Soaked		500 Dry		500 Soaked		Plastic Limit		Liquid Limit		Plasticity Index	
	Chapman	ISHC	Chapman	ISHC	Chapman	ISHC	Chapman	ISHC	Chapman	ISHC	Chapman	ISHC	Chapman	ISHC
74-54621	99.6	--	99.6	--	99.7	99.0	99.2	99.7	same		same		same	
74-54684	90.1	80.5	74.8	54.8	79.8	71.1	56.8	44.1	21.2	20.5	36.9	36.5	15.7	16.0
74-54716	79.7	79.8	56.6	46.3	58.4	36.5	40.3	27.9	19.4	19.9	40.6	36.3	21.2	16.4
75-155018	80.1	75.1	16.6	32.3	28.4	14.8	7.7	4.8	22.2	20.8	40.6	36.1	18.4	15.3
75-55315	98.8	98.9	98.3	98.4	97.8	98.3	97.6	98.4	same		same		same	

LABORATORY NUMBER - - - - - - - - - - - - -	7454646
COUNTY - - - - - - - - - - - - - - - - -	PERRY
GEOLOGICAL SYSTEM - - - - - - - - - - - - -	MISSISSIPPIAN
GEOLOGICAL SERIES - - - - - - - - - - - - -	CHESTER
GEOLOGICAL STAGE - - - - - - - - - - - - -	[illegible]
PHYSIOGRAPHIC UNIT - - - - - - - - - - - -	CRAWFORD UPLAND
SLAKING INDEX CYCLE 1 - - - - - - - - - - -	2.6
SLAKING INDEX CYCLE 5 - - - - - - - - - - -	51.1
SLAKE DURABILITY INDEX 200 REV DRY - -	71.5
SLAKE DURABILITY INDEX 200 REV SOAKED -	42.5
SLAKE DURABILITY INDEX 500 REV DRY - -	73.4
SLAKE DURABILITY INDEX 500 REV SOAKED -	47.4
FISSILITY NUMBER - - - - - - - - - - - - -	-0
MODIFIED SOUNDNESS TEST (PERC LOSS) - -	100.0
TEXTURAL CLASSIFICATION - - - - - - - - - -	SILTY CLAY
AASHTO CLASSIFICATION - - - - - - - - - - -	A 6(16)
PLASTIC LIMIT (PERC) - - - - - - - - - - -	21.9
LIQUID LIMIT (PERC) - - - - - - - - - - - -	36.6
PLASTICITY INDEX (PERC) - - - - - - - - - -	14.7
SAND (PERC) - - - - - - - - - - - - - - - -	3
SILT (PERC) - - - - - - - - - - - - - - - -	54
CLAY (PERC) - - - - - - - - - - - - - - - -	43
COLLOIDS (PERC) - - - - - - - - - - - - - -	20
NATURAL WET DENSITY (LB/CUFT) - - - - - -	151.0
NATURAL DRY DENSITY (LB/CUFT) - - - - - -	141.1
NATURAL MOISTURE CONTENT (PERC) - - - - -	7.0
SPECIFIC GRAVITY - - - - - - - - - - - - -	2.73
PH -	7.6
SHRINKAGE LIMIT (PERC) - - - - - - - - - -	16.5
LINEAL SHRINKAGE (PERC) - - - - - - - - -	4.7
LOSS OF IGNITION (PERC) - - - - - - - - - -	7.0
MOISTURE DENSITY RELATIONS DONE ON - -	MINUS 0.75 INCH MATERIAL
MAXIMUM WET DENSITY (LB/CUFT) - - - - - -	138.6
MAXIMUM DRY DENSITY (LB/CUFT) - - - - - -	125.2
OPTIMUM MOISTURE CONTENT (PERC) - - - - -	10.4
AS COMPACTED CBR (PERC) - - - - - - - - -	10.3
AFTER SOAKING CBR (PERC) - - - - - - - - -	6.6
AVERAGE SWELL (PERC) - - - - - - - - - - -	1.4

Figure 6. Typical Print-out of a Data Set

TABLE 7

Detail of Cards for Sorting Data on CDC of Purdue University Computer Center by Utilizing the SORT/MERGE System

Cards	Comments
JOB CARD	
PASS =	
FORTRAN.	
LOAD(LGO,RUNL1B2)	
EXECUTE(,INPUT)	
REWIND(TAPE2)	
RETURN,LGO.	
SORTMRG.	
REWIND(TAPE3)	Control. Start in Column 1.
FORTRAN.	
LOAD(LGO, RUNL1B2)	
EXECUTE(,TAPE3,FILE4)	
RETURN,LGO.	
REWIND(FILE4)	
MNF(N)	
LGO(FILE4)	
7/8/9	
PROGRAM IN(TAPE1,TAPE2)	Program to write 4 card
INTEGER ARRAY(320)	series (80 characters each)
1 CALL READS(1,ARRAY(1),80,K)	as one string of 320
IF (K.LE.O) STOP	characters. The use of this
CALL READS (1,ARRAY(81)80,K)	special input/output
IF (K.LE.O) STOP	capabilities is described in
CALL READS(1,ARRAY(161),80,K)	PUCC publication IO-XFORTIO
IF (K.LE.O) STOP	Punching starts in Column 7.
CALL READS(1,ARRAY(241),80,K)	
IF (K.LE.O) STOP	
CALL WRITES(2,ARRAY,320)	
GO TO 1	
END	
7/8/9	
Data	
7/8/9	
SORT(1,1,330)	Sorting of data, see description
FILE(TAPE2,S,D)	below. Punching starts in
KEY(A,C,251,5)	Column 1. See PUCC publication
FILE(TAPE3,O,D)	M2-SORTMRG.
RECORD(I,U,330)	
END	

TABLE 7 (Continued)

```
7/8/9
     PROGRAM OUT(TAPE1,TAPE2)
     INTEGER ARRAY(320)
 1   CALL READS(1,ARRAY,320,K)
     IF (K.LE.0) STOP
     CALL WRITES(2,ARRAY(1),80)
     CALL WRITES(2,ARRAY(81),80)
     CALL WRITES(2,ARRAY(161),80)
     CALL WRITES(2,ARRAY(241),80)
     GO TO 1
     END
7/8/9
```

Program to write 320 character string into 4 groups of 80 characters each. See publication above for detail. Punching starts in Column 7.

Program of Appendix A

6/7/8/9

Sorting of data

The only card to be changed here is the KEY-card.

One key card must be specified for each field to be sorted. The order of importance of the keys is indicated by the order in which the KEY control cards occur in the SORT/MERGE control deck.

KEY(p1,....,p4)

p1 Sort order
- A = Ascending
- D = Descending

p2 Key mode designator
- C = character mode key
- X = Fixed point key
- F = Floating point key
- L = Logical key
- N = Numeric BCD Field.

p3 Position indicator
- For C and N key modes; position of the first 6-bit byte of the key
- For L key mode; relative bit position of the first bit of the key
- For X and F key modes; relative word position of the key

p4
- For C and N key modes; length of key in 6-bit bytes
- For L key mode; length of key in bits
- For X and F keys; ignored.

The example included above therefore means that the data sets will be sorted in an ascending order (p1=A); we are dealing with character mode key (p2=C); the sorting will start in Column 251(p3=251) therefore in Column 11 on card 4 (see Table 3) that is natural wet density; the sorting will be done for the next 5 columns (p4=5). This example will, therefore sort the data according to values of natural wet density in ascending order before printing the data sets as in Fig. 6 .

Any parameter can be used for sorting as indicated in Table 7. The print-out is still the same as that in Figure 6 and all the data sets included in the data submitted with the program will be printed. Separate parameters can therefore be sorted but no detailed sorting, e.g., all data sets containing liquid limits higher than 25% and belonging to the Mississippian system included in the Clore stage, can be done with the SORT-MERGE package. It was felt that a general sorting program is not justified at this stage because of the small number of data sets in the present system.

A general sorting program would be necessary to use the stored data for statistical manipulation. For the present study, detailed sorting was done by hand prior to some of the statistical analyses.

The program in Appendix C is a very basic program and is only meant for reading and printing data. Modifications of this program would be necessary if anything more is necessary.

7. Statistical Analysis of Data.

The statistical analysis was done by using the routines available in the statistical package for the social sciences (SPSS) (Nie, et al., 1975). This package is available at the Purdue University Computer Center.

This section will describe the different analyses performed as well as the results obtained.

7.1 Frequency Analysis

The first step in the statistical analysis was to do a complete frequency analysis of all the data available. For this analysis the

CODEBOOK routine of SPSS was used. The data can be analyzed as 'single points' or as grouped data. The data were first analyzed as single points in order to obtain minima and maxima of each parameter. The values of each parameter were then divided into 10 intervals in order to obtain histograms. A number of statistics are computed by this program. The different statistics and the way that they are calculated in the program are given in Table 8.

The results of the statistics of the different parameters are given in Table 9. The first line of results for every parameter gives the values obtained by using single points, while the second line gives the results for grouped data. The histograms are given in Figure 7.

The last two columns of Table 9 give the number of values which are valid and also the missing values, e.g., for SDI1, 131 data sets had values reported for this parameter while it was not reported for 32 data sets. The lowest number of valid values is 26 for the modified soundness test, a reasonably low number of test values is also available for the California Bearing Ratio and average percentage swell (53). The number of valid values will play a very important role when the regression analysis is done.

The low values obtained for the skewness for liquid limit (QL) and percent silt (PSI) indicate that the distribution of these two parameters are almost symmetric-bell shaped (refer to Figure 7). Low values of coefficient of variance were also obtained for these two variables which confirms the small relative spread of values. Low values of the coefficient of variation are to be expected for SG and pH while the low values for the coefficient of variation obtained for the

TABLE 8

Statistics Available from CODEBOOK

1. Minimum value
2. Maximum value
3. Range
4. Mode - value which occurs most often
5. Median - the numerical value of the middle case or the case lying exactly on the 50th percentile, once all the cases have been ordered from highest to lowest. In computing the median from grouped data, the values within each category are assumed to be distributed evenly throughout.
6. Mean

$$\bar{X} = \frac{\sum_{i=1}^{N} X_i}{N}$$

7. Variance

$$S^2 = \frac{\sum_{i=1}^{N} X_i^2 - N\,\bar{X}^2}{N - 1}$$

8. Standard deviation - S
9. Standard Error: If we were to draw an infinite number of equal-sized samples from a given population, the mean of each sample would be an estimate of the true population mean, but not all of them would be identical. The pattern of these means would actually constitute a normal distribution and would have a standard deviation. The standard deviation of this distribution is the standard error. Standard error cannot be computed exactly, but it can be estimated by dividing the standard deviation by the square root of the number of cases.

TABLE 8 (Continued)

10. Skewness

$$= \frac{\left\{\left[\sum_{i=1}^{N} X_i^3 - 3\bar{X}\left(\sum_{i=1}^{N} X_i^2\right) + 3\bar{X}^2\left(\sum_{i=1}^{N} X_i\right)\right]\Big/N\right\} - \bar{X}^3}{\left\{\left[\left(\sum_{i=1}^{N} X_i^2\right) - N\,\bar{X}^2\right]/N-1\right\}^{3/2}}$$

Skewness is a statistic to determine the degree to which a distribution of cases approximates a normal curve, since it measures deviations from symmetry. It will take on a value of zero when the distribution is a completely symmetric bell-shaped curve. A positive value indicates that the cases are clustered more to the left of the mean with most of the extreme values to the right. A negative value indicates clustering to the right.

11. Kurtosis

$$= \frac{\left\{\left[\sum_{i=1}^{N} X_i^4 - 4\bar{X}\left(\sum_{i=1}^{N} X_i^3\right) + 6\bar{X}^2\left(\sum_{i=1}^{N} X_i^2\right) - 4\bar{X}^3\left(\sum_{i=1}^{N} X_i\right)\right]\Big/N\right\} + \bar{X}^4}{\left\{\left[\left(\sum_{i=1}^{N} X_i^2\right) - N\,\bar{X}^2\right]\Big/(N-1)\right\}^{2}} - 3$$

Kurtosis is a measure of the relative peakedness or flatness of the curve defined by the distribution of cases. A normal distribution will have a kurtosis of zero. If the kurtosis is positive, then the distribution is more peaked (narrow) than would be true for a normal distribution, while a negative value means that it is flatter.

12. Coefficient of Variation

$$V = 100\,\frac{S}{\bar{X}}$$

This is a measure of dispersion. This value is not given by SPSS but was calculated by hand.

Table 9

Statistics Obtained by CODEBOOK

	Mean	Median	Mode	Variance	Std. Dev.	Std. Error	Coef. of V.	Kurtosis	Skewness	Min.	Max.	Range	Valid V.	Missing V.
SDI1	30.537 31.565	19.775 20.5	0.800 5.0	967.33 877.73	31.102 29.626	2.717 2.588	101.85 93.86	-1.117 -1.102	0.586 0.613	0 0	99.0 95.0	99.0 95.0	131 131	32 32
SDI2	57.247 57.405	71.575 71.154	0.500 95.0	1 419.14 1 285.9	37.671 35.86	3.291 3.133	65.8 62.47	-1.526 -1.532	-0.338 -0.345	0 0	100.0 95.0	100.0 95.0	131 131	32 32
SD2D	70.482 69.93	80.638 81.786	99.5 95.0	809.26 800.34	28.45 28.29	3.33 3.311	40.36 40.45	-0.326 -0.47	-0.919 -0.925	0.2 5.0	99.7 95.0	99.5 90.0	73 73	90 90
SD5D	58.625 58.94	71.275 72.06	93.8 95.0	1 116.48 1 086.17	33.41 32.96	3.013 2.972	56.99 55.92	-1.363 -1.377	-0.399 -0.413	0 0	99.5 95.0	99.5 95.0	123 123	40 40
SD2S	52.96 52.33	57.38 55.0	99.4 25.0	1 091.5 1 051.45	33.04 32.43	3.867 3.795	62.39 61.97	-1.353 -1.376	-0.107 -0.122	0 0	99.5 95.0	99.5 95.0	73 73	90 90
SD5E	44.23 44.25	40.65 41.67	99.0 5.0	1 105.38 1 075.87	33.25 32.8	2.81 2.772	75.18 74.12	-1.376 -1.305	0.242 0.252	0 0	99.1 95.0	99.1 95.0	140 140	23 23
FN	42.45 41.65	34.5 35.0	100.0 25.0	676.6 656.21	26.01 25.617	2.872 2.829	61.27 61.51	-0.482 -0.67	0.654 0.558	0 0	100.0 95.0	100.0 95.0	82 82	81 81
MS	41.78 40.77	18.0 15.33	100.0 5.0	1 605.81 1 473.39	40.07 38.385	7.859 7.528	95.91 94.15	-1.515 -1.549	0.479 0.486	0.5 5.0	100.0 95.0	99.5 90.0	26 26	137 137
PL	20.54 20.486	20.65 20.55	18.5 19.5	12.827 14.01	3.582 3.743	0.345 0.360	17.7 18.27	8.604 7.060	-1.608 -1.386	0 0	28.40 28.50	28.40 28.50	108 108	55 55
QL	33.536 33.539	32.72 33.136	23.0 33.0	62.01 67.70	7.875 8.228	0.758 0.792	23.48 24.5	2.632 2.075	-0.053 -0.106	0 0	55.30 57.00	55.30 57.00	108 108	55 55
PI	12.995 12.792	12.55 12.25	10.00 10.50	36.07 36.44	6.006 6.037	0.578 0.581	46.22 47.19	0.462 0.097	0.697 0.565	0 0	31.50 28.50	31.50 28.50	108 108	55 55
PSA	14.381 13.889	9.167 9.20	2.00 2.50	189.43 167.212	13.763 12.931	1.324 1.244	95.84 93.10	1.207 0.428	1.362 1.212	1.00 2.50	60.00 47.50	59.00 45.0	108 108	55 55
PSI	48.972 48.611	48.9 48.71	49.0 55.0	144.31 152.259	12.013 12.339	1.156 1.187	24.53 25.38	-0.362 -0.302	-0.130 -0.053	16.00 15.0	75.00 75.0	59.00 60.0	108 108	55 55
PCL	21.657 21.389	19.357 19.464	17.00 17.50	100.994 96.417	10.05 9.819	0.967 0.945	46.41 45.91	1.874 0.578	1.167 0.863	4.00 2.5	61.00 47.5	57.00 45.0	108 108	55 55
PCOL	17.269 16.64	16.40 15.938	17.00 17.5	58.0 60.172	7.62 7.754	0.79 0.804	44.13 46.6	0.007 0.113	0.533 0.570	1.00 2.5	38.00 37.5	37.00 35.0	93 93	70 70
WD	149.16 149.306	150.9 150.875	151.1 152.5	61.734 64.233	7.857 8.015	0.756 0.771	5.27 5.37	0.851 0.584	-0.783 -0.738	122.3 122.5	164.9 162.5	42.6 40.0	108 108	55 55
DD	138.192 139.49	141.93 141.5	145.0 147.5	146.26 110.14	12.095 10.495	1.091 0.906	8.71 7.52	0.249 -0.902	-0.806 -0.343	101.5 122.5	159.7 157.5	58.2 35.0	123 123	40 40
AMC	6.132 6.183	4.575 5.092	3.4 1.5	24.332 24.54	4.933 4.953	0.418 0.42	80.45 80.11	2.469 2.827	1.464 1.486	0.4 1.5	27.2 28.5	26.8 27.0	139 139	24 24
SG	2.752 2.745	2.756 2.747	2.77 2.75	0.001 0.002	0.034 0.040	0.004 0.004	1.24 1.46	-0.465 3.078	-0.078 -0.445	2.68 2.65	2.84 2.85	0.16 0.20	93 93	70 70
PH	7.141	7.328 7.255	7.30 7.5	0.933 0.974	0.966 0.987	0.101 0.103	13.53 13.97	4.197 2.917	-1.80 -1.666	3.4 3.5	8.6 8.5	5.2 5.0	92 92	71 71
SL	16.784 16.845	16.075 15.083	16.50 16.50	21.645 19.973	4.652 4.469	0.499 0.479	27.72 26.53	2.226 0.360	1.386 0.970	10.6 10.5	35.3 28.5	24.7 18.0	87 87	76 76
SH	5.586 5.506	5.175 5.056	4.100 4.50	6.932 6.515	2.633 2.552	0.282 0.274	47.14 46.35	-0.290 -0.679	0.400 0.235	0 0	12.70 10.50	12.70 10.50	87 87	76 76
XY	7.222 7.184	6.067 6.044	4.80 4.50	19.65 20.77	4.433 4.56	0.455 0.468	61.38 63.47	5.627 5.938	2.262 2.265	1.20 1.50	27.10 28.50	25.90 27.0	95 95	68 68

TABLE 9 (Continued)

	Mean	Median	Mode	Variance	Std. Dev.	Std. Error	Coef. of V.	Kurtosis	Skewness	Min.	Max.	Range	Valid V.	Missing V.
PM	12.365	12.325	11.30	8.304	2.882	0.363	23.31	-0.348	0.045	6.90	19.20	12.30	63	100
	12.63	12.29	12.5	6.05	2.46	0.31	19.48	-0.463	0.027	9.50	18.50	9.0	63	100
WO1	137.68	134.12	134.2	55.59	7.46	1.076	5.62	9.899	-2.811	97.5	141.4	43.9	48	115
	132.71	133.89	132.5	57.40	7.58	1.094	5.71	8.647	-2.481	97.5	142.5	45.0	48	115
DO1	116.82	117.9	117.9	43.37	6.58	0.829	5.63	3.356	-1.43	90.1	126.7	36.6	63	100
	116.79	117.5	117.5	46.66	6.83	0.861	5.85	2.013	-1.041	92.5	127.5	35.0	63	100
CBR1	11.77	9.0	9.6	61.66	7.85	1.079	66.69	0.761	1.44	2.10	31.80	29.70	53	110
	11.630	8.929	7.5	59.271	7.699	1.058	66.19	0.549	1.346	1.50	28.50	27.0	53	110
CBR2	6.02	3.605	2.1	33.22	5.76	0.792	95.68	0.164	1.108	0	21.80	21.80	53	110
	6.057	3.938	1.5	33.401	5.779	0.794	95.41	0.441	1.189	0	22.50	22.50	53	110
AS	1.442	0.863	0	2.788	1.67	0.23	115.81	2.857	1.658	0	7.80	7.80	53	110
	1.325	0.750	0.25	2.074	1.440	0.198	108.65	0.096	1.115	0	4.75	4.75	53	110

Note: First line for every parameter gives the values obtained by using single points, while the second line gives the results for grouped data (10 equal groups in range of values).

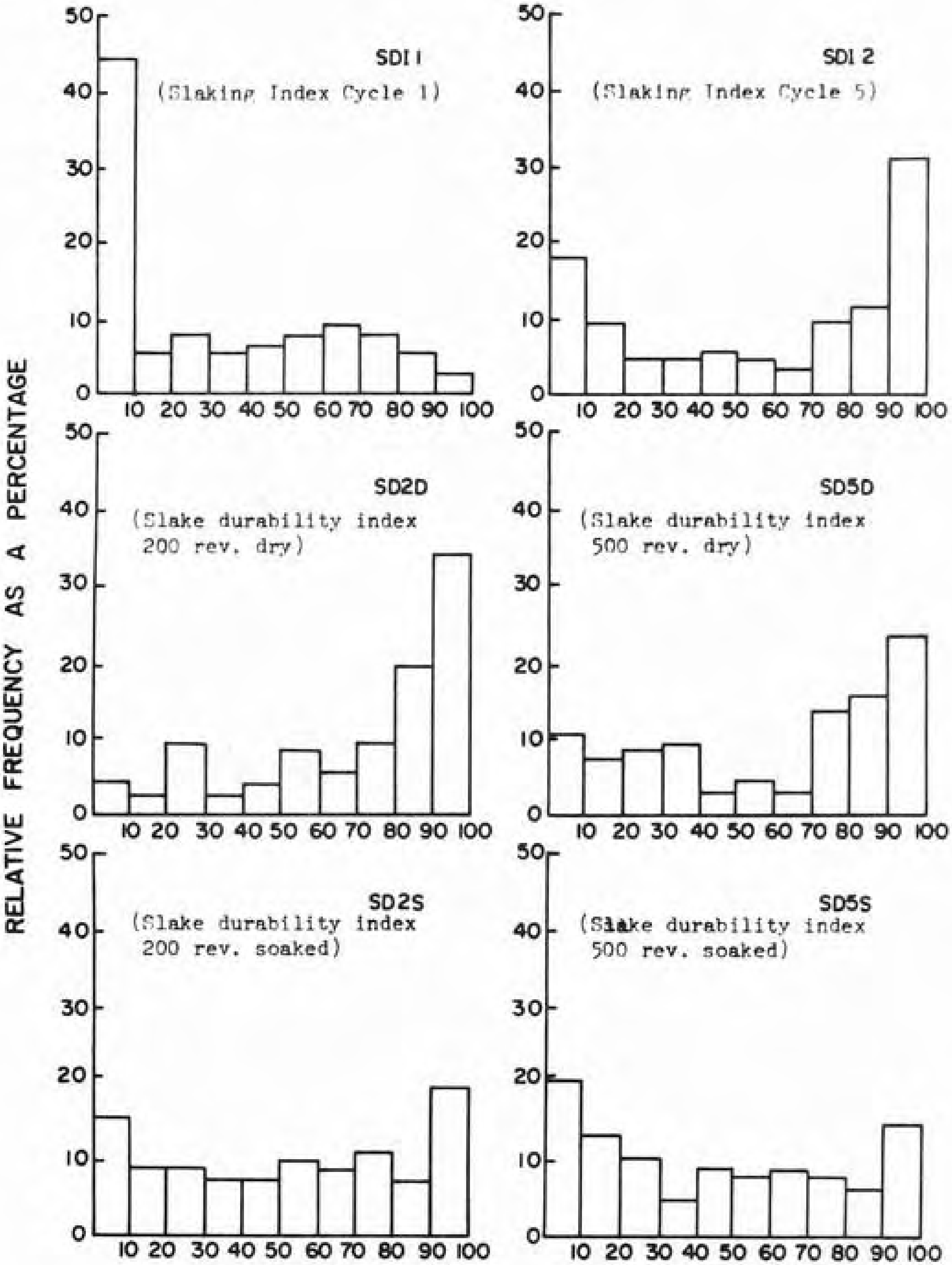


FIGURE 7. HISTOGRAMS FOR GROUPED DATA

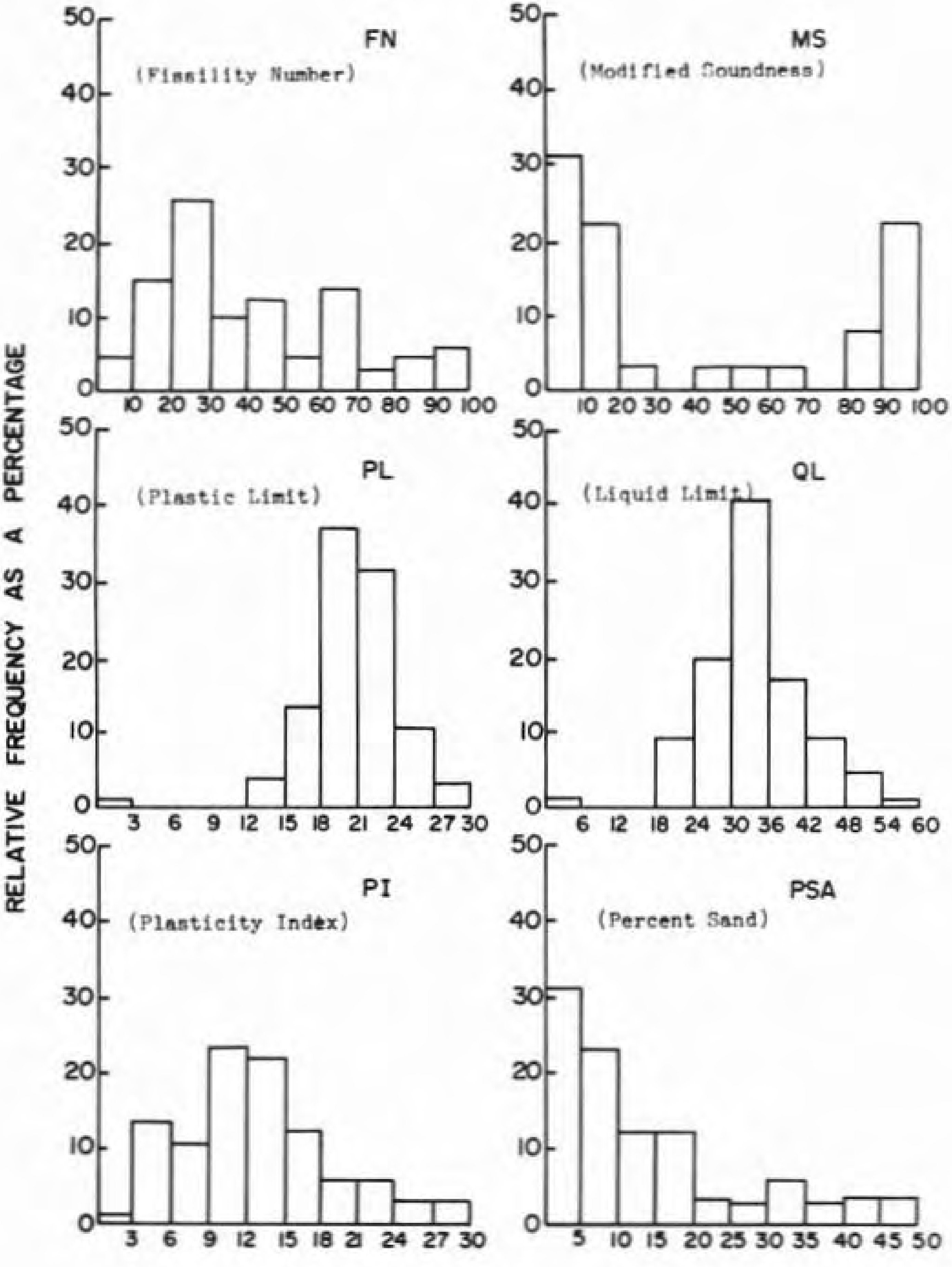


FIGURE 7. (CONTINUED)

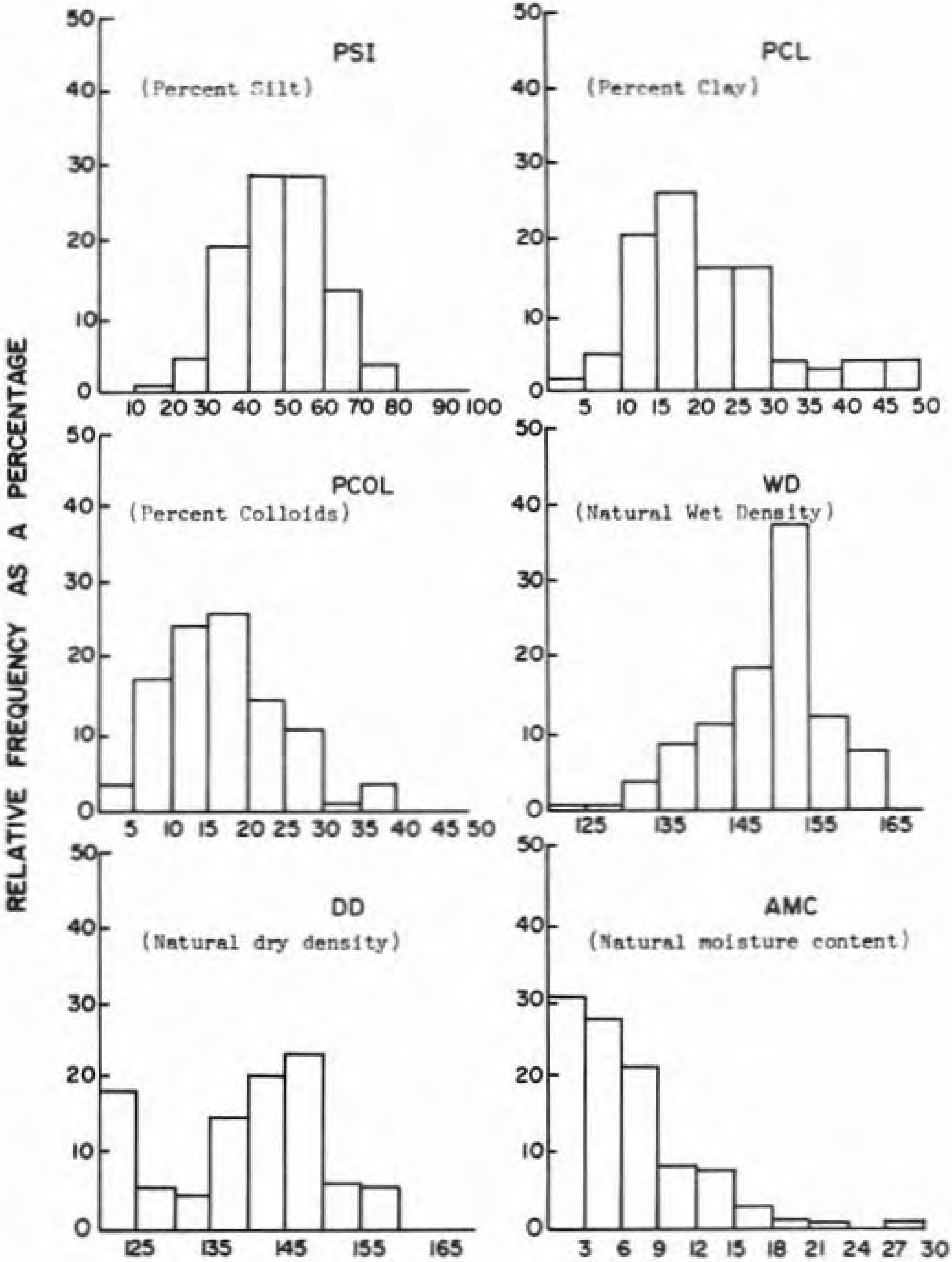


FIGURE 7. (CONTINUED)

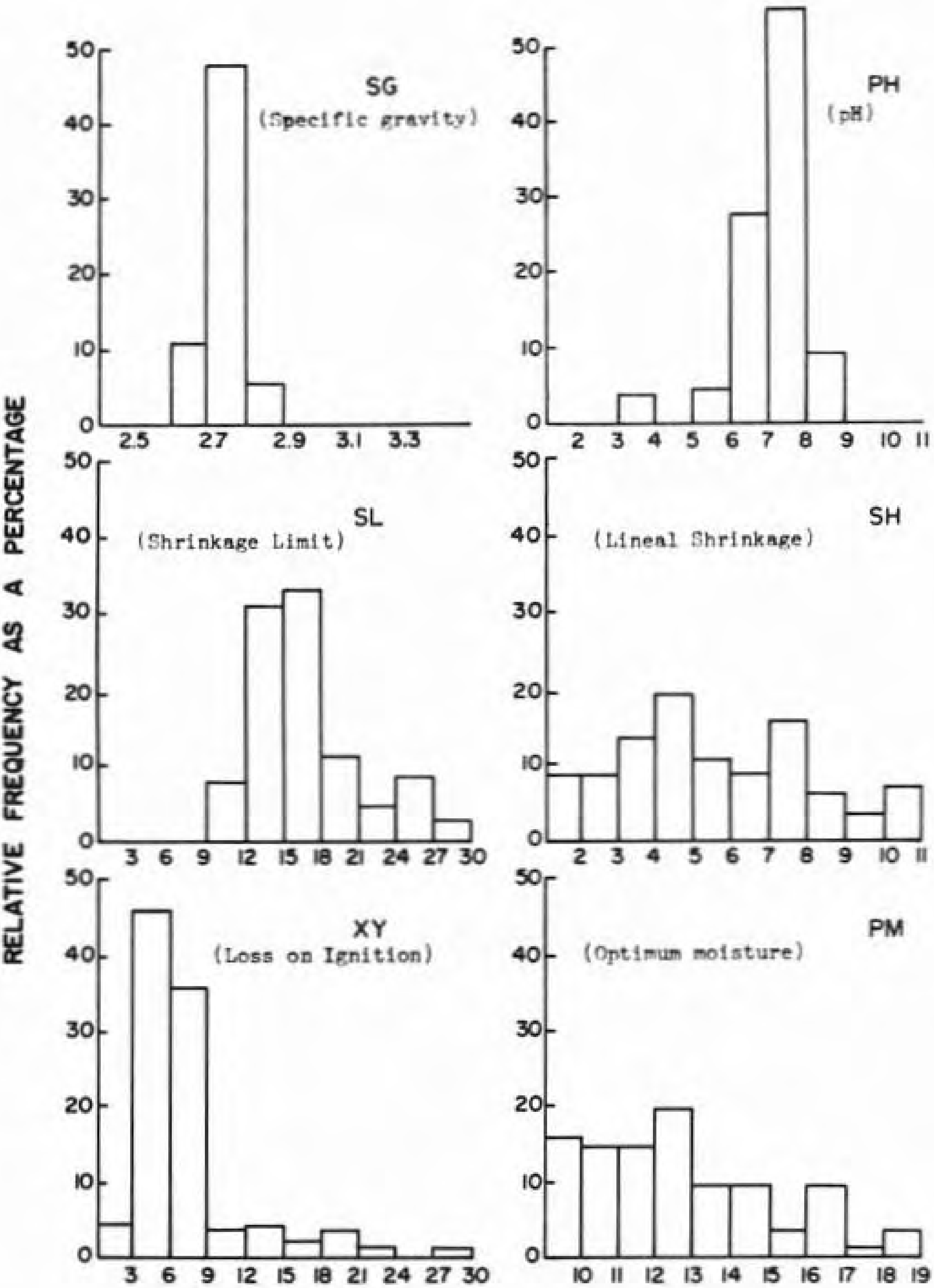


FIGURE 7. (CONTINUED)

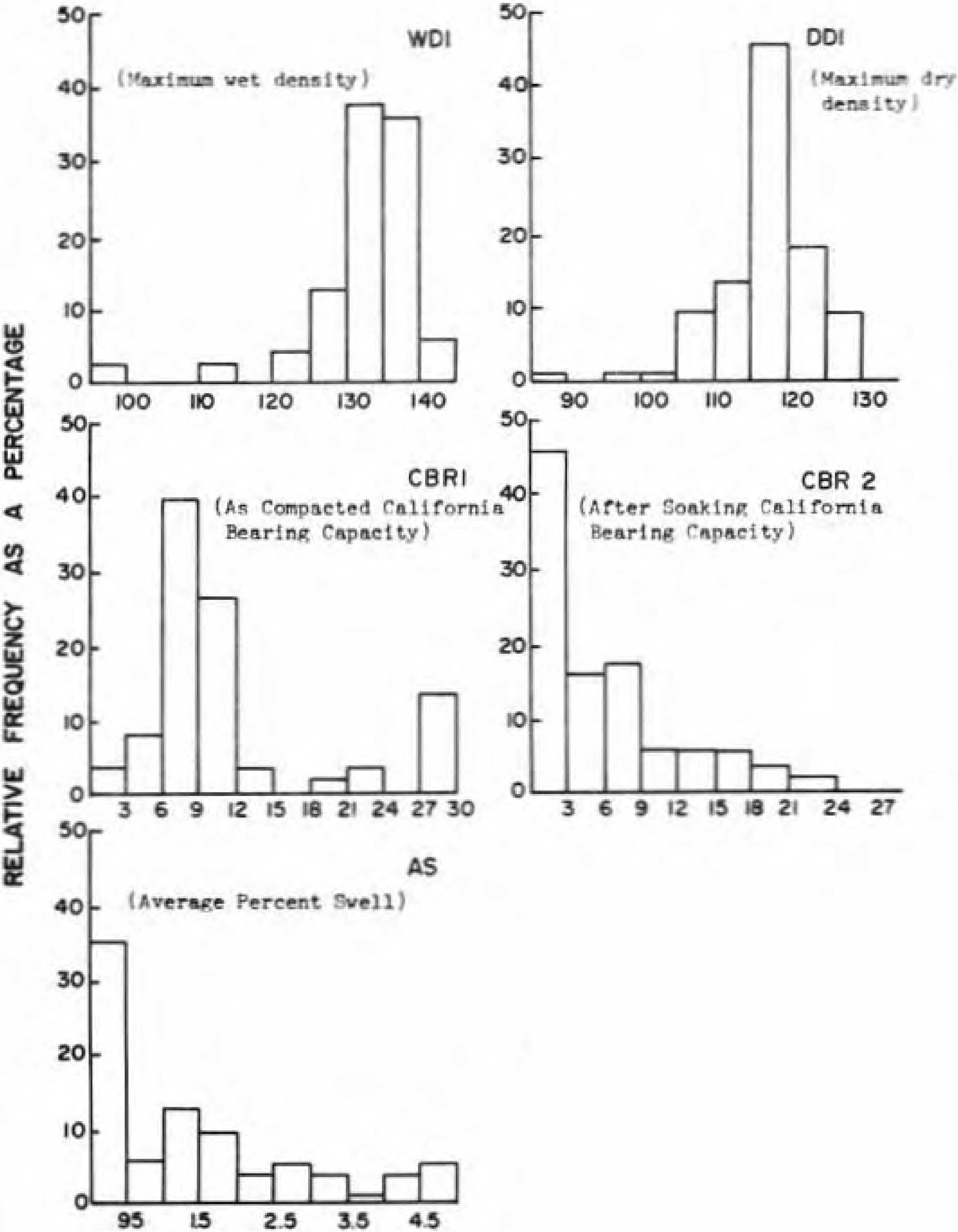


FIGURE 7. (CONTINUED)

different densities reflect the high average values and small spread of these parameters. The relative low value of coefficient of variation for percent silt (25%) may be the result of the preparation for the grain-size analysis. The method used can result in breaking down the material to a reasonably constant size which is silt size. Another possibility is that shales are mostly made up of silt size particles. or still another reason might be that the silt size particle is much more stable and therefore resistant against degradation.

It is interesting to note the relatively small values of coefficient of variation for the Atterberg limits. The Atterberg limits can therefore be estimated with reasonable confidence if a few test results are available. Assuming that the plastic limit and liquid limit are normally distributed (which is reasonable as shown in Figure 7) it can be said that 68% of all values will be within one standard deviation of the mean, i.e., the range of values for plastic limit is 19.9 to 24.1 and 25.4 to 41.4 for the liquid limit.

It is clear from Figure 7 that some distinction can be made between low and high durability shales based on the histograms. The dispersion of the data is however significant. It is possible that further analysis based on separate geologic groupings will distinguish between strong and weak or durable and nondurable shales.

7.2 Bivariate Correlation Analysis

In order to determine whether any simple correlations can be established between the different parameters, bivariate correlation analyses were performed using the SCATTERGRAM routine of the SPSS package. This program determine the statistics indicated in Table 10 as well as a two-dimensional plot of data points.

TABLE 10

Statistics Available from SCATTERGRAM

1. Correlation (r)

The Pearson correlation coefficient r is used to measure the strength of relationship between two internal-level variables. The strength of the relationship indicates the goodness of fit of a linear regression line to the data.

$$r = \frac{\sum_{i=1}^{N} X_i Y_i - \left(\sum_{i=1}^{N} X_i\right)\left(\sum_{i=1}^{N} Y_i\right)/N}{\left\{\left[\sum_{i=1}^{N} X_i^2 - \left(\sum_{i=1}^{N} X_i\right)^2/N\right]\left[\sum_{i=1}^{N} Y_i^2 - \left(\sum_{i=1}^{N} Y_i\right)^2/N\right]\right\}^{1/2}}$$

If the value of r approaches + 1.0 or - 1.0, we can assume there is a strong linear relationship.

2. r^2 - this explains the proportion of variance in one variable explained by the other.

3. Significance tests are reported for each coefficient and are derived from the use of student's t with N-2 degrees of freedom for the computed quantity

$$r\left[\frac{N - 2}{1 - r^2}\right]^{1/2}$$

4. Standard error of estimate - this statistic is the standard deviation of the residuals. Residuals are the errors made in predicting Y from X by use of the regression equation.

$$S_e = \left\{\frac{\sum_{i=1}^{N} Y_i^2 - a\sum_{i=1}^{N} Y_i - b\sum_{i=1}^{N} X_i Y_i}{N - 2}\right\}^{1/2}$$

TABLE 10 (Continued)

5. Intercept (a) of the equation $Y = a + b\,X$

$$a = \frac{\left(\sum_{i=1}^{N} Y_i \sum_{i=1}^{N} X_i^2\right) - \left(\sum_{i=1}^{N} X_i \sum_{i=1}^{N} X_i\,Y_i\right)}{\left(N \sum_{i=1}^{N} X_i^2\right) - \left(\sum_{i=1}^{N} X_i\right)^2}$$

6. Slope (b)

$$b = \frac{\left(N \sum_{i=1}^{N} X_i\,Y_i\right) - \left(\sum_{i=1}^{N} X_i \sum_{i=1}^{N} Y_i\right)}{\left(N \sum_{i=1}^{N} X_i^2\right) - \left(\sum_{i=1}^{N} X_i\right)^2}$$

7. Plotted values.

8. Excluded values (caused by changing the scale of the plot).

9. Missing values.

The above analysis was performed for all combinations of the variables, and plots were obtained. The values of r (correlation) and the number of data sets with reported values for both the parameters are given in Table 11. The plots were inspected, and it was decided to include all those with $r \geq 0.8$, even those which involved no obvious engineering logic. It was further decided to include complete data on all the analyses which gave a 'good' correlation, $r \sim 0.7$ was used as a cut-off point. These results are given in Table 12.

The compaction data are all generated in the standard AASHTO test, but the maximum size was in some cases the No. 4 sieve, and in other cases the 3/4 in. sieve. The data were examined separately, but since no trend was recognized, they were lumped, viz., Figures 15, 18, 20(b) and 20(c).

The plotted results can be divided into three important parts, i.e.,

a) Good straight line correlation between parameters - well enough defined over a wide enough range so that results of the one can be used to estimate values for the other. This can be seen from Figures 9, 10, 12, 16, 17 and 18.

b) A definite trend between two parameters although the correlation is low. This type of correlation is useful in determining qualitative relationships which may assist in future research. An example of this is given in Figure 20.

c) After plotting the data, certain boundaries may be established within which all the data presently available fall. This type of diagram may be used in the future to determine the reliability of laboratory testing. The boundaries may change when more data become available and new 'groupings' may be identified. Examples of this type of plot are given in Figures 8 and 21.

Table 11

Values of Coefficient of Correlation and the Number of Data Sets with Reported Values for Both Parameters

	BOD1	BOD2	CODD	BOD5D	CODS	BOD5S	FW	MD	PL	GL	PI	PSA	PSI
BOD2	131 0.8873												
CODD	72 -0.7006	72 -0.73											
BOD5D	107 -0.7291	107 -0.8399	73 0.7892										
CODS	72 -0.7106	72 -0.86	73 0.7197	73 0.7752									
BOD5S	117 -0.6305	117 -0.8	73 0.6549	123 0.8233	73 0.8101								
FW	63 -0.1182	63 -0.1323	48 0.036	75 0.2398	48 0.1785	82 0.2578							
MD	11 0.6347	11 0.5742	8 -0.5802	26 -0.6111	8 -0.6186	26 -0.7278	73 0.4137						
PL	81 0.0368	81 0.1614	54 -0.2488	90 -0.2722	54 -0.0717	101 -0.1817	75 0.0254	26 0.0409					
GL	81 0.2801	81 0.5538	54 -0.4648	90 -0.6094	54 -0.3999	101 -0.6044	75 -0.1519	26 0.3948	108 0.6873				
PI	81 0.3479	81 0.632	54 -0.4718	90 -0.6808	54 -0.5112	101 -0.6852	75 -0.2276	26 0.5651	108 0.3048	108 0.9013			
PSA	81 0.0349	81 -0.1608	54 0.0933	90 0.3423	54 0.1075	101 0.4372	75 0.0081	26 -0.2277	108 -0.259	108 -0.4671	108 -0.4401		
PSI	81 -0.2626	81 -0.3123	54 0.1106	90 0.0381	54 0.1529	101 -0.0953	75 -0.164	26 0.0249	108 -0.0414	108 -0.1723	108 -0.2012	108 -0.4937	
PCL	81 0.1182	81 0.3047	54 -0.1663	90 0.0039	54 -0.2084	101 -0.005	75 0.2258	26 0.0402	108 0.1791	108 0.2135	108 0.1993	108 -0.3038	108 -0.4027
POOL	81 0.1875	81 0.422	54 -0.1729	75 -0.4897	54 -0.3186	86 -0.3994	60 -0.008	11 0.5926	93 0.3791	93 0.6868	93 0.6978	93 -0.4406	93 -0.5364
VD	101 0.0072	101 -0.0507	66 -0.073	94 0.1119	66 -0.1578	108 -0.0783	65 0.0047	11 -0.1931	82 -0.1739	82 -0.2446	82 -0.214	82 -0.0466	82 0.3187
DD	101 -0.1099	101 -0.2069	66 0.1755	109 -0.0174	66 0.0621	123 -0.1145	80 -0.2324	26 -0.0357	97 -0.1169	97 -0.0474	97 0.0095	97 -0.1735	97 0.4743
AMC	126 0.4451	126 0.5031	73 -0.4633	105 -0.4626	73 -0.3998	119 -0.408	67 -0.118	11 0.9195	88 0.2184	88 0.2773	88 0.2281	88 -0.1718	83 -0.1612
BD	81 -0.0173	81 0.0483	54 -0.0468	75 0.0213	54 0.048	86 0.0643	60 0.0158	11 -0.348	93 0.1488	93 -0.0597	93 -0.1659	93 -0.1033	93 0.0081
FV	81 0.0439	81 0.07	53 0.0499	74 -0.1146	53 0.0016	85 -0.1655	60 -0.0531	11 0.2619	92 0.1016	92 0.2354	92 0.2453	92 -0.1389	92 -0.0313
EL	79 -0.4718	79 -0.4712	51 0.3346	72 0.5534	51 0.4464	83 0.56	60 0.1813	11 -0.7235	87 -0.0379	87 -0.4079	87 -0.5146	87 0.178	87 0.0641
BR	79 0.4826	79 0.5971	51 -0.426	72 -0.6214	51 -0.4095	83 -0.5718	60 -0.119	11 0.279	87 0.3508	87 0.7116	87 0.7214	87 -0.2155	87 -0.2461
ET	83 -0.737	83 -0.3436	56 0.2559	76 0.2472	56 0.3634	88 0.3644	64 0.0146	11 -0.7583	86 0.1052	86 0.0275	86 -0.0278	86 -0.182	86 -0.104
PW	44 0.328	44 0.3943	39 -0.6419	60 -0.6298	39 -0.5153	60 -0.678	45 -0.0153	24 0.7694	62 0.2375	62 0.5631	62 0.3579	62 -0.7489	62 0.046
VOL	44 -0.0628	44 0.0182	39 0.2587	45 -0.0485	39 0.0066	45 -0.2087	30 -0.3793	9 0.8141	47 -0.4599	47 -0.1207	47 0.0016	47 0.0004	47 0.0761
DD1	44 -0.2243	44 -0.1785	39 0.3661	60 0.1661	39 0.2165	60 0.0543	45 -0.3379	24 0.2333	62 -0.1817	62 -0.2804	62 -0.1272	62 0.033	62 0.1641
CHA1	37 -0.1625	37 -0.04	33 -0.1511	52 0.5197	33 -0.1141	52 0.5873	42 0.1909	22 -0.6700	53 -0.2527	53 -0.5419	53 -0.3795	53 0.432	53 -0.317
CHA2	37 -0.3374	37 -0.647	33 0.3302	52 0.6175	33 0.5752	52 0.7332	42 0.1047	22 0.7203	53 -0.0337	53 -0.4618	53 -0.5571	53 0.4469	53 -0.2596
AB	37 0.2456	37 0.5131	33 -0.3578	52 -0.3548	33 -0.400	52 -0.4764	42 0.3001	22 0.0167	53 0.1317	53 0.3443	53 0.3532	53 -0.2763	53 -0.0663

	PCL	POOL	VD	DD	AMC	BD	FV	EL
POOL	93 0.6128							
VD	82 -0.0825	82 -0.3413						
DD	97 -0.5377	82 -0.4005	108 0.8768					
AMC	88 0.1408	88 0.3709	108 -0.127	108 -0.5759				
BD	93 0.2267	93 -0.0746	82 -0.0067	82 -0.1074	88 0.1124			
FV	92 0.0842	92 0.1597	81 0.1621	81 0.0709	87 0.1146	92 0.0467		
EL	87 -0.0267	87 -0.3341	79 -0.1182	79 -0.0701	82 -0.0307	87 0.4148	87 -0.382	
BR	87 0.2958	87 0.3204	79 -0.1836	79 -0.2703	82 0.1314	87 -0.1638	87 0.2046	87 -0.6541
ET	86 0.2938	86 0.1871	84 -0.3582	84 -0.1474	90 -0.0664	86 0.0721	86 0.0045	84 0.0882
PW	62 -0.1244	47 0.344	44 -0.3784	59 -0.0442	47 0.3148	47 -0.0094	46 -0.0115	42 -0.1477
VOL	47 -0.1945	47 0.0571	44 0.3038	44 0.1483	47 0.0019	47 -0.1108	46 0.3073	42 -0.5204
DD1	62 -0.7131	47 -0.083	44 0.367	59 0.3163	47 -0.1376	47 -0.0088	46 0.302	42 -0.4479
CHA1	53 0.2352	38 -0.1348	36 -0.1151	51 -0.3936	37 -0.0618	38 0.1076	38 -0.0036	30 0.2073
CHA2	53 0.0679	38 -0.1548	36 0.1675	51 -0.1672	37 -0.4084	30 -0.0083	38 -0.146	38 0.1962
AB	53 0.4654	38 0.2412	36 -0.3092	51 -0.4459	37 0.4336	38 0.1567	38 0.1128	38 -0.0375

	BR	ET	PW	VOL	DD1	CHA1	CHA2
ET	84 -0.0734						
PW	42 0.214	42 -0.2386					
VOL	42 0.1134	42 -0.3987	48 -0.0189				
DD1	42 0.0039	42 -0.5043	63 -0.3489	48 0.9305			
CHA1	38 -0.2108	37 0.0359	53 -0.7348	38 -0.353	53 0.0981		
CHA2	33 -0.0577	37 0.4655	53 -0.7085	38 -0.2578	53 0.1074	53 0.0305	
AB	38 0.065	37 -0.2324	53 0.4903	38 -0.0074	53 -0.2047	53 -0.3136	53 -0.1966

TABLE 12

Bivariate Correlations with $r \geq 0.7$

Independent var. (down)	Dependent var. (across)	r	Std. error of estimate	Intercept A	Std. error of A	Slope B	Std. error of B	Plotted values
SDI1	SDI2	0.8273	17.539	-8.565	2.795	0.683	0.0408	131
SDI1	SD2D	-0.7006	19.83	71.436	6.373	-0.685	0.0834	72
SDI1	SD5D	-0.7291	21.07	62.773	3.959	-0.673	0.062	107
SDI1	SD2S	-0.7106	19.554	54.449	4.405	-0.594	0.0703	72
SDI2	SD2D	-0.73	24.609	115.143	7.909	-0.9253	0.1035	72
SDI2	SD5D	-0.8399	20.638	103.835	3.877	-0.9578	0.0604	107
SDI2	SD2S	-0.86	18.375	99.129	4.139	-0.9311	0.066	72
SDI2	SD5S	-0.8	22.595	92.151	3.45	-0.9445	0.066	117
SD2D	SD5D	0.789	17.593	32.273	4.086	0.685	0.0632	73
SD2D	SD2S	0.7197	19.89	37.667	4.42	0.6197	0.071	73
SD5D	SD2S	0.7752	20.867	15.069	4.637	0.7695	0.074	73
SD5D	SD5S	0.8238	19.018	20.885	2.918	0.8189	0.0512	123
SD5D	PM	0.6998	22.015	156.324	12.608	-7.5146	1.0072	60
SD2S	SD5S	0.8101	19.5067	18.579	3.733	0.7983	0.0686	73
SD5S	MS	-0.7278	17.369	95.44	4.972	-0.4506	0.0867	26
SD5S	PI	-0.6852	24.319	89.66	5.749	-3.832	0.4095	101
SD5S	PM	-0.678	24.874	148.354	14.246	-7.994	1.133	60
MS	AMC	0.9195	18.381	-26.439	12.679	17.999	2.565	11
MS	SL	-0.7235	32.278	201.748	48.125	-7.342	2.335	11
MS	XY	-0.7583	30.482	115.705	20.04	-7.209	2.066	11
MS	PM	0.7694	26.803	-68.162	20.07	10.635	1.883	24
MS	WD1	0.8141	28.437	-247.38	83.466	2.403	0.648	9
MS	CBR1	-0.678	29.579	82.51	12.415	-2.629	0.637	22
MS	CBR2	-0.7203	27.916	84.674	11.61	-4.484	0.966	22
PL	QL	0.6873	2.614	10.058	1.105	0.3126	0.0321	105
QL	PI	0.9013	3.427	18.179	0.789	1.1818	0.0552	108
QL	PCOL	0.6868	5.612	22.513	1.449	0.6925	0.0768	93
QL	SH	0.71155	5.473	22.835	1.383	2.093	0.224	87
PI	PCOL	0.6978	4.256	4.419	1.099	0.5414	0.0583	93
PI	SH	0.7214	4.0936	4.914	1.034	1.6104	0.1677	87
WD	DD	0.8768	3.796	42.528	5.692	0.7513	0.04	108
PM	CBR2	-0.7695	1.875	14.467	0.3743	-0.3883	0.045	53
WD1	DD1	0.9385	2.6027	19.283	0.163	0.9697	0.0526	48
CBR1	CBR2	0.8025	4.731	5.1903	0.9442	1.0935	0.1138	53

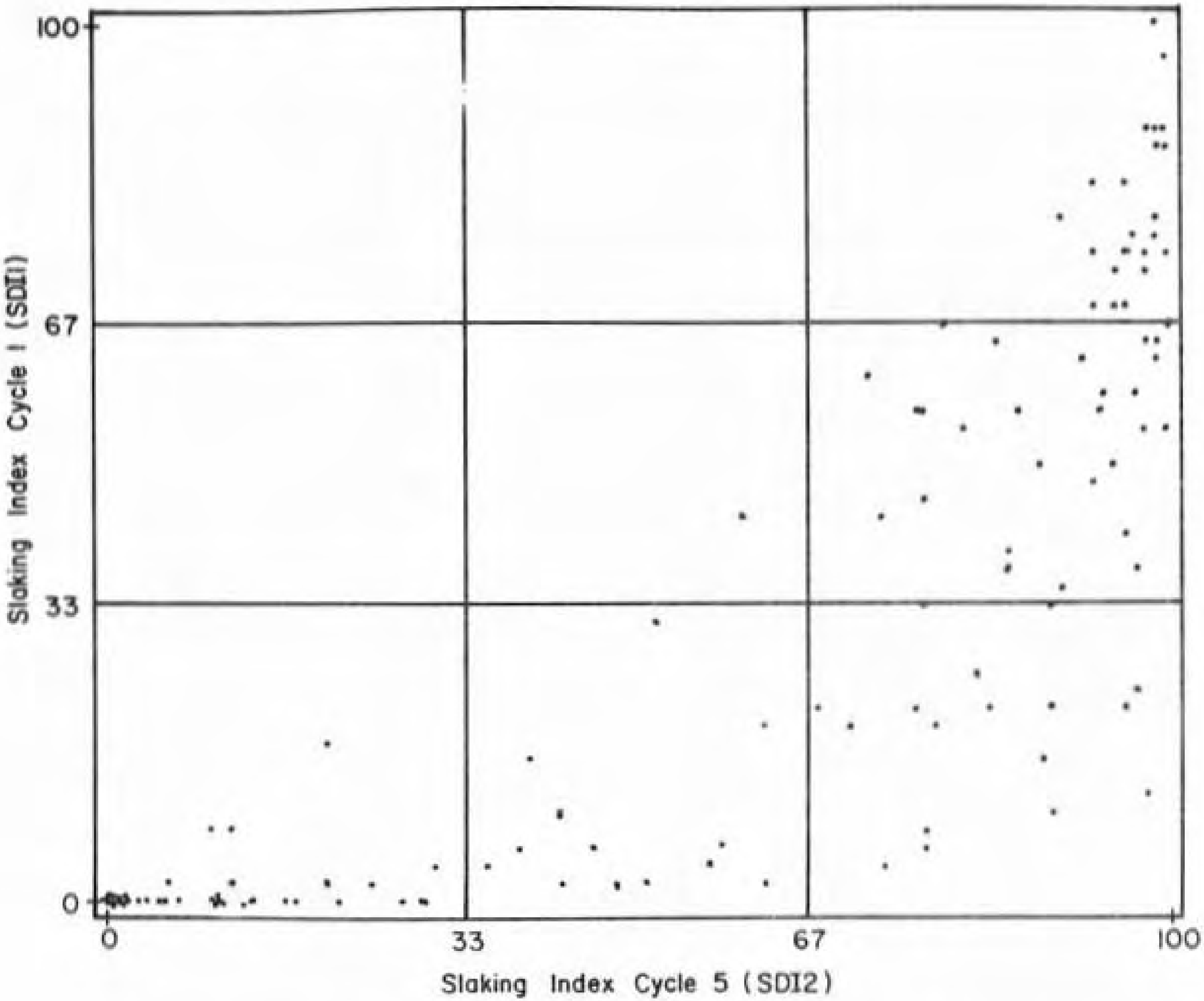


FIGURE 8. SDI2 VS SDI1 (r=0.83)

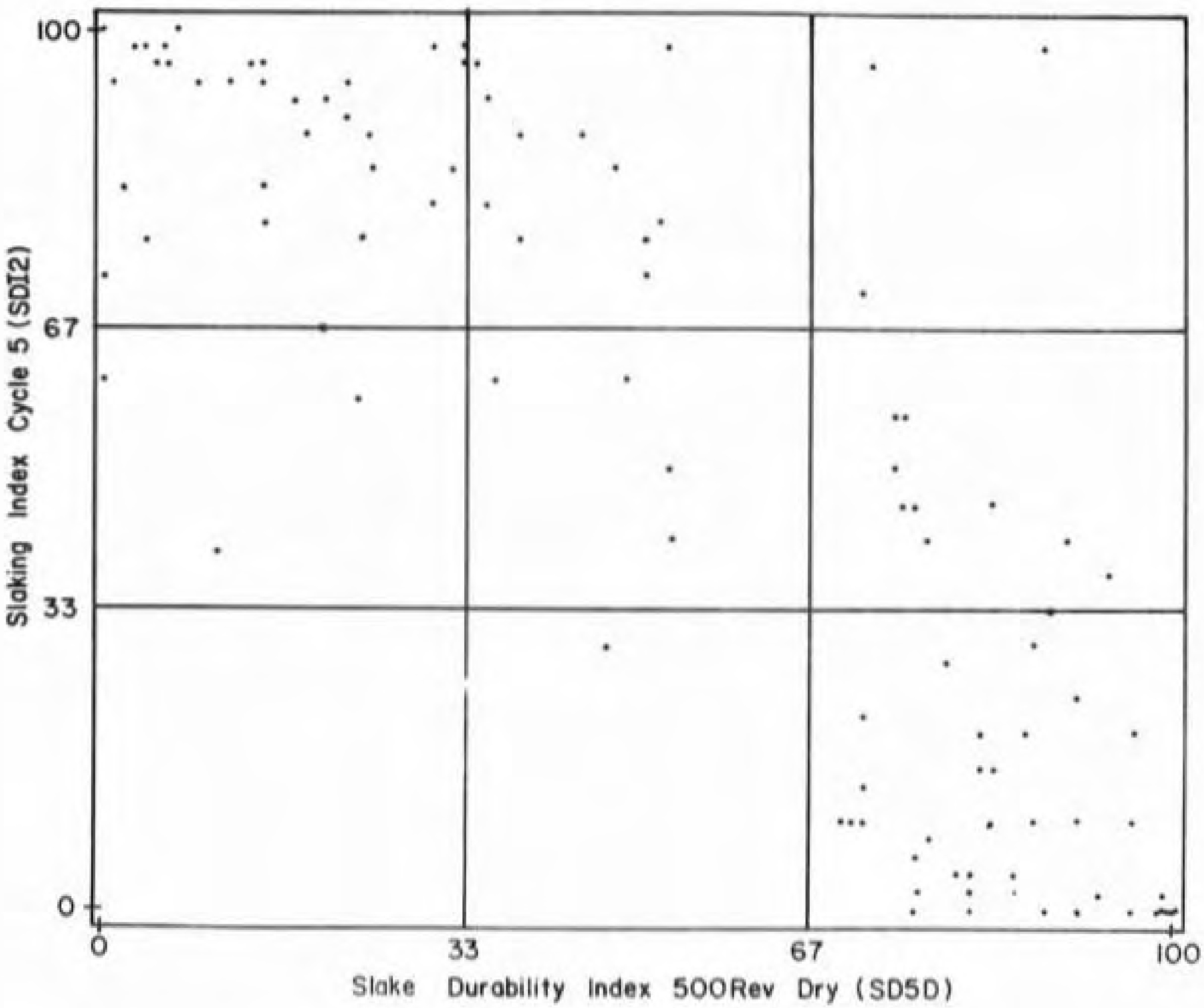


FIGURE 9. SD5D VS SDI2 (r= -0.84)

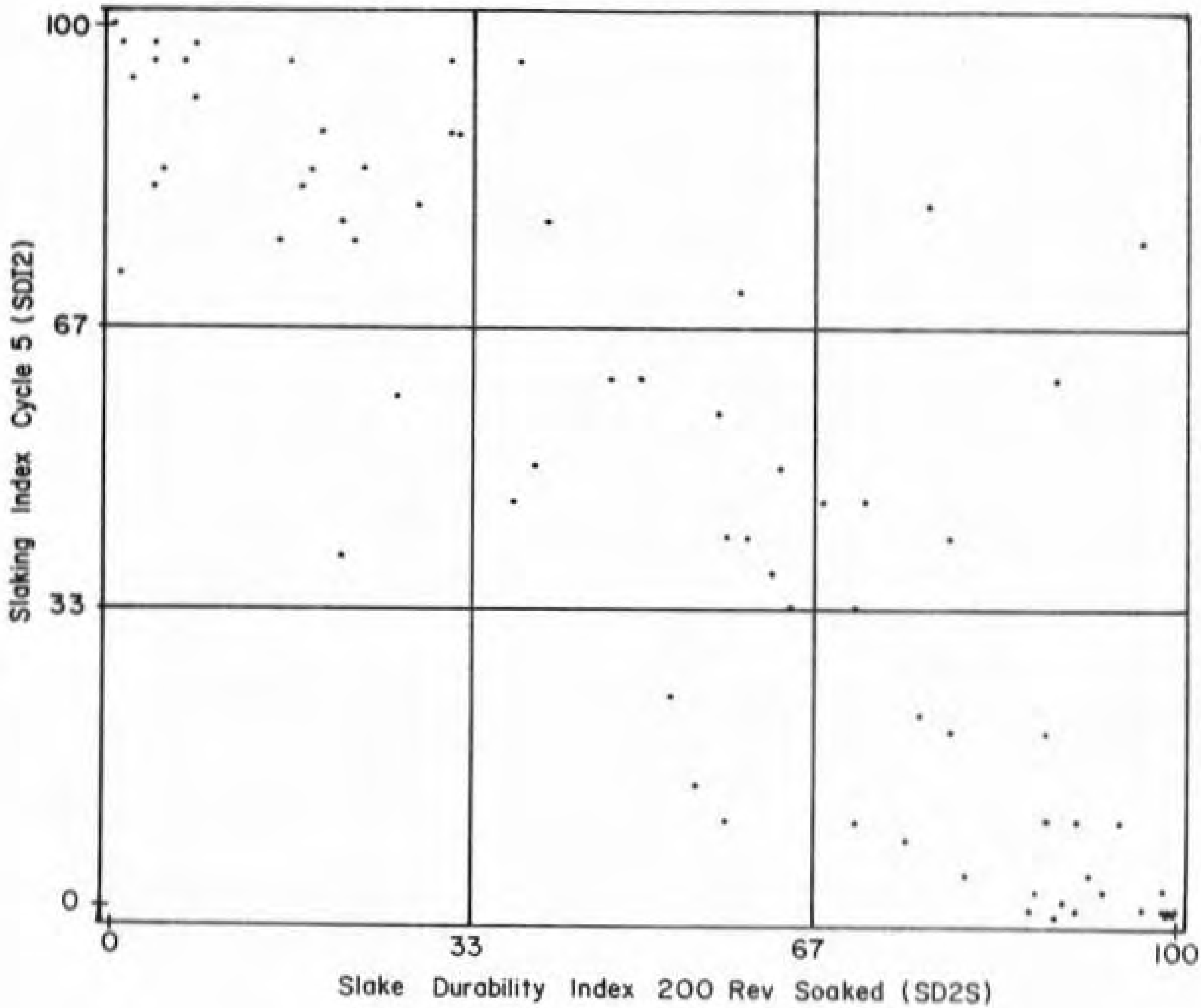


FIGURE 10. SD2S VS SD12 (r= -0.86)

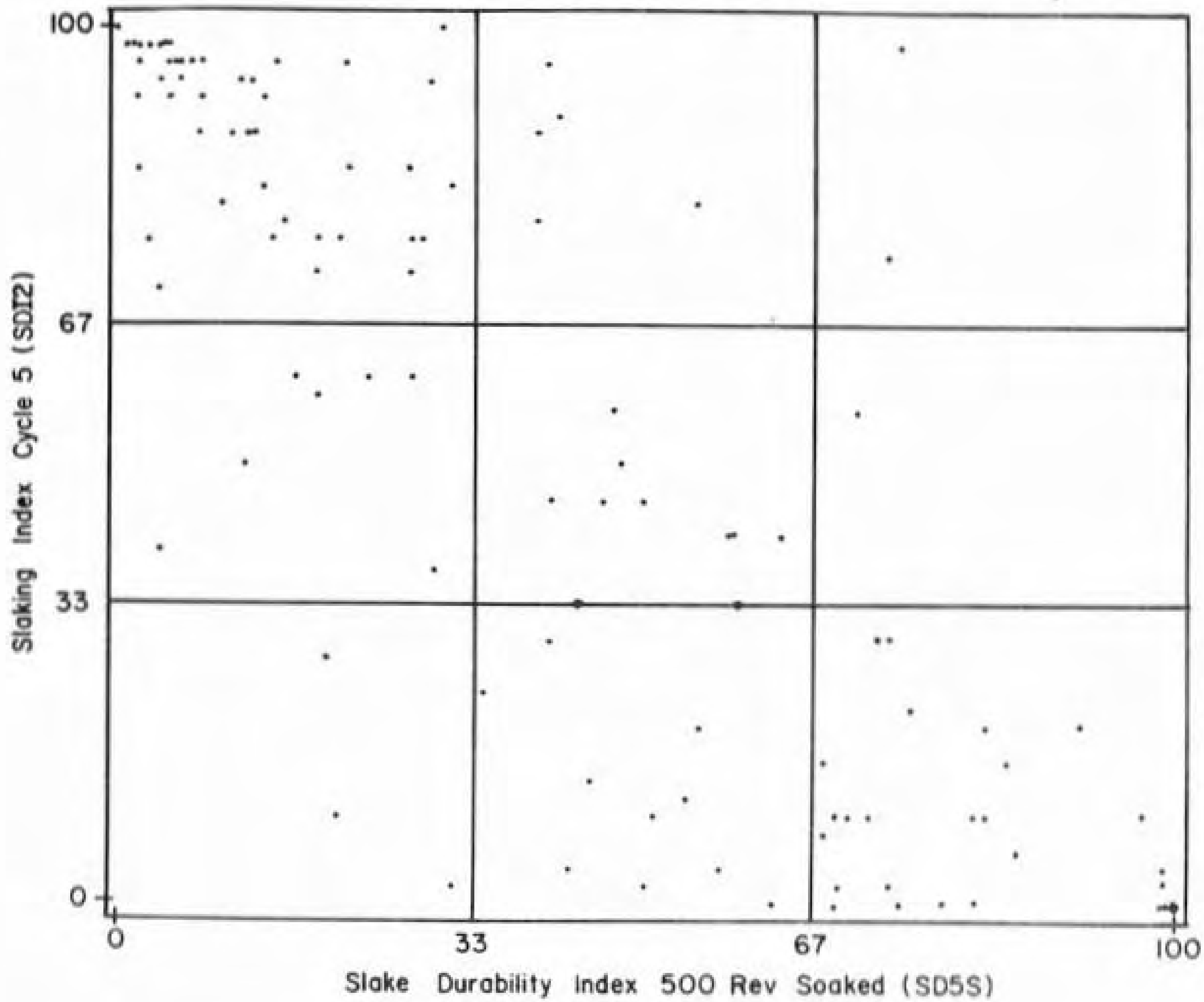


FIGURE 11. SD5S VS SD12 (r= -0.8)

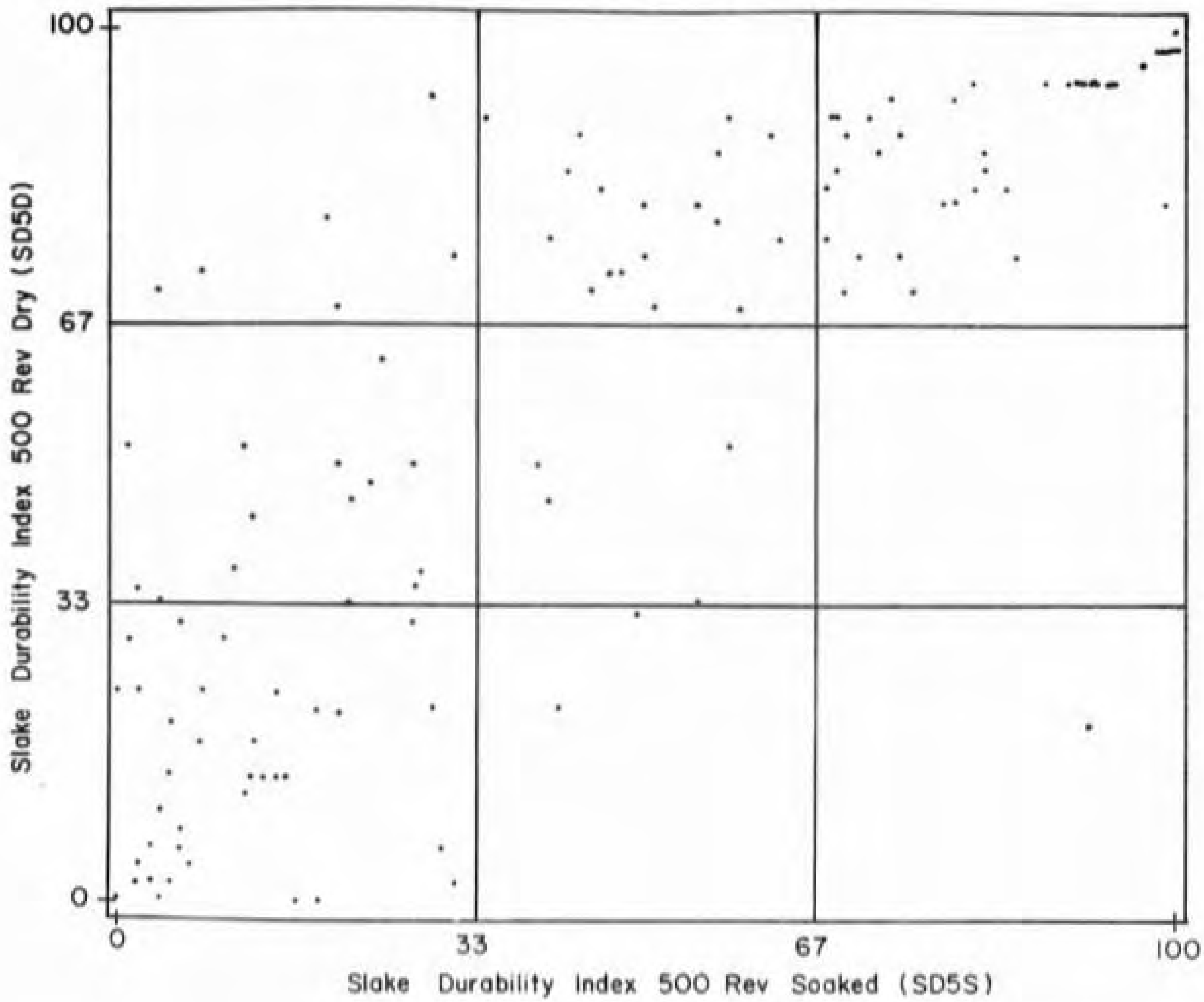


FIGURE 12. SD5S VS SD5D (r = 0.82)

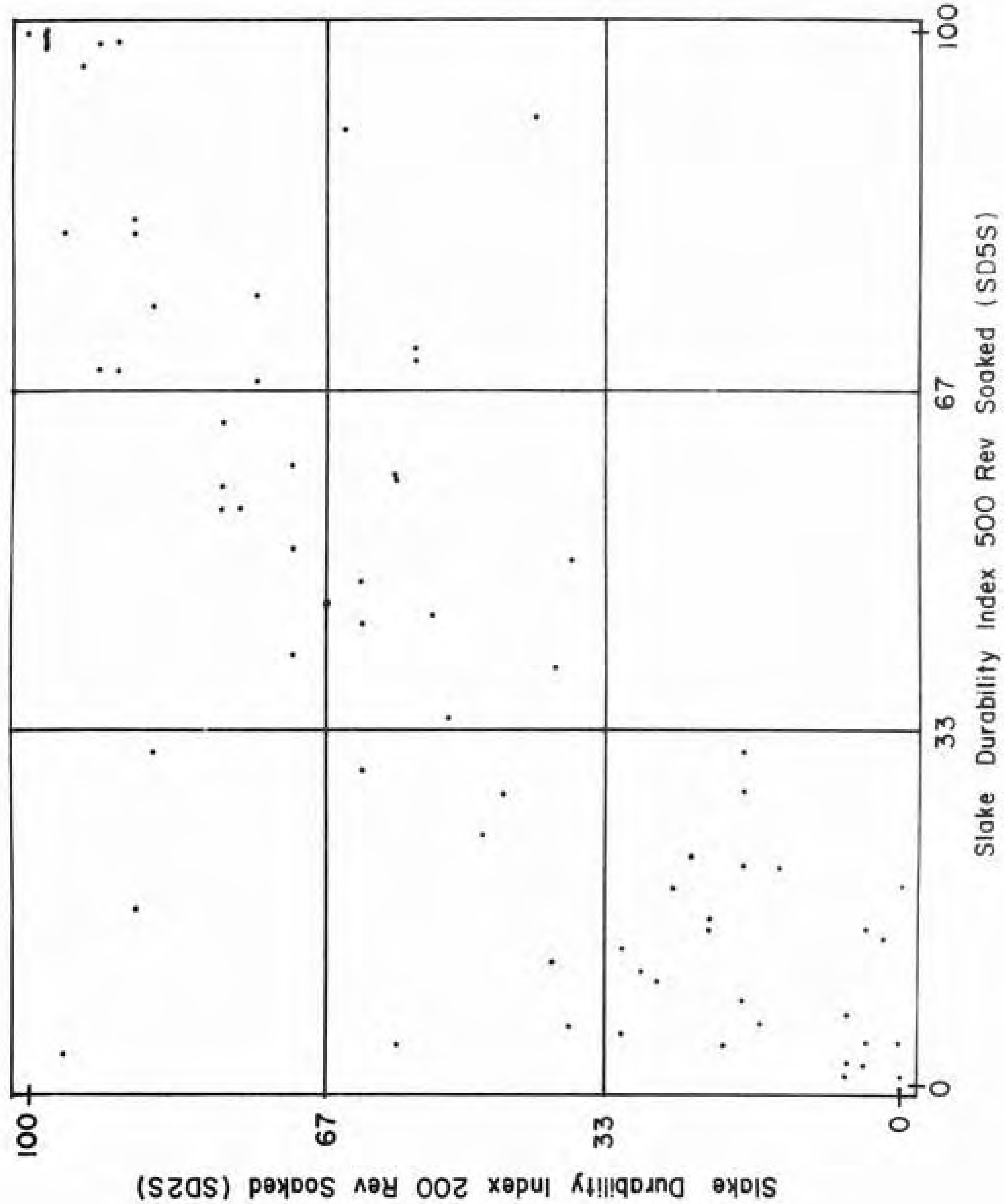


FIGURE 13. SD5S VS SD2S (r= 0.81)

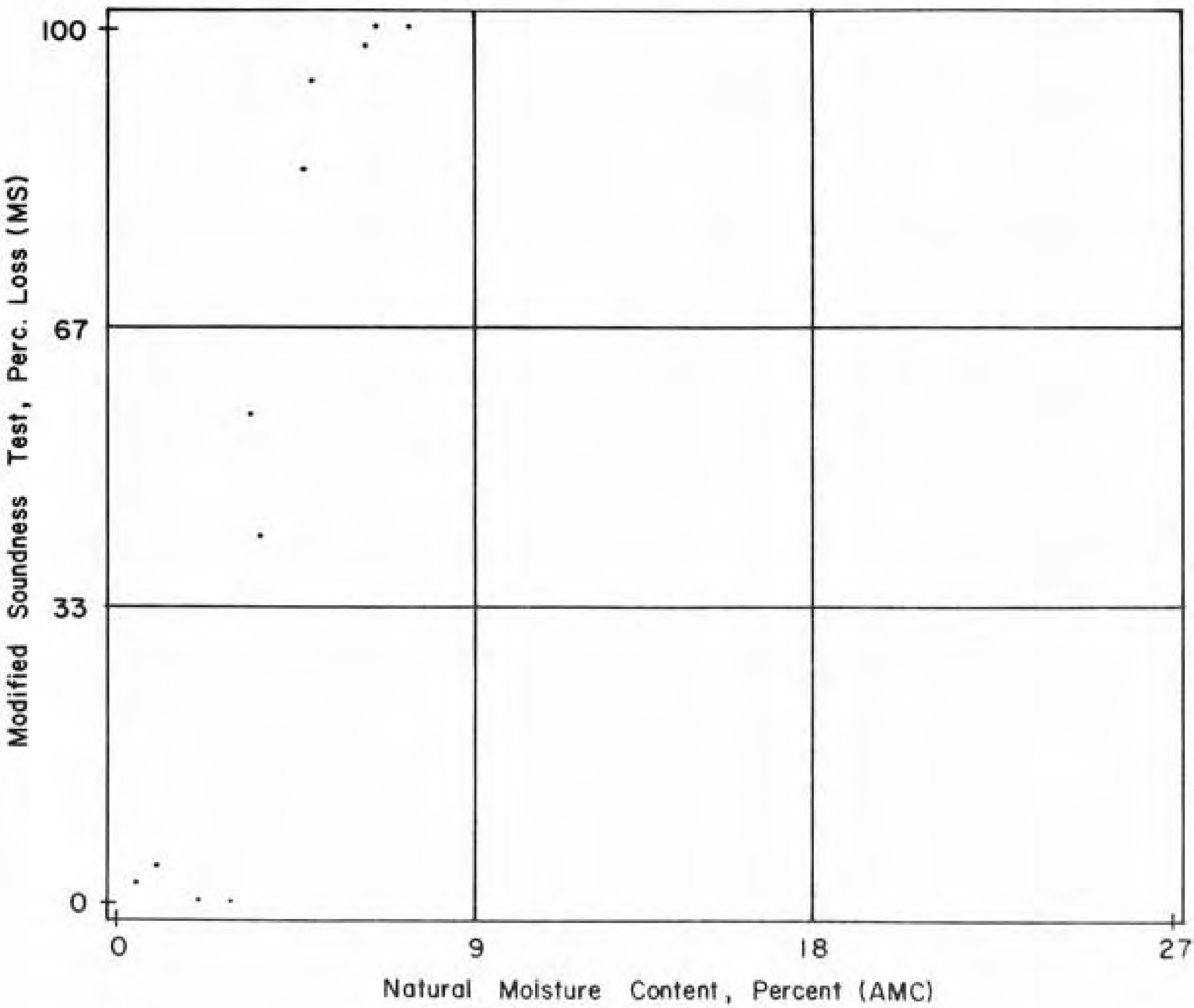


FIGURE 14. AMC VS MS (r= 0.92)

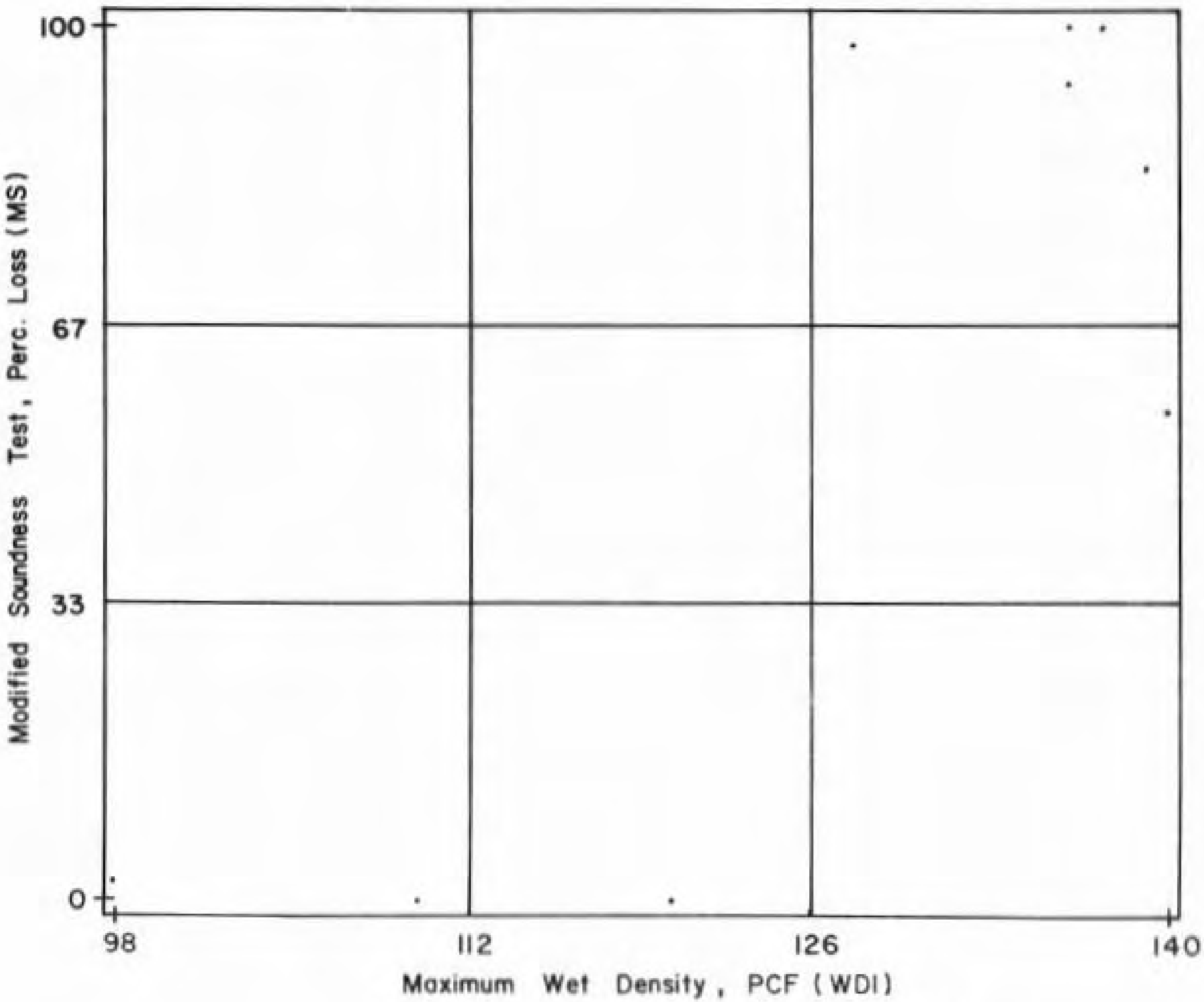


FIGURE 15. WDI VS MS (r= 0.81)

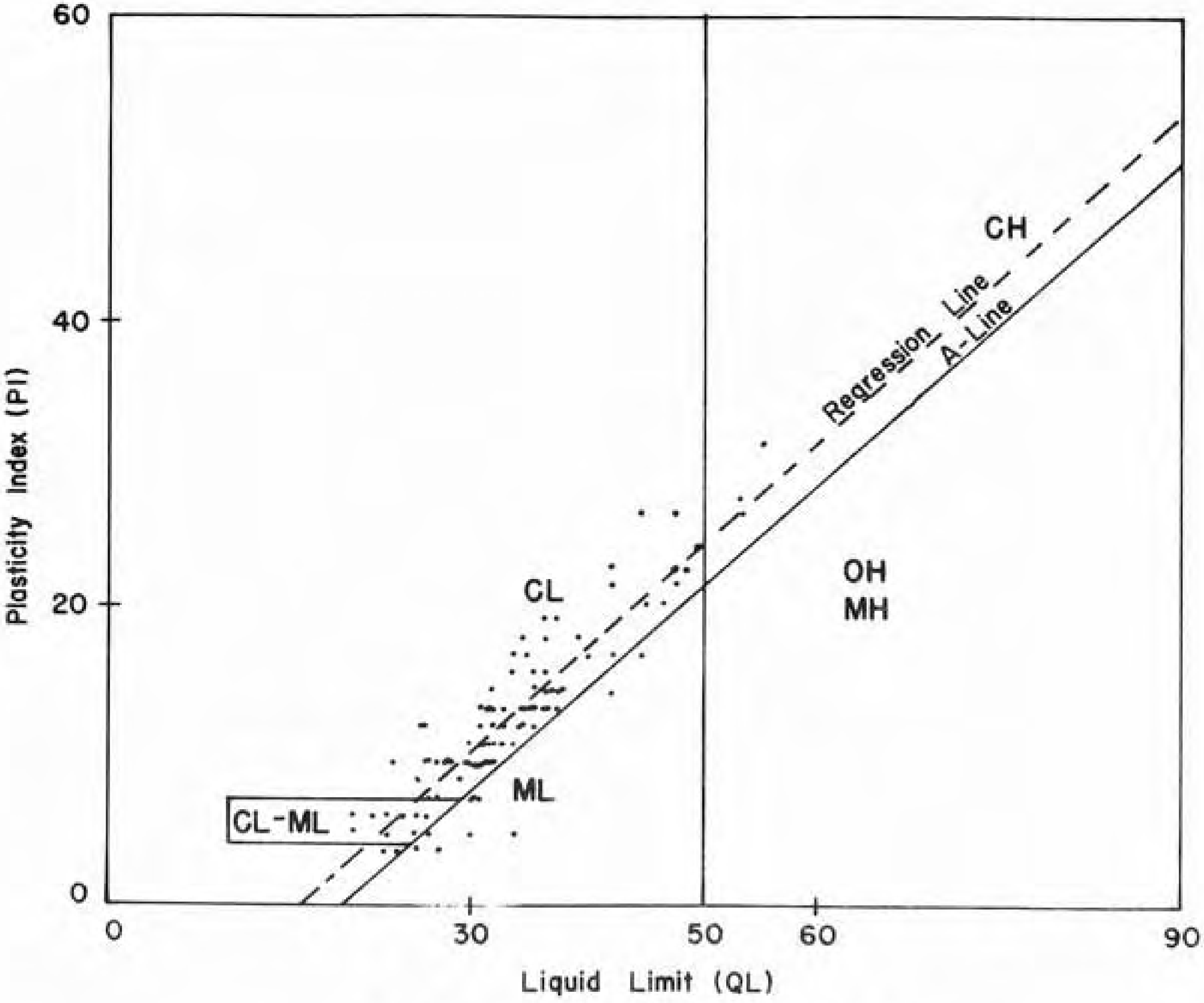


FIGURE 16. QL VS PI (r = 0.9)

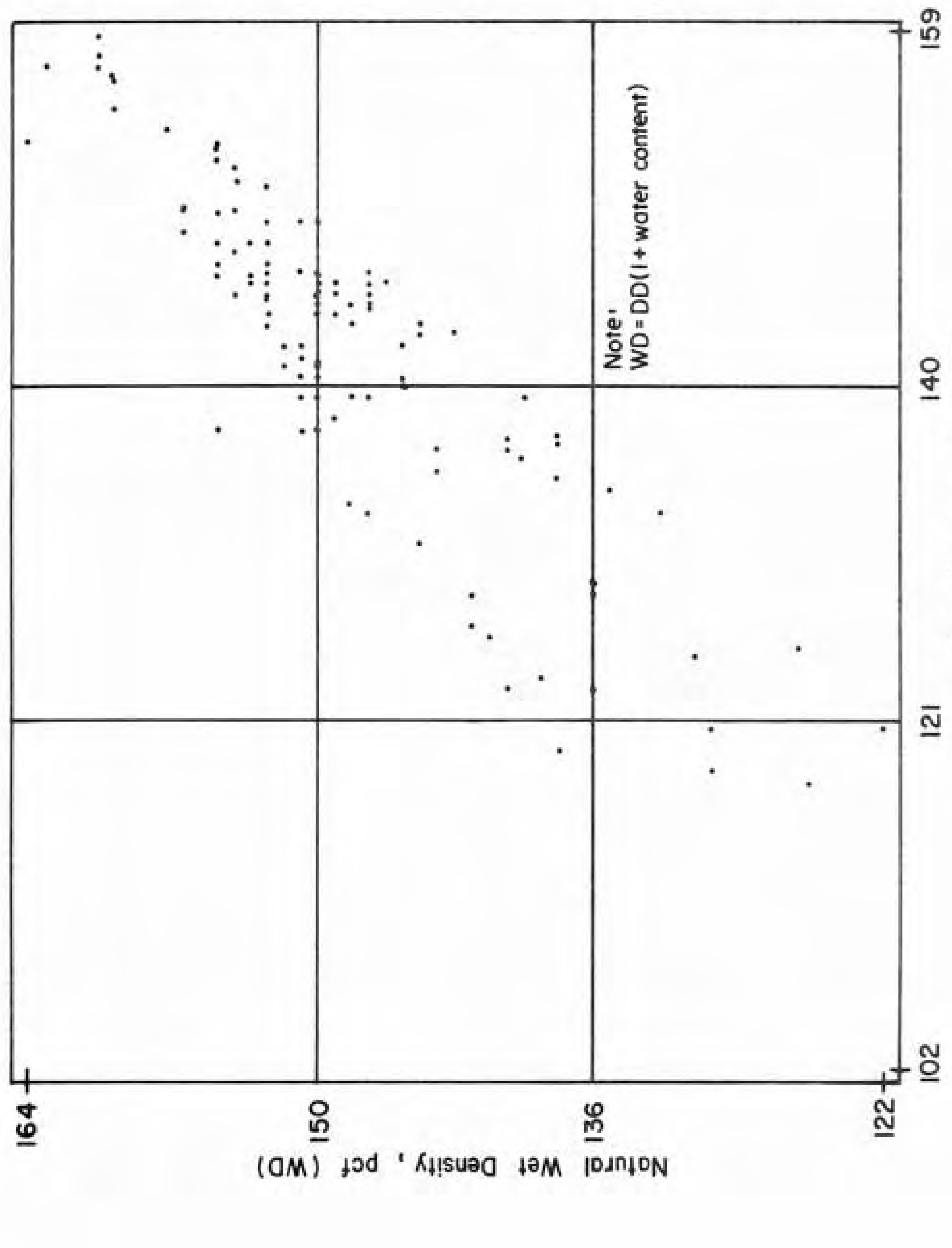


FIGURE 17. DD VS WD (r = 0.88)

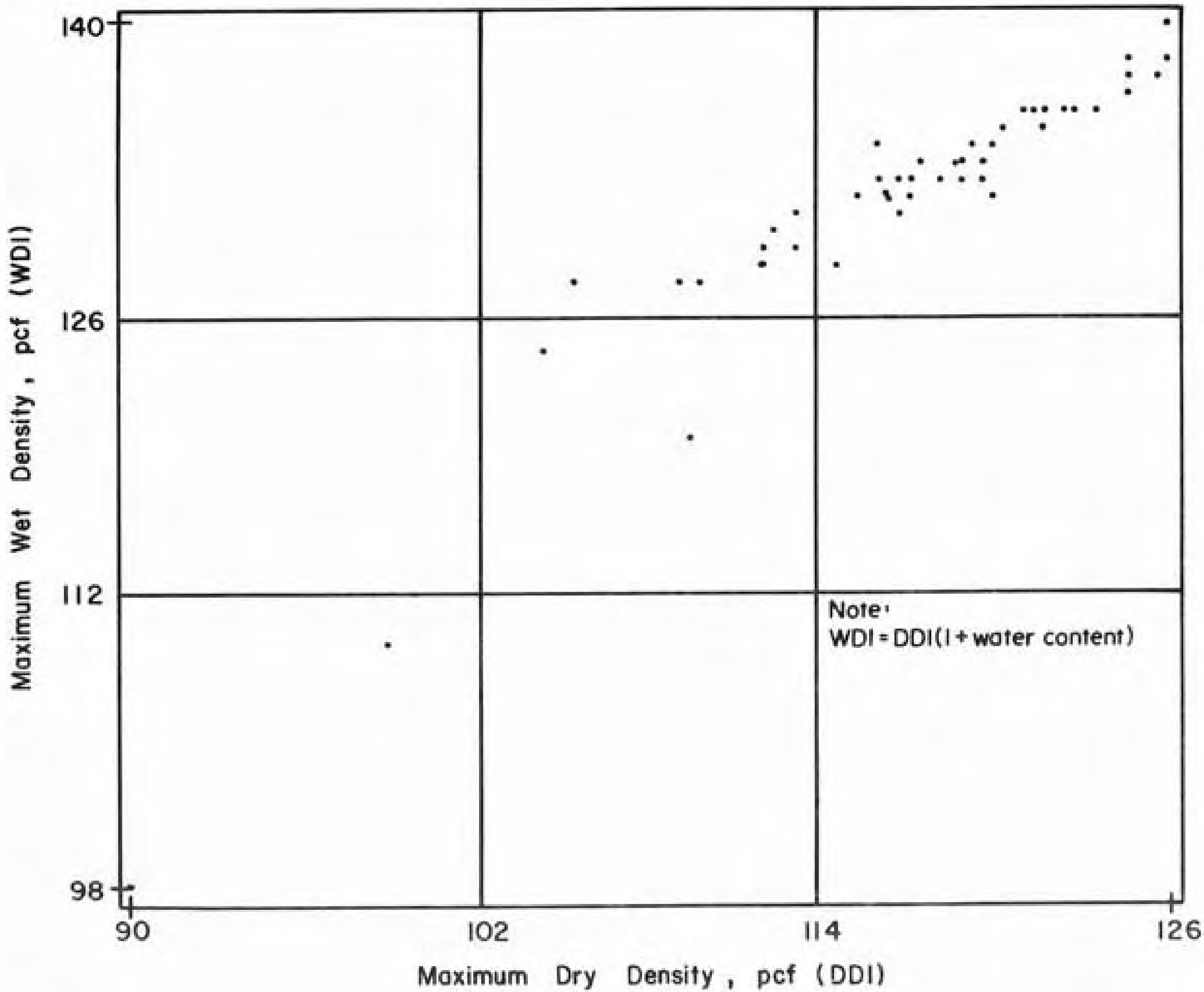


FIGURE 18. DDI VS WDI (r = 0.94)

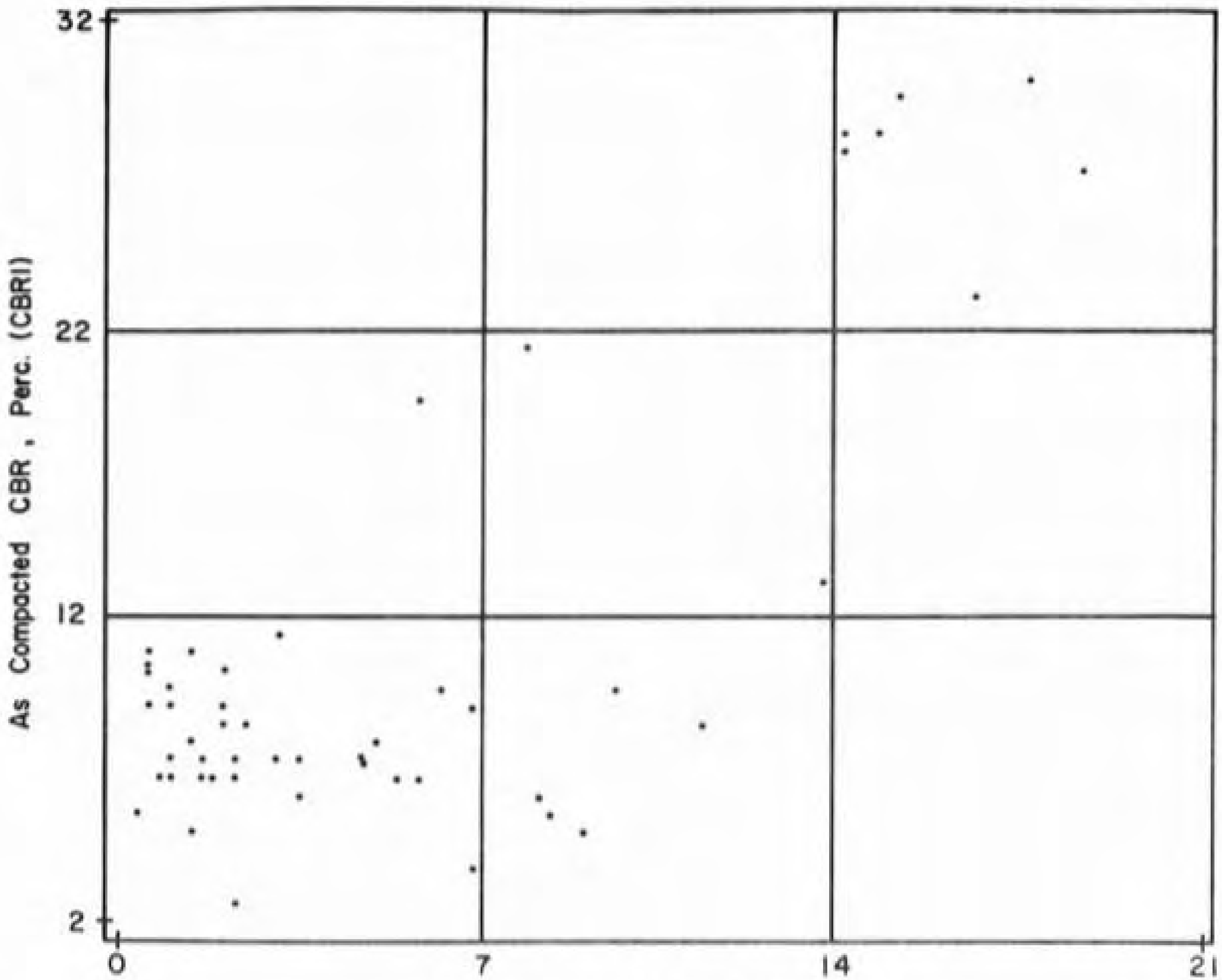


FIGURE 19. CBR2 VS CBRI (r = 0.8)

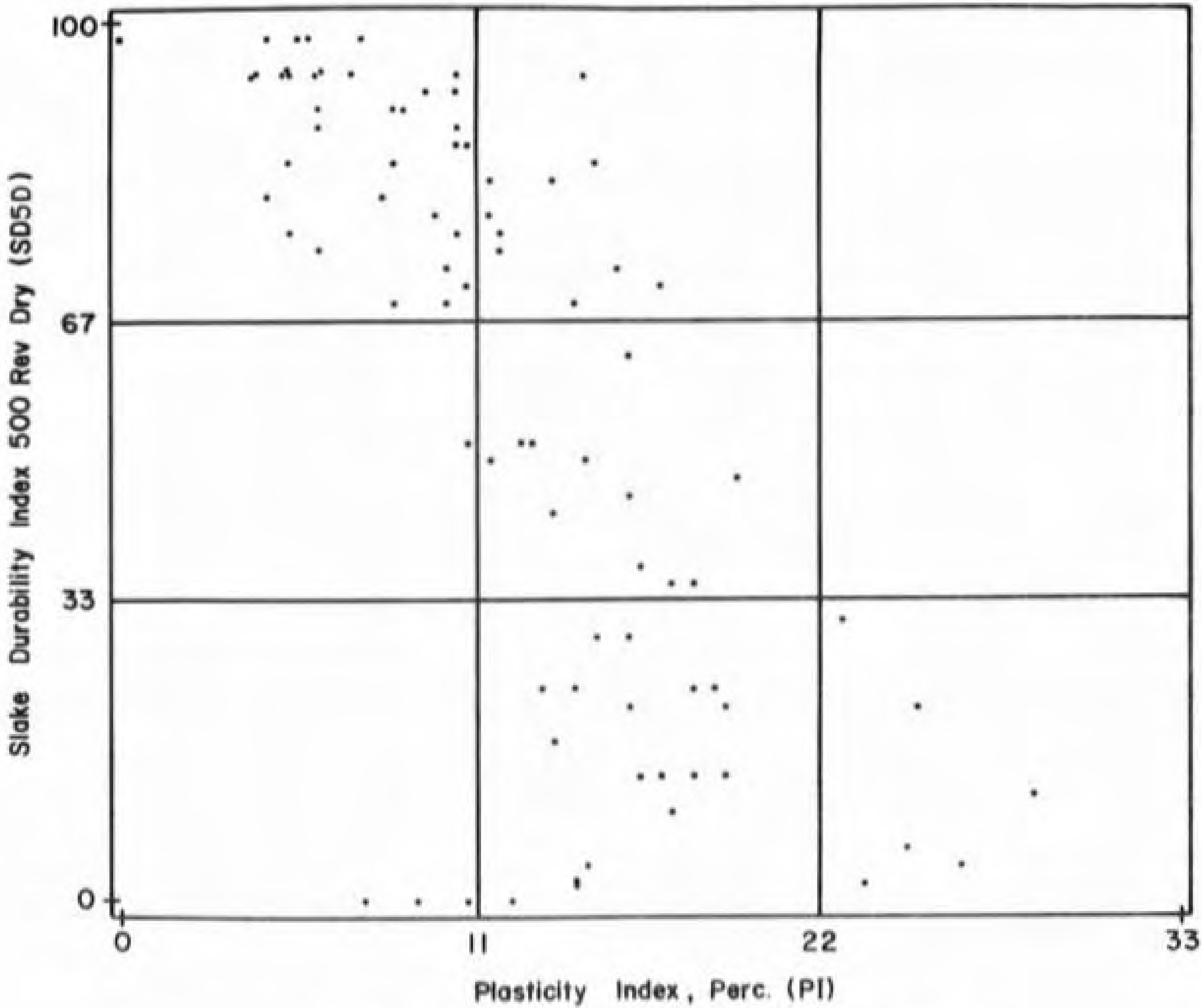


FIGURE 20(a) PI VS SD5D (r= -0.68)

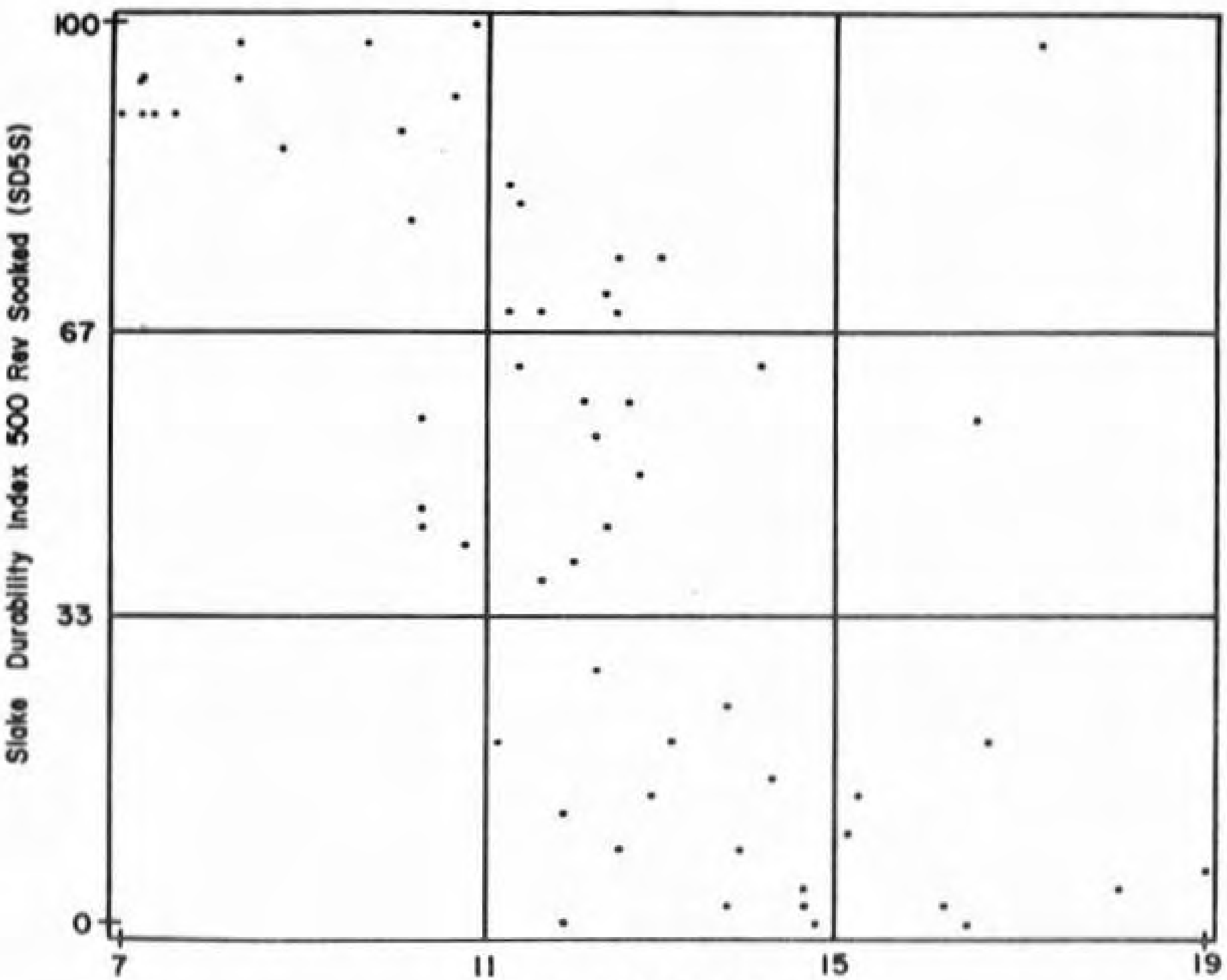


FIGURE 20(b) PM VS SD5S (r= -0.68)

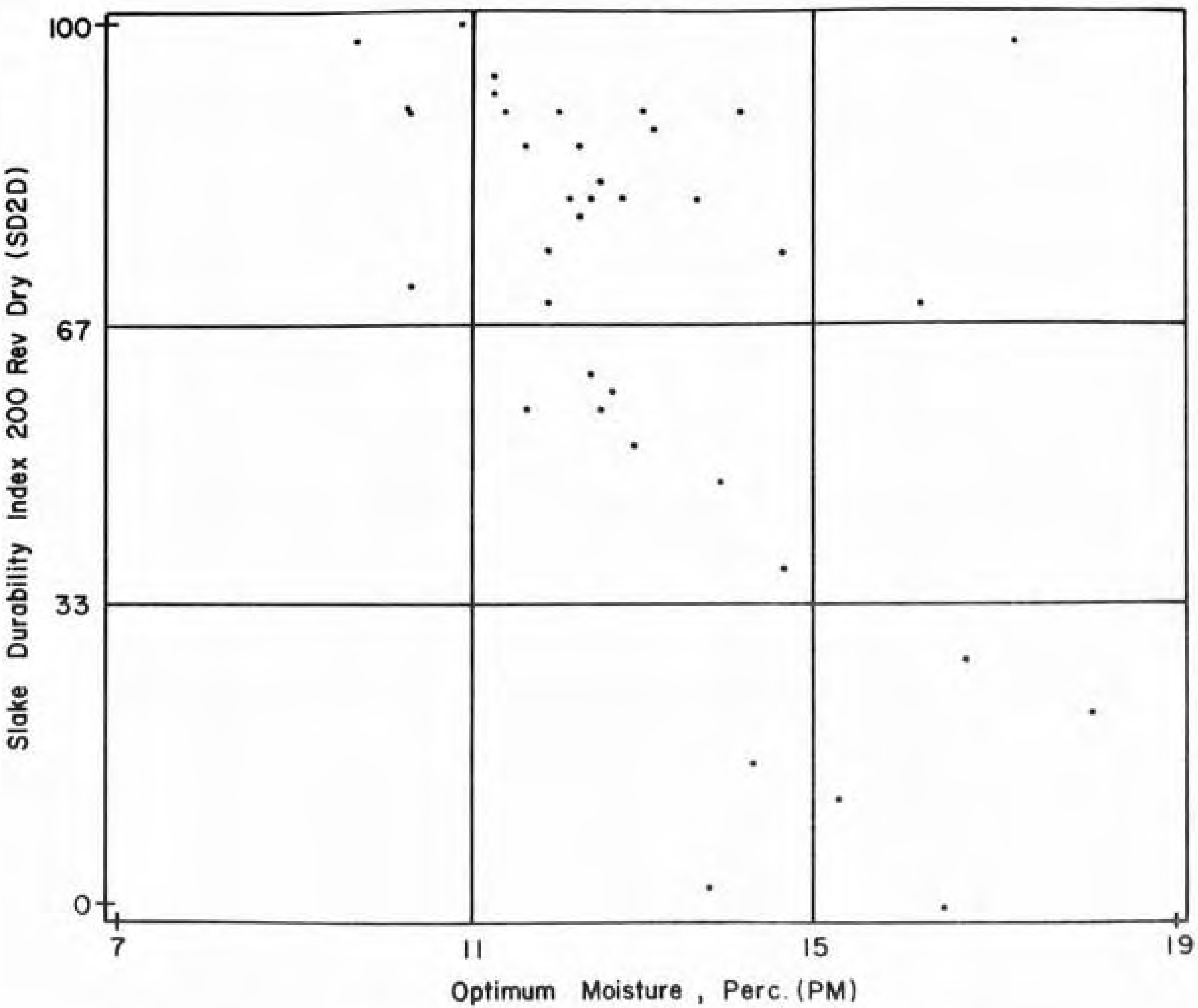


FIGURE 20(c) PM VS SD2D (r= 0.64)

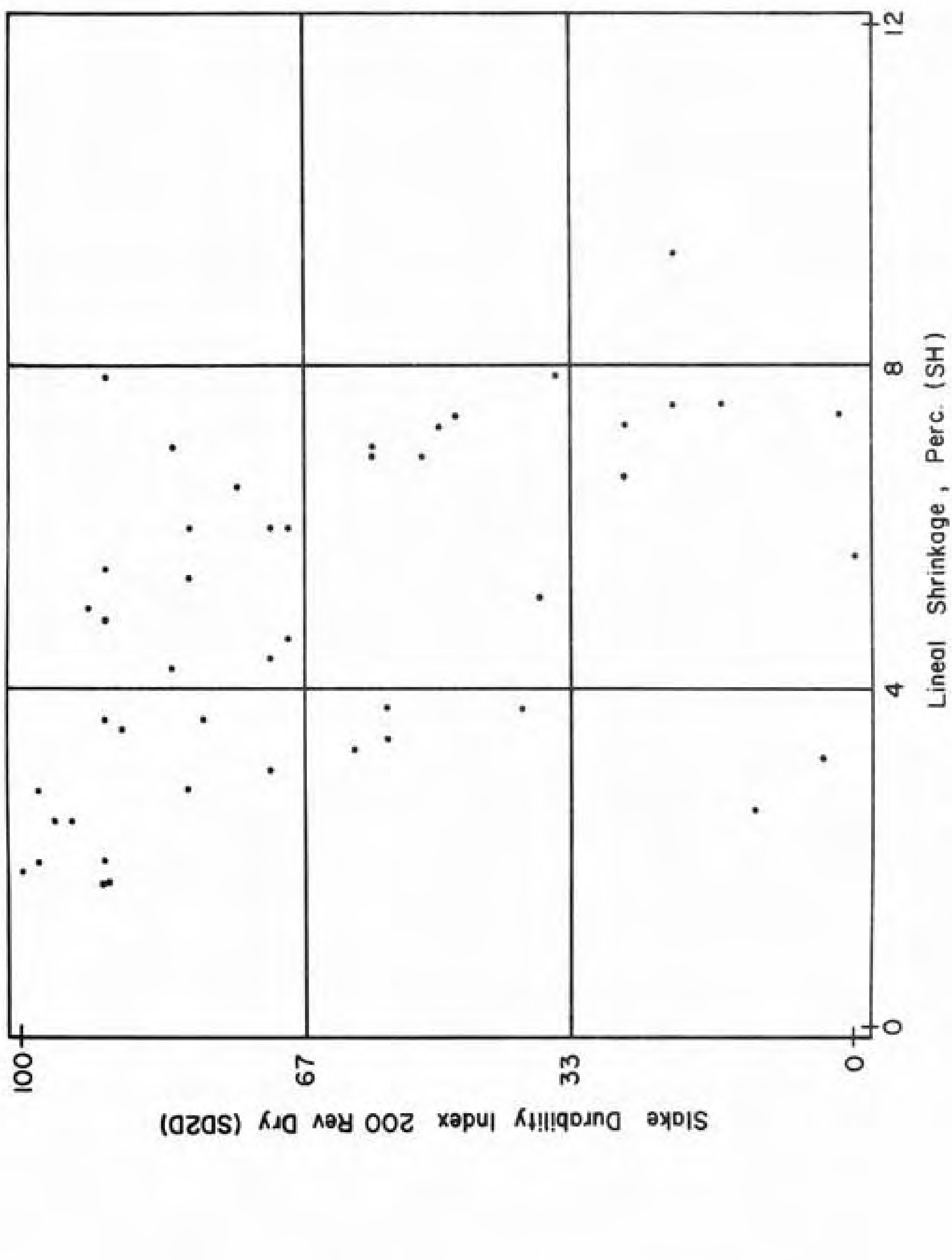


FIGURE 20(d) SH VS SD2D (r=-0.43)

From the summary in Table 11 it is clear that very few good correlations exist on a one to one basis for all the shale data. It should, however, be remembered that the Indiana shales cover a wide range of characteristics. With this in mind it was decided to analyze some of the data after dividing the data sets according to the geology.

From the description of the geology the following division was used:

a. Ordovician - all formations

b. Devonian - all formations plus New Albany of Mississippian

c. Mississippian - Borden Group

Locust Point

New Providence

d. Mississippian - rest of formations

e. Pennsylvanian - all formations.

Not all the parameters were analyzed but only those containing some notion of durability and strength. Table 13 indicates which analyses were performed.

Some results included very few data points, and the results were considered to be significant only if more than 9 data points were included and the value of $r^2 > 0.65$. This division is very arbitrary, but it is felt that values obtained by this method can surely be considered as 'significant'. These values are given in Table 14. The results from this Table indicate that there exists reasonably good correlation between the different slake durability measures. When these results are compared to that in Table 11, it is clear that there are some differences between the different geological formations. The basic trends are, however, still recognizable.

TABLE 13

Combinations of Parameters Analyzed After Dividing the Data According to Geological Differences

	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	PCL	DD	DD1	PM	CBR1	CBR2
SDI1		X	X	X	X	X	X	X	X	X		X	X
SDI2			X	X	X	X	X	X	X	X		X	X
SD2D				X	X	X	X	X	X	X		X	X
SD5D					X	X	X	X	X	X		X	X
SD2S						X	X	X	X	X		X	X
SD5S							X	X	X	X		X	X
FN								X	X	X		X	X
PCL											X		

TABLE 14

Significant Correlations of Analyses After Dividing the Data According to Geological Differences

Dependent var. (y)	Independent var. (x)	r^2	No. of Points	a*	b*
a. Ordovician					
SD5S	SDI2	0.714	9	99.0208	-1.229
b. Devonian plus New Albany of Mississippian					
SDI2	SDI1	0.979	10	0.1778	0.1043
SD2D	SDI1	0.936	9	16.244	-0.1602
SD5D	SDI1	0.9426	10	17.61	-0.1754
SD2S	SDI1	0.946	9	13.32	-0.1328
SD5S	SDI1	0.902	10	13.465	-0.1337
SD2D	SDI2	0.9865	9	156.943	-1.5693
SD5D	SDI2	0.8733	10	159.698	-1.602
SD2S	SDI2	0.9657	9	126.457	-1.28
SD5S	SDI2	0.8141	10	120.374	-1.206
SD5D	SD2D	0.788	9	3.6552	0.9621
SD2S	SD2D	0.9552	9	20.323	0.806
SD5S	SD2D	0.7166	9	28.007	0.716
SD2S	SD5D	0.875	9	28.707	0.712
SD5S	SD5D	0.9254	12	28.215	0.722
SD5S	SD2S	0.821	9	5.819	0.929
c. Mississippian - Borden Group, Locust Point, New Prov.					
SD5S	SD5D	0.6871	24	66.688	0.292
CBR1	SD5D	0.681	16	73.853	0.733
CBR1	SD5S	0.642	16	36.22	1.9287
d. Rest of Mississippian					
SDI2	SDI1	0.6566	61	-13.484	0.787
SD5D	SDI2	0.6932	52	100.623	-0.908
SD2S	SDI2	0.6603	36	94.97	-0.86
CBR2	SDI2	0.697	17	104.26	-9.552
DD1	SD2D	0.656	17	-391.67	3.788
CBR2	SD5D	0.678	18	11.9599	7.196
CBR2	SD2S	0.729	16	4.84	7.99
CBR2	SD5S	0.701	18	-0.656	7.126
e. Pennsylvanian					
SD5S	SDI2	0.631	27	92.62	-0.957
SD2S	SD2D	0.781	13	16.99	1.092

* $y = a + bx$

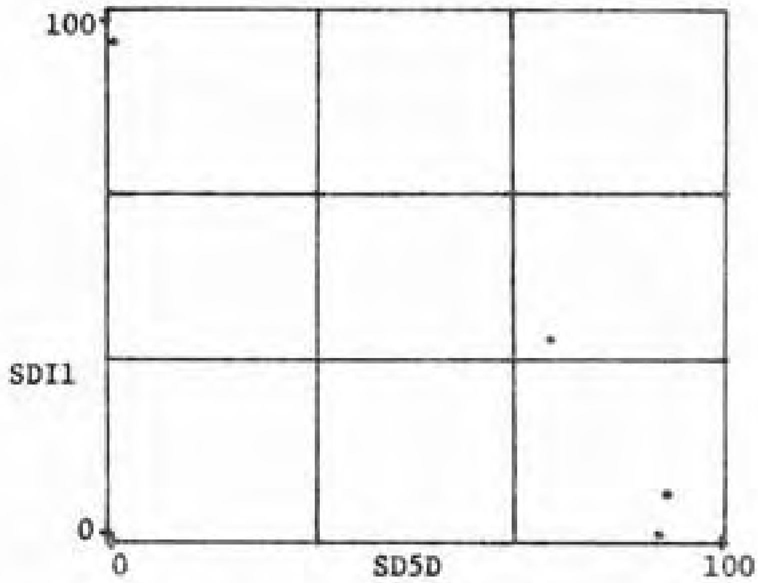
The good correlations between the different slake durability measures are to be expected and there will be an elaboration on this aspect in the next section.

Inspection of the different plots indicated that 'boundaries' can also be established for certain parameters after dividing the data according to geology. An example of this is given in Figure 21. This series of plots of Slake Durability Index 500 rev dry vs. Slaking Index Cycle 1 show distinct groupings of the data for the different geologic formations. This presentation not only gives insight in the typical properties of the different formations, but may also be of help in determining the reliability of laboratory results. For example, if a result of the formations in Figure 21(h) gives: SDI1 = 90, SD5D = 90, then there is a high possibility that this answer is wrong. The reliability of this will improve as more data become available. Also the data in Figure 21(g) may be broken up further, which may explain the single point in the upper right hand corner. This point may, however, also be the result of a 'faulty' laboratory test. There exist therefore many possible applications for this type of analysis, and it should be pursued in the future.

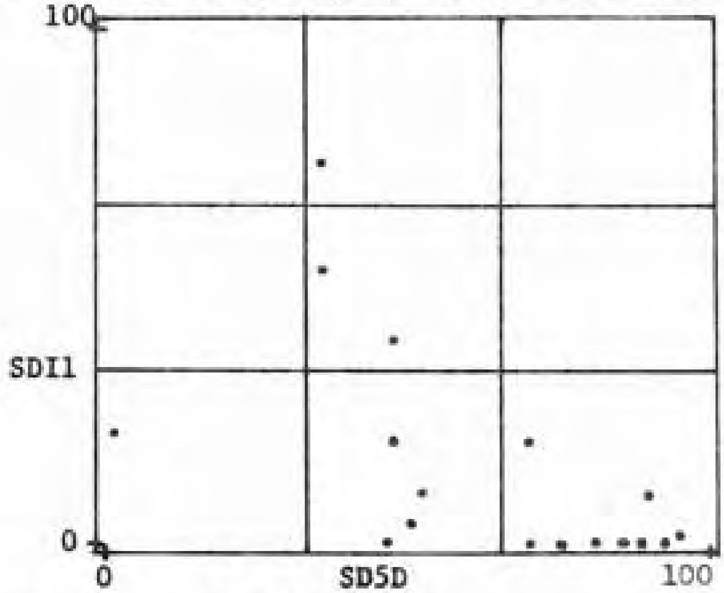
7.3 Multiple Regression Analysis

The REGRESSION routine of the SPSS package was used to carry out the multiple regression analysis.

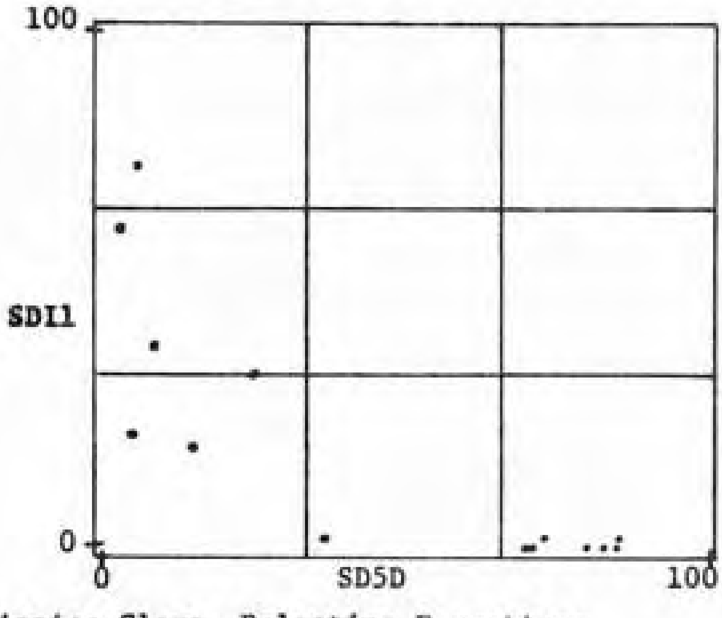
With the large number of parameters available in the data on shales, various regression models might be possible to predict various parameters using the others. For this study, attempts were made to predict California Bearing Ratio (CBR) from some of the other parameters. The reason for this is that CBR is considered to be the most time consuming test.



(a) Pennsylvanian-Shelburn, Dugger, Petersburg, Brazil Formations

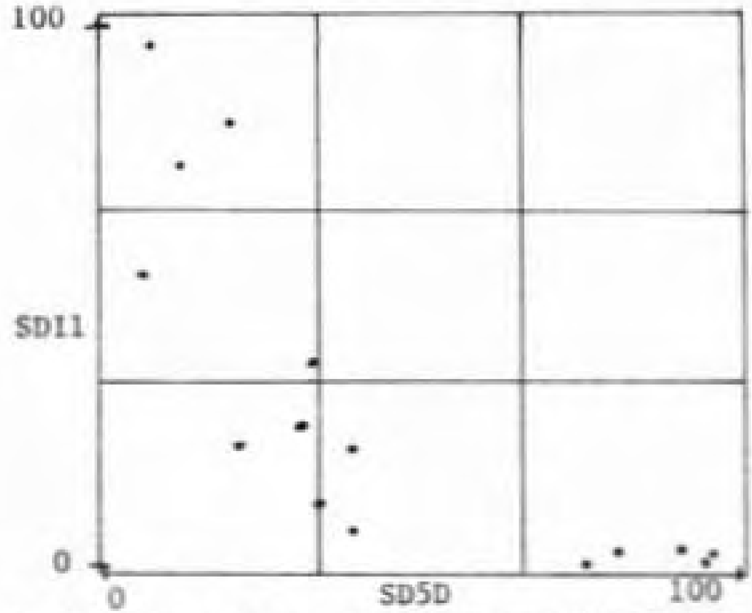


(b) Pennsylvanian-Mansfield Formation

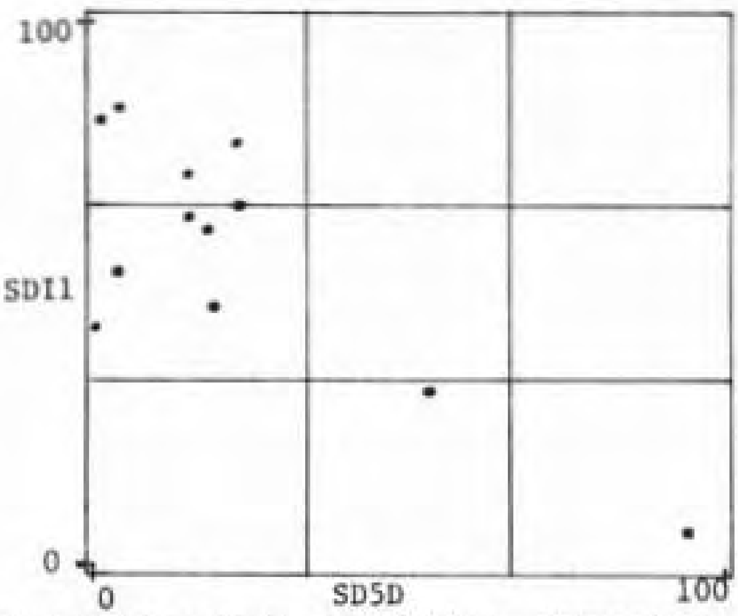


(c) Mississippian-Clore, Palestine Formations

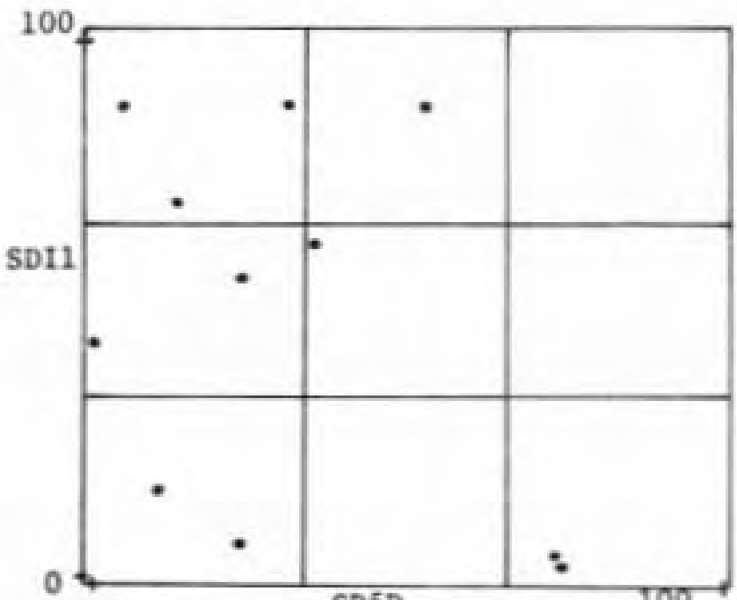
FIGURE 21. Slake Durability Index 500 Rev. Dry vs. Slaking Index Cycle 1 for Different Geological Formations.



(d) Mississippian-Watersburg, Tar Springs Formations

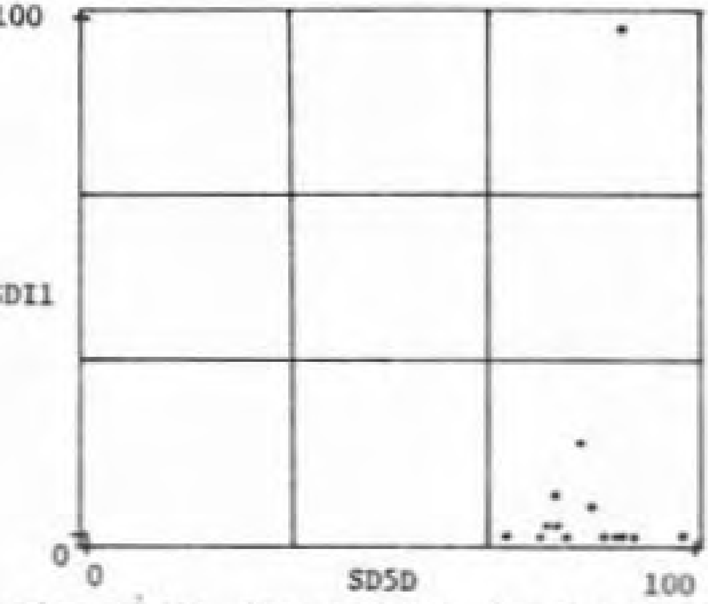


(e) Mississippian-Glen Dean, Hardinsburg Formations

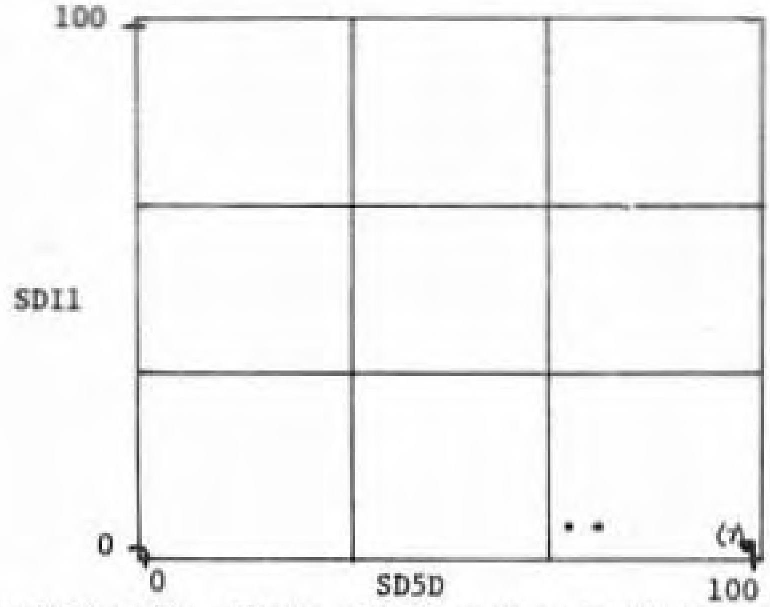


(f) Mississippian-Haney, Big Clifty, Elwren, Sample, Bethel Formations

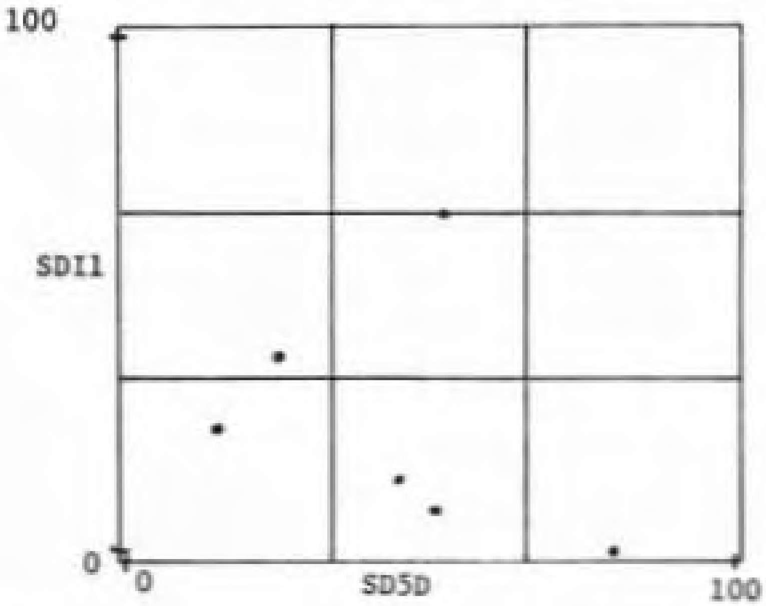
FIGURE 21. (continued)



(g) Mississippian-Borden, Locust Point, New Providence Formations



(h) Mississippian-New Albany and Devonian (all) Formations



i(i) Ordovician

FIGURE 21. (continued)

It was first of all necessary to pick out those data sets with data points for all the different parameters to be used in the analyses. Eventually 24 sets of data were used.

In order to determine the first models, a table similar to Table 11 was inspected and five parameters including 2 durability measures, Atterberg limits, grain size analysis and one density measure, with the highest one-on-one correlation with CBR1 and CBR2, were chosen. The models were then set up to include first order, second order and combination terms. A stepwise regression was performed in which the variable with the highest correlation is introduced into the model first, followed by the second highest, etc., until the standards set by the program are reached. See Table 15 for the parameters used in the first models as well as the results. It can be seen that one parameter (SD2S) (DD1) was removed during the stepwise regression for CBR1. Also it can be seen that in order to predict CBR1 and CBR2, values of all five parameters must be known. The testing to determine these might take as long as the testing for CBR1 and CBR2, which makes the above analysis really an academic exercise. Even though these models gave satisfactory correlations, it should be pointed out that only 24 data sets were used and they need further validating as additional data sets become available.

Another model was set up, for which more data sets had the values of all the parameters available. The original 24 data sets were used to set up the model and it was then tested against the data of Deo (1972), i.e., laboratory numbers 1 - 15. This model to predict CBR1 is given in Table 16. Figures 22 and 23 indicate how well the model fits the data of the 24 data sets and also the data by Deo (1972). The latter is over a

TABLE 15

Regression Models to Predict CBR1 and CBR2 Based on High One-to-One Correlation

1. Parameters used for:

CBR1: SD2S, FN, PL, PCOL, DD1
CBR2: SD5S, FN, PI, PCOL, PM

2. Results for CBR1 (stepwise):

Variable	Multiple r	r^2	r^2 change	Overall F	Significance
(SD2S)(PCOL)	0.3513	0.1234	0.1234	3.097	0.092
$(PCOL)^2$	0.3780	0.1429	0.0195	1.7508	0.198
(PCOL)	0.4638	0.2151	0.0722	1.8268	0.175
(SD2S)(DD1)	0.5267	0.2774	0.0624	1.8238	0.166
$(SD2S)^2$	0.582	0.3388	0.0613	1.8442	0.155
$(DD1)^2$	0.6306	0.3977	0.0589	1.8708	0.145
(SD2S)(PL)	0.6759	0.4568	0.0591	1.922	0.132
(PL)(PCOL)	0.7137	0.5094	0.0526	1.9465	0.127
(SD2S)	0.7707	0.594	0.0846	2.2756	0.081
(SD2S)(FN)	0.7918	0.627	0.033	2.1848	0.094
(FN)	0.7983	0.6373	0.0104	1.9169	0.139
(FN)(PL)	0.8789	0.7724	0.1351	3.1116	0.035
Remove					
(SD2S)(DD1)	0.8788	0.7723	-0.0001	3.7009	0.017
Add					
$(FN)^2$	0.9088	0.8259	0.0536	4.3485	0.01
(FN)(PCOL)	0.922	0.8505	0.0254	4.3743	0.012

Final model with r = 0.922:

Variable	B^*	Variable	B^*
(SD2S)(PCOL)	0.001553	(SD2S)	0.2382
$(PCOL)^2$	0.02454	(SD2S)(FN)	-0.004075
(PCOL)	-2.5188	(FN)	0.9224
$(SD2S)^2$	-0.0028	(FN)(PL)	-0.03936
$(DD1)^2$	0.0009553	$(FN)^2$	0.002976
(SD2S)(PL)	0.001369	(FN)(PCOL)	-0.004183
(PL)(PCOL)	0.06984	Constant	1.3565

TABLE 15 (Continued)

3. Results for CBR2 (stepwise):

Variable	Multiple r	r^2	r^2 change	Overall F	Significance
$(SD5S)^2$	0.6441	0.4149	0.4149	15.6	0.001
(FN)(PM)	0.6806	0.4632	0.0483	9.06	0.001
(SD5S)(PCOL)	0.6916	0.4783	0.0151	6.112	0.004
(SD5S)(PM)	0.7189	0.5168	0.0385	5.08	0.006
(PCOL)	0.7476	0.5589	0.0421	4.561	0.007
$(PCOL)^2$	0.7676	0.5892	0.0303	4.0636	0.01
(FN)(PI)	0.7923	0.6278	0.0386	3.8549	0.012
(PI)	0.7965	0.6345	0.0067	3.2543	0.023
(FN)(PCOL)	0.8097	0.6556	0.0211	2.9609	0.034
(PI)(PCOL)	0.8158	0.6656	0.01	2.5874	0.056
$(FN)^2$	0.8184	0.6698	0.004	2.2131	0.094
(FN)	0.8363	0.6995	0.0296	2.1334	0.110

Final model with r = 0.8363:

Variable	B *
$(SD5S)^2$	0.0006265
(FN)(PM)	-0.005126
(SD5S)(PCOL)	0.008285
(SD5S)(PM)	-0.01236
(PCOL)	-0.6047
$(PCOL)^2$	0.005335
(FN)(PI)	0.024
(PI)	-1.4375
(FN)(PCOL)	-0.01171
(PI)(PCOL)	0.03876
$(FN)^2$	0.001742
(FN)	-0.2141
Constant	23.6259

* $CBR2 = B_1(SD55)^2 + B_2(FN)(PM) + B_3(SD55)(PCOL) + \ldots$

TABLE 16

Model to Predict CBR1, Set Up for 24 Data Sets and Tested for 15 Different Sets

1. Parameters used:

   SD5D, FN, PI, PSI, PM

2. Results for CBR1 (stepwise):

Variable	Multiple r	r^2	r^2 change	Overall F	Significance
(SD5D)(FN)	0.2816	0.0793	0.0793	1.8952	0.182
(PM)	0.4109	0.1688	0.0895	2.1326	0.143
(FN)(PI)	0.4593	0.211	0.0421	1.7823	0.183
$(FN)^2$	0.5207	0.2711	0.0602	1.7666	0.177
(FN)	0.6808	0.4636	0.1925	3.1107	0.034
$(PM)^2$	0.7256	0.5264	0.0629	3.1495	0.029
$(PI)^2$	0.7343	0.5392	0.0128	2.6746	0.049
(PI)(PM)	0.7795	0.6076	0.0684	2.9034	0.036
Remove					
(FN)(PI)	0.7795	0.6076	-0.00001	3.5393	0.017
Add					
$(SD5D)^2$	0.7959	0.6335	0.0259	3.2411	0.024
(SD5D)(PM)	0.8129	0.6607	0.0272	3.0296	0.031
(PI)	0.8317	0.6918	0.031	2.9178	0.037
(PI)(PSI)	0.8647	0.7477	0.0559	3.2324	0.028
Remove					
(PM)	0.8647	0.7476	-0.00004	3.8512	0.013
Add					
$(PSI)^2$	0.8704	0.7575	0.0099	3.408	0.023
(SD5D)(PSI)	0.8734	0.7629	0.0054	2.949	0.042
Remove					
$(PI)^2$	0.8734	0.7628	-0.0001	3.5078	0.020
Add					
(FN)(PM)	0.8807	0.7757	0.0129	3.17	0.033
(FN)(PSI)	0.8948	0.8007	0.0250	3.0906	0.04

Final model with r = 0.8948:

Variable	B	Variable	B
(SD5D)(PI)	-0.005012	(PI)	-1.4378
$(FN)^2$	-0.00431	(PI)(PSI)	0.01197
(FN)	0.50302	$(PSI)^2$	-0.004016
$(PM)^2$	-0.004572	(SD5D)(PSI)	0.0036007
(PI)(PM)	0.07577	(FN)(PM)	-0.01907
$(SD5D)^2$	0.0009055	(FN)(PSI)	0.0031716
(SD5D)(PM)	-0.01654	Constant	11.927105

TABLE 16 (Continued)

3. Results for CBR2 (stepwise):

Variable	Multiple r	r^2	r^2 change	Overall F	Significance
(SDI2)(PH)	0.7016	0.4922	0.4922	21.324	0.000
$(SDI2)^2$	0.7503	0.563	0.0708	13.5247	0.000
(PH)	0.8237	0.6784	0.1155	14.0647	0.000
$(XY)^2$	0.826	0.6822	0.0038	10.1976	0.000
(SDI2)(XY)	0.8417	0.7084	0.02619	8.7462	0.000
$(DD)^2$	0.8513	0.7248	0.0164	7.4612	0.000
(SDI2)(AMC)	0.8594	0.7386	0.0138	6.457	0.001
(DD)(AMC)	0.8706	0.7579	0.0194	5.8702	0.002
(XY)	0.8918	0.7954	0.03745	6.0459	0.002
(SDI2)	0.9091	0.8265	0.0312	6.1947	0.002
(PH)(AMC)	0.9138	0.8351	0.0086	5.5242	0.003
(PH)(XY)	0.9175	0.8418	0.0067	4.8759	0.007
Remove $(DD)^2$	0.9175	0.8417	-0.00001	5.8022	0.003
Add $(AMC)^2$	0.9186	0.8438	0.002	4.9507	0.006
Remove (DD)(AMC)	0.9186	0.8438	-0.0000	5.8917	0.002
Add $(PH)^2$	0.92	0.8464	0.0026	5.0507	0.006

Final model with r = 0.92:

Variable	B
(SDI2)(PH)	0.012821
$(SDI2)^2$	0.0004225
(PH)	6.80998
$(XY)^2$	-0.17319
(SDI2)(XY)	0.00738
(SDI2)(AMC)	0.02098
(XY)	4.2569
(SDI2)	-0.37786
(PH)(AMC)	-0.35246
(PH)(XY)	-0.30195
$(AMC)^2$	0.04786
$(PH)^2$	-0.22927
Constant	-21.7448

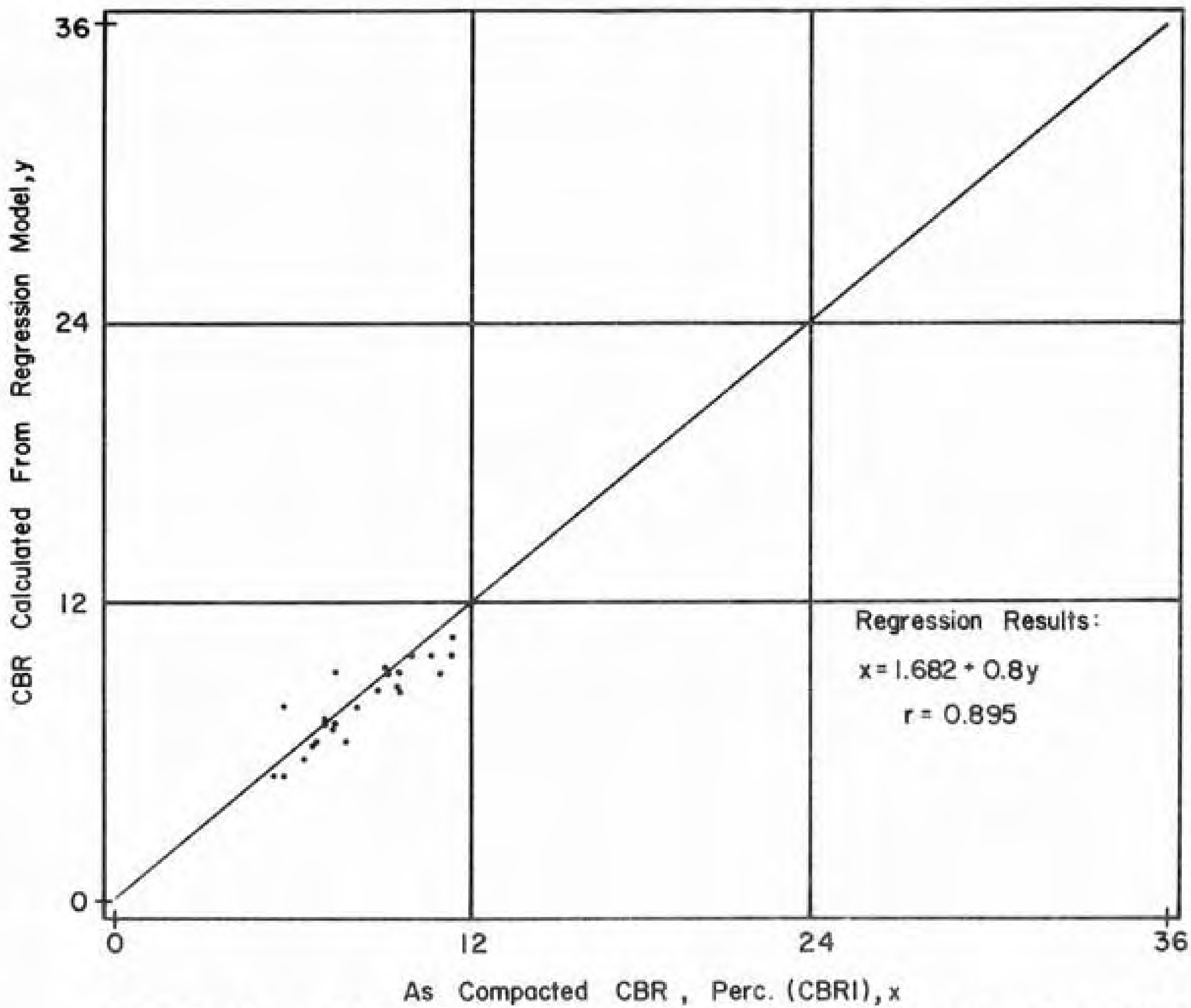


FIGURE 22 GOODNESS OF FIT OF REGRESSION MODEL FOR DATA USED TO SET UP THE MODEL (24 DATA SETS)

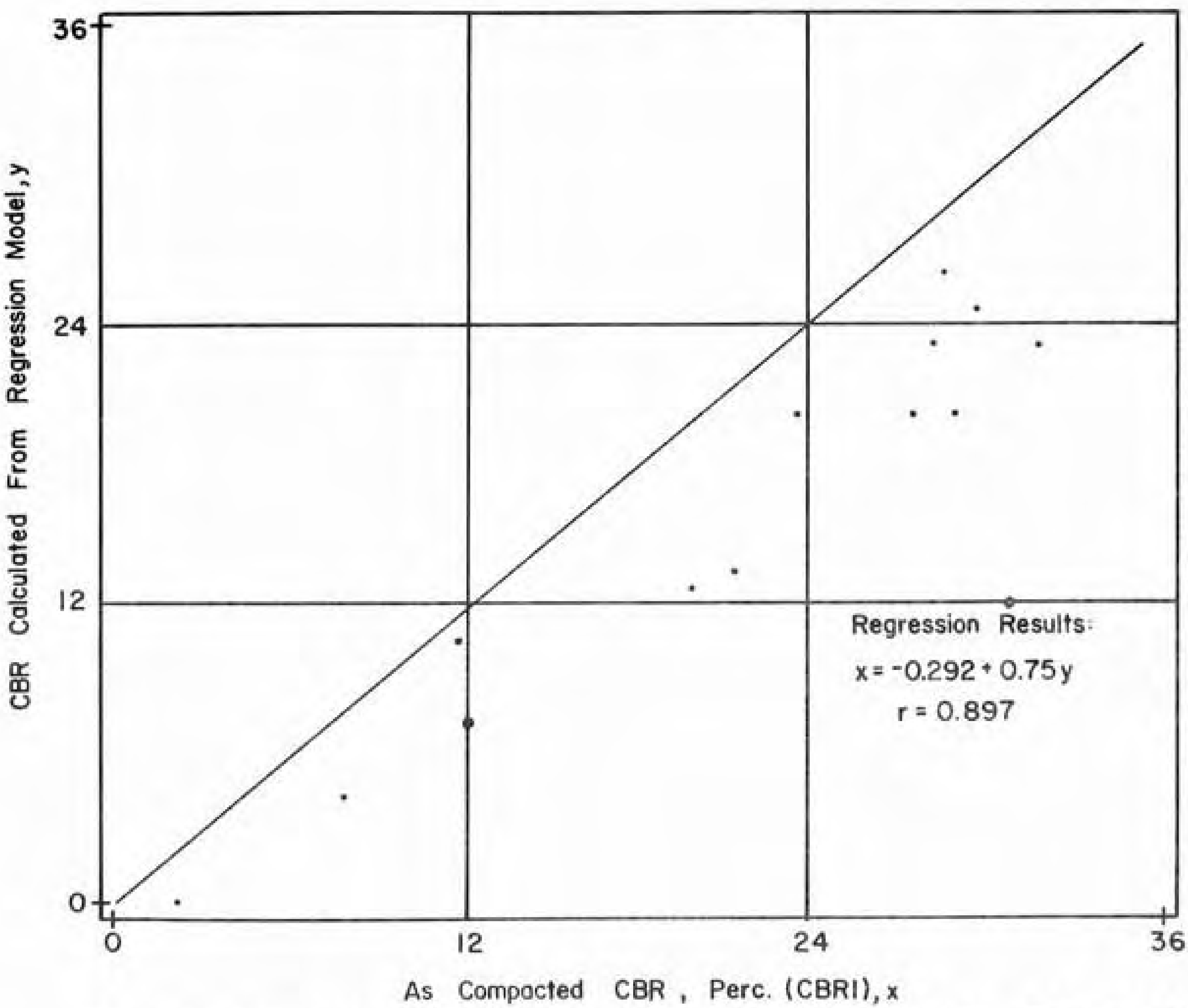


FIGURE 23 GOODNESS OF FIT OF REGRESSION MODEL FOR DATA USED TO VERIFY THE MODEL (15 DATA SETS)

larger range, and the fit (r from regression analyses) is better than that of the model although the regression line does not correspond well with the line x = y. This model still includes difficult-to-determine parameters, and might therefore be impractical. It should, however, be tested as more data become available.

A final model based on simple-to-perform tests was tried. The parameters and the results are given in Table 17. It can be seen that both models are very good for the 24 sets of data. This model must still be validated, and it is proposed that this be done as more data become available.

With the good correlations obtained between the different slake durability parameters on a one-to-one basis it was decided to analyze these correlations again using second order equations and the REGRESSION program. For example, the relationship between SDI1 and SDI2 would be determined by the equation:

$$SDI2 = C_1(SDI1)^2 + C_2(SDI2)(SDI1) + C_3(SDI1) + C_4$$

The results of the different analyses are given in Table 18. It is clear that the correlations are much higher than those given in Table 11 which were based on bivariate analysis. It is therefore recommended that these second order equations be used for predicting the different slake durability parameters when one is known. It should be remembered that these models are based on all 163 sets of data and were not validated. New data that become available should be used for validating these models so that their reliability can be increased.

TABLE 17

Regression Models to Predict CBR1 and CBR2 from Simple-To-Perform Tests

1. Parameters used (for CBR1 and CBR2)

   SDI2, DD, AMC, PH, XY

2. Results for CBR1 (stepwise):

Variable	Multiple r	r^2	r^2 change	Overall F	Significance
(SDI2)(PH)	0.3909	0.1528	0.1528	3.9672	0.059
(SDI2)(XY)	0.6444	0.4153	0.2625	7.4563	0.004
$(DD)^2$	0.6578	0.4328	0.0175	5.086	0.009
(DD)(AMC)	0.6951	0.4832	0.0504	4.4409	0.011
(PH)	0.7052	0.4973	0.0141	3.561	0.021
(SDI2)(DD)	0.7179	0.5154	0.0181	3.0128	0.034
$(PH)^2$	0.766	0.5868	0.0714	3.2458	0.024
(AMC)	0.7757	0.6016	0.0149	2.8318	0.039
(XY)(AMC)	0.7787	0.6063	0.0047	2.3959	0.069
$(XY)^2$	0.7944	0.6311	0.0248	2.224	0.089
(DD)(XY)	0.8099	0.6559	0.0248	2.0793	0.112
(PH)(AMC)	0.8167	0.667	0.0111	1.8361	0.162
(SDI2)(AMC)	0.8366	0.7	0.0329	1.7943	0.18
(PH)(XY)	0.8501	0.7227	0.0228	1.6755	0.22
$(AMC)^2$	0.8555	0.7319	0.0092	1.4561	0.302
$(SDI2)^2$	0.8657	0.749	0.0175	1.308	0.375

Final model with r = 0.8657:

Variable	B	Variable	B
(SDI2)(PH)	0.05855	(XY)(AMC)	-0.26375
(SDI2)(XY)	0.017099	$(XY)^2$	0.06404
$(DD)^2$	0.0028604	(DD)(XY)	-0.023976
(DD)(AMC)	-0.026762	(PH)(AMC)	-0.25951
(PH)	-14.8706	(SDI2)(AMC)	-0.01517
(SDI2)(DD)	-0.0030687	(PH)(XY)	0.46754
$(PH)^2$	0.84256	$(AMC)^2$	-0.142685
(AMC)	10.9822	$(SDI2)^2$	0.0004864
		Constant	-6.4060052

3. Results for CBR2 (stepwise)

Variable	Multiple r	r^2	r^2 change	Overall F	Significance
(SDI2)(PH)	0.7016	0.492	0.492	21.324	0.000
$(SDI2)^2$	0.7503	0.563	0.0708	13.525	0.000
(PH)	0.8237	0.678	0.1155	14.065	0.000
$(XY)^2$	0.826	0.682	0.0038	10.198	0.000
(SDI2)(XY)	0.8417	0.708	0.0262	8.746	0.000
$(DD)^2$	0.8513	0.7248	0.0164	7.4612	0.000
(SDI2)(AMC)	0.8594	0.7386	0.0138	6.457	0.001
(DD)(AMC)	0.8706	0.7579	0.0194	5.8702	0.002
XY	0.8918	0.7954	0.0375	6.0459	0.002
SDI2	0.9091	0.8265	0.0312	6.1947	0.002
(PH)(AMC)	0.9138	0.8351	0.0086	5.5242	0.003
(PH)(XY)	0.9175	0.8418	0.0067	4.8759	0.007
Remove $(DD)^2$	0.9175	0.8417	-0.00001	5.8022	0.003
Add $(AMC)^2$	0.9186	0.8438	0.00203	4.9507	0.006
Remove (DD)(AMC)	0.9186	0.8438	0.0	5.8917	0.002
Add $(PH)^2$	0.92	0.8464	0.0026	5.0507	0.006
(XY)(AMC)	0.9205	0.8474	0.001	4.2712	0.014
(DD)(XY)	0.9208	0.8478	0.0004	3.5802	0.030
(DD)(AMC)	0.9222	0.8504	0.0027	3.0328	0.059
(DD)	0.9231	0.852	0.0016	2.519	0.110

Final model with r = 0.9231

Variable	B	Variable	B
(SDI2)(PH)	0.04195	(PH)(AMC)	-0.57757
$(SDI2)^2$	0.005662	(PH)(XY)	-0.44896
(PH)	8.12046	$(AMC)^2$	0.086209
$(XY)^2$	-0.12584	$(PH)^2$	-0.264604
(SDI2)(XY)	0.021707	(XY)(AMC)	-0.24453
(SDI2)(AMC)	0.021051	(DD)(XY)	-0.045907
(XY)	12.2994	(DD)(AMC)	0.018094
(SDI2)	-0.694905	(DD)	0.13003
		Constant	-49.9787

TABLE 18

Results of Regression on Second Order Equations for Durability Parameters

Dependent variable (y)	Independent variable (x)	C_1	C_2	C_3	C_4	Multiple r
SDI2*	SDI1	-0.03101	0.03247	0.36789	19.1696	0.9018
SD2D	SDI1	-0.01763	0.01784	-2.6874	90.5737	0.8984
SD5D	SDI1	0.02093	0.01759	-2.8427	83.325	0.8998
SD2S	SDI1	0.02414	0.02177	-3.0096	78.699	0.8981
SD5S	SDI1	0.02507	0.0282	-2.993	69.224	0.8399
SD2D	SDI2	0.00614	0.01205	-1.6672	97.144	0.9798
SD5D	SDI2	0.00956	0.0142	-1.97098	92.5352	0.9759
SD2S	SDI2	0.01203	0.01374	-2.166	93.406	0.9808
SD5S	SDI2	0.01478	0.01638	-2.3413	85.7386	0.9495
SD5D	SD2D	-0.00888	0.01223	0.6633	3.2595	0.9899
SD2S	SD2D	-0.00978	0.01266	0.7319	2.063	0.9808
SD5S	SD2D	-0.00598	0.01181	0.4334	3.901	0.9732
SD2S	SD5D	-0.00696	0.0144	0.1184	20.87	0.9045
SD5S	SD5D	-0.00753	0.01309	0.4312	7.8161	0.9626
SD5S	SD2S	-0.00914	0.01236	0.6928	2.7344	0.9795

*$y = C_1 x^2 + C_2 xy + C_3 x + C_4$

For example: $SDI2 = C_1(SDI1)^2 + C_2(SDI2)(SDI1) + C_3(SDI1) + C_4$

8. Conclusions

1. The storage and retrieval system described in this report is only a first attempt and should be improved in the future by the inclusion of additional data as they become available.
2. The shales of Indiana cover a wide range of characteristics and it is necessary to have complete data sets on as many different shales as possible in order to obtain good statistical correlations.
3. The values of all the slake durability indices can be estimated if one is known by using the second order equations of Table 18, which are of the form, $SDI2 = C_1(SDI1)^2 + C_2(SDI2)(SDI1) + C_3(SDI1) + C_4$.
4. Various relations exist between the data on a one-to-one basis which give reasonable correlations. Details of the most significant relations are given in Table 12.
5. Various regression models can be obtained to predict some parameters by using others. Good models were obtained for estimating CBR by using 5 parameters. It should be remembered that the data used for the models come from all the different geological series. Better models may result in the future when more complete data sets are available for separate geological formations.
6. This partial analysis indicates that the data can be divided into groups based on their geological origin. This area should be expolored more fully in the future.

9. Recommendations

1. A general sorting program should be written so that the sorting of data can be done in a more detailed manner. It is desirable to have a program to sort and print only certain data sets or parts of data sets. Sorting of this kind can be accomplished at this stage by using some routines of the SPSS package.
2. The statistical analyses presented in this report should be seen as first approximations. More detailed analyses should be done at a later date when more data are available. It is important to create models with some of the data available and test it with the rest otherwise very little confidence can be placed on the models obtained.
3. The notion of 'grouping' data according to geological origin should be further explored. It is necessary to obtain more complete data sets from some of the geological formations before this can be done with high statistical confidence. A complete project in this area may prove to be one of the most useful for the practitioner. Data from Illinois, Kentucky and Ohio may help to prove the findings of any local study.
4. The maintenance of a shale data bank should be assumed at an early data, by the Indiana State Highway Commission. Periodic statistical examination of data from this bank by both ISHC and Purdue University is envisioned.

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APPENDIX A

DESCRIPTION OF TESING METHODS USED BY ISHC

A-1. Method of Test for Determining Loss-On-Ignition*

Test Method No. Ind. 501-76

1. Scope

1.1 This method covers the determination of organic matter (Loss-On-Ignition) in soils. The procedure is based on oxidizing all of the organic material present and stabilizing the organic residue at 1200°F.

2. Apparatus

2.1 Electrical Muffle Furnace

The electric muffle furnace should have good air circulation and be capable of having its temperature regulated at 1200°F. ±50°F.

2.2 Porcelain Crucibles

The crucibles shall be 1-3/8 inch in depth and 1-5/8 inch in diameter. Similar dishes of platinum or silica may be used.

2.3 Balance

A balance conforming to the requirements of AASHTO M231, Class C.

2.4 Oven

A thermostatically controlled drying oven, capable of maintaining temperatures of 110°C. ± 5°C. (230°F. ± 9°F.) for drying soil samples.

2.5 Spatula

A spatula or pen knife having a blade about 3 inches (76 mm) in length and about 3/4 inch (19 mm) in width.

*This test method is only tentative and is under consideration by the Chief of the Division of Materials and Tests of ISHC.

2.6 Desiccator

A desiccator, about 8 inches (approximately 200 mm) in diameter, containing anhydrous silica gel or other suitable desiccant.

3. Sampling

3.1 A sample weighing about 50 gm. shall be taken from the thoroughly mixed portion of the material passing the (No. 10) 2.00 mm sieve, which has been obtained in accordance with the Standard Method of Dry Preparation of Disturbed Soil Samples for Tests (AASHTO T 87-721).

3.2 The sample shall be free from contaminating substances, and thoroughly representative of the material to be tested.

4. Procedure

4.1 The air-dried soil shall be placed in a container and oven-dried for 12 hours or to constant weight at 110°C. ± 5°C. (230°F. ± 9°F.).

4.2 A representative oven-dried portion of 5.00 gm.± 0.005 gm. shall be placed in the crucible (two crucibles per sample). The crucibles shall then be placed in an electric muffle furnace for 4 hours at 1200°F. ± 50°F.

4.3 After ignition is completed at 1200°F. the samples shall be placed in a desiccator and weighed as soon as cool.

5. Calculation and Report

5.1 Report the organic content as the weight per cent of the original sample which is calculated as follows:

$$\text{Loss-On-Ignition} = \frac{(B-A) \times 100}{B}$$

Where:

A = Weight of sample after ignition. (4.3)

B = Weight of sample originally taken. (4.2)

A-2. Method of Test for Determining The Slake Durability Index of Shale*

Test Method No. Ind. 503-77

1. Scope

1.1 The slake durability test is a measure of the abrasion durability of a shale while submerged in water. This weight loss is then expressed as the durability number (I_d).

2. Apparatus

2.1 Oven

A thermostatically controlled drying oven capable of maintaining temperatures of 110°C. ± 5°C. (230°F. ± 9°F.) for drying shale samples.

2.2 Balance

A balance conforming to the requirements of AASHTO M231, Class D.

2.3 Containers

Containers for moisture content, made of metal or other suitable material, with close-fitting lids to prevent loss of moisture prior to or during weighing.

2.4 Soak Tank

A tank of sufficient size to allow complete immersion, of the Apparatus from the Slake Durability Test, in water.

2.5 Slake Durability Apparatus

The Slake Durability Apparatus shall consist of a motor drive unit mounted on a base board and capable of revolving a test

*This test method is only tentative and is under consideration by the Chief of the Division of Materials and Tests of ISHC.

drum at a speed of 20 revolutions per minute. The test drum shall be manufactured of brass comprising 2.0 mm standard mesh cylinder of unobstructed length 100 mm and 140 mm diameter. Both ends of the cylinder shall be solid and incorporate suitable driving clogs. One side plate shall incorporate a quick release mechanism to permit easy sample handling. The test drum shall be supported on water lubricated bearings allowing 40 mm unobstructed clearance below the drum and a trough water level 20 mm below the axis of the drum.

The water trough shall be manufactured by Perspex ^{tm}.

3. Test Sample

3.1 The shale material shall be in an unweathered condition.

3.2 The material shall be at nature moisture content.

3.3 The sample shall be free from contaminating substances, and thoroughly representative of the material to be tested.

3.4 Forty pieces of shale shall be selected such that they are each roughly equidimensional, and weighing between 60 gm. and 70 gm.

4. Procedure: Slake Durability Dry, (I_d)d.

4.1 Two samples of ten representative shale pieces, each weighing 600 gm. to 700 gm., shall be placed in a container and oven-dried for 12 hours or to constant weight at 110°C. ± 5°C. (230°F. ± 9°F.) (See note 1). The moisture shall be calculated and recorded as (MI_d)d.

4.2 The shale material shall be allowed to cool for 30 minutes at room temperature. The oven-dried shale material then shall be placed in the test drum and the weight recorded (see note 1).

4.3 The sample and test drum shall be immersed in the water bath of the Slake Durability Apparatus. The trough water level shall be two (2) cm. below the axis of the drum (see note 1).

4.4 One sample shall be rotated for 200 revolutions and the second sample for 500 revolutions.

4.5 At the conclusion of section 4.4, the test drum and sample shall be removed from the water bath of the Slake Durability Apparatus and oven-dried for 12 hours or to constant weight at 110°C. ± 5°C. (230°F. ± 9°F.), and the weight recorded (see note 1).

5. Procedure: Soaked Slaked Durability Index, $(I_d)s$.

5.1 Two samples of ten representative shale pieces, each weighing 600 gm. to 700 gm., shall be oven-dried for 12 hours or to constant weight at 110°C. ± 5°C. (230°F. ±9°F.) (see note 1). The moisture shall be calculated and recorded as $(MI_d)s$.

5.2 The shale material shall be allowed to cool for 30 minutes at room temperature. The oven-dried shale material then shall be placed in the test drum and the weight recorded (see note 1).

5.3 The sample and test drum shall be immersed in the Soak Tank for 24 hours. At the conclusion of soaking, the sample and test drum shall be immersed in the water bath of the Slake Durability Apparatus. The trough water level shall be two (2) cm. below the axis of the drum (see note 1).

5.4 One sample shall be rotated for 200 revolutions and the second sample for 500 revolutions.

5.5 At the conclusion of section 5.4, the test drum and sample shall be removed from the water bath of the Slake Durability

Apparatus and oven-dried for 12 hours or to constant weight at 110°C. ± 5°C. (230°F. ± 9°F), and the weight recorded (see note 1).

6. Calculations and Report

6.1 Report the moisture, $(MI_d)d$ or $(MI_d)s$, as the weight loss in per cent of the oven-dried material, calculated as follows:

$$(MI_d)d \text{ or } (MI_d)s, \text{ Per Cent} = \frac{(A - B)}{B - C} \times 100$$

Where: A = Weight of container and natural material

B = Weight of container and oven-dried material.

C = Weight of container.

6.2 Report the Slake Durability Index, $(I_d)d$ or $(I_d)s$, calculated as follows:

$$(I_d)d \text{ or } (I_d)s = \frac{(E - F)}{D - F} \times 100$$

Where: D = Weight of drum plus oven-dried material before Test.

E = Weight of drum plus oven-dried material retained after test.

F = Weight of clean and dry drum.

6.3 Report the classification of the shale material with respect to Figure A-1. Durability is determined based on the 500 revolution values. The 200 revolution values shall be reported as additional information.

Note 1: Care should be taken to minimize additional breakdown of the material.

A-3. Method of Test for Determining the Slaking Index of Shale

Test Method No. Ind. 502-73

1. Scope

1.1 This method covers the determination of the Slaking Index to be used in classifying shale. The procedure is based on the slaking characteristics of shale in water with five cycles of wetting and drying.

2. Apparatus

2.1 Oven

A thermostatically controlled drying oven capable of maintaining temperatures of 110°C. ± 5°C. (230°F. ± 9°F.) for drying shale samples.

2.2 Balance

A balance conforming to the requirements of AASHTO M231, Class C.

2.3 Beakers

Pyrex beakers 600 ml.

3. Test Sample

3.1 The test sample shall consist of six pieces of shale carefully selected to be representative of the shale sample submitted for testing, (Note 1.). Each piece shall be approximately equi-dimensional, shall weigh between 100 and 150 grams, and shall be free of foreign or contaminating substances. Trimming or breaking of pieces to obtain approximately equal dimensions is permissible.

Note 1. Shale samples received for testing shall be kept in sealed containers to retain the natural moisture content to minimize weathering.

4. Procedure

4.1 Each piece of the test sample shall be placed in a separate beaker, weighed, then oven-dried to constant weight at 110°C. ± 5°C. (230°F. ± 9°F.). (Note 2). The moisture content shall be calculated and recorded.

4.2 The shale material shall be allowed to cool for 30 minutes at room temperature. Distilled water then shall be poured into the beakers so that the material is covered by at least 1 cm. of water. (Note 3).

4.3 The condition of the shale samples shall be observed at 5 minutes, 30 minutes, 2 hours, 4 hours, and 24 hours after immersion. The condition of the material shall be recorded as: complete breakdown, partial breakdown, or no change. If the material appears to remain intact, the cloudiness of the water shall be noted. If there is variability in the condition of the 6 test pieces, the variability shall be recorded.

Note 2. Checking every moisture content sample to determine that it is dried to a constant weight is impractical. In most cases, drying of a moisture content sample overnight (15 or 16 hr.) is sufficient. In cases where there is doubt concerning the adequacy of overnight drying, drying should be continued until the weights after two successive periods of drying indicate no change in weight.

Note 3. Care shall be taken to minimize additional breakdown of the material.

4.4 At the conclusion of the 24 hours of immersion in water, the material in each beaker shall be washed with distilled water on a 2.00 mm (No. 10) sieve. The material retained on the sieve shall then be washed back into the beaker, decanted and oven-dried to constant weight at a temperature of 110°C. ± 5°C. (230°F. ± 9°F.) and weighed. (Notes 2 and 3). The percent loss from initial oven-dried weight shall then be calculated and recorded (Slaking index for that cycle).

4.5 Repeat steps 4.2 through 4.4 for five complete cycles or until the material is completely slaked, whichever occurs first.

5. Calculation and Report

5.1 Calculate the moisture content as follows:

$$\text{Moisture, percent} = \frac{A-B}{B-C} \times 100$$

A = Total weight of the 6 beakers and natural material.

B = Total weight of the 6 beakers and oven-dried material.

C = Total weight of the 6 beakers.

Report the moisture content to the nearest 0.1%.

5.2 Report the condition of shale material for each cycle as set out in 4.3

5.3 Calculate the Slaking Index at the end of each cycle as follows:

$$\text{Slaking Index} = \frac{B-D}{B-C} \times 100$$

B = Total Weight of the 6 beakers and oven-dried material of 4.1.

C = Total Weight of the 6 beakers.

D = Total Weight of the 6 beakers and oven-dried material retained on the 2.00 mm (No. 10) sieve.

Report the Slaking Index for each cycle to the nearest 0.1%.

5.4 Report the Classification of the shale material, with respect to Figure A-1. (Note 4).

A-4. Method of test for determining Fissility Number (Deo, 1972)

1. Breaking Characteristics of Shales.

The breaking characteristics may be the most descriptive feature for shales. They can be classified as massive, flaky-fissile and flaggy-fissile. Fissility is associated with a parallel arrangement of clay particles, and non-fissility with a random arrangement. The nature of cementing agents is also an important factor in influencing fissility.

Massive rocks have no preferred directions of cleaving and breaking. Most of the fragments are blocky. Flaggy rocks will split into fragments of varying thickness, but the width and length are many times greater than the thickness, and the two essentially flat sides are approximately parallel. Flaky shales split along irregular surfaces parallel to the bedding, and into uneven flakes, thin chips, and wedge-like fragments whose length seldom exceeds three inches.

Shales were broken by: (a) a hammer having a large area of contact, and (b) by striking pieces of shale against each other. About 1000 gm of shale was broken in this way, and approximately the same breaking effort was applied to each shale.

Shale pieces with massive, flaggy and flaky characteristics were visually separated and weighed. Proportions of the three different

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Note 4. Additional tests are necessary to classify the shale material if it does not slake completely.

breaking types were determined to the nearest 10 percent.

2. Determining Fissility Number.

Flaky and flaggy are two characteristics of fissility, and therefore the fissility number should be some weighted sum of the two. It was assumed that the fissility number should be equal to the percent flaky component plus a constant times the percent flaggy component. Though the size and weight of flaggy or flaky pieces for a given shale varies with the breaking effort, the flaggy pieces will be heavier than the flaky pieces, for a given breaking effort. Typically the weight of flaky pieces varied between 5 and 100 percent of flaggy pieces, and the average weight of flaky pieces was 0.35 times the average weight of flaggy pieces.

Therefore, the fissility number was defined as the sum of percent flakiness and 0.35 times percent flagginess.

A-5. Method of test for determining Modified Soundness (Deo, 1972).

This test measures the degradation of shales when subjected to five cycles of alternate wetting and drying in a sodium sulfate solution.

The test was modified from ASTM C 88-63, which is used to determine the resistance of aggregates to disintegration by sodium sulfate or magnesium sulfate. The standard test uses a fully saturated solution, but this is too severe for shales, and after a series of trials, the saturation was reduced to 50%.

The charge of shale fragments was 1000 gm, of which 330 gm was between 1/2 in. and 3/8 in., and 670 gm was between 3/4 in. and 1/2 in. Pieces in this size range were roughly equidimensional. Larger pieces tended to be plate shaped, due to the laminated nature of the sediment.

Definition of size by a sieving process of course becomes more arbitrary as the pieces depart from a bulky shape. The sample is washed with water, and oven dried at 105 to 110°C before weighing.

A saturated solution of anhydrous granular sodium sulfate is prepared in accordance with ASTM C 88-63 procedures. The solution is diluted to 50% saturation by adding an equal amount of water. The solution is prepared at least 24 hours in advance of the start of test.

The sample is immersed in the sodium sulfate solution for not less than 16 hours and not more than 18 hours. The solution covers the shale chunks to a depth of at least 1/2 in. The immersion is conducted at a room temperature of 72° ± 2°F. The sample is removed from the solution, drained for 16 minutes, placed in the drying oven at 105 to 110°C, and dried to constant weight. After the sample has cooled to room temperature, the process is repeated.

Upon completion of five cycles of immersion and drying, the sample is washed with water until free of sodium sulfate, as determined by the reaction of the wash water with barium chloride ($BaCl_2$). It is then dried and fractioned on a 5/16 in. sieve. The weight retained on the sieve is determined. Each test is repeated at least once, and average values are reported.

The Soundness Index, is defined as the percent retained by weight on the 5/16 in. sieve. Durability is considered to increase with increase in I_s value.

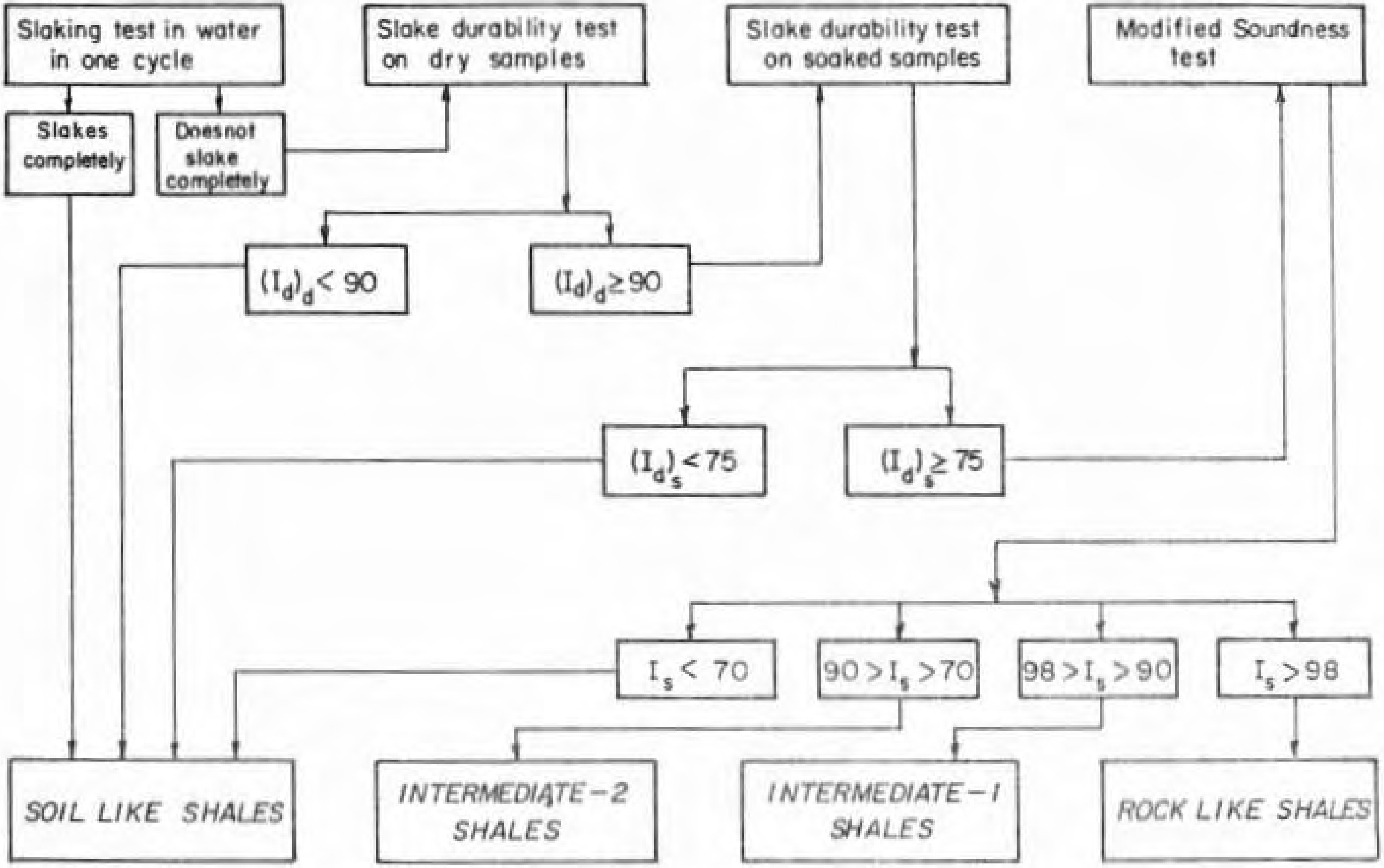

FIGURE A-1

CLASSIFICATION of SHALES

MODIFIED AFTER DEO (1972)

APPENDIX B

DATA SEGREGATED ACCORDING TO GEOLOGICAL FORMATIONS

PENNSYLVANIAN Shelburn Formation

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
74-50592									X	X	X	X	X	X	X			X	X	X				X	X	X			
74-50506									X	X	X	X	X	X	X			X	X	X				X	X	X			
74-50560	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			

PENNSYLVANIAN Dugger Formation

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
76-55125	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
76-55182	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						

PENNSYLVANIAN Petersburg Formation

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
14-				X		X	X	X	X	X	X	X	X	X	X		X							X		X	X	X	X
7655484	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						

PENNSYLVANIAN   Brazil Formation

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
75-55022	X	X																X											

PENNSYLVANIAN Mansfield Formation

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CHR1	CBR2	AS
74-54624	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54665	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54967	X	X	X	X	X	X										X	X	X											
74-54966	X	X		X		X										X	X	X											
74-54962	X	X	X	X	X	X										X	X	X											
74-54960	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54878	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54370	X	X	X	X	X	X										X	X	X											
74-54922	X	X		X		X												X											
74-54927	X	X		X		X												X											
74-54986	X	X	X	X	X	X										X	X	X											
74-54985	X	X	X	X	X	X										X	X	X											
75-55029	X	X	X	X	X	X	X									X	X	X											
75-55028	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55027	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55026	X	X				X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55246	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55572	X	X		X		X										X	X	X											
75-55571	X	X				X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55570	X	X		X		X										X	X	X											
75-55569	X	X				X										X	X	X											
75-55568	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55567	X	X		X		X										X	X	X											

MISSISSIPPIAN Clore Limestone

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PX	WDI	DDI	CBR1	CBR2	AS
74-54666	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55653	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

MISSISSIPPIAN: Palestine Sandstone

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	PN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	MD	DD	AMC	SG	PH	SL	SH	XY	PM	MDI	DDI	CBR1	CBR2	AS
74-54879	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54836	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54716	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-55055	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-55054	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-55[illegible]	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55252	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55247	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55222	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55231	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55230	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55224	X	X																X											
75-55223	X	X																X											
75-55205	X	X																X											
75-55132	X	X																X											
75-55041	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
11				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X

MISSISSIPPIAN Waltersburg Sandstone

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SC	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
74-54664	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54475	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
74-54768	X	X		X		X																							
74-54767	X	X		X		X																							
74-54766	X	X		X		X																							

MISSISSIPPIAN Tar Springs Formation

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
[illegible]	X	X	X	X	X	X										X	X	X											
74-54[illegible]	X	X	X	X	X	X										X	X	X											
74-54[illegible]	X	X	X	X	X	X												X											
74-54334	X	X	X	X	X	X												X											
74-54[illegible]	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54332	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54331	X	X	X	X	X	X												X											
74-54330	X	X	X	X	X	X												X											
74-54323	X	X	X	X	X	X												X											
76-55120						X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
76-55129						X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
76-55128							X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
76-55127						X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
76-55126						X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
[illegible]-55[illegible]	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

MISSISSIPPIAN Glen Dean Limestone

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SC	PH	SL	SH	XY	PK	WDI	DDI	CBR1	CBR2	AS
75-55022	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55021	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55020	X	X				X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						

MISSISSIPPIAN Hardinsburg Formation

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
73-51703			X	X	X	X			X	X	X	X	X	X	X	X	X	X	X					X	X	X			
74-54965	X	X	X	X	X	X										X	X	X											
74-54964	X	X		X		X										X	X	X											
74-54956	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54982	X	X		X		X										X	X	X					X						
74-54981	X	X				X										X	X	X					X						
74-54980																		X					X						
74-54979	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54978																		X					X						
74-54977																		X					X						
74-54976									X	X	X	X	X	X	X			X	X	X			X						
74-54975	X	X				X										X	X	X											
74-54974						X										X	X	X											
74-54971	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55019	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54374	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54983	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X							
75-55024	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55023									X	X	X	X	X	X	X				X	X	X	X	X						
76-55723	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

MISSISSIPPIAN Haney Limestone

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SC	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
74-54959	X	X	X	X	X	X										X	X	X											
74-54972	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55025						X																							

MISSISSIPPIAN   31- Clifty Formation

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
74-54952	X	X		X		X	X											X											
74-54957	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54972	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						

MISSISSIPPIAN Elwren Formation

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SC	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
76-55451	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

MISSISSIPPIAN Sample Formation

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
76-55452	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54622	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
76-55454	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
76-55453	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

MISSISSIPPIAN Bethel Formation

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SC	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
75-55767	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55717									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55716	X	X				X										X	X	X											

MISSISSIPPIAN Borden Group

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
10				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
9				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
8				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
7				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
5				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
6				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
4				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
3				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
2				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
1				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
75-55316	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
75-55315	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
75-55564	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
76-55252	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
76-55251	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X				X	X	X			
76-55250	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			

MISSISSIPPIAN Locust Point Formation

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
74-54611	X	X		X		X										X	X	X						X	X	X			
74-54601	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
74-54600	X	X		X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55715	X	X		X		X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						

MISSISSIPPIAN New Providence Shale

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
75-55731	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55505	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
76-55530	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
76-55529	X	X		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						

MISSISSIPPIAN New Albany Shale

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
74-54621				✓		X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
75-55040	X	X	X	X	X	X	X									X	X	X					X						
75-55043	X	X	X	X	X	X	X									X	X	X					X						
75-55042	X	X	X	X	X	X	X									X	X	X					X						
75-55041	X	X	X	X	X	X	X									X	X	X					X						

DEVONIAN Antrim Shale

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
75-55732	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

DEVONIAN New Albany Shale

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SC	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
13				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
12				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
75-55712	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55524	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
75-55487	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55486	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

ORDOVICIAN Whitewater Formation

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
76-55055									X	X	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X	X
76-55[illegible]	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

ORDOVICIAN Dillsboro Formation

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SC	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
15				X		X	X	X	X	X	X	X	X	X			X							X		X	X	X	X
74-54234	X	X				X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X						
74-54832	X	X				X			X	X	X	X	X	X	X				X	X	X	X	X						
75-55440	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
75-55291	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55583	X	X		X	X	X												X											

ORDOVICIAN Kope Formation

Laboratory Number	SDI1	SDI2	SD2D	SD5D	SD2S	SD5S	FN	MS	PL	QL	PI	PSA	PSI	PCL	PCOL	WD	DD	AMC	SG	PH	SL	SH	XY	PM	WDI	DDI	CBR1	CBR2	AS
74-54305	X	X							X	X	X	X	X	X	X			X	X	X	X	X							
75-55018	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
75-55308	X	X																X											
75-55307	X	X																X											
75-55206	X	X																X											
75-55305	X	X																X											
75-55304	X	X																X											
75-55303	X	X																X											
75-55302	X	X																X											
75-55265	X	X																X											
75-55678	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
76-55554	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

APPENDIX C

PROGRAM FOR PRINTING DATA ON DATA CARDS

```
 06/05/76   UNIVERSITY OF MINNESOTA FORTRAN FORSCE VERSION MOD NO. 3  FS44.3     07/21/76. 13.56.22.
        MNF(ID)
 000000R       1.          PROGRAM DATA(INPUT,OUTPUT)
                     CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
                     C     THIS PROGRAM READS THE DATA OF    C
                     C     THE LABORATORY TESTS ON SHALES    C
                     C     DONE BY ISHC, AND PRINTS IT       C
                     CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
 002051B       2.          DO 200 K=1,41
 002052B       3.          PRINT 10
 002057B       4.       10 FORMAT(1H1)
 002057B       5.          READ 20,NO,CO,GST1,GST2,GSE1,GSE2,GST1,GST2,PHU1,PHU2
 002075B       6.       20 FORMAT(I10,A10,A10,A5,A10,A5,A10,A5,A10,A5)
 002075B       7.          PRINT 25,NL,CO,GST1,GST2,GSE1,GSE2,GST1,GST2,PHU1,PHU2
 002113B       8.       25 FORMAT(30X,'LABORATORY NUMBER - - - - - - - - - - - - ',I10,/,30X,'C
                          1OUNTY - - - - - - - - - - - - - - - - - - ',A10,/,30X,'GEOLOGICAL SYS
                          2TEM - - - - - - - - - - - - - ',A10,A5,/,30X,'GEOLOGICAL SERIE - - -
                          3- - - - - - - - - ',A10,A5,/,30X,'GEOLOGICAL STAGE - - - - - - - -
                          4- - - ',A10,A5,/,30X,'PHYSIOGRAPHIC UNIT - - - - - - - - - - - ',A1
                          50,A5)
 002113B       9.          READ 30,NO,SDI1,SDI2,SD25,SD50,SE25,SD55,FN,FS
 002130B      10.       30 FORMAT(I10,8F5.1)
 002130B      11.          PRINT 35,SDI1,SDI2,SD25,SD25,SD50,SD55,FN,FS
 002144B      12.       35 FORMAT(/,30X,'SLAKING INDEX CYCLE 1 - - - - - - - - - - ',F5.1,/,30X
                          1,'SLAKING INDEX CYCLE 5 - - - - - - - - - - ',F5.1,/,30X,'SLAKE DURA
                          2BILITY INDEX 200 REV DRY - - ',F5.1,/,30X,'SLAKE DURABILITY INDEX
                          3 200 REV SOAKED - ',F5.1,/,30X,'SLAKE DURABILITY INDEX 500 REV DRY
                          4 - - ',F5.1,/,30X,'SLAKE DURABILITY INDEX 500 REV SOAKED - ',F5.1
                          5,/,30X,'FISSILITY NUMBER - - - - - - - - - - - - ',F5.1,/,30X,'MODI
                          6FIED SOUNDNESS TEST (PERC LOSS) - - ',F5.1)
 002144B      13.          READ 40,NO,TEX1,TEX2,ASH,PL,LL,PI,PSA,PSI,PCL,PCOL
 002163B      14.       40 FORMAT(I10,A10,A5,A10,3F5.1,4I5)
 002163B      15.          PRINT 45,TEX1,TEX2,ASH,PL,LL,PI,PSA,PSI,PCL,PCOL
 002201B      16.       45 FORMAT(/,30X,'TEXTURAL CLASSIFICATION - - - - - - - - - ',A10,A5,/,3
                          10X,'AASHTO CLASSIFICATION - - - - - - - - - - ',A10,/,30X,'PLASTIC L
                          2IMIT (PERC) - - - - - - - - - - ',F5.1,/,30X,'LIQUID LIMIT (PERC) -
                          3 - - - - - - - - - ',F5.1,/,30X,'PLASTICITY INDEX (PERC) - - - - -
                          4 - - - ',F5.1,/,30X,'SAND (PERC) - - - - - - - - - - - - - - - ',I5,
                          5/,30X,'SILT (PERC) - - - - - - - - - - - - - - - ',I5,/,30X,'CLAY (P
                          6ERC) - - - - - - - - - - - - - - - ',I5,/,30X,'COLLOIDS (PERC) - - -
                          7 - - - - - - - - - - ',I5)
 002201B      17.          READ 50,NO,WC,ZD,AMC,SG,PH,SL,SH,XY,MD,PR,WD1,DD1,CCM1,CCM2,NS
 002225B      18.       50 FORMAT(I10,3F5.1,F5.2,4F5.1,I1,F4.1,5F5.1)
 002225B      19.          PRINT 55,WD,DD,AMC,SG,PH,SL,SH,XY
 002241B      20.       55 FORMAT(/,30X,'NATURAL WET DENSITY (LB/CUFT) - - - - - ',F5.1,/,30X
                          2,'NATURAL DRY DENSITY (LB/CUFT) - - - - - ',F5.1,/,30X,'NATURAL MO
                          3ISTURE CONTENT (PERC) - - - - ',F5.1,/,30X,'SPECIFIC GRAVITY - -
                          4- - - - - - - - - ',F5.2,/,30X,'PH - - - - - - - - - - - - - - - - -
                          5- - - ',F5.1,/,30X,'SHRINKAGE LIMIT (PERC) - - - - - - - - - ',F5.1
                          6,/,30X,'LINEAR SHRINKAGE (PERC) - - - - - - - - ',F5.1,/,30X,'LOSS
                          7 OF IGNITION (PERC) - - - - - - - - - ',F5.1)
 002241B      21.          GO TO (100,110,120,130),MC
 002241B      22.  100     PRINT 140
 002252B      23.  140     FORMAT( 30X,'MOISTURE DENSITY RELATIONS DONE ON - - FINES NO. 4
                          2MATERIAL')
 002252B      24.          GO TO 70
 002252B      25.  110     PRINT 150
 002257B      26.  150     FORMAT( 30X,'MOISTURE DENSITY RELATIONS DONE ON - - FINES 0.74 I
```

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                              2PCH MATERIAL')
  002257P      27.             GO TO 70
  002257P      28.    120      PRINT 160
  002264P      29.    160      FORMAT(  30X,'MOISTURE DENSITY RELATIONS DONE ON  - - SEE LABORATO
                              2RY REPORT')
  002264P      30.             GO TO 70
  002264P      31.    130      PRINT 170
  002271P      32.    170      FORMAT(  30X,'MOISTURE DENSITY RELATIONS DONE ON  - - NOTHING INDI
                              2CATED ON REPORT')
  002271P      33.    70       PRINT 60,WD1,DD1,PM,CBR1,CBR2,AS
  002303P      34.    60       FORMAT(  30X,'MAXIMUM WET DENSITY (LB/CUFT) - - - - - ',F5.1,/,30X
                              2,'MAXIMUM DRY DENSITY (LB/CUFT) - - - - - ',F5.1,/,30X,'OPTIMUM MO
                              3ISTURE CONTENT (PERC) - - - - ',F5.1,/,30X,'AS COMPACTED CBR (PERC
                              4) - - - - - - - - - ',F5.1,/,30X,'AFTER SOAKING CBR (PERC)  - - - -
                              5- - - ',F5.1,/,30X,'AVERAGE SWELL (PERC)  - - - - - - - - - ',F5.1
                              6)
  002303P      35.     200     CONTINUE
  002305P      36.             STOP
  002310P      37.             END
```