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# Diggability of Plains Overburdens with Bucket Wheel Excavators

by

©

Roman M.Krzanowski

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Diggability of Plains Overburdens with Bucket Wheel Excavators submitted by Roman M.Krzanowski in partial fulfilment of the requirements for the degree of Master of Science in Mining.

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# ABSTRACT

The goal of this study was to determine the feasibility of mining the plains overburdens with Bucket Wheel Excavators (BWE), in particular to define the diggability of overburden formations.

Up to now, both the production rates and overburden thickness in Plains mines made the traditional mining methods such as draglines shovels and trucks, the most feasible for economic reasons. However, as mines are becoming deeper the need for new excavation techniques , assuring high productivity at low cost, is growing. One such technique is continuous excavation as facilitated by the use of bucket wheel excavators.

Despite their huge dimensions the performance of bucket wheel excavators is very dependent on geotechnical properties of the dug material. This is why the primary problem in a BWE selection is the determination of the required digging forces or more generally, the definition of material diggability.

This study defines digging properties of selected overburdens by extensive geotechnical testing of samples. Results of the tests were correlated with material cuttability and diggability thus permitting development of the diggability classification for studied overburdens and also allowing for formulation of mathematical relations between cuttability and some other rock properties. Correlation analysis of the test results and material

cuttability permitted definition of rock properties which best describe the rock cuttability and diggability.

The following conclusions are drawn from the study:

1. Most of the tested plains overburdens can be mined with Bucket Wheel Excavators.
2. Cutting resistance of tested materials is highly correlated with rock strength (defined in the study by point-load test and NCB (National Coal Board) cone indenter test results) and with slake-durability index.
3. Specific cutting resistance related to the length of the cutting blade is better correlated with geotechnical properties of material than the specific cutting resistance related to the cross-section area of the cut.
4. Identified correlations between the rock properties and its cutting resistance are useful in predictions of material cuttability and diggability; however, further verification of these correlations is required.

The study also identifies directions of further research related to the definition of material diggability. The most important of these appears to be the development of correlations between the material diggability and shock wave velocity. This method is likely to allow for quantification of material structure in addition to its strength.

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# 1. Formulation of the problem

## 1.1 General remarks

Selection of the BWE is a complex process in which one has to consider technical, economical and site specific aspects of the mining project.

The importance of selecting a right BWE is emphasized by the fact that the BWE is a main link of a mine production system. Its cost and size does not allow for quick modifications or replacement. Mistakes in BWE selection can cause major problems during mine operations. An over-estimation of difficulties will result in oversized design of a BWE, low utilization and excessive capital and operating costs. On the other hand underestimation of difficulties will cause production slowdown, frequent equipment breakdowns caused by excessive wear of undersized parts, low production rates and high operating costs.

Correct selection of a BWE calls for a proper match of digging forces available on the bucket with the digging resistance of the excavated material. Whereas the specific digging forces on the bucket can be calculated from the BWE technical parameters,[1] digging resistance of the material is a very elusive value. Satisfactory solution to BWE selection problem in Europe was only possible after years of studies combined with experience of manufacturers. In case

---

[1] There are many empirical equations allowing for calculation of digging forces based on: power on the wheel, wheel diameter, bucket dimensions. For detailed description of the problem see (22, 35)

of new mining ventures, where time constraints do not allow for extensive studies and where there is no previous experience with this type of equipment misapplications of a BWE are possible (34).

## 1.2 Diggability,definition and monitoring

The digging process can be described on micro and macro scales.

On micro scale the digging process is reduced to the discussion of the cutting forces on the edge of the individual bucket and a friction between the cutting tool and cut material.

On macro scale cutting and friction forces on simultaneously digging buckets are summarized and considered as one resultant force called total cutting resistance or more properly - digging resistance.

The difference of these two approaches lies in a fact that when in micro scale the cutting force is a resultant of material strength and friction resistance only, on macro scale apart from these two factors the following components of a digging process have to be considered:

- lifting force
- influence of structural features of dug formation
- dynamic character of a digging process.

to list the most important.

Experience shows, that these factors can have a major influence on determination of diggability.

Figure 1 presents cutting process on micro scale (as defined by Nitshimatsu) related to the edge of a cutting knife.

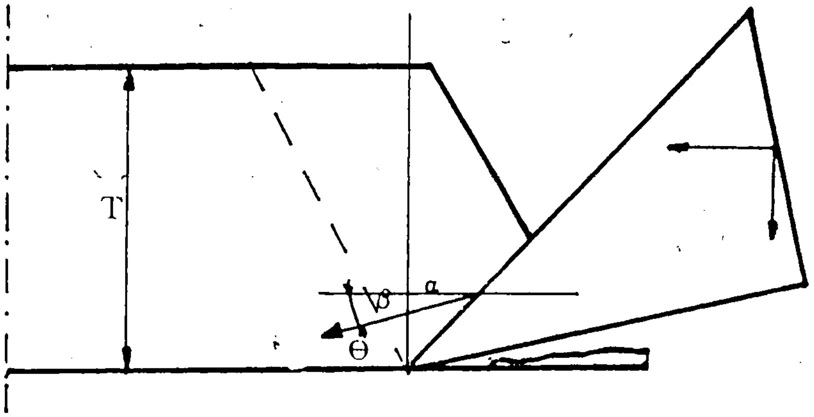
On macro scale cutting forces on individual buckets are summarized, what is only possible for the specific case where all the parameters of the equipment as well as of the digging process are known.

Faced with the problem of estimation of digging forces from geotechnical parameters of the dug formation one has to bear in mind that according to Kolkiewicz " ... attempt to determine the digging forces from estimation of various geotechnical tests failed because of their local character".

In that case, when both macro and micro scale approaches fail for unadequacy of considered factors, determination of digging forces has to be reduced to the evaluation of diggability, in other words to qualitative classification of digging resistance of the formation by comparison of its geotechnical properties with geotechnical properties of the material with known digging forces.This approach is reffered to as a simplified macro scale approach as it, to some degree, determine the digging forces in the understanding of a macro scale approach.

For this comparison, only factors which characterize the dug formation and, in the same time, are possible to quantify have to be considered. Among them are :

- Rock and soil stength
- formation structural features



n - Stress Distribution factor
S - Shear Strength
K - Coefficient of Internal Friction
T - Depth of Cut
$\beta$ -
$\Theta$ - As of Figure
$\alpha$ -

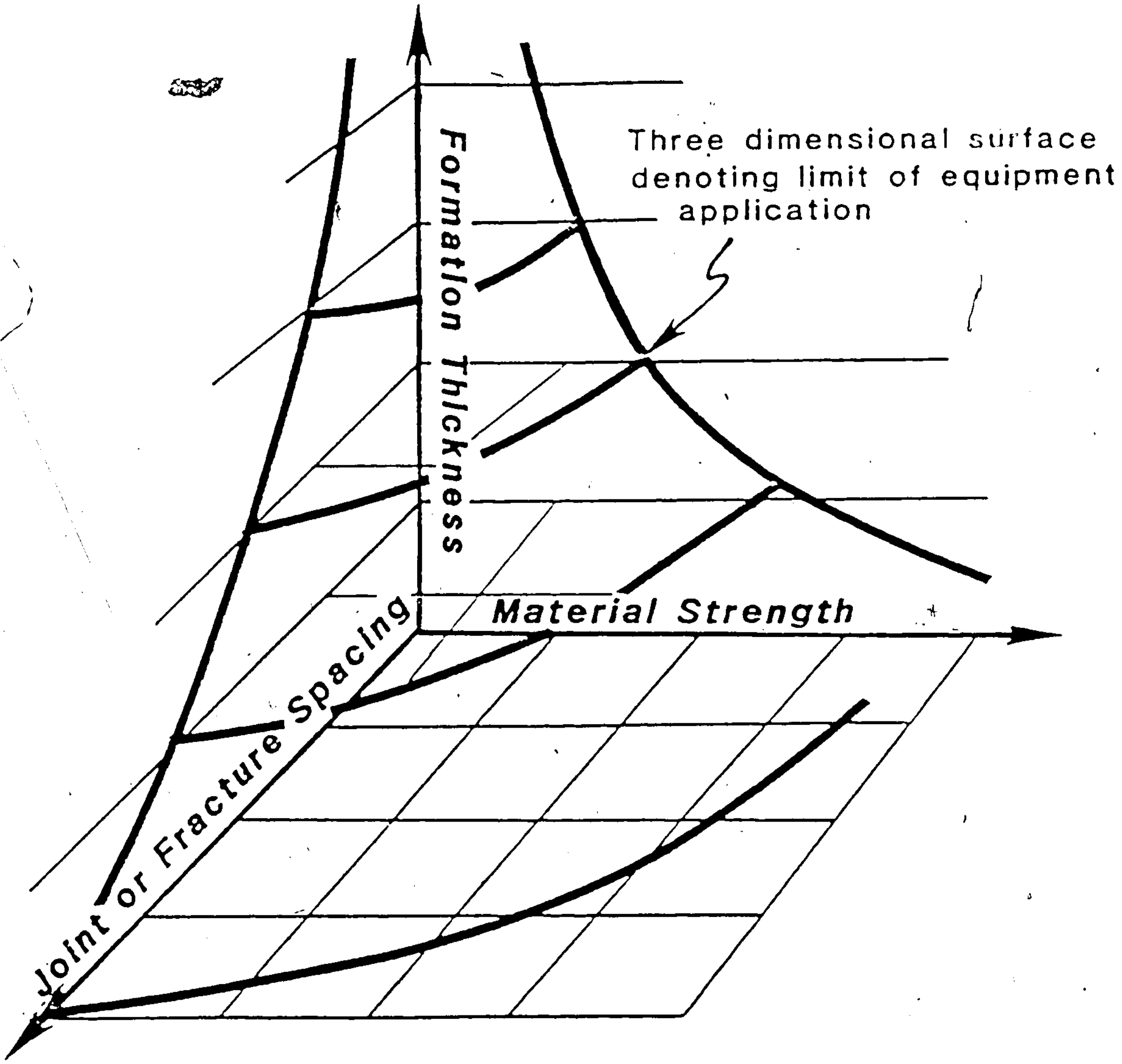
Cutting Force

$$Fc= \frac{2}{N+1} * S * t * \frac{\cos K}{1- \sin(K- \alpha + \beta )}$$

Total Cutting Force

$$Ft= Fcut + Ffric$$

FIGUR 1. Cutting Model



Data points plotting above the surface would indicate a field condition where the equipment should not be applied. In reality such a surface would have a thickness indicating a zone of marginal application.

FIGURE 2. Three dimentional cuttability plot

- weather conditions
- presence of irregularly located boulders,buried tree trunks.

To sum up, simplified macro scale approach is used for diggability studies conducted in the early stage of mine planning where there is no data on the equipment to be used. Macro scale approach is used when the equipment and digging process related studies are known. Micro scale approach is rather not significant is diggability studies.

Further discussion of the digging problem in this study would be therefore related to the simplified macro scale approach to the digging process.

The following definitions are introduced to facilitate understanding of the digging process:

**DIGGING RESISTANCE** - is defined as a total force needed on the wheel of a BWE during digging. The units of digging resistance are ratio of digging force to the area of a chip cross-section or to the length of a cutting tool( bucket edge) and are a measure of a specific digging resistance. Digging resistance determined qualitatively is called **Diggability** and is assigned the following descriptive terms: easy diggable , diggable, difficult to dig, not diggable. To some extend it is possible to use digging resistance and digability as synonyms.

**DIGGING FORCE** is defined as a total force applied at the wheel cutting teeth needed to to overcome digging resistance.

**CUTTING FORCE** is defined as a force required to cut the sample in a test designed to characterize digging process such as the O&K cutting test or DEMAG test.

The studies to determine the relation of digging resistance to the geotechnical properties of material done so far follow two directions:

1. Theoretical studies which depend on the formulation of a mathematical model of the digging process allowing for solution of cases for which a model was developed (11, 27).
2. Empirical models which depend on the determination of digging resistance on the basis of experiments.

Theoretical studies of the problem allow for explanation of some aspects of the digging process, however they do not allow for reliable prediction of the generated forces. More attention must therefore be paid to experiments. Here two approaches can be distinguished: experimental measurement of digging resistance by monitoring digging forces on a BWE, (the method gives accurate and reliable results close to the real values of digging resistance but is difficult and costly to implement) and investigations of cutting resistance of samples taken from the dug material(the method monitors only one component of digging resistance, i.e. material strength)

In spite of the differences between cutting and digging resistance it is possible to determine the digging resistance from cutting resistance. The method involved are discused by Kolkiewicz (22), Gorylewicz (15), Colleman (4) and Rasper (34). To allow for comparison of digging and cutting resistance the common units are introduced. Specific digging resistance is defined as being related to the length of an engaged cutting edge (kN/m) or to the cross-section area of a chip (kPa). Cutting resistance is referred to the length of a cutting tool or a circumference of a cut (kN/m) or to the cross-section area of a cut (kPa). Those relations are preferred as they have a direct reflection in BWE parameters. Other methods define the cutting resistance in units of uniaxial compressive strength (referred to the area of cross-section perpendicular to the cutting force).

Over the past few years several testing methods for cuttability determination have been developed, implemented, and used by major BWE manufacturers: Krupp, Orenstein and Koppel and Demag Lauchhammer.

**Krupp** estimates cutting resistance of material in the test where a cube-shaped sample (0.05m x 0.05m x 0.05m) is compressed between two platens, perpendicularly to sample stratification. Figure 3 presents this method. The results of Krupp test compared with BWE performance can be used to classify rocks for their diggability.

**Orenstien & Koppel** use the test as presented on figure 4. The testing wedge of 0.065 m length, 0.05 m width and 34 tip angle is pressed into a sample embedded in a sandbox. The test can be carried out on the cylindrical samples of a diameter of 0.15m and 0.15m long or on cubes 0.15m x 0.15m x

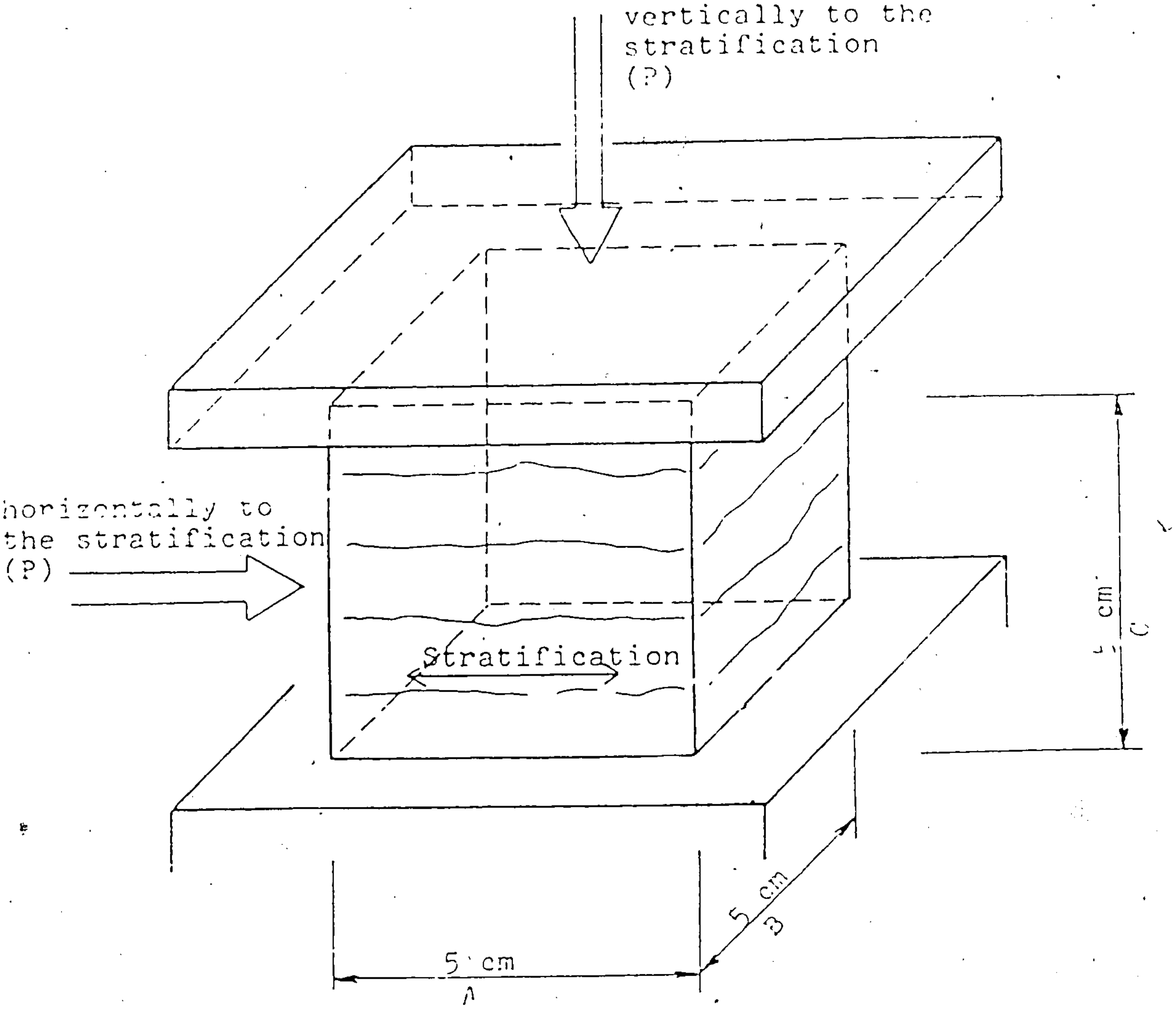


FIGURE 3. KRUPP testing method.

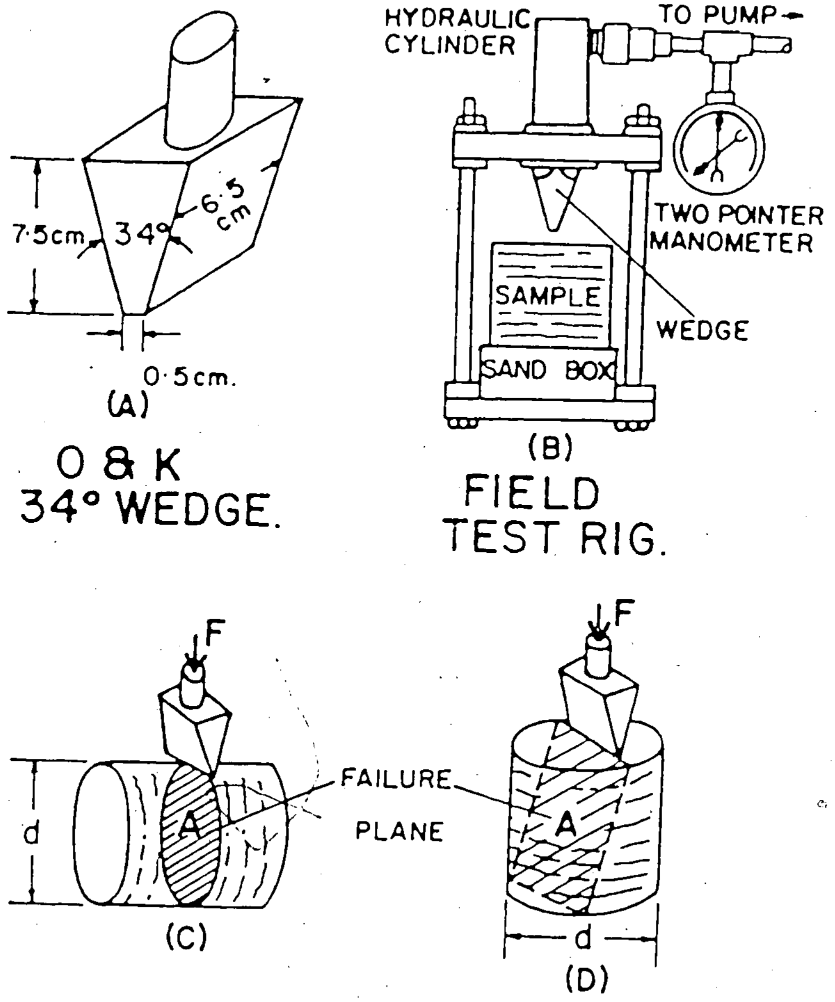


FIGURE 4. O & K cutting resistance test.

0.15m.

Further tests can be carried out on parts of the samples remaining after the first test run. In this test the splitting force, the length of the cut and the area of failure plain A are monitored. Three values are reported as the test results:

- value of splitting (cutting) force per area of the cut,
- value of splitting force per length of the cut,
- value of splitting force per length of the cutting wedge.

This test gives the value of cutting resistance in the same units as those used for definition of digging resistance. For its portable equipment and simple procedure, this test is most frequently used in cuttability determination. The results of this test were used to develop the classification in the study done by CANMET [2] (44).

**Demag Lauchhammer** testing equipment measures the cutting forces during simulation of a digging process. The test sample is located on the table of a parallel-planning bench and is moved relatively to a stationary cutting edge. The test set-up permits the sample to be cut into any desired direction. The cutting speed may be varied between 5 and 50m/min.It is measured and recorded through a tacho-generator (Figure 5). The approximate sample dimensions are 1 x 1 x 2 m. The samples are embedded in concrete and attached to the base frame. Test results,

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[2] Canada Centre for Mineral and Energy Technology (CANMET) in Calgary.

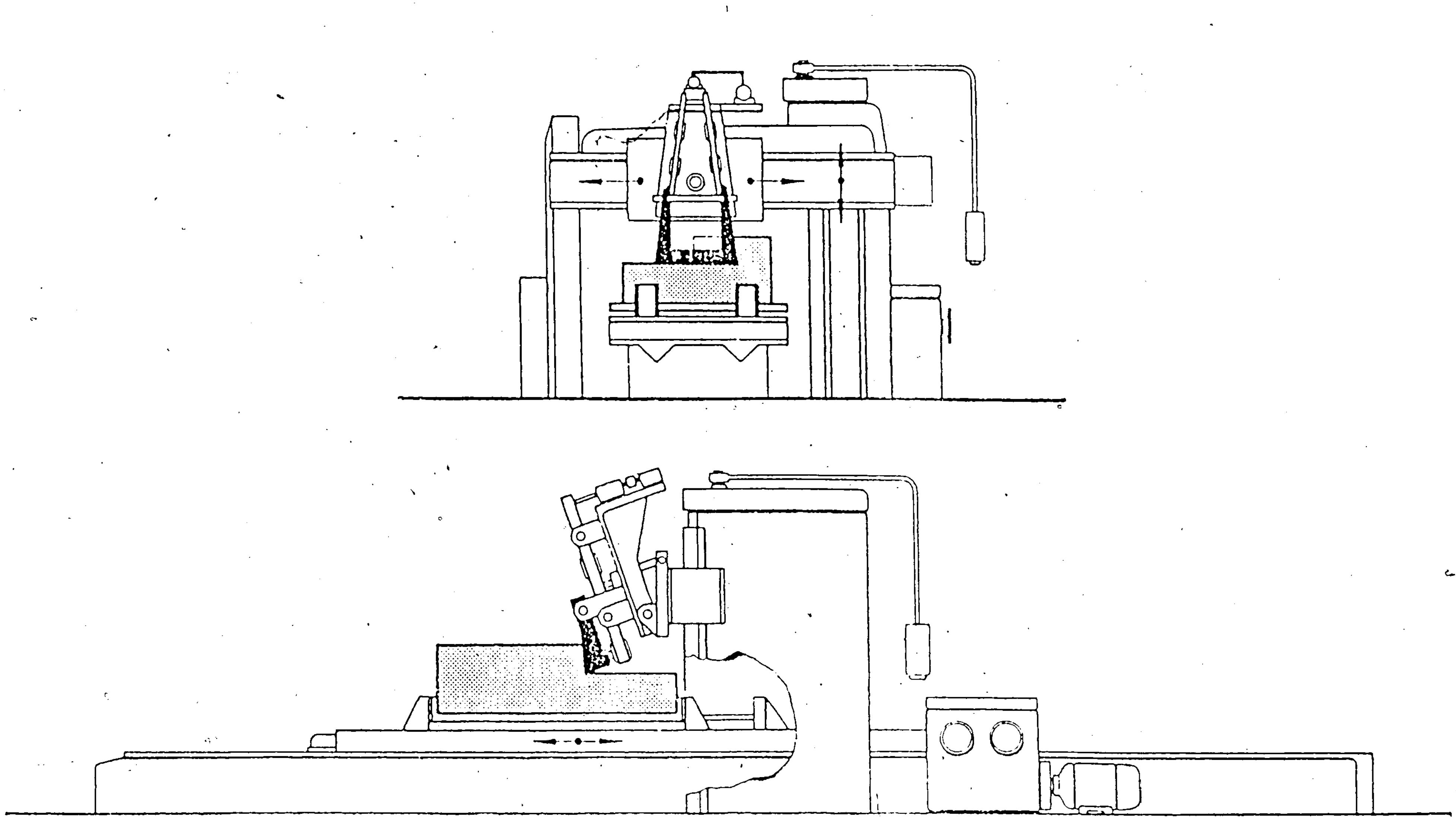

FIGURE 5. DEMAG testing equipment

cutting force per area of cut or length of cut, are derived from the graph of cutting forces recorded during the test. The Demag method does not seem to be very popular at present and its applications are not known.

All tests presented above define the rock strength interpreted as cutting resistance but tell little about diggability of material formed from the tested rocks. As shown earlier, the digging resistance is a function of three variables, only one of these defined by the described tests. Two other variables i.e. the formation thickness and fracture spacing are not quantified.

The only practical way to relate the tested rock strength with its diggability is to use rock classifications, where empirically determined rock diggability is correlated to its strength. If used carefully, this approach may by helpful in a BWE

Several diggability classifications were proposed. Unfortunately, they differ substantially. Some use uniaxial compression strength as classification factor while others use cutting resistance or digging resistance. But usually, it is only by a reference to the short petrographic description of each class that a rock with defined cuttability can be assigned certain class of diggability.

### 1.3 Review of diggability classifications

Diggability classifications discussed in this chapter were developed in Europe (15,22,23) and Australia (4).

Gorylewicz (15) classifies the overburdens in an open pit sulphur mine in Tarnobrzeg (central Poland) as follows:

- **class I and II** - loose rocks with Protodiakonow index fp<0.5 and specific digging force Fd <40 kN/m. [3]
- **class III and IIa** - medium compact rocks with fp = 0.5 to 1.0 and Fd = 40 to 50 kN/m.
- **class IV and V** - compact rocks with fp = 1.0 to 4.5 and Fd = 75 to 200 kN/m.
- **class VI and VII** - very compact rocks with fp = 4.5 to 12.0 and Fd > 200 kN/m.

Experience shows that rocks in class I to V can be dug without any preparation (fragmentation, loosening, etc.).

Kolkiewicz (22) proposes the rock diggability classification based on the experience gained in the lignite mines of central Poland (Table 1). This classification is based on the *nominal digging resistance*, defined as an average resistance recorded during digging of a chip with the cross-section area 0.175 m (0.35 m x 0.50 m). This classification divides rocks into five classes :

- Class I and II described as rocks diggable or fairly diggable.
- Class III and IV as difficult and extremely

---

[3] fp - Protodiakonow index is defined as 0.01 x ( uniaxial compressive strength).
Fd - is a specific digging force as defined by measurements on an operating excavator.

| DIGGABILITY CLASS | CLASS DEFINITION | NOMINAL DIGGING RESISTANCE | | ROCK TYPE |
|---|---|---|---|---|
| | | Fl kN/m | Fa kPA | |
| I | Easy diggable | 0-20 | 0-170 | sands<br>gravel |
| II | Diggable | 20-40 | 170-360 | sandy clays |
| III | Difficult to dig | 40-60 | 360-540 | clays, loams |
| IV | Very difficult to dig | 60-90 | 540-800 | hard shale |
| V | Diggable only with special equipment | >90 | >800 | limestone |

TABLE 1. Diggability scale by Kolkiewicz.

difficult to dig.

- Class V as class requiring special digging equipment.

Kozlowski (23) improves this classification adding to each class the geotechnical description (moisture and fines content - Table 2) of the dug formation. Although moisture and fines content do not reveal correlation with diggability, they undoubtly help to characterize the dug material.

Presented classifications use the digging resistance as a scale base nevertheless the Protodiakonow index used by Gorylewicz and geotechnical description of dug formation in Kozlowski's scale provide some insight into properties of materials in each diggability class.

Example of comparison between the rock strength as determined in tests and rock diggability is given by Coleman (4) in his feasibility study analysing the possibility of BWE application in Leigh Creek Coalfield in South Australia.

The overburden there is formed of low strength sandstones, loose sands and hard partings (low to medium strength sandy mudstones). The results of point-load test carried out on these rocks and compared with the fracture spacing factor of overburden formations form diggability classification. Author suggests that this classification is very tentative and is more valuable as an approach rather than as a mathematical model. Nevertheless some interesting conclusions can be drawn:

| CALSS | CLASS DEFINITION | NOMINAL DIGGING RESISTANCE | | ROCK TYPE | CLAY FRAC | MOIST> |
|---|---|---|---|---|---|---|
| | | Fl kN/m | Fa kPa | - | % | % |
| I | Easy diggable | 0-20 | 0-170 | loose clayely | 10 - 30 | 6 - 20 |
| | | | | loamy | 30 | 18-50 |
| II | Diggable | 20-40 | 170-360 | clayely | 10-30 | 6-20 |
| | | | | loamy | 30 | 18-50 |
| III | Difficult to dig | 40-60 | 360-540 | clayely | 10-30 | 6-20 |
| | | | | loamy | 30 | 18-50 |
| IV | Very difficult to dig | 60-90 | 540-800 | clayely | 10-30 | 6-20 |
| | | | | loamy | 30 | 18-50 |
| V | Diggable only with special equipment | >90 | >800 | | | |

TABLE 2. Diggability scale by Kozlowski.

1. Rock diggability is invertly proportional to the rock strength (as determined by tests) and fracture spacing factor.
2. It is possible to determine "zones of BWE applicability". In other words, knowing the geotechnical properties of a formation, one can determine the BWE applicability by definition of formations which can be mined by a BWE without or only with some additional help of rock fragmentation.

The analysis of diggability of overburdens of Leigh Creek Coalfield is based on the analysis of diggability and geotechnical properties (material strength and fracture spacing) of formations in Ekibastus (29), Ptolemeis and Neyveli (35) mines, known for their extremely difficult digging conditions.

The only study of rock diggability related to Plains materials was done by CANMET(46). The authors performed Orentein & Koppel cutting test on samples collected from open pit coal mines in Western Canada and compared the results with similar tests done in mines all over the world. The following classification of rock diggability [4] was proposed:

1. 0- 1000 kPa - can be dug with BWE,
2. 1000-1500 KPa - diggable with certain loss of productivity,
3. 1500-2400 KPa material fragmentation required,

---

[4] Classification uses rock specific rock cutting resistance related to the cut area as defined in O & K test.

4. more then 2400 KPa - not diggable except special conditions.

CANMET report give conclusion that a classification based on material strength gives only partial information about its diggability as diggability is also influenced by structural features of geological formations.

Comparison of rock strength classification with BWE performance was undertaken by Strzodka (40). He uses rock classification based on the Protodiakonov index and assumes that specific digging resistance can be derived from the Protodiakonov index by the formula:

$$Fl=fp * 100 \quad kN/m$$

According to Strzodka modern BWE can operate in rocks of up to 1500 kN/m (digging resistance) or up to 1.5 of Protodiakinov index (see classification of rock strength according to Protodiakonow - Table 3).

The presented review of the curren literature related to the topic allows for the following conclusions:

1. There is no single, commonly accepted and reliable classification of rock diggability.
2. Rock diggability cannot be defined by a single factor; it should be perceived as a set of geological and geotechnical properties of dug formation limiting BWE applicability .
3. In spite of the difficulties in quantifying some components of rock diggability, it is possible to define the diggability classification, however its

| CLASS | STRENGTH DEGREE | ROCKS | PROTODIAKONOV INDEX | COMPRES. STRENGTH |
|---|---|---|---|---|
| - | - | - | - | MPa |
| I | rocks of max strength | dense basalts | 20 | 200 |
| II | rocks of high strengh | granite | 15 | 150 |
| III | hard rocks | had sandstone | 10 | 100 |
| IV | fairly hard rocks | common snadstone | 6 | 60 |
| V | rocks of medium strength | hard clayely shale | 4 | 40 |
| VI | fairly soft rock | soft shale<br>chalk | 2 | 20 |
| VIa | like VI | broken shale<br>pit coal | 1.5 | 15 |
| VII | soft rocks | hard clay<br>pit coal | 1.0 | 10 |
| VIIa | like VII | sandy clay | 0.8 | - |
| VIII | earthy rocks | peat, loam<br>sand | 0.6 | - |
| IX | loose rocks | sand, brown coal | 0.5 | - |
| X | silty rocks | silty soils | 0.3 | - |

TABLE 3. Classification of rock strength according to Protodiakonov.

applicability is limited.

4. By comparison of different classifications some insight can be gained into rock diggability but final conclusions have to be supported by the geological and geotechnical investigations of the site in question.
5. Diggability classifications should consider, apart from the rock strength, structure of material which could be represented by shock wave velocity as in rippability scale (5), or general rock classification proposed by Scoble (38).

## 1.4 Outline of the project

The goal of the project was to explore the possibility of a BWE application in Plains coal mining or in other words to asses diggability of Plains overburdens.

It was to be accomplished by extensive geotechnical testing of material samples from selected overburdens and comparing these to the available rock diggability classifications to allow the estimation of digging conditions in the area under study. The study was not expected to give a decisive answer but to provide a better understanding of the problems a BWE can face once introduced in Alberta.

The second goal of the project was to define the rock properties correlated with its cutting resistance. Any correlations found would help in prediction of diggability.

# 2. Material and test selection

## 2.1 Characteristics of testing materials

Three major physiographic regions can be distinguished in Alberta (31):

1. The Interior Plains.
2. Foothills region.
3. Rocky Mountain region.

The Interior Plains is a region of low to moderate relief underlain, (in northern part of Alberta) by Devonian carbonate and evaporate rocks and in the remaining part by Createaceous and Tertiary sandstones and shales formations dipping to the South and West.

Foothills are built from folded Jurassic and Cretaceous sandstone and shale formations while Rocky Mountains are composed of carbonate and granite formations ranging in age from Precambrian to Triassic.

Alberta, except for the Rocky Mountain region, is covered by unconsolidated glacial sediments thick from a few inches to several hundred feet. These formations consist mainly of sand, gravel, clay, and mixture of all these materials - a till.

Coal deposits occur in the Plain and Foothills regions (Figure.6). Most of the coal overburdens in this area is formed by rocks classified as transitive rocks (12,24,25,43).

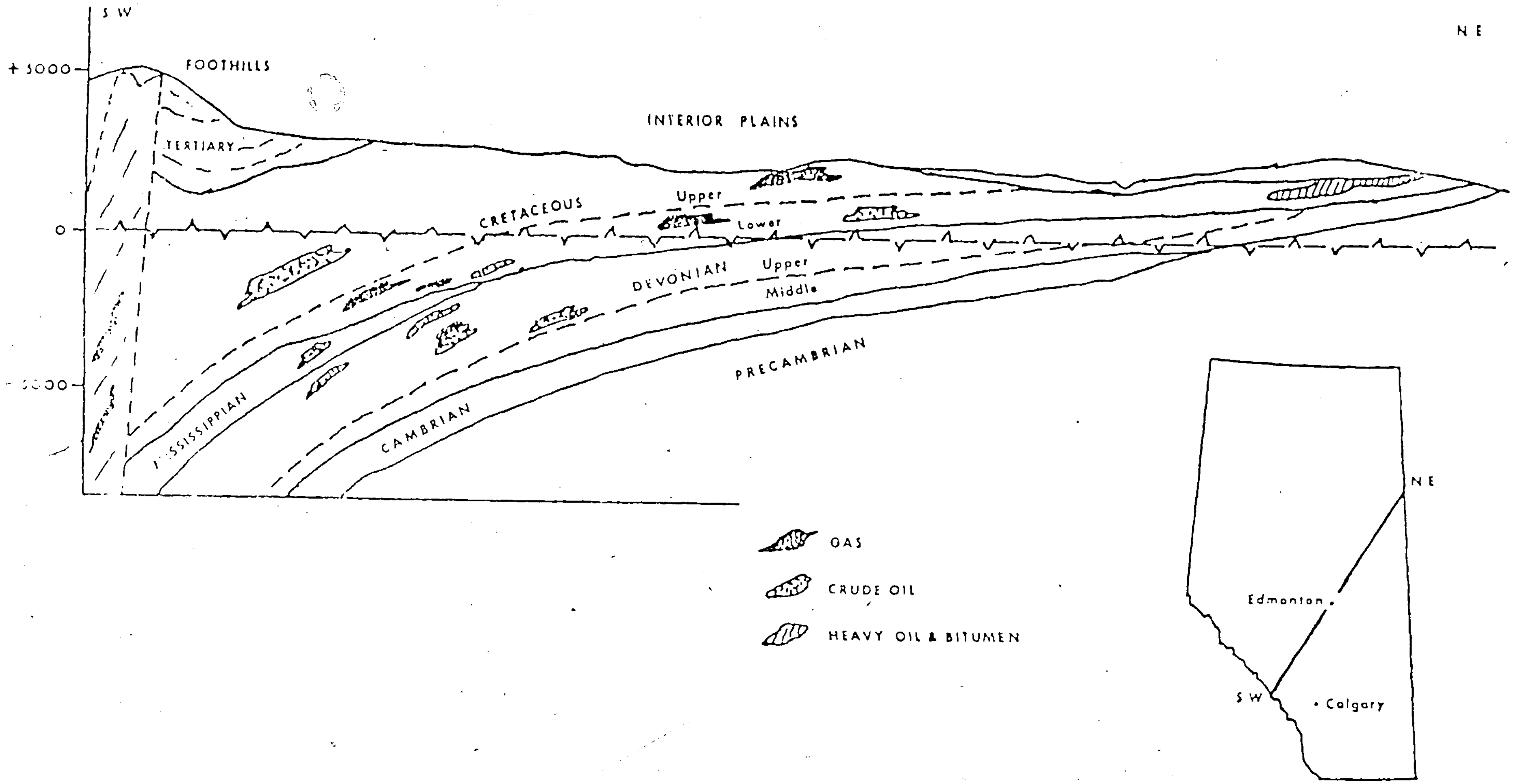

FIGURE 6. Alberta Schematic Cross Section.

This kind of material forming 50% to 70% of sedimentary rocks on the Earth crust is not readily classified as either soil or rocks. It is composed primarily of clay and silt-sized particles.On the basis of observed distribution of particle size, mineralogy, type and degree of bonding between grains, these materials have been assigned several names. Clay, shale, siltstone, mudstone, claystone are only but a few.

Transitional materials, in general, have low durability, low shear strength and high swelling or rebound potential. The presence of montmorillonites and other expandable clay minerals tends to increase the plasticity of transitional materials(19). Because of the variety of exhibited properties transitive rocks are very difficult to characterize. Many attempts have been made to differentiate them but no agreement has been reached yet on the commonly accepted classification. Shales (name adopted here for all transitive rocks) can be subdivided into two major groups:

1. Compacted or "soil-like" shales.
2. Cemented or "rock-like" shales.

Generally speaking, most of the compacted shales can be excavated with modern earth moving equipment. While some of the cemented shales can be excavated likewise, it is usually more economical to excavate these harder shales with fragmentation.

The properties of shales change entirely when they undergo metamorphism (heat, pressure and chemical changes).

They become harder and are called argillite, phyllite, shist or etc.

Two ways of characterization of shales are possible: geological and engineering. geological characterization is usually not precise enough for engineering purposes but it gives some insight into the shale properties and for this reason it is briefly discussed below.

## Significant geological properties.

### Grain size.

Shales are often classified as clayey, silty or sandy, depending on grain size distribution. But as the analysis of shales to determine particle size distribution is very difficult, use of grain size distribution as the single basis of shales characterization, is not frequent.

### Chemical and mineralogical components.

Tourtelot (1962) revealed that chemical composition of shales is very similar throughout the world. The average shale contains approximately 60% SiO ; 10% Al O , 5%-10% Fe O ; 2% Mg; 5%-8% K O and other salts and elements.Siliceous shales contain up to 85 % Si0 and calcareus shales from 25% to 35% of Ca CO .

Because the average chemical composition of all shales is so similar, it cannot be used for their characterization or identification.

In the analysis of shale mineralogical composition, it is important to identify as accurately as possible, the predominant clay mineral comprising the clay fraction of a shale.

A mineralogical study of the clay fraction of shales is important from engineering view point and can be used to characterize them. Shales which have the clay fraction containing high percentage of illite and montmorillonite generally have lower shear strength,higher swelling potential and other undesirable properties than do shales with clay fractions consisting predominantly of kaolinite, chlorite or only low percentage of illite montmorillonite or other mixed-layers minerals.

**Fissility.**

Shales exhibit different degrees of fissility or breaking characteristics which have been used for classification and identification purposes. Numerous descriptive terms such as blocky, slabby, flaggy, platty and papery have been used to describe fissility of shales. Three dominant types of breaking characteristics are distinguished:-

1. massive,
2. flaggy,
3. flaky.

**Massive shales** have no preferred direction of cleaning or breaking. Most of the fragments are blocky. The claystones and some clay shale exhibit this breaking characteristic and often break into irregular conchoidal blocky shapes like a popcorn.

**Flaggy shales** split into fragments of varying thickness but with the width and length many times greater then thickness and with two essentially flat sides, approximately parallel. **Flaky shales** split along irregular surfaces parallel to the bedding into uneven flakes, thin chips and wedge-like fragments whose length seldom exceeds 8 cm.

It was observed that the type of fissility observed in weathered shale at the outcrop may be entirely different from the fissility observed in a fresh exposure of an excavation (because weathering of shales determines to a large degree the way the potential fissility will be expressed). It is doubtful if a classification based on fissility alone would be of much value to the engineer.It is certainly not conclusive as some shales exhibit all degrees of fissility within the same beds.

### Slaking behavior.

Several classification systems founded on slaking behavior of shales have been proposed (6,26). The results of those investigations revealed that by accepting standardized test procedure (eg. proposed by Franklin (14)) it is possible to discriminate between various types of shales and their slaking characteristics can be used as an index in rock classification.

## Significant enginnering properties.

### Strength.

The compressive strength of shales ranges from less then 1.2 KPa for weak shales, to more then 720 KPa for well cemented, strong shales.As most shales have the adequate bearing capacity to support large structures it seems that the critical factor is rather shear strength than compressive strength.

However, it is difficult to use shear strength alone as a method of classifying transitive rocks because there are many variations in testing procedures. Further, the literature is not precise in reporting as to whether shear strength values shown are total or effective.

**Moisture, density, void ratio**

The natural moisture content of shales varies from less then 5% to as high as 35% for some of the clay shales. The moisture content referred to here is based on the weight of the water in a shale specimen divided by the weight of the solids and is expressed as a percentage of weight. Moisture ratio is usually greater in weathered zones because the shale beds near the surface have expanded due to load removal and the void ratio has increased.

**Atterberg limits**

Numerous investigations have been made to determine the Atterberg limits for shales. However, Atterberg limits are not easy to determine because of the difficulty in breaking the sample down to the required particle size. However, when reasonably accurate results are obtained they can be useful in the engineering classification of shales.

### Conclusions

Shales are among the most difficult earth materials to characterize. These materials are intermediate in behavior between soil and rock. Therefore, tests which are suitable to classify soils are not adequate for these transitional materials; neither are those tests normally used to classify the more compacted rocks satisfactory (6). The physical properties of shales are closely interrelated and it is difficult to discuss one property without mentioning the others.

Based on the above review it is apparent that shale strength, solubility, Atterberg limits and clay content can be regarded as the most promising for shale characterization.

## 2.2 Test selection

The analysis of shale properties points out which tests should be selected for this study. Rock related properties such as rock strength and bulk density should be tested in a rock oriented tests whereas soil related properties as Atterberg limits, clay content, particle density and solubility should be tested in a soil oriented tests. Selected tests have to satisfy the following conditions (9,10, 32, 42, 45):

1. Standardized procedure.
2. Correlation with other tests.
3. Possibility to perform in a field laboratory.

The above considerations lead to the selection of the following tests :

**Rock oriented tests:**

- Point-load test.
- NCB cone indenter test.
- Bulk density(dry density) test.

**Point-load test** was selected as it is easy to perform in field conditions. The test was successfully correlated with O&K cutting test (4) and the regression equation of point-load test index vs. cutting resistance is also available. Point-load test results are is correlated with uniaxial compressive strength and are frequently used as a quick index test in rock classification. Sample preparation is simple as test can be carried out on irregular samples. The detailed test description is available in the literature (13).

**NCB cone indenter test** is a relatively new nondestructive test developed by the National Coal Board in Great Britain. It is easy to perform. Test sample can be very small and does not require much preparation. The necessary equipment can be easily carried by one person. It is also important that NCB cone indenter index was correlated with uniaxial compressive strength for hard rocks and for Alberta transitive rocks (39).

**Bulk density test** is easy to carry out even in field laboratory and values of bulk density are often used in rock characterization.

**Soil-oriented tests:**

- Hydrometer analysis.
- Soil density test(grain density).
- Atterberg limits test.
- Slake durability test.
- Moisture content test.

**Hydrometer analysis** is a widely described and used procedure to determine the grain size distribution in a sample. In the same time it gives percentage of clay and silt fractions. The test results are correlated with Atterberg limits. No correlation with O & K cutting resistance has been reported.

**Particle density test** has to be performed in relation to hydrometer analysis (as the particle density is used in grain size calculations).The procedure for the test is well described (17). It is a test of a great accuracy regarding other soil or rock tests.

**Atterberg limits** are traditional engineering soil tests. The procedures for them are well described and documented. The results reveal good correlation with other soil tests. The extensive applications of these tests for description of transitive rocks can be found in related literature (14,24).

**Slake durability test** provides information on solubility of transitive rocks which was pointed out as one of their important properties. No other test for rock slaking characterization has procedure accepted by the

International Standard Organization (3). The results of this test are expected to correlate well with O&K cutting resistance.

**Moisture content** is one of the classical soil tests widely applied in earth sciences. However, the results of the test depend on the method of sampling and this can sometimes give erroneous results.

In summary, the selected tests allow for monitoring of the following material properties:

- Rock strength(NCB cone indenter test,point-load test).
- Dry density(bulk density test).
- Particle density.
- Porosity.
- Clay content (hydrometer analysis).
- Slaking characteristics(slake-durability test).
- Moisture content.
- Liquid limits, plastic limits, plasticity index, clay activity.

## 2.3 Testing procedures

### POINT-LOAD TEST

**Apparatus.**

The equipment used in the test is a portable loading frame with hydraulic pump and mounted pressure gauge used to monitor the applied pressure. The frame is equipped with two point-load wedges and a device to measure the distance between them.

**Procedure.**

Rock samples of approximately 50mm diameter and the length to width ratio of 1.0 to 1.4 are trimmed and inserted into the testing apparatus. The distance between the two wedges is recorded and load is being applied and increased until the rock breaks. The test should be repeated at least 20 times.

**Calculations.**

The point-load strength index is calculated as follows:

$Is = P/D^2$ P - breaking force

D - sample diameter

The correction of the index should be made to reflect the specimen diameter and the final results should be reported using the standard index I(50). The correction can be made using the correction chart as given in literature (13).The median value of results should be calculated by systematically deleting highest and lowest values until only two remain. The average of these two is the median value. The results can be recalculated for the uniaxial compressive strength from the formula:

$\partial = 24 \times Is(50)$ MPa

$Is(50)$ - point-load index

$\partial$ - uniaxial compression strength

**Notes.**

The detailed description of the test is given by Franklin (13).

## NCB CONE INDENTER TEST

### Apparatus.

The only apparatus required in this test is the NCB cone indenter. It consists of a portable steel frame in which a steel strip is clamped along a longitudinal axis. In the middle of one longitudinal side of the frame a dial gauge is inserted in such a way that its probe is in contact with one side of the steel strip. In the middle of the opposite longitudinal side of the frame is fitted a micrometer with a hollow spindle into which is inserted a tunsgren carbide cylinder with a conical tip having a 40 deg cone angle. The flat base of the cylinder is in contact with a steel ball so that the cylinder is free to rotate in its mounting.

### Procedure.

The detailed procedure is described in the apparatus manual (44). The main steps to be followed are:

a. Selected chips of rock with approximative dimensions of 12 x 12 x 6 mm with sound and clean surface are inserted into the testing equipment.

b. The micrometer is to be turned until the cone touch the sample.

c. Dial is to be set to 0.0, and the micrometer reading is taken.

d. The micrometer is to be turned until it shows 0.635 deflection,(for weak rocks 0.230).

e. The dial reading is to be taken.

**Calculations.**

The penetration of the cone into the specimen is calculated from the formula:

$M = M_1 - M_0$ — $M_0$ - first micrometer reading; $M_1$ - second micrometer reading

The standard cone indenter number is calculated from the formula:

$$I = \frac{D}{M - D}$$

I - NCB cone index
D - 0.635 for standard cone index

for weak rocks:

D= 0.230 for weak rocks

**Notes.**

The detailed description and interpretation of results are given in literature (39, 47).

## BULK DENSITY TEST

**Apparatus.**

The following equipment is necessary:

1. Volumetric cylinder with convenient diameter and the smallest possible graduation.
2. Scale capable of reading with accuracy of 1 g.
3. paraffin wax and bath for wax melting.
4. Oven to dry the sample.

**Procedure.**

The following procedure is recommended and was applied:

1. Prepare the specimen(the specimen should be trimmed to a

fairly regular shape with a sound surface)

2. Weigh the specimen to the nearest 1 g.
3. Apply the first coat of paraffin wax by brushing the molten wax on the surface,then immerse the whole sample in the wax-bath, remove and allow the wax to set. Repeat this step two or three times.
4. Weigh the waxed sample to the nearest 1 g.
5. Immerse the sample in the cylinder filled with water.
6. Record the change in the water level, as a volume of a waxed sample.

**Calculations.**

The bulk density is calculated as follows:

$$\rho = \frac{m}{V} \quad ; \quad V = V - \frac{m}{\rho'}$$

$\rho$ - calculated bulk density; m - sample mass
V - sample volume ; V - volume of waxed sample
m - wax mass; $\rho'$ - wax density

**Notes.**

The test procedure is given in the British Standard (BS) 1377;1975, test 15(F) (17).

## HYDROMETER ANALYSIS

**Apparatus.**

The following equipment is necessary to perform hydrometer analysis:

- Soil hydrometer.
- Two 1000ml glass measuring cylinders.
- Thermometer (0 - $100^{0}$C).
- Stop clock.

- Mixer.
- Dispersants.
- Scale, 0.01g accuracy.

**Procedure.**

The following procedure is used in this test:

1. The soil sample passing 63 m sieve is divided into two parts about 40g each.
2. The sample is put into a beaker equipped with the stirer.
3. 10 ml of 100gpl of Daxal and 10 ml of 100gpl sodium pyrophosphate together with 500 ml of distilled water is added.
4. The content is mixed for 5min and transferred to the measuring cylinder.
5. Cylinder is filled up to 1000ml, shook for 1 min and placed on the table.
6. The readings are taken at the prescribed times.

**Calculations.**

The following calculations should be performed:

The calibration of the hydrometer if there is no calibration chart available.

Calculations of particle size:

$$D = 0.005531\sqrt{\frac{\nu H}{(G - 1)t}}$$

D - particle size ; $\nu$ - viscosity of water
H - effective depth ;G - specific density of particles
t - elapsed time

Calculations of percentage of particles finer than D:

$$K = \frac{G}{m(G - 1)} \times R \times 100\ \%$$

m - mass of dry soil ; R - fully corrected hydrometer reading

**Notes.**

The test procedure is given in BS 1377:1975.Test 7(D) (17).

## ATTERBERG LIMITS

### Liquid Limits.

The test is intended to measure the liquid limits of a material by using Casagrande Method (17).

**Apparatus.**

The following equipment is required:

1. Casagrande apparatus.
2. Grooving tool.
3. Flat glass plate.
4. Standard moisture content equipment.

**Procedure.**

1. Select the sample, mix it with water and leave it to mature.
2. Place the sample in a bowl, cut the groove with the grooving tool.
3. Apply blows, repeat runs.
4. Measure the moisture content.
5. Perform next run.

**Calculations.**

The liquid limits are the moisture content at 25 blows. They can be calculated by fitting a linear equation to test data.

**Notes.**

The test procedure is given in BS 1377: 1975, Test 2(3) (17).

### Plastic limits.

The test is intended to measure the lowest moisture content at which the soil is still plastic.

### Apparatus.

The following equipment is used in test.

1. Glass ruler.
2. Standard equipment for moisture content measurements.

### Procedure.

The following procedure is used:

1. Mix the sample with water, leave it to mature then roll it into ball then into thread.
2. Roll the tread till it starts crash(at 3mm dia).
3. Take the sample for moisture content test.
4. Repeat the run at least three times.

The moisture content should be calculated from each run. The average value is reported as a plastic limits.

With plastic limits, liquid limits and clay content the calculations of plasticity index and clay activity should follow.

The plasticity index is calculated from the following formula:

$$PI = LL - PL$$

PI - plasticity index ; LL - liquid limits
PL - plastic limits

Activity is calculated from the formula:

$$Ac = \frac{PI}{Clay}$$

clay - clay content

All Atterberg limits should be reported together.

**Notes.**

The test procedure is given in BS 1377:1975, test 3 (17).

## MOISTURE CONTENT TEST

**Apparatus.**

The following equipment is required:

1. Thermostatically controlled drying oven capable of maintaining the temperature of 105 C for at least 20 h.
2. Scale reading to 0.01 g.
3. Numbered glass stoppers.

**Procedure.**

The following steps are used:

1. Weigh glass stoppers.
2. Place the sample on the glass stopper and weigh it.
3. Put the specimen into oven and keep it in a constant temperature of 105 C for 20-24 h.
4. Allow specimen to cool in a desicator.
5. Weigh the dried specimen.

**Calculations.**

The moisture content is calculated as follows:

$$W = \frac{m_3 - m_1}{m_1 - m_2} \times 100\%$$

$m_2$- mass of container ; $m_3$- mass of container with wet soil
$m_1$- mass of container with dry soil

At least 5 runs should be done. The average of those runs calculated to 0.01% should be reported as a moisture content.

**Notes.**

The test procedure is given in BS 1377:1975,Test 1(A) (17).

## PARTICLE DENSITY TEST

**Apparatus.**

The following equipment is required for this test:

1. Density bottles (50 ml)with stoppers.
2. Vacuum pump and vacuum dessicator.
3. Analytical balance reading to 0.001g.

**Procedure.**

The following steps are recommended and were used:

1. Dry the bottles and weigh them to the 0.001g.
2. The sample of about 30g passing 2mm sieve should be put into bottles then weighed.
3. Add de-aired liquid(can be water) to each bottle and place the bottles under vacuum to allow the entrapped air to escape.
4. Fill up the bottles with liqu  and weigh.
5. Wash the bottles, dry them and fill with liquid and weigh.

**Calculations.**

The specific density Gs is calculated from the following formula:

$$G_s = \frac{m_2 - m_1}{m_4 - m_1 - m_3 + m_2}$$

$G_s$- specific density of soil; $m_1$- mass of density bottle
$m_2$- mass of bottle+dry soil; $m_3$- mass of bottle+soil+liquid
$m_4$- mass of bottle+liquid

At least three runs should be done with the difference from average value not more then 0.003.

**Notes.**

The test procedure is given in BS:1377,1975 test 6(31) (17).

## SLAKE DURABILITY INDEX TEST

**Apparatus.**

The equipment necessary for this test includes:

1. Slake-durability drum testing apparatus.
2. Dry oven capable of maintaining the temperature of 105 C. for at least 12h.
3. Scale with a 0.5 g accuracy.

**Procedure.**

The following steps are recommended and were used:

1. Selected samples of roughly spherical shape and of mass of around 40-60g should be dried for at least 6h.
2. The mass of a drum with a sample is recorded.
3. The drum with the sample is mounted in the apparatus and containers are filled with water up to 20mm below the drum axis.
4. The drum is rotated for 10 min.
5. Sample with the drum is removed and dried to constant mass.
6. The drum with sample is cooled and weighed.
7. The cycle is then repeated.

**Calculation.**

The slake-durability index is calculated from the following formula:

$$I = \frac{C - D}{A - D}$$

C - mass of drum + sample after 2nd cycle
D - mass of drum ; A - initial mass of sample

At least 10 runs should be done and the final result is the average of all of them.

### Notes.

For detailed description of the test see (3).

## ORENSTEIN & KOPPEL CUTTING TEST

The Oerstein & Koppel (O & K) chisel cutting test has has a special place among the tests used in this study. This test is widely used for cuttability testing by the mining industry. The test results are interpreted in this study as a measure of material cutting resistance and are used in the project for diggability assessment.

### Apparatus

The testing equipment has a form of a loading frame with the head in a wedge-like shape. To ensure the even load distribution the tested sample is embedded in a sand box during the test. The geometry of the wedge is standardized-Figure 4. The chisel has an angle of 34 , length of the blade is 6.5cm, width-0.5cm. The equipment has a pressure gauge for monitoring of the applied force.

### Procedure

The tested sample should conform to O&K specifications. Core sample or cube sample(15x15x15 cm) should be used. The selected sample should be carefully described regarding any

cracks or others features influencing its strength.
The sample is placed in a sand box. Then the wedge is placed in the center of the sample and load is applied. The load should be applied slowly [5] until the sample is separated. The length of cut, cutting depth and force splitting have to be recorded. To obtain a large number of readings each sample can be cut several times. The testing procedure is illustrated in the Figure (4).

**Calculations**

The following calculations should be performed in this test:

**Specific cutting resistance per area of split**

$$Fa = \frac{F}{A}$$

A - area of split ; F - splitting force

**Specific cutting resistance per the cut length**

$$Fl = \frac{F}{L}$$

L - length of cut

**Specific cutting resistance per the blade length**

$$Fls = \frac{F}{Ls}$$

Ls - cutting blade length

---

[5] Original O&K instruction does not provide any information on the loading rate. For [illegible] study [illegible] testing equipment (MTS testing system in the rock mech[illegible] laboratory of Mineral Engineering Department of U[illegible] the rate of loading as recommended for the uniaxial compression test (0.5-1.0 MPa/s) was selected.

## 2.4 Sampling

When collecting the samples for testing a preference was given to areas where BWE are most likely to be applied in the near future. In the same time the effort was made to assure that geology of sampled materials is representative for the whole region under consideration.

The Highvale mine overburden was selected as the first sampling place for the following reasons:

1. The Highvale mine is considering significant expansion of its operations and implementation of the Bucket Wheel Excavator systems there is likely.
2. Highvale mine geology is to some extent representative for the plains area(i.e. the coal seams in plains are located in the same geological formations).

The Suncor mine in Fort McMurray was also selected as a sampling place. This choice was dictated by the fact that Suncor is the only mine in Alberta using large BWE in overburdens operations. It is believed that the definition of characteristics of materials dug by a BWE in Suncor operations will help in the development of correlations between the material cutting resistance and its diggability.

**Highvale mine**

The Highvale mine is located 75 km west of Edmonton, owned by TransAlta Utilities and operated by Manalta Coal. The present yearly production of 9 mln tonnes of coal is burned at the Sundace Power Generating Station.

The minable coal formations occur in the upper cretaceous and tertiary rocks in 6 seams of aggregate thickness of 5 to 12 meters. The overburden, thick up to 15 m in the mined area, consists of till and sand. Those materials vary in hardness, density, permeability; in general their properties depend on their composition and age(which influence compaction), height of the water table and weathering. Typical geology of the Highvale mine is presented on Figure 7.

### Suncor mine

The Suncor mine is located 50 km north of Fort McMurray on the bank of the Athabasca river. The mining operations and extraction plant are build close together. Mining operations start with land cleaning, drainage and removal of muskeg and removal of the overburden (average 20m). The orebody, of average thickness 50m is mined in two BWE benches.

The orebody consist of an oil-impregnated sand, silt and clay of lower cretaceous age. The overburden is formed by sands and shales of pleistocene and cretaceous age.The general cross-section of the oil-sand deposit is presented on figure 8. Samples were taken from pleistocene and cretaceous formations (for a cross-section of the oil- sand deposit see Appendix D).

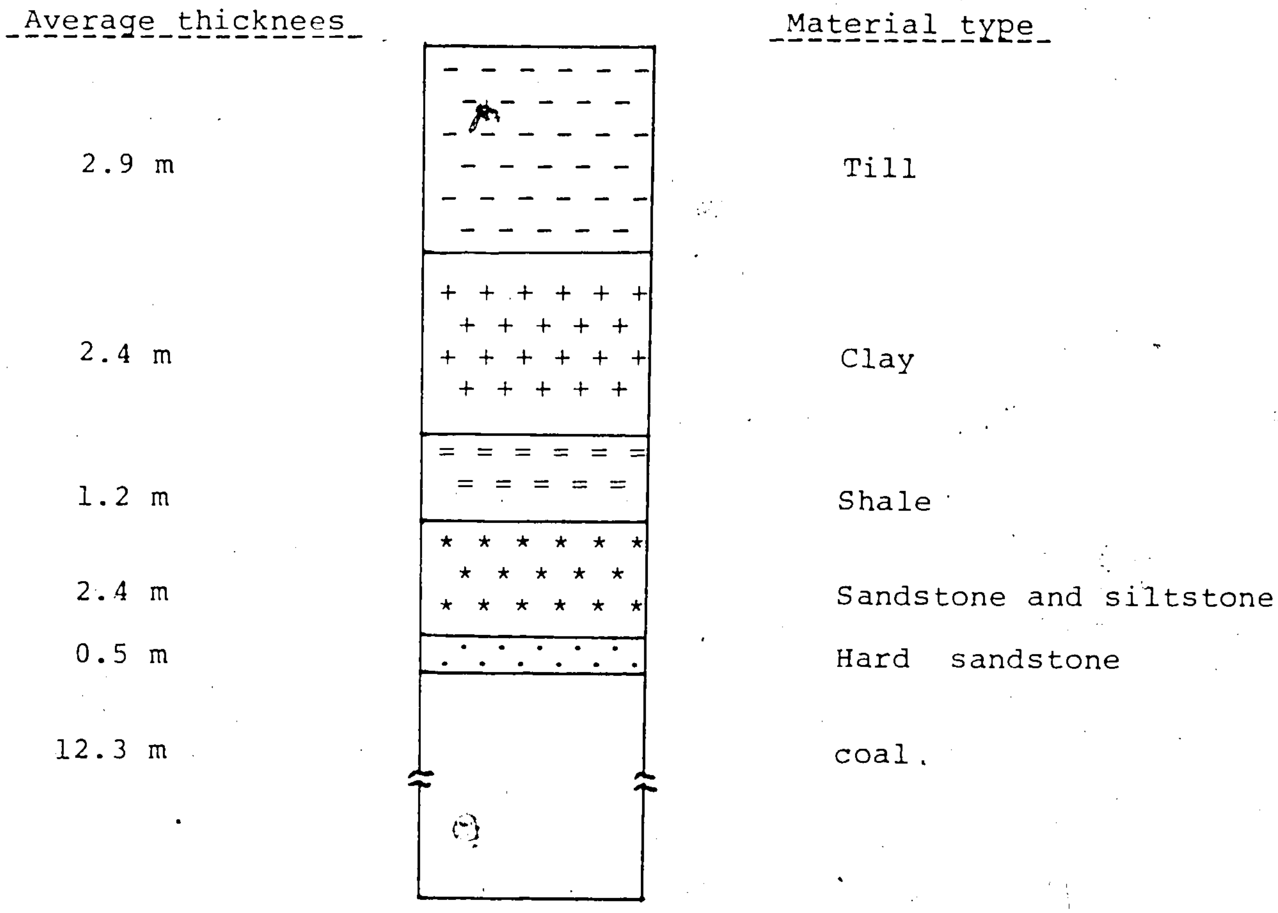

FIGURE 7. Typical geology of Highvale mine.

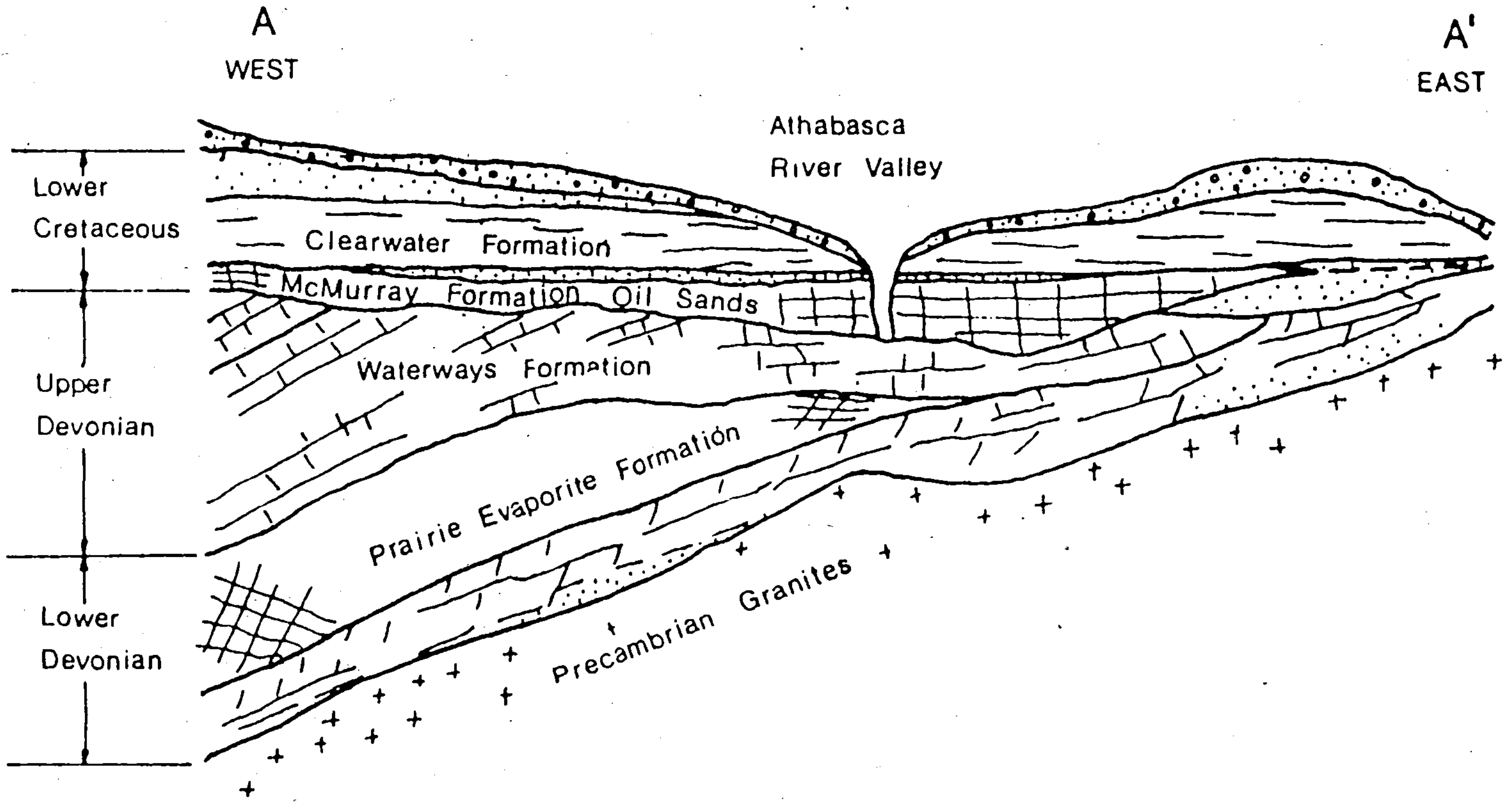

FIGURE 8. General Stratigraphy of The Oil Sand deposits.

## 2.5 Collection of samples

Generally the samples of hardest rocks in a mine were selected for testing. From Highvale mine the following types of material were taken:

From West end of pit 0-3 (strata 10m below surface- May 9,1983, exposed for 3 days):

- * gray sandy siltstone with coal fragments code named "sample A",
- * grey sandstone with coalificated plant fragments code named "sample B",
- * coarse grey sandy siltstone code named "sample C",
- * coarse sandstone code named " sample D".

From the West end of pit 0-3 (July 7, 1983, approx.3m below surface, bench open for 5 days) the following sample was taken:

- * yellow coarse sandstone code named "sample F".

The same day from the overburden in East end of pit 0-3 (approx. 3m below surface) the following sample was taken:

- * gray coarse sandstone code named "sample G".

The locations from which the samples were taken are marked on the mine plan (see Appendix D).

The following samples were taken from Suncor mine in Fort McMurray (collected on July 28, 1983 from the face mined by the BWE 1340):

- * brown glacial till code named "sample K".
- * green glauconitic shale (Clear Water formation) code named "sample L".

All samples were cube shaped with the mass of 30 to 60 kg. In total 8 different types of material were sampled, total mass of samples was 700kg as the big loss of material was expected during sample preparation.

Collection and preparation of samples was done in such a way as to assure:

1. preservation of natural moisture,
2. preservation of natural structure,
3. random selection of material in the mine,
4. random selection of the sample from the material.

## 2.6 Preparation of samples

In the Highvale mine the samples in the West-end of pit 0-3 were collected using axe and hammer. Samples from the East-end of the pit 0-3 were collected from among the loose blocks mined by a dragline. In the Suncor mine the samples were taken from materials pointed out by the BWE operator as the most difficult to dig. Samples were taken at random from the bench being open by the BWE.

In all cases the collected samples were packed in plastic bags to protect them from excessive exposure to the atmosphere which could cause changes in moisture content and rock strength. All samples were transported to the rock mechanics laboratory at The University of Alberta and stored in the cold room.

**Samples for O & K test:** the selected blocks of rock were cut with the saw without water cooling to prevent any changes in sample strength.The big pieces of material were first cut down using chisel and hammer. The sample was shaped as required by the testing procedure and immediately tested to avoid long exposure to atmosphere. The time of sample preparation varied from 1 to 2 days depending on the number of cuts to be done and material hardness.

**Samples for point-load test:** The test was designed as a test on irregular samples.Care was taken to select samples of a roughly similar shape and size. To size the sample a chisel and hammer were used. The samples were then shaped using sand tape to dispose of all excessive irregularities.Similarly as for O&K test, samples were tested as soon as they were prepared.

**Samples for NCB cone indenter test:** Test was carried out on small irregular samples. The samples were taken from the same material as those for the point-load test. The samples were taken at random to prevent any bias. Finally, the samples were shaped using the sand tape machine to smooth the surface and ensure the uniformity of load distribution during the test.

**Samples for moisture content test:** The samples for this test were selected at random from the material left over from the O&K test.Care was taken not to give any preferences to the surface or internal part of the tested rock. Samples were roughly the same in size as limited by the crucible diameter.The test was carried out immediately after collection of samples.

**Samples for bulk density test:**the samples were taken from the same material as used in O&K test.The following points were observed to decrease the variability of results: (1)all samples were similar in size, (2)all samples were fairly regular. The samples were trimmed on the grinder to fit the volumetric cylinder.

**Samples for particle density test:** the samples were desintegrated in the series of thaw and freezing cycles. Approximately 10 to 20 cycles were required depending on the sample type. The material was then dried and sieved through the sieve 600m. The obtained undersize (-600 m)was mixed and divided into six equal parts, three of which were tested. All tested samples were of about the same weight.

**Samples for hydrometer analysis:** Material for this test underwent the same preparation process as that used for the particle density test. As the time between sample preparation and testing was up to 6 days the prepared material was stored in plastic bags.

**Samples for Atterberg limits test:** Samples for this test underwent the same preparation as the samples for the specific density and hydrometer analysis tests.No special sample treatment was required.

**Samples for slake durability test:** the samples were taken at random without giving preference to any part of tested rock. The samples were round shaped roughly the same in size. To prevent undue loss of material during the test, samples were ground to ensure smooth surfaces.

# 3. Presentation of tests results

## 3.1 Introduction

Test results were analysed in order to determine their validity. The first part of analysis provides the descriptive statistics for results of each test. For the cutting test, moisture content, bulk density and particle density the following statis[illegible] calculated: mean, variance, standard deviation and [illegible]ient of variation (to express the dispersion of [illegible]ults on a percentage basis). The following formulas, given by Kennedy (21), were used to calculate the statistics:

Mean of the sample

$$\bar{X} = \frac{\Sigma X}{N}$$

Variance of the sample

$$S_x^2 = \frac{1}{N}\sum X^2 - \frac{1}{N^2}\left(\sum X\right)^2$$

Standard deviation of the sample

$$S_x = \sqrt{S_x^2}$$

Coefficient of variation:

$$V = \frac{S_x}{\bar{X}}$$

Calculations were performed on a hand held calculator TI - 55-II.

Results of NCB cone indenter test and slake-durability test were processsed using Interactive Statistical Package. The output of the analysis gives the following statistics:sample size, range, mean, median, variance, standard deviation(SD), mean+1SD, mean+2SD, quantiles 0.10 0.20 0.25 0.30 0.40 0.50(median) 0.60 0.70 0.75 0.80 0.90, and linear plot of analysed data.

For point-load test the analysis of results was performed using Biomedical Statistical Package (BMDP) ‘. The output of this program gives the following statistics: mber of analysed cases,range, variance, standard ation, interquantile range, mean and its standard error, median, standard error of median, mode, skewness,

$$\gamma_3 = \frac{M^3}{\sigma^3}$$

kurtiosis

$m^2$ - second moment
$\sigma^2$ - variance

$$\gamma_4 = \frac{M^4}{\sigma^4} - 3$$

and their ratio to standard errors (to test analysed data for normality), quantiles and mean+ 1SD. Analyzed data are plotted in a form of histogram. All location estimates are also plotted on the linear graph of tested data.

The analysis of bivariate relations among the analysed samples was performed using BMDP Statistical Package and

---

‘As availabl om MTS.

Interactive Statistical Package. This part of the analysis includes: scatterplots for all the paired tests, frequency of plotted points, correlations between analysed data, mean and standard deviation for each data set, regression lines of X on Y and of Y on X, residual mean square error:

$$MSE = \frac{\sum e^2}{n-2} \qquad e - \text{residual error}$$

On the frame of each plot the X signs show where the line X=bY+a intersects the frame of the plot and Y signs show where the line Y=aX+b intersects the frame of the plot. For the correlations r=0.7-1.0 additional analysis was performed, including plot of the regression line and ratio F(v,v) where:

$$F = \frac{\hat{Y} - \bar{Y}}{Y - \hat{Y}}$$

F - Fisher test ; $\hat{Y}$ - y predicted
Y - y measured
$\bar{Y}$ - mean y

and $R^2$

$$R^2 = \frac{\sum(\hat{Y} - \bar{y})^2}{\sum(y - \bar{y})^2}$$

giving the percentage of explained variation(due to regression) to total variation (8). For detailed description of tests and programs see the literature (45,7).

### 3.2 Test results

A total of 500 runs for 9 tests and 8 different samples in each test were performed. The number of runs was defined by expected variability of results and the specific requirements imposed by the test procedure.

Appendix A contains raw results of tests classified by sample code and test type. The following pages present the results of the analysis of obtained test data. APPENDIX B contains the BMDP programs and data files.

### 3.2.1 O & K cutting test

Tests were done for 8 types of rocks, an average of 3 to 5 runs per sample. The analysis of the test results was performed on the hand-held TI-58 II calculator and its results are presented in Tables 4, 5, and 6.
Table 4 presents the obtained values of cutting resistance calculated per area of cut. Test variability is in the range of 7.3% (sample K) to 40% (sample F) and values of cuttability change from 98.0kPa (sample K) to 2624.0kPa (sample L).

Table 5 presents the obtained values of cutting resistance per cut length. Test results variability is in the range of 4.2% (sample K) to 28.1% (sample F) and value of cutting resistance changes from 13.17kN/m (sample K) to 424.0kN/m (sample L).
Table 6 presents the obtained values of cutting resistance per cutting blade length. Test variability is in the range of 0.09%(sample G) to 61.0%(sample C) and cuttability changes from 33.48kN/m (sample K) to 723.4kN/m(sample L).

### 3.2.2 Point-load test

The test was performed on 8 types of material, an average of 19 runs per sample . The results of the analysis are presented in Tables 7 to 14.

ORENSTEIN & KOPPEL CUTTING TEST

Breaking force per area of split Fa

Units KPa

| SAMPLE | N | Fa | S | V | RANGE |
|---|---|---|---|---|---|
| A | 4 | 383.0 | 42.66 | 11.0% | 84.0 |
| B | 2 | 484.0 | 44.50 | 9.2% | 63.0 |
| C | 4 | 950.0 | 120.9 | 12.7% | 289.0 |
| D | 4 | 820.0 | 190.0 | 23.2% | 449.0 |
| F | 8 | 117.0 | 47.0 | 40.0% | 115.0 |
| G | 5 | 1251.0 | 296.0 | 28.1% | 708.0 |
| L | 5 | 2624.0 | 811.0 | 30.8% | 1832.0 |
| K | 5 | 98.0 | 7.0 | 7.3% | 19.0 |

N - number of tests; S - estimated standard deviation
V- variability of results; RANGE - range of results
Fa - average berak ing force

TABLE. 4 O&K cutting test results.

## ORENSTEIN & KOPPEL CUTTING TEST

Breaking force per length of cut F1

Units KN/m

| SAMPLE | N | F1 | S | V | RANGE |
|---|---|---|---|---|---|
| A | 4 | 38.37 | 4.27 | 11.1% | 8.41 |
| B | 2 | 58.50 | 12.18 | 20.8% | 17.23 |
| C | 4 | 49.87 | 21.32 | 42.7% | 48.4 |
| D | 4 | 86.22 | 22.63 | 26.2% | 48.4 |
| F | 8 | 15.23 | 4.29 | 28.1% | 11.54 |
| G | 5 | 175.38 | 23.61 | 13.4% | 137.1 |
| L | 5 | 424.2 | 88.16 | 20.7% | 184.3 |
| K | 5 | 13.17 | 5.54 | 42.0% | 13.45 |

N- number of tests; S- estiamted standard deviation
V- variability of results; RANGE- range of results
F1 - average value of breaking force

TABLE 5. O&K cutting test results.

## ORENSTEIN & KOPPEL CUTTING TEST

Breaking force per blade length Fls

Units KN/m

| SAMPLE | N | Fls | S | V | RANGE |
|---|---|---|---|---|---|
| A | 4 | 94.07 | 16.80 | 17.8% | 40.59 |
| B | 2 | 123.5 | 44.39 | 35.9% | 62.79 |
| C | 4 | 91.31 | 55.78 | 61.1% | 109.86 |
| D | 4 | 176.8 | 46.55 | 26.0% | 105.5 |
| F | 8 | 31.65 | 18.77 | 59.3% | 46.2 |
| G | 5 | 431.2 | 40.1 | 0.09% | 83.7 |
| L | 5 | 723 | 175.39 | 24.2% | 372.7 |
| K | 5 | 33.38 | 16.75 | 50.0% | 33.51 |

N- number of tests; S- estimated standard deviation.
V- variability of results; RANGE- range of results
Fls- average breaking force

TABLE 6. O&K cutting test results.

```
  ************
  * X(1)     *                                MAXIMUM         0.9110000             PLT A
  ************                                MINIMUM         0.0660000
                                              RANGE           0.8450000
VARIABLE NUMBER . . . . . .        1          VARIANCE        0.0647324
NUMBER OF DISTINCT VALUES .       22          ST.DEV.         0.2544256
NUMBER OF VALUES COUNTED. .       25          (Q3-Q1)/2       0.1999998                                                  EACH 'H'
NUMBER OF VALUES NOT COUNTED       0          MX.ST.SC.       1.74                                                      REPRESENTS
                                              MN.ST.SC.      -1.58                                                           1
                                                                                                               H         COUNT(S)
LOCATION ESTIMATES                                 ST.ERROR                                                H   HH
                   MEAN              0.4687596      0.0508851                                            H HHH HH H H
                   MEDIAN            0.5000000      0.0750555                                            HHHHHHHHHHHHH
                   MODE             NOT UNIQUE                                                          L-------------U

                                                                                              EACH '-' ABOVE =       0.0750
                                                                                                            L=       0.0
                                                                                                            U=       0.9750
                                                                                       CASE NO. OF MIN. VAL. =    1
                                                                                       CASE NO. OF MAX. VAL. =    7

                                                                                                                   Q1=    0.2500000
                                                                                            VALUE   VALUE/S.E.     Q3=    0.6499998
                                                                          SKEWNESS           0.08         0.17     S-=    0.2143340
                                                                          KURTOSIS          -1.25        -1.27     S+=    0.7231852

                                                                                              EACH '.' BELOW =       0.0075
                             S    Q                                                    Q         S
         M                   -    1                            M   M                   3         +                        M
         I.....................................................E...E......................................................A
         N                                                     A   D                                                      X
                                                               N   I

                      PERCENTS                        PERCENTS                        PERCENTS                        PERCENTS
      VALUE    COUNT  CELL  CUM       VALUE    COUNT  CELL  CUM       VALUE    COUNT  CELL  CUM       VALUE    COUNT  CELL  CUM
       0.06600     1   4.0  4.0        0.30000     1   4.0 32.0        0.57000     1   4.0 64.0        0.80000     1   4.0 88.0
       0.07500     1   4.0  8.0        0.32000     2   8.0 40.0        0.58000     1   4.0 68.0        0.85000     1   4.0 92.0
       0.15000     1   4.0 12.0        0.40000     1   4.0 44.0        0.60000     1   4.0 72.0        0.86000     1   4.0 96.0
       0.17600     1   4.0 16.0        0.50000     2   8.0 52.0        0.65000     1   4.0 76.0        0.91100     1   4.0100.0
       0.21000     2   8.0 24.0        0.50100     1   4.0 56.0        0.68000     1   4.0 80.0
       0.25000     1   4.0 28.0        0.52000     1   4.0 60.0        0.72000     1   4.0 84.0
----------------------------------------------------------------------------------------------------------------------------------
```

TABLE 7. Point- Load Test Results- Sample A.

```
PAGE   2  BMDP2D PLT SAMPLE B

  ************
  * X(1)     *                                     MAXIMUM          1.0999994
  ************                                     MINIMUM          0.1799999
                                                   RANGE            0.9199995
VARIABLE NUMBER . . . . . . .       [illegible]    VARIANCE         0.0577271
NUMBER OF DISTINCT VALUES .      26                ST.DEV.          0.2402847
NUMBER OF VALUES COUNTED. .      30                (Q3-Q1)/2        0.1700000                                       EACH 'H'
NUMBER OF VALUES NOT COUNTED      0                MX.ST.SC.        2.18                       H                    REPRESENTS
                                                   MN.ST.SC.       -1.65                       HH                       1
                                                                                               HH                   COUNT(S)
LOCATION ESTIMATES                                     ST.ERROR                               HHH  H  H
                   MEAN              0.5753326         0.0438661                             HHHHH H  H
                   MEDIAN            0.5200000         0.0490748                            HHHHHHHHHHHHH
                   MODE              0.5200000                                             L-------------U

                                                                                    EACH '-' ABOVE =        0.0750
                                                                                                 L=         0.1500
                                                                                                 U=         1.2000
                                                                               CASE NO. OF MIN. VAL. =   11
                                                                               CASE NO. OF MAX. VAL. =    8

                                                                                                          Q1=     0.4100000
                                                                                  VALUE   VALUE/S.E.      Q3=     0.7500000
                                                                    SKEWNESS       0.52         1.15      S-=     0.3350679
                                                                    KURTOSIS      -0.83        -0.93      S+=     0.8155974

                                                                                    EACH '.' BELOW =        0.0075
                         S        Q                M      M                    Q       S
 M                       -        1                M      M                    3       +                                  M
 I.............................................E......E..................................................................A
 N                                                 D      A                                                               X
                                                   I      N

                   PERCENTS                            PERCENTS                            PERCENTS                            PERCENTS
  VALUE    COUNT   CELL   CUM     VALUE    COUNT   CELL   CUM     VALUE    COUNT   CELL   CUM     VALUE    COUNT   CELL   CUM
  0.1800      1     3.3    3.3    0.4100      1     3.3   26.7    0.5500      1     3.3   60.0    0.9200      1     3.3   86.7
  0.2600      1     3.3    6.7    0.4200      2     6.7   33.3    0.5800      1     3.3   63.3    0.9400      1     3.3   90.0
  0.3000      1     3.3   10.0    0.4500      1     3.3   36.7    0.6200      1     3.3   66.7    0.9500      1     3.3   93.3
  0.3200      1     3.3   13.3    0.4600      1     3.3   40.0    0.6800      2     6.7   73.3    0.9800      1     3.3   96.7
  0.3450      1     3.3   16.7    0.5000      1     3.3   43.3    0.7500      1     3.3   76.7    1.1000      1     3.3  100.0
  0.3540      1     3.3   20.0    0.5010      1     3.3   46.7    0.8000      1     3.3   80.0
  0.3800      1     3.3   23.3    0.5200      3    10.0   56.7    0.8500      1     3.3   83.3
-------------------------------------------------------------------------------------------------------------------------------
```

TABLE 8. Point-Load Test Results - Sample B.

```
PAGE    2  BMDP2D PLT SAMPLE C

  ************                           MAXIMUM         1.1199999
  * X(1)     *                           MINIMUM         0.4100000
  ************                           RANGE           0.7099999
VARIABLE NUMBER . . . . . . .      1     VARIANCE        0.0334812
NUMBER OF DISTINCT VALUES .       16     ST.DEV.         0.1829786
NUMBER OF VALUES COUNTED. .       20     (Q3-Q1)/2       0.1224999                                 EACH 'H'
NUMBER OF VALUES NOT COUNTED       0     MX.ST.SC.       2.36                                     REPRESENTS
                                         MN.ST.SC.      -1.53                                          1
                                                                                         H          COUNT(S)
LOCATION ESTIMATES                                  ST.ERROR                            H HH
               MEAN            0.6890497     0.0409153                                 HHHHHHH
               MEDIAN          0.6699996     0.0433013                                 HHHHHHHH H
               MODE            0.6700000                                              L--------------U

                                                                      EACH '-' ABOVE =          0.0750
                                                                                   L=          0.3000
                                                                                   U=          1.2750
                                                                   CASE NO. OF MIN. VAL. =    4
                                                                   CASE NO. OF MAX. VAL. =    7
                                                                                               Q1=    0.5499997
                                                                       VALUE    VALUE/S.E.     Q3=    0.7949996
                                                          SKEWNESS      0.41          0.75     S-=    0.5060711
                                                          KURTOSIS     -0.45         -0.41     S+=    0.8720284

                                                                      EACH '.' BELOW =          0.0075
                 S   Q                    M M         Q      S
             M   -   1                    E E         3      +                       M
             I........................................................................A
             N                            D A                                        X
                                          I N

                    PERCENTS                         PERCENTS                         PERCENTS                         PERCENTS
   VALUE    COUNT  CELL   CUM      VALUE   COUNT   CELL   CUM      VALUE   COUNT   CELL   CUM      VALUE   COUNT   CELL   CUM
   0.4100     1     5.0    5.0    0.5800     1      5.0  30.0     0.7300     2     10.0  65.0     0.8800     1      5.0  85.0
   0.4200     1     5.0   10.0    0.6000     1      5.0  35.0     0.7500     1      5.0  70.0     0.8900     1      5.0  90.0
   0.4710     1     5.0   15.0    0.6200     1      5.0  40.0     0.7800     1      5.0  75.0     0.9400     1      5.0  95.0
   0.5200     2    10.0   25.0    0.6700     3     15.0  55.0     0.8100     1      5.0  80.0     1.1200     1      5.0 100.0
---------------------------------------------------------------------------------------------------------------------------------
```

TABLE 9. Point-Load Test Results - Sample C.

```
PAGE   2  BMDP2D PLT SAMPLE F

  ************
  * X(1)     *                               MAXIMUM         0.1370000
  ************                               MINIMUM         0.0460000
                                             RANGE           0.0910000
VARIABLE NUMBER . . . . . .        1         VARIANCE        0.0005840
NUMBER OF DISTINCT VALUES .       13         ST.DEV.         0.0237483
NUMBER OF VALUES COUNTED. .       16         (Q3-Q1)/2       0.0137500                                                 EACH 'H'
NUMBER OF VALUES NOT COUNTED       0         MX.ST.SC.         1.83                                                   REPRESENTS
                                             MN.ST.SC.      -2.01                                                           1
                                                                                                             HH        COUNT(S)
LOCATION ESTIMATES                                ST.ERROR                                                   HH
                   MEAN             0.0936248      0.0059371                                                 HHH
                   MEDIAN           0.0950000      0.0077942                                             HHH HHHHHH
                   MODE            NOT UNIQUE                                                           L------------U

                                                                                             EACH '-' ABOVE =      0.0100
                                                                                                          L=       0.0400
                                                                                                          U=       0.1600
                                                                                      CASE NO. OF MIN. VAL. =   9
                                                                                      CASE NO. OF MAX. VAL. =   6

                                                                                                                 Q1=    0.0814999
                                                                                           VALUE   VALUE/S.E.    Q3=    0.1090000
                                                                         SKEWNESS          -0.21        -0.34    S-=    0.0698764
                                                                         KURTOSIS          -0.66        -0.54    S+=    0.1173730

                                                                                             EACH '.' BELOW =      0.0007
                                    S              Q                                   Q          S
    M                               -              1              M M                  3          +                         M
    I.............................................................E.E.......................................................A
    N                                                             A D                                                       X
                                                                  N I

                      PERCENTS                       PERCENTS                        PERCENTS                       PERCENTS
     VALUE    COUNT  CELL   CUM      VALUE   COUNT  CELL   CUM      VALUE    COUNT  CELL   CUM      VALUE   COUNT  CELL   CUM
      0.04600     1   6.3   6.3       0.08200     1  6.3  31.3       0.10000     2  12.5  68.8       0.13700     1  6.3  100.0
      0.06000     1   6.3  12.5       0.08900     2 12.5  43.8       0.10900     2  12.5  81.3
      0.06500     1   6.3  18.8       0.09300     1  6.3  50.0       0.11800     1   6.3  87.5
      0.08100     1   6.3  25.0       0.09700     1  6.3  56.3       0.12300     1   6.3  93.8
--------------------------------------------------------------------------------------------------------------------------------
```

TABLE 11. Point-Load Test Results - Sample F

```
PAGE   2  BMDP2D PLT SAMPLE D

  ************
  * X(1)     *                               MAXIMUM         1.0799999
  ************                               MINIMUM         0.4200000
                                             RANGE           0.6800000
VARIABLE NUMBER . . . . . .        1         VARIANCE        0.0409194
NUMBER OF DISTINCT VALUES .       13         ST.DEV.         0.2022854
NUMBER OF VALUES COUNTED. .       20         (Q3-Q1)/2       0.1450000                                               EACH 'H'
NUMBER OF VALUES NOT COUNTED       0         MX.ST.SC.       2.25                                        H  H       REPRESENTS
                                             MN.ST.SC.      -1.01                                        H  H            1
                                                                                                        HH  H         COUNT(S)
LOCATION ESTIMATES                                ST.ERROR                                              HH  H
                   MEAN             0.6243497      0.0452324                                            HH  H  H
                   MEDIAN           0.5530000      0.0750555                                            HHH H  H H
                   MODE            NOT UNIQUE                                                         L-------------U

                                                                                            EACH '-' ABOVE =       0.0750
                                                                                                          L=       0.3000
                                                                                                          U=       1.2750
                                                                                     CASE NO. OF MIN. VAL. =    1
                                                                                     CASE NO. OF MAX. VAL. =   12
                                                                                                                 Q1=    0.4600000
                                                                                           VALUE  VALUE/S.E.     Q3=    0.7500000
                                                                         SKEWNESS           0.72        1.31     S-=    0.4220643
                                                                         KURTOSIS          -0.73       -0.67     S+=    0.8266351

                                                                                            EACH '.' BELOW =       0.0075
                      S   Q                                    Q          S
                      M-  1          M         M               3          +                                M
                      I...............E.........E..........................................................A
                      N               D         A                                                          X
                                      I         N

                         PERCENTS                       PERCENTS                       PERCENTS                       PERCENTS
      VALUE     COUNT  CELL    CUM   VALUE     COUNT  CELL    CUM   VALUE     COUNT  CELL    CUM   VALUE     COUNT  CELL    CUM
       0.4200       2  10.0   10.0    0.4910       1   5.0   45.0    0.7000       1   5.0   65.0    1.0800       1   5.0  100.0
       0.4300       2  10.0   20.0    0.5110       1   5.0   50.0    0.7200       1   5.0   70.0
       0.4600       3  15.0   35.0    0.5950       1   5.0   55.0    0.7500       3  15.0   85.0
       0.4800       1   5.0   40.0    0.6800       1   5.0   60.0    0.9500       2  10.0   95.0
------------------------------------------------------------------------------------------------------------------------------------
```

TABLE 10. Point-Load Test Results- Sample D.

```
PAGE    2  BMDP2D PLT SAMPLE G

  ************
  * X(1)     *                        MAXIMUM         1.9649992
  ************                        MINIMUM         0.5050000
                                      RANGE           1.4599991
VARIABLE NUMBER . . . . . .      1    VARIANCE        0.1759818
NUMBER OF DISTINCT VALUES .     17    ST.DEV.         0.4194781
NUMBER OF VALUES COUNTED. .     19    (Q3-Q1)/2       0.3250000                            EACH 'H'
NUMBER OF VALUES NOT COUNTED     0    MX.ST.SC.       1.91                    H           REPRESENTS
                                      MN.ST.SC.      -1.57                    H               1
                                                                              H            COUNT(S)
LOCATION ESTIMATES                       ST.ERROR                            HH
                 MEAN           1.1635781   0.0962349                      H HH  HHH
                 MEDIAN         1.0199995   0.1391412                      H HHH HHH H
                 MODE          NOT UNIQUE                                 L------------U

                                                             EACH '-' ABOVE =       0.1500
                                                                         L=       0.3000
                                                                         U=       2.1000
                                                        CASE NO. OF MIN. VAL. =    9
                                                        CASE NO. OF MAX. VAL. =    8

                                                                                 Q1=     0.8499999
                                                              VALUE  VALUE/S.E.    Q3=     1.5000000
                                                 SKEWNESS      0.32       0.57     S-=     0.7440981
                                                 KURTOSIS     -1.01      -0.90     S+=     1.5830536

                                                             EACH '.' BELOW =       0.0150
                  S    Q                                    Q   S
          M       -    1      M     M                       3   +                  M
          I...........................E.....E...............................................A
          N                           D     A                                      X
                                      I     N

          PERCENTS                           PERCENTS                           PERCENTS                           PERCENTS
VALUE  COUNT  CELL   CUM     VALUE  COUNT  CELL   CUM     VALUE  COUNT  CELL   CUM     VALUE  COUNT  CELL   CUM
0.5050     1   5.3   5.3    1.0000     1   5.3  36.8    1.3510     1   5.3  68.4    1.7850     1   5.3  94.7
0.5100     1   5.3  10.5    1.0100     1   5.3  42.1    1.4320     1   5.3  73.7    1.9650     1   5.3 100.0
0.8300     2  10.5  21.1    1.0200     2  10.5  52.6    1.5000     1   5.3  78.9
0.8500     1   5.3  26.3    1.0500     1   5.3  57.9    1.6300     1   5.3  84.2
0.9500     1   5.3  31.6    1.1020     1   5.3  63.2    1.7680     1   5.3  89.5
-----------------------------------------------------------------------------------------------------------------
```

TABLE 12. Point-Load Test Results- Sample G.

```
PAGE    2  BMDP2D PLT SAMPLE L

  ************
  * X(1)     *                                   MAXIMUM         3.8799992
  ************                                   MINIMUM         1.6299992
                                                 RANGE           2.2500000
VARIABLE NUMBER . . . . . .       1              VARIANCE        0.2823643
NUMBER OF DISTINCT VALUES .      21              ST.DEV.         0.5313796
NUMBER OF VALUES COUNTED. .      21              (Q3-Q1)/2       0.2049999                                     EACH 'H'
NUMBER OF VALUES NOT COUNTED      0              MX.ST.SC.       2.09                                         REPRESENTS
                                                 MN.ST.SC.      -2.14                               H              1
LOCATION ESTIMATES                                                                                 HH           COUNT(S)
                  MEAN            2.7695179       ST.ERROR                                         HHHH
                  MEDIAN          2.8799992       0.1159565                                   H    HHHH
                  MODE           NOT UNIQUE       0.1068098                                   H HHHHHHH  H
                                                                                            L-------------U

                                                                                   EACH '-' ABOVE =      0.2000
                                                                                                L=       1.4000
                                                                                                U=       4.0000
                                                                              CASE NO. OF MIN. VAL. =   17
                                                                              CASE NO. OF MAX. VAL. =   11

                                                                                                         Q1=     2.6099997
                                                                          VALUE     VALUE/S.E.           Q3=     3.0199995
                                                          SKEWNESS        -0.45        -0.84             S-=     2.2381382
                                                          KURTOSIS        -0.02        -0.02             S+=     3.3008966

                                                                                   EACH '.' BELOW =      0.0200
      M                       S                Q        M    M          Q           S
      I.......................-................1........E....E..........3...........+.....................M
      N                                                 A    D                                           A
                                                        N    I                                           X

                   PERCENTS                            PERCENTS                           PERCENTS                           PERCENTS
  VALUE    COUNT   CELL   CUM       VALUE    COUNT   CELL   CUM       VALUE    COUNT   CELL   CUM       VALUE    COUNT   CELL   CUM
  1.630      1     4.8    4.8       2.640      1     4.8   33.3       2.930      1     4.8   61.9       3.230      1     4.8   90.5
  1.730      1     4.8    9.5       2.740      1     4.8   38.1       2.990      1     4.8   66.7       3.320      1     4.8   95.2
  2.020      1     4.8   14.3       2.750      1     4.8   42.9       3.010      1     4.8   71.4       3.880      1     4.8  100.0
  2.210      1     4.8   19.0       2.820      1     4.8   47.6       3.020      1     4.8   76.2
  2.520      1     4.8   23.8       2.880      1     4.8   52.4       3.110      1     4.8   81.0
  2.610      1     4.8   28.6       2.910      1     4.8   57.1       3.210      1     4.8   85.7
-----------------------------------  ------------------------------------------------------------------------------------------------
```

TABLE 13. Point-Load Test Results- Sample 13.

```
PAGE    2  BMDP2D PLT SAMPLE K

  ************
  * X(1)      *                                        MAXIMUM            0.1100000
  ************                                         MINIMUM            0.0689999
                                                       RANGE              0.0410000
VARIABLE NUMBER . . . . . .               1            VARIANCE           0.0001191
NUMBER OF DISTINCT VALUES .              18            ST.DEV.            0.0109131
NUMBER OF VALUES COUNTED. .              26            (Q3-Q1)/2          0.0070000                                                              EACH 'H'
NUMBER OF VALUES NOT COUNTED              0            MX.ST.SC.          2.03                                                                  REPRESENTS
                                                       MN.ST.SC.         -1.73                                                     H                  1
                                                                                                                            H      H             COUNT(S)
LOCATION ESTIMATES                                           ST.ERROR                                                       H  H  HH  H
                       MEAN                 0.0878459         0.0021402                                                     H  HHHHH  H
                       MEDIAN               0.0890000         0.0028867                                                     H  HHHHHH HHHH
                       MODE                 0.0919999                                                                      L--------------U

                                                                                                                 EACH '-' ABOVE =           0.0030
                                                                                                                               L=           0.0690
                                                                                                                               U=           0.1110
                                                                                                          CASE NO. OF MIN. VAL. =       11
                                                                                                          CASE NO. OF MAX. VAL. =       14

                                                                                                                                         Q1=      0.0790000
                                                                                                              VALUE     VALUE/S.E.       Q3=      0.0930000
                                                                                        SKEWNESS               0.04           0.09       S-=      0.0769328
                                                                                        KURTOSIS              -0.88          -0.92       S+=      0.0987590

                                                                                                                 EACH '.' BELOW =           0.0005

                                                S      Q                                  Q             S
                            M                   -      1                    M   M     M   3             +                          M
                            I...............................................E...E.....O............................................A
                            N                                               A   D     D                                            X
                                                                            N   I     E

                       PERCENTS                          PERCENTS                          PERCENTS                          PERCENTS
     VALUE    COUNT   CELL    CUM      VALUE    COUNT   CELL    CUM      VALUE    COUNT   CELL    CUM      VALUE    COUNT   CELL    CUM
      0.06900     1    3.8    3.8       0.08100     1    3.8   30.8       0.09000     1    3.8   57.7       0.10200     1    3.8   92.3
      0.07100     1    3.8    7.7       0.08200     1    3.8   34.6       0.09200     4   15.4   73.1       0.10500     1    3.8   96.2
      0.07200     2    7.7   15.4       0.08500     2    7.7   42.3       0.09300     1    3.8   76.9       0.11000     1    3.8  100.0
      0.07800     1    3.8   19.2       0.08700     1    3.8   46.2       0.09900     2    7.7   84.6
      0.07900     2    7.7   26.9       0.08900     2    7.7   53.8       0.10000     1    3.8   88.5
------------------------------------------------------------------------------------------------------------------------------------------------------------------
```

TABLE 14.Point-LOad Test Results- Sample K.

The median of test results range from 0.09 MPa (sample K) to 2.88 MPa (sample L). Standard deviation of test results ranges from 0.01MPa (sample K) to 0.53 MPa (sample 1).

### 3.2.3 NCB cone indenter test

Test was performed on 8 types of material , an average of 15 runs per sample. The results of analysis performed on the Statistical Interactive Package are presented in Tables 15 and 16. The value of NCB cone indenter index is in the range of 0.1 (sample K & L) to 1.89(sample L) (weak rock number). Standard deviation of results is from 0.01 (sample C) to 0.36 (sample G).

### 3.2.4 Slake durability test

This test was performed on 8 types of material, an average of 10 runs per sample. The number of runs was defined by the test procedure. The results of the analysis performed on Statistical Interactive Package are presented in Tables 17, 18 and 19.

The value of slake durability index ranges from 58.11%(sample F) to 100.0%(sample G). with standard deviation from 0.78% (sample K) to 20.14% (sample A).

```
                QUANTILE           MEDIAN   QUANTILE
                   |                  |         |
       .255+---+---++----++------+----+-+------+-+----+-----++----+ .49
  |                |                 ||            |              |
MEAN             MEAN            MID- MEAN       MEAN           MEAN
-2 S.D.          -1 S.D.         MEAN            +1 S.D.        +2 S.D


SAMPLE STATISTICS FOR COLUMN  1 NCB-S/A

SAMPLE SIZE  =  18                                      .10 QUANTILE  =  .2772
RANGE        =  .235                                    .20 QUANTILE  =  .29
MEAN         =  .36394                                    .25 QUANTILE  =  .29
MIDMEAN      =  .35911                                  .30 QUANTILE  =  .3098
                                                        .40 QUANTILE  =  .3364
SAMPLE VARIANCE  =  .0052682                               MEDIAN     =  .37
SAMPLE STANDARD DEVIATION  =  .072582                   .60 QUANTILE  =  .3737
MEAN -2 S.D.  =  .21878                                 .70 QUANTILE  =  .411
MEAN -1 S.D.  =  .29136                                   .75 QUANTILE  =  .42
MEAN +1 S.D.  =  .43653                                 .80 QUANTILE  =  .438
MEAN +2 S.D.  =  .50911                                 .90 QUANTILE  =  .4663
```

```
                              .25                 .75
                              QUANTILE MEDIAN     QUANTILE
                                   |     |            |
          .27+---+-+-----------+-+++++-+------++--------+------++-+.56
  |                |                 ||              |                |
MEAN             MEAN            MID- MEAN         MEAN             MEAN
-2 S.D.          -1 S.D.         MEAN              +1 S.D.          +2 S.D.


SAMPLE STATISTICS FOR COLUMN  1 NCB-S/B

SAMPLE SIZE  =  19                                      .10 QUANTILE  =  .296
RANGE        =  .29                                     .20 QUANTILE  =  .373
MEAN         =  .42847                                    .25 QUANTILE  =  .38225
MIDMEAN      =  .42449                                  .30 QUANTILE  =  .3892
                                                        .40 QUANTILE  =  .4007
SAMPLE VARIANCE  =  .0078176                              MEDIAN      =  .42
SAMPLE STANDARD DEVIATION  = [illegible]8417            .60 QUANTILE  =  .4515
MEAN -2 S.D.  =  .25164                                 .70 QUANTILE  =  .464
MEAN -1 S.D.  =  .34006                                   .75 QUANTILE  =  .4985
MEAN +1 S.D.  =  .51689                                 .80 QUANTILE  =  .531
MEAN +2 S.D.  =  .60531                                 .90 QUANTILE  =  .5548
```

```
                                   .25            .75
                                   QUANTILE MEDIAN QUANTILE
                                       |        |    |-
    .35+-------------------+-+-+-+++---+---++++---+++-+---------+--------+.836
             |               |             |              |               |
           MEAN            MEAN          MEAN MID-      MEAN            MEAN
           -2 S.D.         -1 S D.            MEAN      +1 S.D          +2 S.D.


SAMPLE STATISTICS FOR COLUMN  1 NCB-S/C

SAMPLE SIZE  =  21                                      .10 QUANTILE  =  .492
RANGE        =  .486                                    .20 QUANTILE  =  .5304
MEAN         =  .60381                                    .25 QUANTILE  =  .5385
MIDMEAN      =  .60522                                  .30 QUANTILE  =  .5512
                                                         40 QUANTILE  =  .6027
      E VARIANCE  =  .010585                                MEDIAN    =  .613
        STANDARD DEVIATION  =   10288                    60 QUANTILE  =  .621
       2 S.D.  =  .39805                                .70 QUANTILE  =  .6394
       1 S.D.  =  .50093                                  .75 QUANTILE  =  .65925
       1 S.D.  =  .70669                                 80 QUANTILE  =  .669
      +2 S.D.  =  .80957                                 90 QUANTILE  =  .724
```

TABLE 15. NCB Cone Indenter Test Results- Sample A,B, & C

```
                    .25                          .75
                  QUANTILE     MEDIAN          QUANTILE
                      |          |                 |
          .505+-----++--++-+----+++-+--++--+-+-------+++---------+-+-+.88
    |                |               | |              |                    |
  MEAN             MEAN          MID- MEAN          MEAN                 MEAN
  -2 S.D.          -1 S.D.       MEAN               +1 S.D.              +2 S.D.

SAMPLE STATISTICS FOR COLUMN  1 NCB-S/D

SAMPLE SIZE  = 23                                         .10 QUANTILE = .548
RANGE        = .375                                       .20 QUANTILE = .582
MEAN         = .681                                         .25 QUANTILE = .58575
MIDMEAN      = .67046                                     .30 QUANTILE = .6102
                                                          .40 QUANTILE = .6434
SAMPLE VARIANCE = .011625                                     MEDIAN     = .664
SAMPLE STANDARD DEVIATION = .10782                        .60 QUANTILE = .7026
MEAN -2 S.D. = .46536                                     .70 QUANTILE = .7252
MEAN -1 S.D. = .57318                                       .75 QUANTILE = .76675
MEAN +1 S.D. = .78882                                     .80 QUANTILE = .7889
MEAN +2 S.D. = .89664                                     .90 QUANTILE = .8542

                                                       .75
                   QUANTILE MEDIAN                   QUANTILE
                           |   |                        |
            1+-----------+----+-++----------------------+------+2.08
    |                |               | |              |                 |
  MEAN             MEAN          MID- MEAN          MEAN              MEAN
  -2 S.D.          -1 S.D.       MEAN               +1 S.D.           +2 S.D.

SAMPLE STATISTICS FOR COLUMN  1 NCB-S/G

SAMPLE SIZE  = 9                                          .10 QUANTILE = 1.116
RANGE        = 1.08                                       .20 QUANTILE = 1.329
MEAN         = 1.58                                         .25 QUANTILE = 1.3875
MIDMEAN      = 1.5426                                     .30 QUANTILE = 1.424
                                                          .40 QUANTILE = 1.445
SAMPLE VARIANCE = .13497                                      MEDIAN     = 1.49
SAMPLE STANDARD DEVIATION = .36739                        .60 QUANTILE = 1.517
MEAN -2 S.D. = .84522                                     .70 QUANTILE = 1.824
MEAN -1 S.D. = 1.2126                                       .75 QUANTILE = 1.945
MEAN +1 S.D. = 1.9474                                     .80 QUANTILE = 2.026
MEAN +2 S.D. = 2.3148                                     .90 QUANTILE = 2.08

                    .25                               .75
                  QUANTILE MEDIAN                   QUANTILE
                      |      |                          |
        1.54+-----------+---+---+-----+-------+---------+-----++2.21
    |                |               | |              |                 |
  MEAN             MEAN          MID- MEAN          MEAN              MEAN
  -2 S.D.          -1 S.D.       MEAN               +1 S.D.           +2 S.D

SAMPLE STATISTICS FOR COLUMN  1 NCB-S/ 1

SAMPLE SIZE  = 10                                         .10 QUANTILE = 1.625
RANGE        = .67                                        .20 QUANTILE = 1.73
MEAN         = 1.898                                        .25 QUANTILE = 1.75
MIDMEAN      = 1.877                                      .30 QUANTILE = 1.755
                                                          .40 QUANTILE = 1.785
SAMPLE VARIANCE = .050951                                     MEDIAN     = 1.85
SAMPLE STANDARD DEVIATION = .22572                        .60 QUANTILE = 1.94
MEAN -2 S.D. = 1.4466                                     .70 QUANTILE = 2.055
MEAN -1 S.D. = 1.6723                                       .75 QUANTILE = 2.12
MEAN +1 S.D. = 2.1237                                     .80 QUANTILE = 2.16
MEAN +2 S.D. = 2.3494                                     .90 QUANTILE = 2.205
```

TABLE 16. NCB Cone Indenter Test Results-Sample D,G, & L.

```
                     .25                       75
                  QUANTILE      MEDIAN      QUANTILE
                      |            |            |
      24.9+-----------++-----------+++------ ---+-+-+83.5
       |              |            ||          |                 |
     MEAN           MEAN         MEAN MID-    MEAN              MEAN
     -2 S.D         -1 S.D            MEAN    +1 S.D            +2 S.D


SAMPLE STATISTICS FOR COLUMN  1 SD-S/A
                                                      .10 QUANTILE = 33.1
SAMPLE SIZE = 10                                      .20 QUANTILE = 42.15
RANGE       = 58.6                                        .25 QUANTILE = 43
MEAN        = 61.439                                  .30 QUANTILE = 50.95
MIDMEAN     = 63.958                                  .40 QUANTILE = 59.6
                                                          MEDIAN       = 61.045
SAMPLE VARIANCE = 405.95                              .60 QUANTILE = 69.445
SAMPLE STANDARD DEVIATION = 20.148                    .70 QUANTILE = 78.75
MEAN -2 S.D. = 21.143                                     .75 QUANTILE = 80.4
MEAN -1 S.D. = 41.291                                 .80 QUANTILE = 81.8
MEAN +1 S.D. = 81.587                                 .90 QUANTILE = 83.35
MEAN +2 S.D. = 101.74
```

```
                      .25                    .75
                    QUANTILE      MEDIAN   QUANTILE
                       |             |          |
        81.3+---------+-------+----------++-----+-----+---+89.3
         |            |                  | |        |                |
       MEAN          MEAN             MEAN MID-    MEAN             MEAN
       -2 S.D.       -1 S.D.               MEAN    +1 S.D.          +2 S.D


SAMPLE STATISTICS FOR COLUMN  1 SD-S/B
                                                      .10 QUANTILE = 82.1
SAMPLE SIZE = 9                                       .20 QUANTILE = 83.75
RANGE       = 8                                           .25 QUANTILE = 84.425
MEAN        = 86.3                                    .30 QUANTILE = 85.12
MIDMEAN     = 86.701                                  .40 QUANTILE = 86.42
                                                          MEDIAN       = 86.6
SAMPLE VARIANCE = 7.3425                              .60 QUANTILE = 87.5
SAMPLE STANDARD DEVIATION = 2.7097                    .70 QUANTILE = 88.24
MEAN -2 S.D. = 80.881                                     .75 QUANTILE = 88.55
MEAN -1 S.D. = 83.59                                  .80 QUANTILE = 88.82
MEAN +1 S.D. = 89.01                                  .90 QUANTILE = 89.18
MEAN +2 S.D. = 91.719
```

```
                    .25            .75
                  QUANTILE MEDIAN QUANTILE
                      |       |       |
         79.3+-------+----+---+-----+----+-+-+-------------------+89.47
       |             |            ||         |                |
     MEAN          MEAN        MID- MEAN    MEAN             MEAN
     -2 S.D.       -1 S.D.     MEAN         +1 S.D.          +2 S.D.


SAMPLE STATISTICS FOR COLUMN  1 SD-S/C

SAMPLE SIZE = 9                                   .10 QUANTILE = 79.9
RANGE       = 10.17                               .20 QUANTILE = 81.064
MEAN        = 83.59                                   .25 QUANTILE = 81.46
MIDMEAN     = 83.426                              .30 QUANTILE = 81.804
                                                  .40 QUANTILE = 82.41
SAMPLE VARIANCE = 9.2045                              MEDIAN       = 83.4
SAMPLE STANDARD DEVIATION = 3.0339                .60 QUANTILE = 84.48
MEAN -2 S.D. = 77.522                             .70 QUANTILE = 85.048
MEAN -1 S.D. = 80.556                                 .75 QUANTILE = 85.27
MEAN +1 S.D. = 86.624                             .80 QUANTILE = 85.468
MEAN +2 S.D. = 89.658                             .90 QUANTILE = 87.922
```

TABLE 17. Slake-durability test results -sample A,B & C

```
                        .25                               .75
                     QUANTILE MEDIAN                   QUANTILE
                           |     |                         |
        92.2+--------    --+-+--+-+----------------+---+---+96.2
         |                          ||                 |              |
        MEAN           MEAN       MID-  MEAN        MEAN           MEAN
        -2 S.D.        -1 S.D.    MEAN              +1 S.D.        +2 S.D.

  SAMPLE STATISTICS FOR COLUMN  1 SD-S/D

  SAMPLE SIZE = 8                                       .10 QUANTILE = 92.638
  RANGE       = 4                                       .20 QUANTILE = 93.681
  MEAN        = 94.47                                     .25 QUANTILE = 93.765
  MIDMEAN     = 94.466                                  .30 QUANTILE = 93.849
                                                        .40 QUANTILE = 94.031
  SAMPLE VARIANCE = 1.7799                                 MEDIAN      = 94.2
  SAMPLE STANDARD DEVIATION = 1.3341                    .60 QUANTILE = 94.687
  MEAN -2 S.D. = 91.802                                 .70 QUANTILE = 95.615
  MEAN -1 S.D. = 93.136                                   .75 QUANTILE = 95.715
  MEAN +1 S.D. = 95.804                                 .80 QUANTILE = 95.815
  MEAN +2 S.D. = 97.138                                 .90 QUANTILE = 96.092


                        .25                      .75
                      QUANTILE        MEDIAN QUANTILE
                           |              |    |
          54.3+-------------------+-------+--+-+----------+59.2
          |            |                |                |             |
         MEAN         MEAN          MEAN MID-          MEAN          MEAN
         -2 S.D.      -1 S.D.            MEAN          +1 S.D.       +2 S.D.

  SAMPLE STATISTICS FOR COLUMN  1 SD-S/F

  SAMPLE SIZE = 7                                        .10 QUANTILE = 54.54
  RANGE       = 4.9                                      .20 QUANTILE = 55.38
  MEAN        = 56.814                                     .25 QUANTILE = 55.65
  MIDMEAN     = 56.918                                   .30 QUANTILE = 55.86
                                                         .40 QUANTILE = 56.43
  SAMPLE VARIANCE = 2.6648                                  MEDIAN      = 57.2
  SAMPLE STANDARD DEVIATION = 1.632                      .60 QUANTILE = 57.48
  MEAN -2 S.D. = 53.549                                  .70 QUANTILE = 57.68
  MEAN -1 S.D. = 55.182                                    .75 QUANTILE = 57.75
  MEAN +1 S.D. = 58.447                                  .80 QUANTILE = 57.94
  MEAN +2 S.D. = 60.079                                  .90 QUANTILE = 58.92
```

TABLE 18 Slake-Durability Test Results- Sample D & F

```
                  .25                              .75
                QUANTILE          MEDIAN         QUANTILE
                   |                 |              |
      85.1+------------++----------+-----+--+----+---+-----+-+96
          |            |             |              |            |
        MEAN          MEAN          MEAN MID-      MEAN          MEAN
       -2 S.D.       -1 S.D.            MEAN      +1 S.D        +2 S.D

SAMPLE STATISTICS FOR COLUMN  1 SD-S/L

SAMPLE SIZE = 10                                   10 QUANTILE = 86.45
RANGE       = 10.9                                 20 QUANTILE = 87.9
MEAN        = 91.226                                 .25 QUANTILE = 88
MIDMEAN     = 91.352                               30 QUANTILE = 88.9
                                                   40 QUANTILE = 90.4
SAMPLE VARIANCE = 12.817                              MEDIAN     = 91.4
SAMPLE STANDARD DEVIATION = 3.5801                 60 QUANTILE = 92.43
MEAN -2 S.D. = 84.066                              70 QUANTILE = 93.63
MEAN -1 S.D. = 87.646                                75 QUANTILE = 94.2
MEAN +1 S.D. = 94.806                              80 QUANTILE = 94.85
MEAN +2 S.D. = 98.386                              90 QUANTILE = 95.75
```

```
                     .25                    .75
                  QUANTILE       MEDIAN QUANTILE
                      |               |     |
      97.2+--------------+---+----------------+-+-+-+-+----------+99.8
          |              |             ||          |              |
        MEAN           MEAN          MEAN MID-    MEAN           MEAN
       -2 S.D.        -1 S.D             MEAN    +1 S D         +2 S D

SAMPLE STATISTICS FOR COLUMN  1 SD-S/K

SAMPLE SIZE = 10                                   10 QUANTILE = [illegible]55
RANGE       = 2.6                                  20 QUANTILE = 98.05
MEAN        = 98.68                                  .25 QUANTILE = 98.2
MIDMEAN     = 98.78                                30 QUANTILE = 98.2
                                                   40 QUANTILE = 98.55
SAMPLE VARIANCE = .61067                              MEDIAN     = 98.95
SAMPLE STANDARD DEVIATION = .78145                 60 QUANTILE = 99.05
MEAN -2 S.D. = 97.117                              70 QUANTILE = 99.15
MEAN -1 S.D. = 97.899                                75 QUANTILE = 99.2
MEAN +1 S.D. = 99.461                              80 QUANTILE = 99.25
MEAN +2 S.D. = 100.24                              90 QUANTILE = 99.55
```

TABLE 19. Slake-Durability Test Results-Sample L & K

### 3.2.5 Bulk density,particle density and moisture content tests

**Bulk density** test was performed on 8 types of material with 5 to 8 runs per sample. There was no special requirements on the number of runs for this test. The analysis was performed on the programable calculator TI-58 and its results are presented in Table 20.
The value of bulk density ranges from 1.91Mg/m (sample F) to 2.43Mg/m (sample L) and its standard deviation from 0.02Mg/m (sample K) to 0.16Mg/m (sample A).

**Specific density test** was performed on 8 types of rocks. Three runs per sample were performed. Obtained particle density was from 2.53Mg/m(sample A) to 2.89Mg/m (sample L). The standard deviation was from 0.0 to 0.02Mg/m. It was the most accurate test performed in this project. The test result are presented in Table 21.

**Moisture content test** was performed on 8 types of material. The required number of runs was 5, however 6,7 or 8 runs were carried out to increase the test reliability. The moisture content ranged from 3.7% (sample K) to 9% (sample B) and test results variability was from 2%(sample F) to 29.0%(sample C). The results of analysis are presented in Table 22.

### 3.2.6 Atterberg limits,porosity and clay content tests

Atterberg limits tests were performed on 7 types of material only, as it was impossible to break sample L down

## BULK(DRY) DENSITY TEST

Bulk density B

Units Mg/$m^3$

| SAMPLE | N | B | S | V | RANGE |
|---|---|---|---|---|---|
| A | 5 | 2.17 | 0.16 | 7.7% | 0.40 |
| B | 8 | 2.07 | 0.10 | 5.1% | 0.22 |
| C | [illegible] | 2.03 | 0.07 | 3.5% | 0.15 |
| D | 7 | 2.16 | 0.09 | 4.5% | 0.26 |
| F | 8 | 1.91 | 0.06 | 3.2% | 0.18 |
| G | 7 | 2.08 | 0.04 | 1.9% | 0.11 |
| L | 5 | 2.25 | 0.02 | 1.1% | 0.07 |
| K | 5 | 2.43 | 0.04 | 1.6% | 0.11 |

N- number of tests; S- estimated satndard deviation;
V- variability of results; RANGE - range of results;
B- average bulk(dry) density

TABLE.20 Bulk(dry) density test results.

## SPECIFIC(PARTICLE) DENSITY TEST

Specific desity SD

Units Mg/$m^3$

1

| SAMPLE | N | SD | S | V | RANGE |
|---|---|---|---|---|---|
| A | 3 | 2.53 | 0.02 | 0.9% | 0.04 |
| B | 3 | 2.64 | 0.0 | 0.0 | 0.0 |
| C | 3 | 2.58 | 0.015 | 0.5% | 0.03 |
| D | 3 | 2.57 | 0.02 | 0.7% | 0.04 |
| F | 3 | 2.63 | 0.02 | 0.8% | 0.04 |
| G | 3 | 2.61 | 0.01 | 0.3% | 0.02 |
| L | 3 | 2.56 | 0.0 | 0.0 | 0.0 |
| K | 3 | 2.89 | 0.01 | 0.3% | 0.02 |

N- number of tests; S- estiamted standard deviation; V- variability of results; RANGE- range of results; SD- average value of spcific density,

TABLE 21. Specific density test results

MOISTURE CONTENT TEST

Moisture content M

Units %

| SAMPLE | N | M | S | V | RANGE |
|---|---|---|---|---|---|
| A | 8 | 8.54 | 1.32 | 15.5% | 4.42 |
| B | [illegible] | 9.00 | 1.03 | 11.0% | 2.70 |
| C | [illegible] | 8.86 | 2.65 | 29.9% | 7.10 |
| D | 8 | 5.71 | 0.59 | 10.4% | 1.43 |
| F | 5 | 6.54 | 0.13 | 2.0% | 0.32 |
| G | 5 | 5.75 | 0.23 | 4.1% | 0.58 |
| L | 5 | 5.68 | 0.42 | 7.4% | 1.17 |
| K | 5 | 3.76 | 0.55 | 14.7% | 1.4 |

N- number of tests; S- estimated standard deviation;
V- variability of results; RANGE- range of results;
M- average moisture content

TABLE 22. Moistuire content test results.

to the required grain size.

**Liquid limits** were calculated from the regression line based on 5 points. An average of two tests was reported as a final test result. The regression equation (straight line model) was calculated using programmable calculator TI-58. The results of analysis are presented in Table 23. Liquid limits for tested samples range from 24.0% (sample G) to 75.0% (sample A).

**Plastic limits** were calculated as an average of 5 runs. The results are presented in Table 23. They range from 19.2%(sample D) to 22.8%(sample A).

**Porosity** was calculated on the basis of bulk (dry) density and particle density tests. The results are presented in Table 23.

**Clay content** was calculated from hydrometer analysis as an average of two runs by cutting off the grain size on the cumulative distribution curve below 0.02mm. The results of tests are presented in Table 23.

## 3.3 Results of bivariate analysis

The analysis of bivariate relations between tests was performed using BMDP Statistical Package(program code - P6D). The following test results were taken as independent variables:

1. mean of NCB cone indenter test,
2. median of point-load test,
3. mean of bulk density test,

| SAMPLE - | LLIM % | PLIM % | PINDX | POROS % | ACTIV | CLAY % |
|---|---|---|---|---|---|---|
| A | 75.9 | 22.8 | 53.1 | 14.2 | 1.58 | 34 |
| B | 54.4 | 21.9 | 32.4 | 21.6 | 1.28 | 25 |
| C | 50.6 | 23.7 | 26.4 | 21.3 | 1.13 | 23 |
| D | 57.6 | 19.2 | 38.4 | 19.0 | 1.46 | 26 |
| G | 24.6 | -- | -- | 27.4 | -- | 13 |
| F | 28.5 | 21.6 | 6.8 | 21.0 | .46 | 15 |
| L | -- | -- | -- | 19.0 | -- | -- |
| K | 61.0 | 27.0 | 39.0 | 12.1 | 1.03 | 38 |

LLIM- liquid limits; PLIM- plastic limits;
PINDX- plasticity index; POROS- porosity;
ACTIV- clay activity; CLAY- clay content;

TABLE.23 Results of Attenberg limits tests, hydrometer analysis,porosity,activity and plasticity index Calculations.

4. mean of specific gravity test,
5. mean of clay content,
6. mean of moisture content,
7. mean of slake-durability index,
8. liquid limits,
9. plastic limits,
10. calculated plasticity index,
11. calculated activity,
12. calculated porosity.

The following test results were taken as response variables:

1. Cutting resistance calculated per unit of area of cut.
2. Cutting resistance calculated per unit of cut length.
3. Cutting resistance calculated per unit of blade length.

Two sets of test results were used in bivariate analysis. First set included results of tests on all 8 samples. Second set included only results of tests on 6 samples from Highvale mine. Two sets of results were received. As tested material represent two different geological formations, it was expected that some correlations between tested material properties could be lost in analysis of nonhomogenous data set (samples from the Highvale and Suncor mine).

The results of correlation analysis are presented in Table 25 in which columns 1,2 and 3 present the correlation calculated for all cases. Columns 4, 5 and 6 present results calculated for only 6 cases i.e. for Highvale mine. The complete results of analysis on all the pairs of variables (78 combinations) with fitted regression models and scatter

| No.of samples | 8 | 8 | 8 | 6 | 6 | 6 |
|---|---|---|---|---|---|---|
| Test | Fa | Fl | Fls | Fa | Fl | Fls |
| PLOAD | .9825 | .9854 | .9538 | .9008 | .8799 | .8613 |
| NCBC | .9046 | .9189 | .9669 | .8317 | .9830 | .9770 |
| BLKDEN | .6485 | .6879 | .9669 | .8317 | .9830 | .9770 |
| SPDEN | .8531 | .9015 | .8370 | -.1534 | .0946 | .0958 |
| MOIST | -.1046 | -.2416 | -.2569 | -.2209 | -.5377 | -.5381 |
| SLDUR | .5691 | .5590 | .6046 | .8687 | .8198 | .7555 |
| LLIM | -.2561 | -.4695 | -.4823 | -.1479 | -.4152 | -.4341 |
| PLIM | -.0308 | -.4886 | -.5132 | -.0174 | -.5581 | -.5815 |
| CLAY | -.4525 | -.5517 | -.5402 | -.1844 | -.4306 | -.4452 |
| PLINDEX | .1455 | .2986 | .4006 | .2985 | .4846 | .5997 |
| POR | .0404 | .0173 | .0261 | -.2523 | -.1496 | -.1493 |
| ACTIV | .5010 | .6566 | .7294 | .4982 | .6857 | .7678 |

Fa-cutting res. per area kPa
Fl-cutting res. per length of cut kN/m
Fls-cutting res. per blade length kN/m
PLOAD- point-load t.MPa ,NCBC- NCB cone inden. t.,
BLKDEN- bulk density t.Mg/m,SPDEN- specific density t.Mg/m
MOIST- moisture cont.t.%,SLDUR- slake-durability t. %
LLIM- liquid limits t.%,PLIM- plastic limits t.%,
CLAY- clay content %,PLINDEX- plasticity index %,
POR- porosity %,ACTIV- clay activity,

TABLE.24 Correlation coeficients between test results diagrams are presented in APPENDIX C.

The following limits were set on correlation coefficient:[7]

High degree of correlation - ABS $r > 0.7$;

Average degree of correlation - ABS $r$ => 0.5;

Low degree of correlation - ABS $r$ (0.5.

In the first group of correlations the following values were recorded: [*]

| Dependent Variable | Independent Variable | "r" |
|---|---|---|
| Fa(8) | PLOAD | 0.9825 |
| | NCBCONE | 0.9046 |
| | SP.GRAV | 0.8531 |
| * | | |
| Fl(8) | PLOAD | 0.9854 |
| | NCBCONE | 0.9189 |
| | SP.GRAV | 0.9015 |
| * | | |
| FLS(8) | PLOAD | 0.9538 |
| | NCBCONE | 0.9669 |
| | SP.GRAV | 0.8370 |
| | ACTIV | 0.7294 |

---

[7] R is a ratio of a variation explained by regression model to the total variation. Square root of R is r- correlation coefficient. So R= 50% ( means that proposed regression model accounts for 50% of variation) and r=.707. For R = 25% r= 0.5. The similar interpretation of R and r can be found in literature (8,21,24).

[*] The following code is used : Fa(8) - specific cutting resistance per area of cut for 8 samples set. Fl - specific cutting resistance per length of cut. Fls - specific cutting resistance per blade length. ... (6) means six samples set.

*

| | | |
|---|---|---|
| Fa(6) | PLOAD | 0.9008 |
| | NCBCONE | 0.8317 |
| | SL.DURAB | 0.8687 |

*

| | | |
|---|---|---|
| Fl(6) | PLOAD | 0.8799 |
| | NCBCONE | 0.9830 |
| | SL.DURAB | 0.8198 |

*

| | | |
|---|---|---|
| Fls(6) | PLOAD | 0.8613 |
| | NCBCONE | 0.9770 |
| | SL.DURAB | 0.7555 |
| | ACTIV | 0.7671 |

In the class of average correlation the following values were recorded.

| | | |
|---|---|---|
| [illegible] | BULKDEN | 0.6485 |
| | SL.DURAB | 0.5691 |
| | ACTIV | 0.5010 |

*

| | | |
|---|---|---|
| Fl(8) | BULKDEN | 0.6879 |
| | SL.DURAB | 0.5590 |
| | CLAY | -0.5517 |
| | ACTIV | 0.6566 |

*

| | | |
|---|---|---|
| Fls(8) | BULKDEN | 0.6282 |
| | SL.DURAB | 0.6046 |
| | PLIM | -0.5132 |

Fa(6) no values recorded

*

| | | |
|---|---|---|
| Fl(6) | MOIST | -0.5377 |
| | PLIM | -0.5581 |
| | ACTIV | 0.6857 |

*

| | | |
|---|---|---|
| Fls(6) | MOIST | -0.5383 |
| | PLIM | -0.5818 |
| | PINDX | 0.5997 |

The low degree of correlation was recorded for the following variables.

| | | |
|---|---|---|
| Fa(8) | MOIST | -0.1046 |
| | LLIM | -0.2561 |
| | PLIM | -0.0308 |
| | CLAY | -0.4525 |
| | PINDX | 0.1455 |
| | PORSOS | 0.0404 |

*

| | | |
|---|---|---|
| Fl(8) | MOIST | -0.2416 |
| | LLIM | -0.4695 |

| | | |
|---|---|---|
| | PLIM | -0.4886 |
| | PINDX | 0.2986 |
| | POROS | 0.0173 |
| * | | |
| Fls(8) | MOIST | -0.2569 |
| | LLIM | -0.4823 |
| | PINDX | -0.4006 |
| | POROS | 0.0261 |
| | ACTIV | 0.4982 |
| * | | |
| Fa(6) | BULKDEN | 0.3310 |
| | SP.GRAV | -0.1534 |
| | MOIST | 0.2209 |
| | LLIM | -0.1479 |
| | PLIM | -0.0174 |
| | CLAY | -0.1844 |
| | PINDX | 0.2985 |
| | POROS | -0.2525 |
| | ACTIV | 0.4982 |
| * | | |
| Fl(6) | BULKDEN | 0.2543 |
| | SP.GRAV | 0.0946 |
| | LLIM | -0.41[illegible] |
| | CLAY | -0.430[illegible] |
| | PINDX | 0.4868 |
| | POROS | -0.1496 |
| * | | |

| | | |
|---|---|---|
| Fls(6) | BULKDEN | 0.2289 |
| | SP.GRAV | 0.0958 |
| | LLIM | -0.4341 |
| | CLAY | -0.4452 |
| | POROS | -0.1496 |

To sum up, the following numbers of variables were recorded for each correlation class:

**Class of high correlations:**

Fa(8)- recorded independent variables - 3.
Fl(8)-recorded independent variables - 3.
Fls(8)-recorded independent variables - 4.
Fa(6)-recorded independent variables - 3.
Fl(6)-recorded independent variables - 3.
Fls(6)-recorded independent variables - 4.

**Class of average correlations:**

Fa(8)-recorded independent variables - 3.
Fl(8)-recorded independent variables - 4.
Fls(8)-recorded independent variables - 3.
Fa(6)-recorded independent variables - 0.
Fl(6)-recorded independent variables - 3.
Fls(6)-recorded independent variables - 3.

**Class of low correlations:**

F(8)-recorded variables - 6.
Fl(8)-recorded independent variables - 5.
Fls(8)-recorded independent variables - 5.

Fa(6)-recorded independent variables - 9.

Fl(6)-recorded independent variables - 6.

Fls(6)-recorded independent variables - 5.

For all high correlated pairs of variables scatter plots with fitted linear regression equations are presented in Appendix D.

# 4. Discussion of results

## 4.1 Cutting test results

The cutting resistance of tested samples permits to distinguish three classes of rock:

1. Weak rock with cutting resistance of up to 100kPa.
2. Medium-weak rocks with cutting resistance of between 100 -1000kPa.
3. Compact rocks with cutting resistance of over 1000kPa.

The first class contains the sample K (*glacial till*) with cutting resistance Fa=98kPa, Fl=13.17kN/m, Fls=33.48kN/m.

The second class contains:

- Sample A (*sandy siltstone*) Fa=383.0kPa, Fl=38.37 kN/m, Fls= 94.07kN/m.
- Sample B (*sandstone*) Fa=484.0kPa, Fl= 58.5kN/m, Fls= 123.5kN/m.
- Sample C (*coarse sandy siltstone*) Fa=950.0kPa ,Fl=49.87kN/m ,Fls=91.31kN/m.
- Sample D (*coarse sandstone*) Fa=820.0kPa ,Fl=86.22kN/m , Fls= 176.8kN/m.
- Sample F (*Yellow sandstone*) Fa=117kN/m, Fl= 15.23kN/m, Fls= 31.65kN/m.

All those samples were collected in the Highvale mine.

Two samples fall in the class of compact rocks:

- Sample G (*gray coarse sandstone*) Fa=1051.0 kPa, Fl=175.38kN/m, Fls=431.4kN/m.

- Sample L (*glauconitic shale*) Fa=2624.0kPa, Fl= 424.2kN/m, Fls=723.4kN/m.

The strongest tested sample is the glauconitic shale from overburden in the Suncor mine in Fort McMurray.

## 4.2 Results of bivariate analysis

Among material properties correlated with its cutting resistance the best correlations were detected for rock strength tests( point-load test and NCB cone indenter test). This correlation was confirmed before by Colleman (correlation between point-load test and O&K test) ,Franklin (correlation between point-load test and uniaxial compression test ) and Stimpson (correlation between NCB cone indenter tests and uniaxial compression test).

High correlations (0.7 ( r ) 1.0) were also detected for :

- Particle density with Fa(8),Fls(8).
- Activity with Fl(8),Fls(8),Fls(6).
- Slake durability with Fa(6),Fl(6),Fls(6) [1]

Correlations between O&K cutting test and rock strength tests, were already published and do not need further verification. However, correlations for slake-durability index, specific density and clay activity, not reported before , require further study .

---

[1] Fa(8)- specific cutting resistance per area of cut for 8 samples set. Fl(8)- specific cutting resistance per length of cut for 8 samples set.Fls(8)- specific cutting resistance per blade length for 8 samples set..(6) means six samples set.

### 4.3 Diggability of tested materials

The estimation of diggability for Highvale mine overburdens can be done by comparison of their cutting resistance or uniaxial compressive strength with the similar parameters of rocks with diggability determined empirically. The following diggability classifications are used:

1. Gorylewicz classification for tertiary overburdens in Tarnobrz g.
2. Kolkiewicz/Kozlowski classification for overburden formations in lignite mines(central Poland).
3. CANMET combined classification of diggability.
4. Protodiakonow classification as amended by Strzodka.

Gorylewicz classification is based on digging resistance and Protodiakonow index, which can be interpreted as uniaxial compressive strength. The uniaxial compressive strength of tested samples is calculated from point-load index using formula given by Franklin (13). In this project NCB cone indenter correlation with uniaxial compression test was not used as no adequate formula for the type of tested rocks was found.[10] Table 25 presents the calculations of Protodiakonow index and uniaxial compression strength for tested samples.

In this classification rocks F and K are classified as medium compact rocks (class III and IIIa), rocks A , B,C , D and G are classified as compact rocks (class IV and V),rock

---

[10] Stimpson gives correlation using standard cone indenter index,NCB manual does not give correlations with transitive weak rocks.

| SAMPLE | I(50) | Uniax.Com.Strengh |  | Protodiakonov Index |
|---|---|---|---|---|
| - | MPa | MPa | kG/cm$^2$ | - |
| A | 0.5 | 12.0 | 120.0 | 1.2 |
| B | 0.51 | 12.24 | 122.4 | 1.2 |
| C | 0.67 | 16.08 | 160.8 | 1.6 |
| D | 0.55 | 13.27 | 132.7 | 1.3 |
| F | 0.09 | 2.23 | 22.32 | 0.22 |
| G | 1.02 | 24.48 | 244.8 | 2.4 |
| L | 2.88 | 69.12 | 691.2 | 6.9 |
| K | 0.09 | 2.13 | 21.3 | 0.21 |

TABLE 25. Protodiakonov index for tested rocks

L is classified as a very compact rock(class VI and VII).

Kozlowski/Kolkiewicz classification (Table.1 & 2) is based on the nominal digging resistance per lengh and area of cut. For this analysis the ratio of digging force to cut area was selected. [11] In this classification, samples **K**, **F**, **A**, **B** fall into a class of diggable rocks. Samples C, **D**, **G**, **L** are in the class of non-diggable rocks. However these conclusions should be regarded with caution, because the classification is based on digging resistance while the tests defined the material cuttability.

CANMET diggability scale,based on data collected from a number of BWE mines world-wide, define all types of tested materials but **L** as diggable.

Strzodka scale based on Protodiakonow index defines rocks **A**, **B**, **D**, **F**, **K** as diggable and rocks **C**, **G**, **L** as not diggable.

The summary of the above findings is presented in Table 26. It is clear that the materials A, B, K & F can be dug by BWE without any problems. Rocks C and D can create some problems, especially when encountered in thick strata. Materials of type L and G may not be diggable with BWE. However, rock L is actually dug in Suncor mine. So, the final estimation of its diggability has to be left until a geological survey of formation is completed.

---

[11] Comparison of cutting resistance of tested samples with nominal digging resistance in on which the scale is based was done using the properties of diggability function outlined in footnote 2 .

| SCALE | DIGGABLE ROCKS | NOT DIGGABLE ROCKS |
|---|---|---|
| GORYLEWICH | F,K,A,B,C D,G | L |
| KOLKIEWICZ/ KOZLOWSKI | K,F,A,B | C,D,G,L |
| CANMET | A,B,C,D, F,G | L |
| STRZODKA | A,B,D,F,K | C,G,L |

TABLE 26. Comparison of diggabilty of tested rocks according to various classifications.

### 4.4 Comparison of study results with the findings of CANMET

For the purpose of validation, the results of this study are compared with similar tests done by CANMET on samples from Highvale mine. In CANMET study specific cutting resistance ,Fa, ranged from 1622.0kPa to 4516.0kPa while in this project specific cutting resistance ranged from 117.0kPa to 1051kPa.

Variability of O & K tests results (value of Fa) in CANMET project was from 35.0% to 88.0% while in this study was from 9.2% to 40.0% The results of tests in this project are characterised by greater stability and therefore can be regarded as more reliable. Statistics of CANMET tests presents Table 25.

According to CANMET classification (Table 26), 3 out of 5 samples from Highvale mine, tested in CANMET study, were defined as nondiggable. Materials from Highvale mine tested in this study were all classified as diggable The difference in the results is probably due to the differences in types of tested materials.

### 4.5 Diggability and rock properties

Tables 29 and 30 present the final results of the analysis of diggability conducted for tested materials. Here the results of geotechnical tests are combined with diggability classifications.

Table 29 presents a range of values of each tested geotechnical property for each diggability class. Table 30

| SAMPLE | | Fls KN/m | Fl KN/m | Fa KPa |
|---|---|---|---|---|
| Siltstone | X | 507.9 | 338.5 | 3648.0 |
| | S | 321.7 | 250.5 | 3231.0 |
| | V | 63.3% | 73.9% | 88.0% |
| Siltstone | X | 587.3 | 514.9 | 4516.0 |
| | S | 314.5 | 314.7 | 1831.0 |
| | V | 53.5% | 61.1% | 40.5% |
| Siltstone | X | 268.3 | 203.3 | 2718.0 |
| | S | 148.1 | 67.9 | 856.2 |
| | V | 55.2% | 33.4% | 31.5% |
| Siltstone | X | 322.4 | 193.6 | 1622.0 |
| | S | 71.0 | 95.9 | 1129.0 |
| | V | 22.0% | 49.5% | 69.6% |

X- average value of test; S- standard deviation
V- variability

TABLE 27. Results of CANMET Cutting Tests

| SAMPLE NUMBER | ROCK TYPE | CONDITION | CUTTING RESISTANCE ($N/cm^2$) |  | DIGABILITY RATING* |  |  |
|---|---|---|---|---|---|---|---|
|  |  |  | First Cut | Strongest Cut | 1 | 2 | 3 |
| Highvale No. 1 | Siltstone; calcareous cement | Unfrozen | 258 | 933 | . . | . . | .X. |
| Highvale No. 3 | Siltstone: calcareous cement | Unfrozen | 366 | 662 | . . | . . | .X. |
| Highvale No. 4 | Sandstone | Unfrozen | 11 | 21 | .X. |  |  |
| Highvale No. 5 | Siltstone; calcareous cement | Unfrozen | 198 | 410 | . . | . . | .X. |
| Highvale No. 6 | Siltstone | Unfrozen | 101 | 356 | .X. |  |  |
| Diplomat No. 1 | Silt Till | Unfrozen | 15 | 30 | .X. |  |  |
| Diplomat No. 2 | Silt Till | Unfrozen | 15 | 57 | .X. |  |  |
| Souris Valley #2 | Calystone; calcareous cement | Unfrozen | 156 | 880 | . . | .X. |  |
| Souris Valley #3 | Claystone; calcareous cement | Unfrozen | 111 | 111** | . . | .X. |  |
| Souris Valley #4 | Claystone; calcareous cement | Unfrozen | 161 | 161** | . . | .X. |  |
| Poplar River #1 | Siltstone; calcareous cement | Unfrozen | 14 | 14** | .X. |  |  |
| Poplar River #2 | Siltstone; calcareous cement | Unfrozen | 34 | 40 | .X. |  |  |
| Poplar River #3 | Siltstone; calcareous cement | Unfrozen | 10 | 40 | .X. |  |  |

*1 - easily digable, 2 - digable with limitations, 3 = nondigable.

** = one cut made

TABLE 28. CANMET Diggability Classification.

| DIGGABILITY | TYPE OF MATERIAL | CUT Fa | PLOAD I(50) | NCB (weak) | BULK | MOIST | LLIM | PLIM | PINDX | CLAY | PORS | SLDUR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | kPa | MPa | Index | MG/m$^3$ | % | % | % | % | % | % | % |
| EASY DIGGABLE | A,B,K,<br>F | 98.0 | 0.09 | 0.1 | 1.91 | 3.76 | 28.6 | 21.6 | 6.8 | 15.0 | 12.1 | 61.4 |
| | | 484.0 | 0.51 | 0.42 | 2.25 | 9.0 | 75.9 | 22.8 | 53.1 | 38.0 | 27.4 | 91.22 |
| DIGGABLE | C,D | 820.0 | 0.55 | 0.60 | 2.03 | 5.7 | 50.6 | 19.2 | 26.4 | 23.0 | 19.0 | 83.5 |
| | | 950.0 | 0.67 | 0.68 | 2.16 | 8.8 | 57.6 | 23.7 | 38.4 | 26.0 | 21.3 | 94.4 |
| CAN CREATE PROBLEMS | L,G | 1051.0 | 1.02 | 1.58 | 2.43 | 5.75 | 24.6 | -- | -- | 13.0 | 21.0 | 98.6 |
| | | 2624.0 | 2.88 | 1.89 | 2.25 | 5.68 | | | | | 19.0 | 100.0 |

CUT- cuttability;PLOAD- point-load test;NCB- NCB cone indenter test;BULK- bulk density test; MOIST- moisture content:LLIM- liquid limits test;PLIM- plastic limits test;CLAY- clay content; PORS- porosity,PINDX- plastisity index;SLDUR- slake- durability index.

TABLE 29. Test results for diggability classes( range).

| DIGGABILITY<br>- | TYPE OF MATERIAL<br>- | CUT Fa kPa | PLOAD I(50) MPa | NCB (weak) Index | BULK $MG/m^3$ | MOIST % | LLIM % | PLIM % | PINDX % | CLAY % | PORS % | SLDUR % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EASY DIGGABLE | A,B,K, F | 270.5 | 0.29 | 0.24 | 2.1 | 6.96 | 54.9 | 22.1 | 32.9 | 28.0 | 18.8 | 74.3 |
| DIGGABLE | C,D | 885.0 | 0.61 | 0.64 | 2.09 | 6.12 | 54.1 | 25.5 | 30.4 | 24.5 | 20.1 | 89.03 |
| CAN CREATE PROBLEMS | L,G | 1840.0 | 1.[illegible] | 1.73 | 2.24 | 5.71 | 24.6 | - | - | 13.0 | 20.0 | 99.3 |

CUT- cuttability;PLOAD- point-load test;NCB- NCB cone indenter test;BULK- bulk density test;
MOIST- moisture content:LLIM- liquid limits test;PLIM- plastic limits test;CLAY- clay content;
PORS- porosity,PINDX- plastisity index;SLDUR- slake- durability index.

TABLE 30 Test results for diggability classes( average).

presents average values of tested properties for each class The following observations can be drawn from the above Tables:

1. Digging conditions deteriorate with increased rock strength and slake-durability.
2. Decrease in clay content worsens the digging conditions.
3. Liquid limits and moisture content show also change from one diggability class to another, but the change fail to fit the linear regression model. Relationships involved may be of a nonlinear character.
4. It is not possible , regarding the requirements of multivariable analysis, to form the prediction equation for cutting resistance, as the number of different cases is too small in comparison with the number of analysed variables.
5. As indicated by CANMET, digging conditions are influenced by structural features of the formation. Diggability classifications (those in Tables 29 and 30) which do not take into account this factor are uncomplete. Consequently, the conclusions about diggability of the Highvale mine overburden should be supported by further studies of overburden structure there.

## 5. Conclusions

1. All the tested rocks from Highvale mine are weaker than rocks actually dug by a BWE in Suncor mine.
2. Overburden in the Highvale mine, as well as in other Plains mines with similar geology, can be mined with a BWE.
3. Geotechnical survey of the diggability of overburden formations has to pay special attention to rocks of type G, L, and D as these are potentially difficult to dig.
4. The O&K cutting test as a test accepted by BWE manufacturers is useful is diggability studies. However, further studies into stability of test results should be carried out.
5. The regression models developed in this study may be useful in cuttability prediction.
6. There is no unique and accurate method for prediction of diggability at present. Rock classifications defined in the Tables 29 and 30 can be of quidance , but final conclusions as to the rock diggability have to be supported by geological studies of overburden in question and by field tests of diggability.
7. High correlation found to exist between the slake-durability index and specific cutting resistance (as it was expected see p. 22) indicates possible new approach to diggability studies.
8. Further diggability studies should concentrate on the point-load test, the NCB cone indenter test, bulk

density test, slake-durability test and clay content.

9. To be fully acceptable in cuttability studies of Plains overburdens NCB cone indenter test should be correlated with compressive strength of weak rocks from Plains.

## 6. Proposals for further research

The limited scope of this study has not permitted to explain all the complexities involved in definition of material diggability. It appears that further research should concentrate on the following:

1. The multivariate regression analysis between the cutting resistance and the geotechnical properties of materials is needed . To facilitate it, the geotechnical database should be expanded by additional testing of 15 to 20 different materials. (see p.59)
2. Research into correlation between shock wave velocity, rock geotechnical properties and formation diggability may permit formulation of better classification for rock diggability. (see p.13 & 59).

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# APPENDIX A

## RAW RESULTS OF TESTS

This appendix presents raw results of the tests.Tables give the following information about results:

- Type of test.
- Test units.
- Sample type.
- Number of runs.
- Test results.

Sample code is as follows:

**Sample** A-gray sandy silstone.

**Sample** B-gray sandstone.

**Sample** C-coarse gray sandstone.

**Sample** D-coarse sandstone.

**Sample** F-yellow coarse sandstone.

**Sample** G-gray coarse sadstone.

**Sample** K-brown glacial till.

**Sample** L-greenish gauconitic shale.

Orenstein & Koppel cutting test.

| SAMPLE | CUTTING RESISTANCE Fls kN/m | Fl kN/m | Fa kPa |
|---|---|---|---|
| A | 112.49 | 43.01 | 430.0 |
| | 98.10 | 37.50 | 375.0 |
| | 71.90 | 34.60 | 346.0 |
| B | 92.11 | 48.89 | 453.0 |
| | 154.90 | 67.10 | 516.0 |
| C | 160.7 | 80.08 | 808.0 |
| | 50.24 | 38.42 | 1097.0 |
| | 41.87 | 32.01 | 914.0 |
| | 113.04 | 48.98 | 979.0 |
| D | 196.7 | 85.7 | 631.0 |
| | 213.5 | 102.8 | 850.0 |
| | 188.4 | 102.0 | 750.0 |
| | 108.8 | 54.4 | 1080.0 |
| F | 54.43 | 17.4 | 98.0 |
| | 19.00 | 19.00 | 166.0 |
| | 16.6 | 16.6 | 145.0 |
| | 62.8 | 20.1 | 144.0 |
| | 41.86 | 14.28 | 86.0 |
| | 16.73 | 31.08 | 180.0 |
| | 25.12 | 10.7 | 70.0 |
| | 16.73 | 8.56 | 51.0 |
| G | 410.4 | 175.5 | 991.0 |
| | 468.9 | 184.7 | 1329.0 |
| | 644.7 | 206.2 | 1353.0 |
| | 385.4 | 141.4 | 930.0 |
| | 460.0 | 169.1 | 650.0 |
| L | 900.2 | 325.0 | 1805.0 |
| | 657.3 | 474.7 | 2637.0 |
| | 921.1 | 332.6 | 1847.0 |
| | 590.3 | 479.6 | 3197.0 |
| | 548.4 | 509.3 | 3637.0 |
| K | 54.43 | 19.65 | 109.0 |
| | 37.67 | 16.32 | 90.0 |
| | 20.92 | 8.0 | 100.0 |
| | 12.55 | 6.8 | 97.0 |
| | 41.86 | 15.11 | 94.0 |

Slake durability index test.(%)

**Sample:**

**A**- 41.3 24.0 60.3 58.9 83.2 61.79 80.4 83.5 77.1 43.0

**B**-81.3 88.4 84.8 86.4 89.0 89.3 83.3 86.6 87.6

C-85.16 80.8 84.6 81.68 89.47 79.3 85.6 83.4 82.3

**D**-95.84 93.66 93.87 95.59 94.30 92.24 96.70 94.1

G- 100% in 10 runs

**F**-57.2 57.8 67.8 59.2 55.5 57.6 54.3 56.1

**K**-93.06 94.2 87.8 96.0 91.8 88.0 91.0 95.5 85.1 89.8

L-99.3 99.2 98.2 99.0 98.9 97.9 98.2 99.1 97.2

**Point-load test** I(50)(KN/m)

**Sample A**-66.0 75.0 176.0 501.0 408.0 650.0 650.0 911.0 320.0 680.0 300.0 720.0 500.0 250.0 520.0 320.0 210.0 500.0 86 850.0 570.0 150.0 800.0 580.0 210.0 600.0

**Sample B**-354.0 850.0 750.0 300.0 520.0 354.0 620.0 1100.0 500.0 480.0 180.0 920.0 980.0 380.0 320.0 450.0 680.0 950.0 420.0 490.0 680.0 520.0 260.0 800.0 501.0 550.0 460.0 410.0 940.0 520.0

**Sample** C-670.0 880.0 600.0 410.0 471.0 810.0 1120.0 620.0 730.0 420.0 670.0 750.0 580.0 940.0 780.0 890.0 520.0 670.0 520.0 730.0

**Sample D**-420.0 420.0 511.0 491.0 430.0 460.0 595.0 680.0 950.0 750.0 950.0 1080.0 460.0 750.0 720.0 460.0 430.0 480.0 750.0 700.0

**Sample F**-89.0 60.0 82.0 65.0 1090.0 137.0 89.0 81.0 46.0 97.0 100.0 109.0 93.0 100.0 118.0 123.0

**Sample G**1020.0 1050.0 1000.0 850.0 1020.0 1768.0 950.0

1965.0 505.0 1500.0 1351.0 1785.0 510.0 1630.0 1010.0 830.0 1420.0 1102.0 830.0

**Sample F**-3230.0 2020.0 3030.0 3210.0 2880.0 1730.0 2740.0 2990.0 3010.0 3320.0 3880.0 2930.0 2940.0 2210.0 2610.0 2820.0 2630.0 2750.0 3110.0 2520.0 2910.0

**Sample K**-99.0 71.0 72.0 90.0 85.0 102.0 79.0 87.0 78.0 92.0 69.0 92.0 81.0 110.0 105.0 99.0 85.0 92.0 89.0 92.0 89.0 72.0 89.0 91.0 93.0 82.0 92.0 79.0 100.0

**NCB cone indenter index test.**

**Sample A**-0.496 0.273 0.460 0.746 0.673 0.343 0.312, 0.321 0.287 0.255 0.444 0.290 0.370 0.380 0.420 0.410 0.370 0.470

**Sample B**-0.38 0.30 0.51 0.45 0.46 0.40 0.38 0.56 0.46 0.54 0.56 0.40 0.42 0.54 0.27 0.29 0.39 0.42 0.37 0.73

**Sample C**-0.83 0.76 0.66 0.52 0.58 0.69 0.54 0.53 0.60 0.50 0.48 0.35 0.62 0.61,0.65 0.60 0.55 0.63 0.67 0.62

**Sample D**-0.88 0.64 0.66 0.73 0.86 0.68 0.71 0.63 0.79 0.69 0.54 0.57 0.85 0.85 0.50 0.58 0.77 0.0.79 0.55 0.64

**Sample F**- less then 0.100

**Sample G**-2.70 1.29 2.08 2.08 1.44 1.0 1.9 1.42,1.49 1.52

**Sample K** see sample F

**Sample L**-2.20 2.12,1.75 1.89 1.76 2.21 1.54 1.88

**Bulk desnity test** (Mg/m).

**Sample:**

**A**-1.99 2.39 2.30 2.16 2.04

**B**-1.97 2.17 2.17 2.17 1.94 1.95 2.16 2.07

**C**-2.01,2.07 1.93 2.01,2.08 2.14 1.97

D-2.24 2.09 2.26 2.20 2.19 2.19 1.98

F-1.90 1.94 2.04 1.85 1.87 1.93 1.94 1.86

G-2.06 2.04 2.04 2.15 2.04 2.09 2.11

K-2.26 2.24 2.26 2.30 2.23

L-2.44 2.43 2.43 2.50 2.39

**Particle density.(Mg/m)**

**Sample:**

A-2.511 2.550 2 554

B-2.649 2.646 2.644

C-2.600 2.584 2.573

D-2.579 2.558 2.590

F-2.658 2.649 2.616

G-2.629 2.611 2.607

K-2.560 2.560 2.560

L-impossible to get the required graine size.

**Natural moisture content test (%).**

**Sample:**

A-6.10 8.71 10.52 9.57 8.28 7.74 8.18 9.25

B-8.59 11.0 8.79 8.23 8.30 9.10

C-10.80 10.47 10.93 11.23 9.19 8.43 4.04 5.79

D-4.91,5.91 6.34 6.33 5.38 6.28 5.66 4.93

F-6.53 6.44 6.64 6.71 6.39

G-6.02,5.69 5.44 5.96 5.65

L-3.0 4.4 3.6 4.2 3.6

K-4.9 5.66 6.07 5.75 6.03

**Attenberg limits**

**Sample A:**

Plastic limits-22.83%

Liquid limits-75.95%

Plasticity index53.12%

Activity-1.58

Liquid limits linear model :y=-0.313x+83.80

(r=-0.989)

**Sample B:**

Plastic limits-21.97%

Liquid limits-54.43%

Plasticity index-32.46%

Activity-1.28

Liquid limits linear model :y=-0.15x+58.18

(r=-0.956)

**Sample C:**

Plastic limits-23.73%

Liquid limits-57.64%

Plasticity index-38.39%

Activity-1.13

Liquid limits linear model :y=-0.08x+52.79

(r=-0.9219)

**Sample D**

Plastic limits-19.25%

Liquid limits-57.64%

Plasticity index-38.39%

Activity - 1.46

Liquid llimits linear model :y=-0.202x+62.69

(r=-0.93)

**Sample G:**

Plastic limits -impossible to determine

Liquid limits-24.67%

Plasticity index - **********

Liquid limits linear model :y=-0.123x+31.63

(r=-0.960)

**Sample F:**

Plastic limits -21.66%

Liquid limits-28.54%

Plasticity Index-6.88%

Activity -.46

Liquid limits linear model :y=-0.123x+31.63

(r=-0.960)

**Sample G** -impossible to desintegrate

**Sample K:**

Plastic limits-22.0%

Liquid limits-61.0%

Plasticity index -39.0%

Activity -1.03

Liquid limits linear model - ??

**Clay content from the hydrometer analysis**

**Sample A**- clay content 34%

**Sample B**- caly content 25 %

**Sample C**- clay content 23 %

**Sample D**- clay content 26 %

**Sample F**- clay content 15 %

**Sample G**- cllay conetnt 13%

**Sample L-** ***********

**Sample K** - clay content 38%

# APPENDIX B

# BMDP PROGRAMS AND DATA FILES

This is BMDP program for bivariate analysis of variables coded as P6D.

```
/PROBLEM  TITLE IS 'DATA DISPLAY'.
/INPUT    MTSFILE IS 'DATABM'.
          VARIABLES ARE 13.
          MCHAR='*'.
          FORMAT IS SLASH.
          CASES ARE 6.
/VARIABLE NAMES ARE CUTTEST,PLOAD,NCBCON,
                    BULKDEN,SPGRAV,MOIST,SLDUR,
                    LLIM,PLIM,CLAY,PINDEX,
                    PORS,ACTIV.
/PLOT     XVAR ARE  PLOAD,NCBCON,BULKDEN,SPGRAV,
                    MOIST,SLDUR,LLIM,PLIM,CLAY,
                    PINDEX,PORS,ACTIV.
          YVAR ARE  CUTTEST,CUTTEST,CUTTEST,CUTTEST,
                    CUTTEST,CUTTEST,CUTTEST,CUTTEST,CUTTEST,
                    CUTTEST,CUTTEST,CUTTEST.
          STAT.
          SIZE=55,20.

/END
```

THIS IS BMDP PROGRAM FOR DATA DESCRIPTON ANALYSIS. THE PROGRAM IS DESCRIBED IN 7 AS P2D.

```
/PROBLEM     TITLE IS 'PLT SAMPLE K'.
/INPUT       VARIABLES ARE 1.
             FORMAT IS SLASH.
             MTSFILE IS P88.
/END.
1
```

THE FOLLOWING FILES ARE PREPARED IN SLASH FORMAT FOR BMDP ANALYSIS.

```
383. .50 .36 2.17 2.53 8.54 61.43 75.95 22.83 34.0 53.22 14.2 1.58/484.
```

```
0.51 .42 2.07 2.64 9.0 86.3 54.43 21.97 25. 32.46 21.6 1.28/950. 0.67 .6
2.03 2.58 8.86 83.59 50.59 23.73 23. 26.46 21.3 1.13/820. .553 .68 2.16
2.57 5.71 94.47 57.64 19.25 26. 38.39 19. 1.46/117. .095 .1 1.91 2.6
6.54 58.18 28.54 21.66 15. 6.88 27.4 .46/1057. 1.02 1.58 2.06 2.61 5.75
100.0 24.67 * 13. * 21. * /2624. 2.88 1.89 2.43 2.89 5.68 98.68 * *  * *
19. * /98. .089 .1 2.25  2.56 3.76 91.22 61. 22. 38. 39. 12.1 1.03
/END
1
38.4 .50 .36 2.17 2.53 8.54 61.43 75.95 22.83 34.0 53.22 14.2 1.58/58.5
.51 .42 2.07 2.64 9.0 86.3 54.43 21.97 25. 32.46 21.6 1.28/49.9 .67 .6
2.03 2.58 8.86 83.59 50.59 23.73 23. 26.46 21.3 1.13/86.2 .553 .68 2.16
2.57 5.71 94.47 57.64 19.25 26. 38.39 19. 1.46/15.2 .095 .1 1.91 2.63
6.54 58.18 28.54 21.66 15. 6.88 27.4 .46/175.4 1.02 1.58 2.06 2.61 5.75
100.0 24.67 * 13. * 21. * /424.2 2.88 1.89 2.43 2.89 5.68 98.68 * *  * *
19. * /13.7 .09 .1 2.25  2.56 3.76 91.22 61. 22. 38. 39. 12.1 1.03
/END
94.1 .5 .36 2.17 2.53 8.54 61.43 75.95 22.83 34.0 53.22 14.2 1.58/123.5
.51 .42 2.07 2.64 9.0 86.3 54.43 21.97 25. 32.46 21.6 1.28/91.3 .67 .6
2.03 2.58 8.86 83.59 50.59 23.73 23. 26.46 21.3 1.13/176.8 .553 .68 2.16
2.57 5.71 94.47 57.64 19.25 26. 38.39 19. 1.46/31.6 .095 .1 1.91 2.63
6.54 58.18 28.54 21.66 15. 6.88 27.4 .46/431.2 1.02 1.58 2.06 2.61 5.75
100.0 24.67 * 13. * 21. * /723.4 2.88 1.89 2.43 2.89 5.68 98.68 * *  * *
19. * /33.5 .089 .1 2.25  2.56 3.76 91.22 61. 22. 38. 39. 12.1 1.03
/END

 THE FOLLOWING FILES ARE PREPARED FOR THE INTERACTIVE STATISTICAL
 PACKAGE ANALYSIS.
(1)CUT/A   (2)CUT/L   (3)CUT/LS   (4)PLT   (5)NCB  (6)BULK  (7)SPGRAV
  383.,     38.37,      94.07,      .500 ,   .36 ,   2.17,     2.53,
  484.,     58.50,     123.50 ,,    .510  ,  .42 ,   2.07,     2.64 ,
  950.,     49.87,      91.31,      .670,    .60 ,   2.03,     2.58 ,
  820.,     86.22,     176.80,      .553,    .68,    2.16,     2.57,
  117. ,    15.23 ,     31.65,     0.095,    .10 ,   1.91,     2.63,
 1057.,    175.38,     431.20,     1.020,   1.58,    2.06,     2.61,
 2624.,    424.20 ,    723.40 ,    2.880 ,  1.89,    2.43,     2.89,
 98.,       13.17 ,     33.48,     0.089 ,   .1,     2.25,     2.56,

(1)CUT/A   (2)CUT/L   (3)CUT/LS   (4)MOIT  (5)SLD  (6)LLIM  (7)PLIM
  383.,     38.37,      94.07,      8.54 , 61.43 , 75.95,    22.83,
  484.,     58.50,     123.50 ,     9.00  ,86.30 , 54.43,    21.97 ,
  950.,     49.87,      91.31,      8.86,  83.59 , 50.59,    23.73 ,
  820.,     86.22,     176.80,      5.71,  94.47,  57.64,    19.25,
  117.,     15.23 ,     31.65,      6.54,  58.18 , 28.54,    21.66,
 1057.,    175.38,     431.20,      5.75,  100.0,  24.67,       0,
 2624.,    424.20 ,    723.40 ,     5.68 , 98.68,     0,        0,
  98.0,     13.17 ,     33.48,      3.76 , 91.22,  61.0,      22.0,

(1)CUT/A   (2)CUT/L   (3)CUT/LS   (4)CLAY  (5)PINX (6)PORS  (7)ACTIV
  383.,     38.37,      94.07,     34.00 , 53.22 , 14.2,        1.58,
  484.,     58.50,     123.50 ,    25.00  ,32.46 , 21.6,        1.28,
  950.,     49.87,      91.31,     23.00,  26.46 , 21.3,        1.13,
  820.,     86.22,     176.80,     26.00,  38.39,    19.0,      1.46,
  117.,     15.23 ,     31.65,     15.00,  6.88 ,   27.4,      0.46,
 1057.,    175.38,     431.20,     13.00,     0,     21.0,     0,
 2624.,    424.20 ,    723.40 ,      0,       0,     19.0,     0 ,
  98.0,     13.17 ,     33.48,      38.,     39.0,   12.1,      1.03,
1
(1)CUT/A   (2)CUT/L   (3)CUT/LS   (4)PLT   (5)NCB  (6)BULK  (7)SPGRAV
  383.,     38.37,      94.07,      .500 ,   .36 ,   2.17,     2.53,
  484.,     58.50,     123.50 ,     .510 ,   .42 ,   2.07,     2.64 ,
```

```
     950.,     49.87,      91.31,      .670,     .60 ,  2.03,     2.58 ,
     820.,     86.22,     176.80,      .553,     .68,   2.16,     2.57,
     117.,     15.23 ,     31.65,    0.0950,     .10 ,  1.91,     2.63,
    1057.,    175.38,     431.20,     1.020,    1.58,   2.06,     2.61,
   1
   (1)CUT/A  (2)CUT/L   (3)CUT/LS   (4)MOIT (5)SLD (6)LLIM (7)PLIM
     383.,     38.37,      94.07,      8.54 , 61.43 , 75.95,    22.83,
     484.,     58.50,     123.50 ,     9.00 ,86.30 , 54.43,    21.97 ,
     950.,     49.87,      91.31,      8.86,  83.59 , 50.59,    23.73 ,
     820.,     86.22,     176.80,      5.71,  94.47,  57.64,    19.25,
     117. ,    15.23 ,     31.65,      6.54,  58.18 , 28.54,    21.66,
    1057.,    175.38,     431.20,      5.75,  100.0,  24.67,       0,

   (1)CUT/A  (2)CUT/L   (3)CUT/LS   (4)CLAY (5)PINX (6)PORS (7)ACTIV
     383.,     38.37,      94.07,    34.00 , 53.22 , 14.2,      1.58,
     484.,     58.50,     123.50 ,   25.00 ,32.46 , 21.6,       1.28,
     950.,     49.87,      91.31,    23.00,  26.46 , 21.3,      1.13,
     820.,     86.22,     176.80,    26.00,  38.39,   19.0,     1.46,
     117.0,    15.23 ,     31.65,    15.00,  6.88 ,  27.4,      0.46,
    1057.,    175.38,     431.20,    13.00,    0,     21.0,     0,
End of file
```

# APPENDIX C

## ANALYSIS OF CORRELATIONS BEWTEEN TESTED VARIABLES

The following abbrevations are used :

**Fa** - cutting resistance per area of cut - KPa

**Fl** - cutting resistance per cut length - KN/m

**Fls**- cuttning resistance per blade length- KN/m

**PLOAD** - point-load MPA

**NCBCON**- NCB cone indenter index

**BULKDEN**- bulk density MG/m

**SPGRAV**- particle density MG/m

**MOIST**- moisture content %

**SLDUR** - slake- durability %

**LLIM** - liquid limits %

**PLIM** - plastic limits %

**CLAY** - clay content %

**PINDEX** - plastisity index %

**PORS** - porosity %

**ACTIV** - activity

The following sets of variables are used:

**SET I** - Fa vs. 8 SAMPLES SET

**SET II** - FL vs. 8 SAMPLES SET

**SET III** - Fls vs. 8 SAMPLES SET

**SET IV** - Fa vs. 6 SAMPLES SET

**SET V** - Fl vs. 6 SAMPLES SET

**SET VI** - Fls vs. 6 SAMPLES SET

SET I

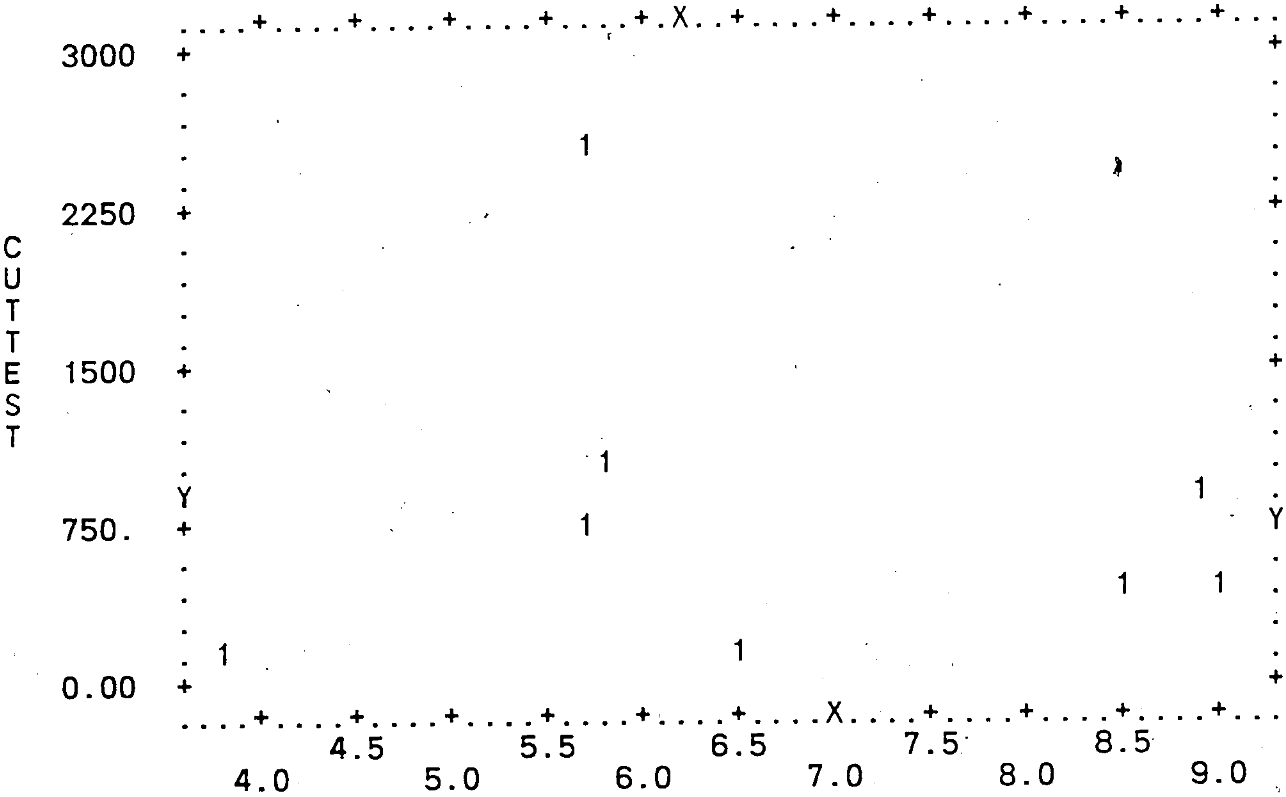
```
PAGE    4  BMDP6D DATA DISPLAY   Fa(KN/sq.m)

         .+....+....+....+....+....+....+....+....+....+....+....XY
    3000 +                                                       +
         .                                                       .
         .                                                       .
         .                                                1      .
         .                                                       .
    2250 +                                                       +
C        .                                                       .
U        .                                                       .
T        .                                                       .
T        .                                                       .
E   1500 +                                                       +
S        .                                                       .
T        .                                                       .
         .                 1                                     .
         .           1                                           .
    750. +         1                                             +
         .                                                       .
         .        11                                             .
         .                                                       .
         . 11                                                    .
    0.00 Y                                                       +
         .+....+....+....+....+....+....+....+....+....+....+....+.
              .30       .90       1.5       2.1       2.7       3.3
         0.0       .60       1.2       1.8       2.4       3.0
N=      8
COR= .9825                                 PLOAD

    MEAN     ST.DEV.    REGRESSION LINE     RES.MS.
X   .78962   .89670   X= .00108*Y-.09343     .03249
Y   816.62   814.75   Y= 892.74*X+ 111.70   26824.



VARIABLE   2 PLOAD    VERSUS VARIABLE   1 CUTTEST
```

```
PAGE   5  BMDP6D DATA DISPLAY





         .....+....+....+....+....+....+....+....+....+....+....+..
   3000  +                                                        +
         .                                                        .
         .                                                        .
         .                                                     1  X
         .                                                        .
   2250  +                                                        Y
C        .                                                        .
U        .                                                        .
T        .                                                        .
T        .                                                        .
E  1500  +                                                        +
S        .                                                        .
T        .                                                        .
         .                                            1           .
         .                1                                       .
   750.  +                  1                                     +
         .                                                        .
         .         1 1                                            .
         .                                                        .
         .  2                                                     .
   0.00  Y                                                        +
         X....+....+....+....+....+....+....+....+....+....+....+..
            .1750     .5250     .8750     1.225     1.575     1.925
                 .3500     .7000     1.050     1.400     1.750
N=     8
COR= .9046                        NCBCON

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   .71625   .66685  X= 740E-6*Y+ .11163   .09425
Y   816.62   814.75  Y= 1105.3*X+ 24.987   140703



VARIABLE   3 NCBCON   VERSUS VARIABLE   1 CUTTEST
```

```
PAGE    6  BMDP6D DATA DISPLAY
        .+....+....+....+....+....+....+....+....+....+....+..X.+.
   3000 +                                                        +
        .                                                        .
        .                                                        .
        .                                                     1  .
        .                                                        .
   2250 +                                                        +
C       .                                                        .
U       .                                                        Y
T       .                                                        .
T       .                                                        .
E  1500 +                                                        +
S       .                                                        .
T       .                                                        .
        .                1                                       .
        .             1                                          .
   750. +                          1                             +
        .                                                        .
        .                 1         1                            .
        .                                                        .
        . 1                                 1                    .
   0.00 Y                                                        +
        .+....+....+X...+....+....+....+....+....+....+....+....+.
             1.95      2.05      2.15      2.25      2.35      2.45
        1.90      2.00      2.10      2.20      2.30      2.40
N=     8
COR= .6485                           BULKDEN

    MEAN      ST.DEV.     REGRESSION LINE     RES.MS.
X   2.1350    .15748    X= 125E-6*Y+ 2.0326    .01677
Y   816.62    814.75    Y= 3355.1*X-6346.5     448766


VARIABLE    4 BULKDEN   VERSUS VARIABLE    1 CUTTEST
```

```
PAGE    7  BMDP6D DATA DISPLAY

         .+....+....+....+....+....+....+....+....+....+....+....+X
   3000  +                                                        +
         .                                                        .
         .                                                        Y
         .                                                     1  .
         .                                                        .
   2250  +                                                        +
C        .                                                        .
U        .                                                        .
T        .                                                        .
T        .                                                        .
E  1500  +                                                        +
S        .                                                        .
T        .                                                        .
         .             1                                          .
         .         1                                              .
   750.  +       1                                                +
         .                                                        .
         . 1               1                                      .
         .                                                        .
         Y      1    1                                            .
   0.00  +                                                        +
         X+....+....+....+....+....+....+....+....+....+....+....+.
             2.555     2.625     2.695     2.765     2.835     2.905
        2.520     2.590     2.660     2.730     2.800     2.870
N=     8
COR= .8830                             SPGRAV

    MEAN      ST.DEV.     REGRESSION LINE      RES.MS.
X   2.6225     .11311   X= 123E-6*Y+ 2.5224    .00329
Y   816.62     814.75   Y= 6360.3*X-15863.     170687

VARIABLE   5 SPGRAV   VERSUS VARIABLE   1 CUTTEST
```

```
PAGE    8  BMDP6D DATA DISPLAY
```



```
N=     8
COR=-.1046                            MOIST

    MEAN     ST.DEV.    REGRESSION LINE     RES.MS.
X   6.7300    1.8870   X=-242E-6*Y+ 6.9278   4.1089
Y   816.62    814.75   Y=-45.147*X+ 1120.5   765991

VARIABLE    6 MOIST     VERSUS VARIABLE    1 CUTTEST
```

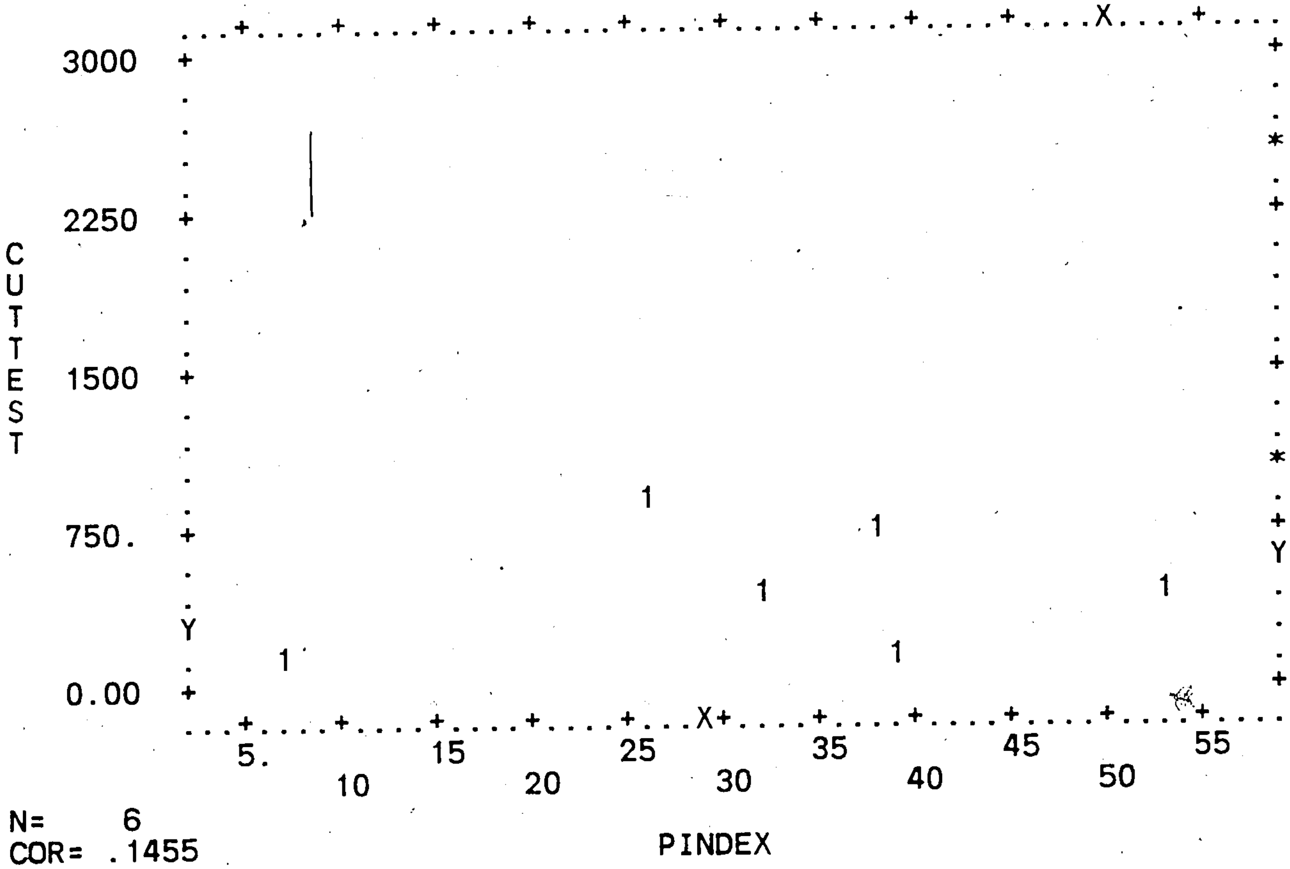
```
PAGE    9  BMDP6D DATA DISPLAY



           ....+....+....+....+....+....+....+....+....+....+....+...
      3000 +                                                        +
           .                                                        .
           .                                                        .
           .                                                   1    .
           .                                                        X
      2250 +                                                        +
C          .                                                        .
U          .                                                        .
T          .                                                        .
T          .                                                        .
E     1500 +                                                        +
S          .                                                        Y
T          .                                                        .
           .                                                     1  .
           .                                1                       .
      750. +                                              1         +
           .                                                        .
           .     1                              1                   .
           .                                                        .
           . 1                                        1             .
      0.00 Y                                                        +
           ....+....+....+....+.X..+....+....+....+....+....+....+...
              60.       68.       76.       84.       92.      100
                   64.       72.       80.       88.       96.
N=     8
COR= .5691                          SLDUR

     MEAN     ST.DEV.    REGRESSION LINE     RES.MS.
X    84.234    16.099   X= .01125*Y+ 75.050   204.45
Y    816.62    814.75   Y= 28.802*X-1609.5    523610

VARIABLE    7 SLDUR     VERSUS VARIABLE    1 CUTTEST
```

```
PAGE  10  BMDP6D DATA DISPLAY

          ...+....+....+....+....+....+....+....+....+....+....+....
    3000  X                                                        +
          .                                                        .
          .                                                        .
          .                                                        *
          .                                                        .
    2250  +                                                        +
C         .                                                        .
U         .                                                        .
T         .                                                        .
T         .                                                        .
E   1500  +                                                        +
S         .                                                        .
T         .                                                        .
          .  1                                                     .
          .                            1                           .
    750.  Y                                   1                    +
          .                                                        .
          .                               1                     1  Y
          .                                                        .
          .      1                               1                 .
    0.00  +                                                        +
          ...+....+....+....+....+....+....+...X+....+....+....+....
             25        35        45        55        65        75
                  30        40        50        60        70
N=     7
COR=-.2561                                LLIM

    MEAN     ST.DEV.    REGRESSION LINE      RES.MS.
X   50.403    18.137   X=-.01190*Y+ 57.050    368.86
Y   558.43    390.19   Y=-5.5089*X+ 836.09    170718


VARIABLE   8 LLIM      VERSUS VARIABLE   1 CUTTEST
```

```
PAGE  11  BMDP6D DATA DISPLAY

         ...+....+....+....+....+....+X...+....+....+....+....+....
   3000  +                                                        +
         .                                                        .
         .                                                        .
         .                                                        *
         .                                                        .
   2250  +                                                        +
C        .                                                        .
U        .                                                        .
T        .                                                        .
T        .                                                        .
E  1500  +                                                        +
S        .                                                        .
T        .                                                        .
         .                                                        *
         .                                                 1      .
   750.  +     1                                                  +
         .                                                        .
         Y                                1       1               Y
         .                                                        .
         .                             1  1                       .
   0.00  +                                                        +
         ...+....+....+....+....+....+....X....+....+....+....+....
                19.5      20.5      21.5      22.5      23.5
           19.0      20.0      21.0      22.0      23.0      24.0
N=     6
COR=-.0308                       PLIM

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   21.907   1.5039  X=-131E-6*Y+ 21.969   2.8244
Y   475.33   353.13  Y=-7.2274*X+ 633.66   155724

VARIABLE   9 PLIM     VERSUS VARIABLE   1 CUTTEST
```

```
PAGE  12  BMDP6D DATA DISPLAY



          ..+....+....+....+....+....+....+....+....+....+....+.....
    3000  +                                                        +
          .                                                        .
          .                                                        .
          .                                                        *
          .                                                        .
    2250  +                                                        +
C         .                                                        .
U         .                                                        .
T         X                                                        .
T         .                                                        .
E   1500  +                                                        +
S         .                                                        .
T         .                                                        .
          .  1                                                     .
          .                      1                                 .
    750.  Y                            1                           +
          .                                                        .
          .                          1                 1           .
          .                                                        Y
          .      1                                             1   .
    0.00  +                                                        +
          ..+....+....+....+....+....+....+....+....X....+....+.....
           12.5      17.5      22.5      27.5      32.5      37.5
                15.0      20.0      25.0      30.0      35.0
N=     7
COR=-.4523                        CLAY

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   24.857   9.1183  X=-.01057*Y+ 30.759   79.364
Y   558.43   390.19  Y=-19.353*X+ 1039.5   145328

VARIABLE  10 CLAY     VERSUS VARIABLE   1 CUTTEST
```

```
PAGE   13  BMDP6D DATA DISPLAY
```



```
N=     6
COR= .1455

    MEAN     ST.DEV.     REGRESSION LINE     RES.MS.
X   32.735    15.484   X= .00638*Y+ 29.703    293.36
Y   475.33    353.13   Y= 3.3179*X+ 366.72    152573

VARIABLE  11 PINDEX   VERSUS VARIABLE    1 CUTTEST
```

```
PAGE  14  BMDP6D DATA DISPLAY

         ...+....+....+....+....+....+.X..+....+....+....+....+....
   3000  +                                                        +
         .                                                        .
         .                                                        .
         .                         1                              .
         .                                                        .
   2250  +                                                        +
C        .                                                        .
U        .                                                        .
T        .                                                        .
T        .                                                        .
E  1500  +                                                        +
S        .                                                        .
T        .                                                        .
         .                                1                       .
         .                                 1                      Y
   750.  Y                         1                              +
         .                                                        .
         .         1                        1                     .
         .                                                        .
         .  1                                                 1  .
   0.00  +                                                        +
         ...+....+....+....+....+...X+....+....+....+....+....+....
                13.5      16.5      19.5      22.5      25.5
           12.0      15.0      18.0      21.0      24.0      27.0
N=    8
COR= .0404                        PORS

    MEAN     ST.DEV.     REGRESSION LINE     RES.MS.
X   19.450    4.7153  X= 234E-6*Y+ 19.259    25.898
Y   816.62    814.75  Y= 6.9762*X+ 680.94    773196



VARIABLE  12 PORS     VERSUS VARIABLE   1 CUTTEST
```

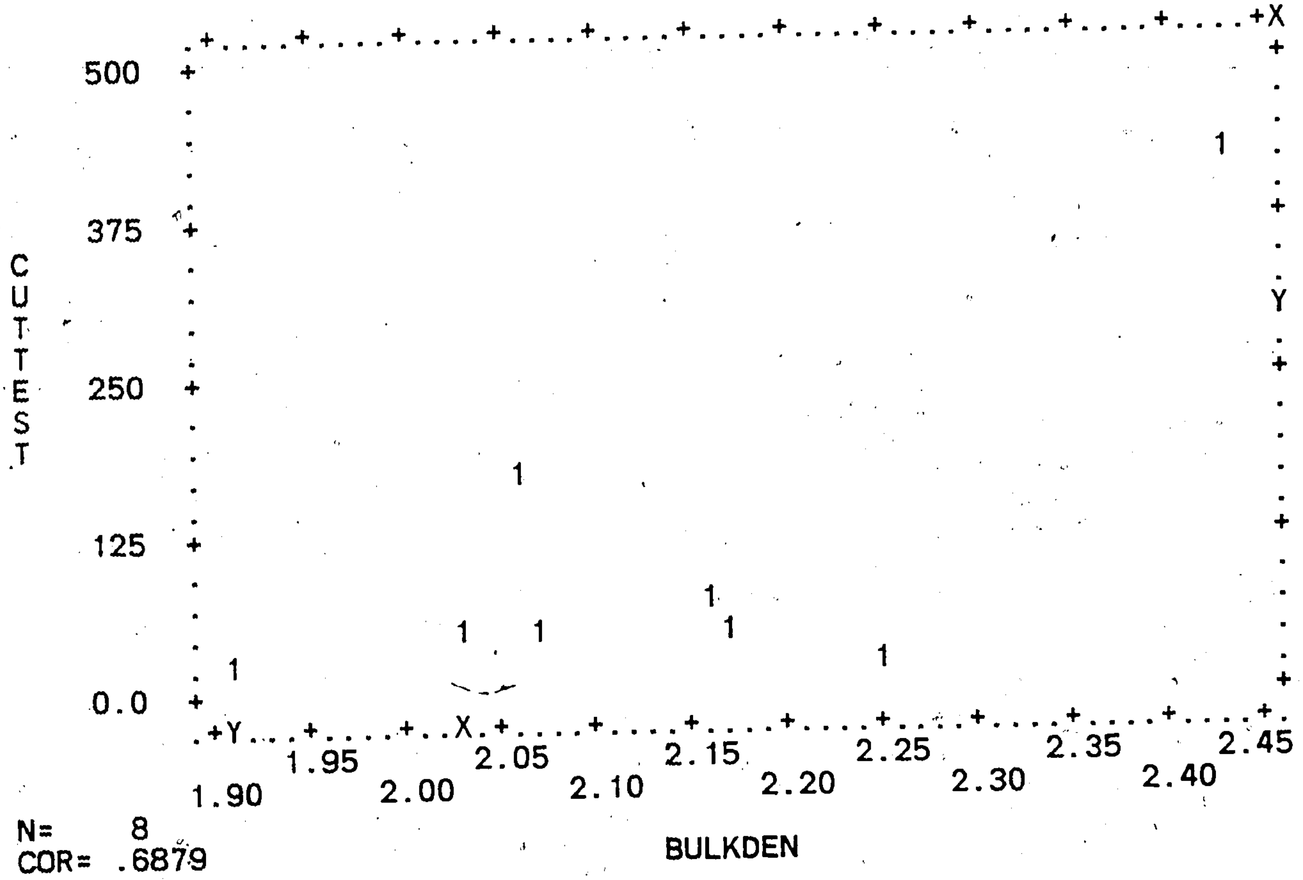
```
PAGE  15  BMDP6D DATA DISPLAY




         ...+....+....+....+....+....+....+....+....+....+....+....
    3000 +                                                        +
         .                                                        .
         .                                                        .
         .                                                        *
         .                                                        .
    2250 +                                                        +
C        .                                                        .
U        .                                                        .
T        .                                                        .
T        .                                                        .
E   1500 +                                                        X
S        .                                                        .
T        .                                                        .
         .                                                        *
         .                                1                       .
    750. +                                             1          Y
         .                                                        .
         .                                      1           1     .
         .                                                        .
         Y     1                      1                           .
    0.00 +                                                        +
         ...+....+....+....+.X..+....+....+....+....+....+....+....
          .3750     .6250     .8750     1.125     1.375     1.625
               .5000     .7500     1.000     1.250     1.500
N=     6
COR= .5010                          ACTIV

    MEAN     ST.DEV.     REGRESSION LINE     RES.MS.
X   1.1567   .39712   X= 563E-6*Y+ .88884    .14765
Y   475.33   353.13   Y= 445.52*X-39.982     116744

VARIABLE  13 ACTIV    VERSUS VARIABLE   1 CUTTEST
CPU TIME USED       0.569 SECONDS
```

```
PAGE    3  BMDP6D DATA DISPLAY

  TABLE OF CONTENTS

  HORIZONTAL       VERTICAL
  VARIABLE         VARIABLE        GROUP       PLOT                     PAGE
  NO. NAME         NO. NAME        NAME        SYMBOL                   NO.

    2  PLOAD         1  CUTTEST                       . . . . . . . .   4
    3  NCBCON        1  CUTTEST                       . . . . . . . .   5
    4  BULKDEN       1  CUTTEST                       . . . . . . . .   6
    5  SPGRAV        1  CUTTEST                       . . . . . . . .   7
    6  MOIST         1  CUTTEST                       . . . . . . . .   8
    7  SLDUR         1  CUTTEST                       . . . . . . . .   9
    8  LLIM          1  CUTTEST                       . . . . . . . .  10
    9  PLIM          1  CUTTEST                       . . . . . . . .  11
   10  CLAY          1  CUTTEST                       . . . . . . . .  12
   11  PINDEX        1  CUTTEST                       . . . . . . . .  13
   12  PORS          1  CUTTEST                       . . . . . . . .  14
   13  ACTIV         1  CUTTEST                       . . . . . . . .  15
```

SET II

```
PAGE   4  BMDP6D DATA DISPLAY




        .+....+....+....+....+....+....+....+....+....+....+....+.
    500 +                                                        Y
        .                                                        .
        .                                                        .
        .                                                1       .
        .                                                        .
    375 +                                                        +
C       .                                                        .
U       .                                                        .
T       .                                                        .
T       .                                                        .
E   250 +                                                        +
S       .                                                        .
T       .                                                        .
        .                 1                                      .
        .                                                        .
    125 +                                                        +
        .                                                        .
        .         1                                              .
        .        11 1                                            .
        . 11                                                     .
    0.0 +                                                        +
        Y+....+....+....+....+....+....+....+....+....+....+....+.
             .30       .90       1.5       2.1       2.7       3.3
        0.0       .60       1.2       1.8       2.4       3.0
N=    8
COR= .9854                        PLOAD

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   .78975   .89659  X= .00641*Y+ .09996    .02715
Y   107.69   137.93  Y= 151.60*X-12.036    642.48

VARIABLE   2 PLOAD    VERSUS VARIABLE   1 CUTTEST
```

```
PAGE    5  BMDP6D DATA DISPLAY





         .....+....+....+....+....+....+....+....+....+....+....+..
    500  +                                                        +
         .                                                        .
         .                                                        .
         .                                                     1  .
         .                                                        X
    375  +                                                        +
C        .                                                        Y
U        .                                                        .
T        .                                                        .
T        .                                                        .
E   250  +                                                        +
S        .                                                        .
T        .                                                        .
         .                                            1           .
         .                                                        .
    125  +                                                        +
         .                                                        .
         .                  1                                     .
         .         1 1    1                                       .
         .  2                                                     .
    0.0  +                                                        +
         YY..X+....+....+....+....+....+....+....+....+....+....+..
            .1750     .5250     .8750     1.225     1.575     1.925
                 .3500     .7000     1.050     1.400     1.750
N=     8
COR= .9189                       NCBCON

    MEAN     ST.DEV.     REGRESSION LINE    RES.MS.
X   .71625    .66685   X= .00444*Y+ .23782   .08070
Y   107.69    137.93   Y= 190.07*X-28.453    3452.4

VARIABLE   3 NCBCON   VERSUS VARIABLE   1 CUTTEST
```



```
N=     8
COR= .6879

      MEAN      ST.DEV.    REGRESSION LINE     RES.MS.
X   2.1350      .15748   X= 785E-6*Y+ 2.0504    .01524
Y   107.69      137.93   Y= 602.51*X-1178.7     11692.

VARIABLE   4 BULKDEN  VERSUS VARIABLE    1 CUTTEST
```

```
PAGE    7  BMDP6D DATA DISPLAY

         .+....+....+....+....+....+....+....+....+....+....+....+.
     500 +                                                        X
         .                                                        .
         .                                                        .
         .                                                        .
         .                                                     1  Y
     375 +                                                        +
C        .                                                        .
U        .                                                        .
T        .                                                        .
T        .                                                        .
E    250 +                                                        +
S        .                                                        .
T        .                                                        .
         .             1                                          .
         .                                                        .
     125 +                                                        +
         .                                                        .
         .       1                                                .
         . 1       1       1                                      .
         .      1         1                                       .
     0.0 +                                                        +
         Y+X...+....+....+....+....+....+....+....+....+....+....+.
             2.555     2.625     2.695     2.765     2.835     2.905
        2.520     2.590     2.660     2.730     2.800     2.870
N=      8
COR= .9015                                 SPGRAV

    MEAN      ST.DEV.     REGRESSION LINE     RES.MS.
X   2.6262    .11275   X= 737E-6*Y+ 2.5469    .00278
Y   107.69    137.93   Y= 1102.8*X-2788.5     4159.0

VARIABLE   5 SPGRAV   VERSUS VARIABLE   1 CUTTEST
```

```
PAGE   8  BMDP6D DATA DISPLAY

          ....+....+....+...X+....+....+....+....+....+....+....+...
    500   +                                                        +
          .                                                        .
          .                                                        .
          .                    1                                   .
          .                                                        .
    375   +                                                        +
C         .                                                        .
U         .                                                        .
T         .                                                        .
T         .                                                        .
E   250   +                                                        +
S         .                                                        .
T         .                                                        .
          Y                     1                                  .
          .                                                        .
    125   +                                                        +
          .                                                        .
          .                    1                                   .
          .                                                1   11  Y
          . 1                          1                           .
    0.0   +                                                        +
          ....+....+....+....+....+....+....+.X..+....+....+....+...
                  4.5       5.5       6.5       7.5       8.5
             4.0       5.0       6.0       7.0       8.0       9.0
N=    8
COR=-.2416                        MOIST

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   6.7300   1.8870  X=-.00331*Y+ 7.0860   3.9118
Y   107.69   137.93  Y=-17.661*X+ 226.54   20900.

VARIABLE   6 MOIST    VERSUS VARIABLE   1 CUTTEST
```

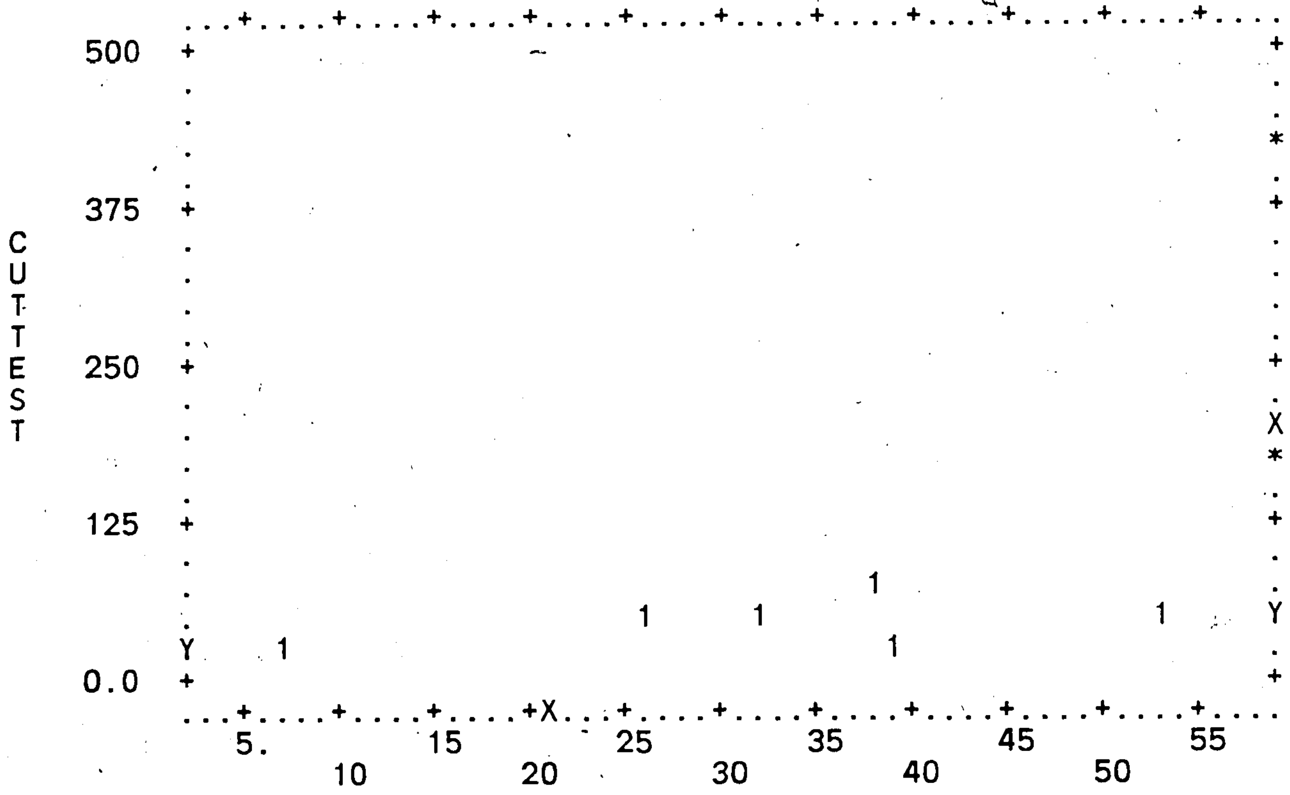
```
PAGE    9  BMDP6D DATA DISPLAY

        ....+....+....+....+....+....+....+....+....+....+....+...
    500 +                                                        +
        .                                                        .
        .                                                        .
        .                                                   1    .
        .                                                        .
    375 +                                                        X
C       .                                                        .
U       .                                                        .
T       .                                                        .
T       .                                                        .
E   250 +                                                        +
S       .                                                        .
T       .                                                        Y
        .                                                     1  .
        .                                                        .
    125 +                                                        +
        .                                                        .
        .                                              1         .
        .     1                          1   1                   .
        . 1                                        1             .
    0.0 +                                                        +
        Y...+....+....+....+...X+....+....+....+....+....+....+...
           60.       68.       76.       84.       92.       100
                64.       72.       80.       88.       96.
N=     8
COR= .5590                              SLDUR

    MEAN    ST.DEV.     REGRESSION LINE      RES.MS.
X   84.234   16.099   X= .06524*Y+ 77.208    207.91
Y   107.69   137.93   Y= 4.7888*X-295.69     15261.

VARIABLE   7 SLDUR     VERSUS VARIABLE   1 CUTTEST
```

```
PAGE  10  BMDP6D DATA DISPLAY



         ...+....+....+....+....+....+....+....+....+....+....+....
    500  +                                                        +
         .                                                        .
         .                                                        .
         .                                                        *
         .                                                        .
    375  +                                                        +
C        .                                                        .
U        .                                                        .
T        .                                                        .
T        .                                                        .
E   250  X                                                        +
S        .                                                        .
T        .                                                        .
         .  1                                                     .
         .                                                        .
    125  +                                                        +
         Y                                                        .
         .                                   1                    .
         .                            1  1                     1  .
         .      1                               1                 Y
    0.0  +                                                        +
         ...+....+....+....+....+....+....+....+...X+....+....+....
            25        35        45        55        65        75
                 30        40        50        60        70
N=     7
COR=-.4695                        LLIM

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   50.403   18.137   X=-.15260*Y+ 59.936   307.74
Y   62.471   55.801   Y=-1.4444*X+ 135.27   2912.9

VARIABLE   8 LLIM     VERSUS VARIABLE   1 CUTTEST
```

```
PAGE  11  BMDP6D DATA DISPLAY





         ...+....+....+....+....+....+....+....+....+....+....+....
    500  +                                                        +
         .                                                        .
         .                                                        .
         .                                                        *
         .                                                        .
    375  +                                                        +
C        .                                                        .
U        .                                                        .
T        .                                                        .
T        .                                                        .
E   250  +                                                        +
S        .                                                        .
T        .                                                        .
         X                                                        *
         .                                                        .
    125  +                                                        +
         .                                                        .
         Y     1                                                  .
         .                                1       1        1      .
         .                             1  1                       Y
    0.0  +                                                        +
         ...+....+....+....+....+....+....+....+....+....+.X..+....
                19.5      20.5      21.5      22.5      23.5
           19.0      20.0      21.0      22.0      23.0      24.0
N=     6
COR=-.4886                        PLIM

    MEAN     ST.DEV.    REGRESSION LINE    RES.MS.
X   21.907    1.5039   X=-.02664*Y+ 23.069    2.1523
Y   43.650   27.583    Y=-8.9606*X+ 239.95    724.02

VARIABLE   9 PLIM      VERSUS VARIABLE    1 CUTTEST
```

```
PAGE  12  BMDP6D DATA DISPLAY

         ..+....+....+....+....+....+....+....+....+....+....+.....
    500  +                                                        +
         .                                                        .
         .                                                        .
         .                                                        *
         .                                                        .
    375  +                                                        +
C        .                                                        .
U        .                                                        .
T        .                                                        .
T        .                                                        .
E   250  +                                                        +
S        .                                                        .
T        X                                                        .
         .  1                                                     .
         .                                                        .
    125  +                                                        +
         Y                                                        .
         .                            1                           .
         .                      1   1                 1           .
         .      1                                             1   .
    0.0  +                                                        Y
         ..+....+....+....+....+....+....+....+....X....+....+.....
          12.5      17.5      22.5      27.5      32.5      37.5
               15.0      20.0      25.0      30.0      35.0
N=    7
COR=-.5517                        CLAY

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   24.857   9.1183  X=-.09015*Y+ 30.489   69.404
Y   62.471   55.801  Y=-3.3762*X+ 146.39   2599.2

VARIABLE  10 CLAY     VERSUS VARIABLE   1 CUTTEST
```

```
PAGE  13  BMDP6D DATA DISPLAY
```



```
N=     6
COR= .2986                              PINDEX

    MEAN     ST.DEV.    REGRESSION LINE    RES.MS.
X   32.735    15.484   X= .16764*Y+ 25.418   272.97
Y   43.650    27.583   Y= .53196*X+ 26.236   866.20

VARIABLE  11 PINDEX   VERSUS VARIABLE   1 CUTTEST
```

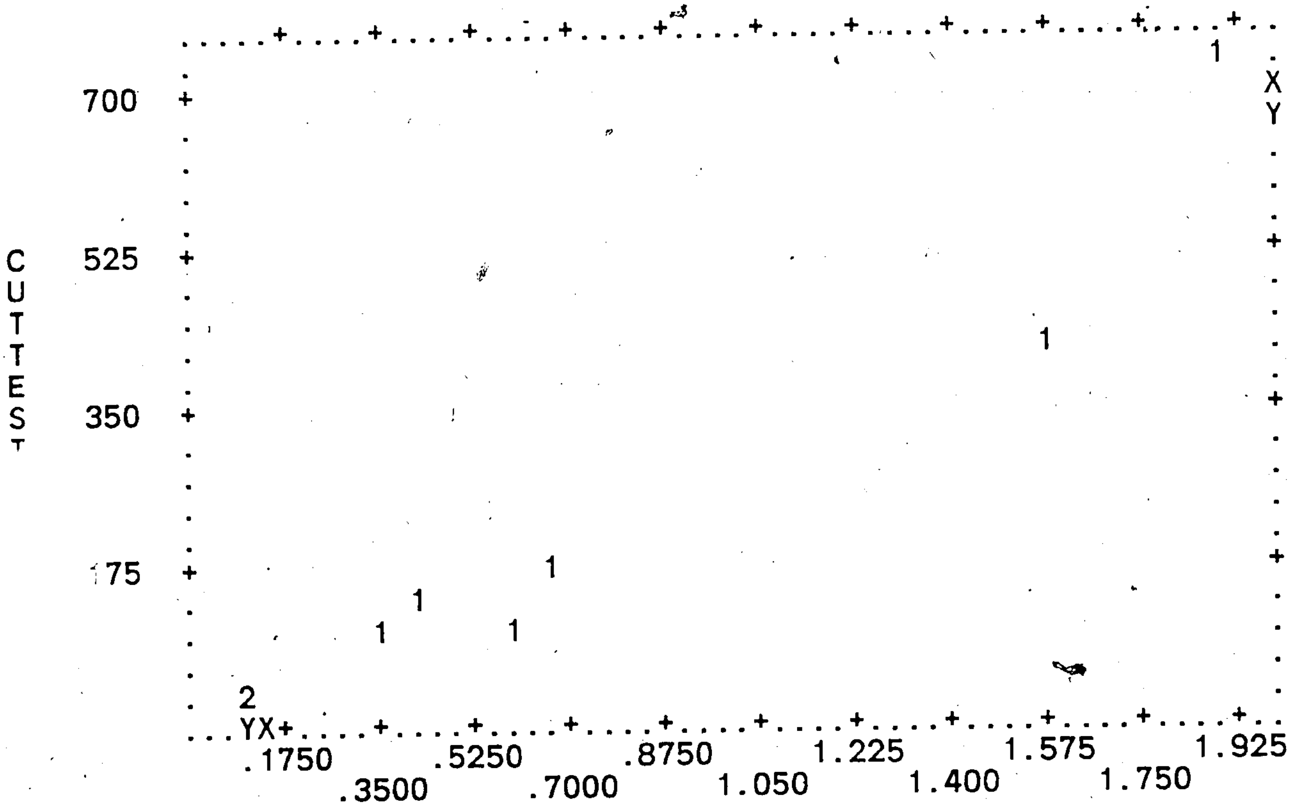
```
PAGE  14  BMDP6D DATA DISPLAY

           ...+....+....+....+....+....+X...+....+....+....+....+....
      500  +                                                        +
           .                                                        .
           .                                                        .
           .                         1                              .
           .                                                        .
      375  +                                                        +
C          .                                                        .
U          .                                                        .
T          .                                                        .
T          .                                                        .
E     250  +                                                        +
S          .                                                        .
T          .                                                        .
           .                                1                       .
           .                                                        .
      125  +                                                        +
           Y                                                        Y
           .                         1                              .
           .         1                       11                     .
           .  1                                                  1  .
      0.0  +                                                        +
           ...+....+....+....+....+....X....+....+....+....+....+....
                  13.5      16.5      19.5      22.5      25.5
             12.0      15.0      18.0      21.0      24.0      27.0
N=      8
COR= .0173                          PORS

     MEAN      ST.DEV.     REGRESSION LINE     RES.MS.
X    19.450    4.7153   X= 592E-6*Y+ 19.386    25.932
Y    107.69    137.93   Y= .50649*X+ 97.836    22189.

VARIABLE   12 PORS      VERSUS VARIABLE    1 CUTTEST
```

```
PAGE  15  BMDP6D DATA DISPLAY













         ...+....+....+....+....+....+....+....+....+....+....+....
    500  +                                                        +
         .                                                        .
         .                                                        .
         .                                                        *
         .                                                        .
    375  +                                                        +
C        .                                                        .
U        .                                                        .
T        .                                                        .
T        .                                                        .
E   250  +                                                        +
S        .                                                        .
T        .                                                        .
         .                                                        *
         .                                                        .
    125  +                                                        +
         .                                                        X
         .                                             1          Y
         .                                1     1           1     .
         .     1                      1                           .
    0.0  Y                                                        +
         ...+....X....+....+....+....+....+....+....+....+....+....
          .3750     .6250     .8750     1.125     1.375     1.625
               .5000     .7500     1.000     1.250     1.500
N=    6
COR= .6566                        ACTIV

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   1.1567   .39712  X= .00945*Y+ .74401    .11214
Y   43.650   27.583  Y= 45.607*X-9.1025     540.97

VARIABLE  13 ACTIV    VERSUS VARIABLE   1 CUTTEST
CPU TIME USED      0.540 SECONDS
```

```
PAGE    3  BMDP6D DATA DISPLAY

  TABLE OF CONTENTS

  HORIZONTAL       VERTICAL
  VARIABLE         VARIABLE        GROUP      PLOT                     PAGE
  NO.  NAME        NO.  NAME       NAME       SYMBOL                    NO.
```

```
PAGE    4  BMDP6D DATA DISPLAY F1s(KN/m)

         .+....+....+....+....+....+....+....+....+....+X..Y+....+.
         .                                                1       .
    700  +                                                        +
         .                                                        .
         .                                                        .
         .                                                        .
         .                                                        .
C   525  +                                                        +
U        .                                                        .
T        .                                                        .
T        .                 1                                      .
E        .                                                        .
S   350  +                                                        +
T        .                                                        .
         .                                                        .
         .                                                        .
         .                                                        .
    175  +         1                                              +
         .         1                                              .
         .        1  1                                            .
         :                                                        .
         . 11                                                     .
         Y+X...+....+....+....+....+....+....+....+....+....+....+.
              .30       .90       1.5       2.1       2.7       3.3
        0.0        .60       1.2       1.8       2.4       3.0
N=     8
COR= .9538                        PLOAD

    MEAN     ST.DEV.     REGRESSION LINE    RES.MS.
X   .78962    .89670  X= .00353*Y+ .03768   .08473
Y   213.17    242.46  Y= 257.89*X+ 9.5362   6194.9

VARIABLE   2 PLOAD    VERSUS VARIABLE   1 CUTTEST
```

```
PAGE    5  BMDP6D DATA DISPLAY
```



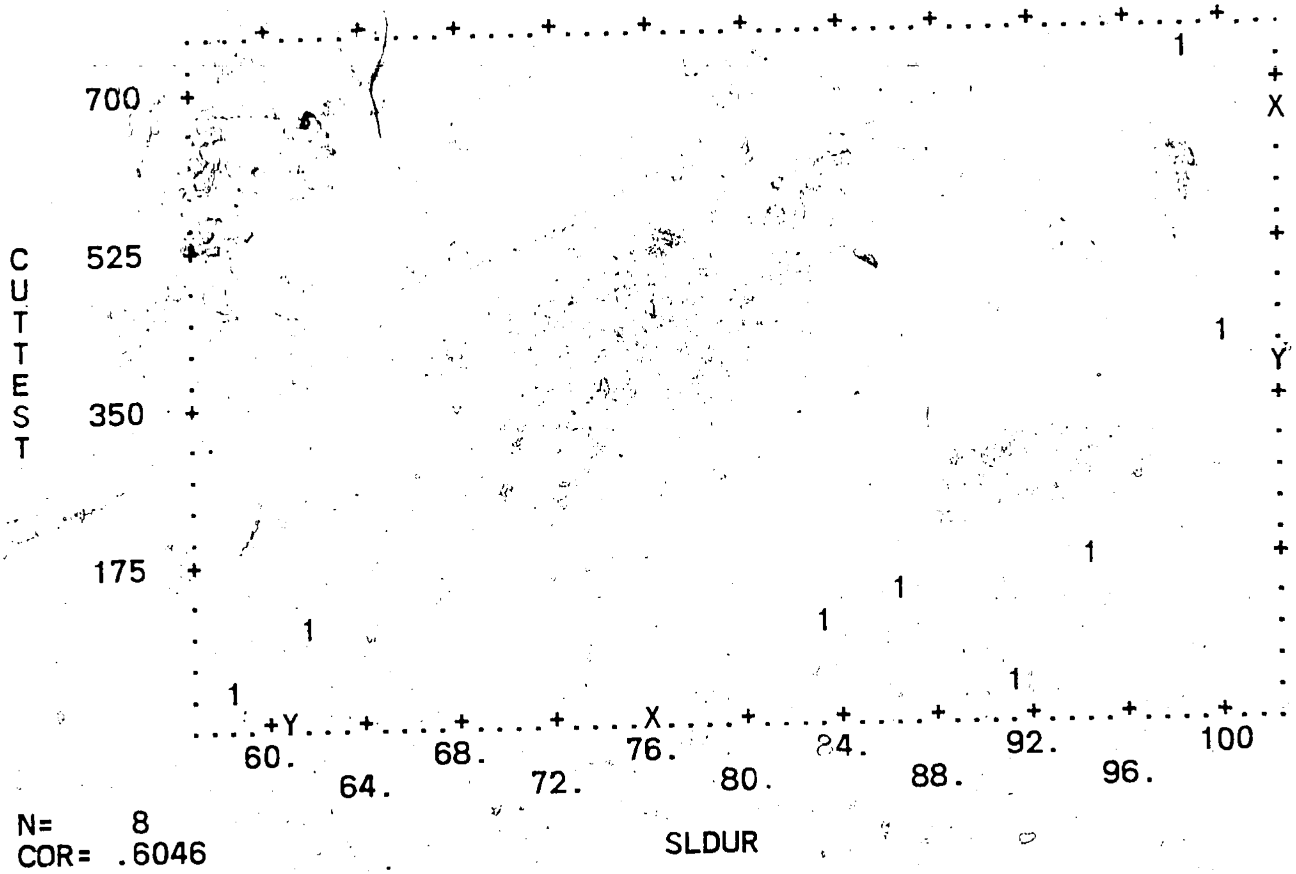
```
N=      8
COR= .9669

     MEAN     ST.DEV.   REGRESSION LINE     RES.MS.
X   .71625    .66685   X= .00266*Y+ .14938   .03381
Y   213.17    242.46   Y= 351.55*X-38.620    4470.1

VARIABLE   3 NCBCON   VERSUS VARIABLE   1 CUTTEST
```

```
PAGE    6  BMDP6D DATA DISPLAY


        .+....+....+....+....+....+....+....+....+....+X...+....+.
        .                                                     1  .
    700 +                                                        +
        .                                                        .
        .                                                        .
        .                                                        .
        .                                                        .
C   525 +                                                        Y
U       .                                                        .
T       .                                                        .
T       .                1                                       .
E       .                                                        .
S   350 +                                                        +
T       .                                                        .
        .                                                        .
        .                                                        .
        .                                                        .
    175 +                          1                             +
        .                 1                                      .
        .             1             1                            .
        .                                                        .
        . 1                                 1                    .
        .+Y...+....+....X....+....+....+....+....+....+....+....+.
             1.95      2.05      2.15      2.25      2.35      2.45
        1.90      2.00      2.10      2.20      2.30      2.40
N=     8
COR= .6282                       BULKDEN

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   2.1350   .15748  X= 408E-6*Y+ 2.0480   .01752
Y   213.17   242.46  Y= 967.19*X-1851.8    41519.

VARIABLE    4 BULKDEN  VERSUS VARIABLE    1 CUTTEST
```

```
PAGE   7  BMDP6D DATA DISPLAY




         .+....+....+....+....+....+....+....+....+....+X...+....+.
         .                                                     1  Y
    700  +                                                        +
         .                                                        .
         .                                                        .
         .                                                        .
         .                                                        .
C   525  +                                                        +
U        .                                                        .
T        .                                                        .
T        .             1                                          .
E        .                                                        .
S   350  +                                                        +
T        .                                                        .
         .                                                        .
         .                                                        .
         .                                                        .
    175  +       1                                                +
         .                 1                                      .
         . 1       1                                              .
         .                                                        .
         .      1         1                                       .
         Y+..X.+....+....+....+....+....+....+....+....+....+....+.
             2.555     2.625     2.695     2.765     2.835    2.905
        2.520     2.590     2.660     2.730     2.800     2.870
N=     8
COR= .8370                        SPGRAV

    MEAN    ST.DEV.    REGRESSION LINE     RES.MS.
X   2.6262   .11275  X= 389E-6*Y+ 2.5433   .00444
Y   213.17   242.46  Y= 1799.8*X-4513.6    20542.

VARIABLE   5 SPGRAV   VERSUS VARIABLE   1 CUTTEST
```

```
PAGE   8  BMDP6D DATA DISPLAY

          ....+....+....+....+X...+....+....+....+....+....+....+...
          .                    1                                   .
     700  +                                                        +
          .                                                        .
          .                                                        .
          .                                                        .
          .                                                        .
C    525  +                                                        +
U         .                                                        .
T         .                                                        .
T         .                     1                                  .
E         .                                                        .
S    350  +                                                        +
T         Y                                                        .
          .                                                        .
          .                                                        .
          .                                                        .
     175  +                    1                                   +
          .                                                     1  Y
          .                                                1   1   .
          .                                                        .
          . 1                          1                           .
          ....+....+....+....+....+....+....+.X..+....+....+....+...
                  4.5       5.5       6.5       7.5       8.5
             4.0       5.0       6.0       7.0       8.0       9.0
N=    8
COR=-.2569                        MOIST

    MEAN    ST.DEV.    REGRESSION LINE   RES.MS.
X   6.7300   1.8870 X=-.00200*Y+ 7.1563   3.8801
Y   213.17   242.46 Y=-33.011*X+ 435.34   64058.

VARIABLE   6 MOIST   VERSUS VARIABLE   1 CUTTEST
```

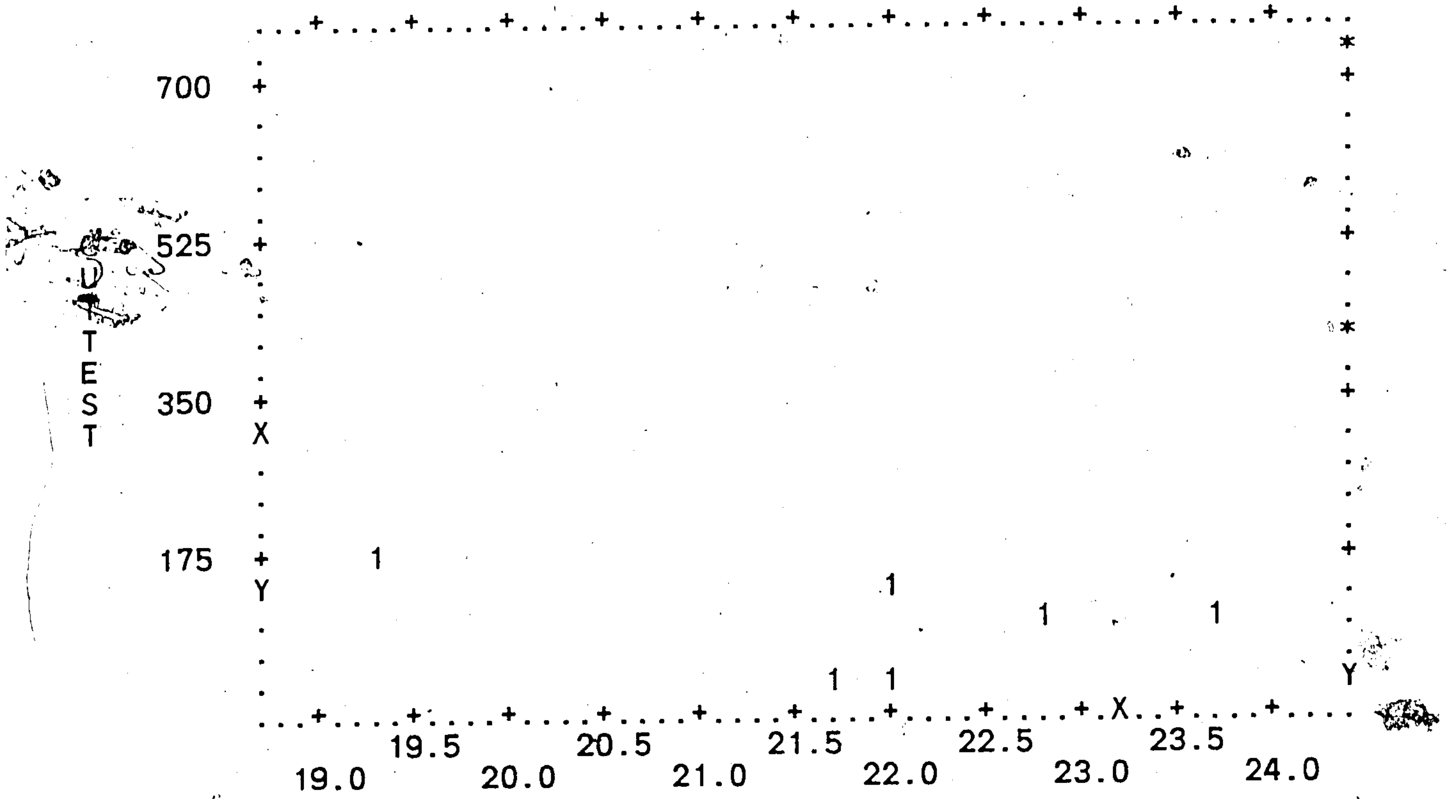
```
PAGE    9  BMDP6D DATA DISPLAY
```



```
N=      8
COR= .6046

       MEAN      ST.DEV.     REGRESSION LINE      RES.MS.
X    84.234      16.099   X= .04014*Y+ 75.676      191.86
Y    213.17      242.46   Y= 9.1051*X-553.78       43516.

VARIABLE    7 SLDUR      VERSUS VARIABLE    1 CUTTEST
```

```
PAGE  10  BMDP6D DATA DISPLAY





         ...+....+....+....+....+....+....+....+....+....+....+....
         .                                                        *
    700  +                                                        +
         .                                                        .
         .                                                        .
         X                                                        .
         .                                                        .
C   525  +                                                        +
U        .                                                        .
T        .                                                        .
T        .  1                                                     .
E        .                                                        .
S   350  +                                                        +
T        .                                                        .
         .                                                        .
         Y                                                        .
         .                                                        .
    175  +                                   1                    +
         .                               1                        .
         .                            1                        1  .
         .                                                        .
         .      1                               1                 Y
         ...+....+....+....+....+....+....+...X+....+....+....+....
            25        35        45        55        65        75
                 30        40        50        60        70
N=    7
COR=-.4823                         LLIM

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   50.403   18.137  X=-.06346*Y+ 59.305   302.94
Y   140.29   137.84  Y=-3.6651*X+ 325.01   17496.

VARIABLE   8 LLIM     VERSUS VARIABLE   1 CUTTEST
```

```
PAGE  11  BMDP6D DATA DISPLAY
```



```
N=     6
COR=-.5132

    MEAN     ST.DEV.    REGRESSION LINE     RES.MS.
X   21.907    1.5039   X=-.01397*Y+ 23.189    2.0824
Y   91.800    55.242   Y=-18.852*X+ 504.79    2809.8

VARIABLE   9 PLIM      VERSUS VARIABLE    1 CUTTEST
```

```
PAGE  12  BMDP6D DATA DISPLAY



         ..+....+....+....+....+....+....+....+....+....+....+.....
         .                                                        *
    700  +                                                        +
         .                                                        .
         .                                                        .
         .                                                        .
         .                                                        .
C   525  X                                                        +
U        .                                                        .
T        .                                                        .
T        .  1                                                     .
E        .                                                        .
S   350  +                                                        +
T        .                                                        .
         .                                                        .
         Y                                                        .
         .                                                        .
    175  +                            1                           +
         .                          1                             .
         .                      1                     1           .
         .                                                        .
         .      1                                             1   .
         ..+....+....+....+....+....+....+....X....+....+....+....Y
          12.5      17.5      22.5      27.5      32.5      37.5
               15.0      20.0      25.0      30.0      35.0
N=     7
COR=-.5402                        CLAY

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   24.857   9.1183  X=-.03573*Y+ 29.870   70.659
Y   140.29   137.84  Y=-8.1657*X+ 343.26   16146.

VARIABLE  10 CLAY     VERSUS VARIABLE   1 CUTTEST
```

```
PAGE  13  BMDP6D DATA DISPLAY




         ...+....+....+....+....+....+....+....+....+....+....+....
         .                                                        *
     700 +                                                        +
         .                                                        .
         .                                                        .
         .                                                        .
         .                                                        .
C    525 +                                                        +
U        .                                                        .
T        .                                                        .
T        .                                                        *
E        .                                                        .
S    350 +                                                        +
T        .                                                        X
         .                                                        .
         .                                                        .
         .                                                        .
     175 +                                   1                    +
         .                             1                          Y
         .                       1                          1     .
         .                                                        .
         Y    1                               1                   .
         ...+....+....+....+.X..+....+....+....+....+....+....+....
            5.        15        25        35        45        55
                 10        20        30        40        50
N=      6
COR= .4006                          PINDEX

    MEAN     ST.DEV.     REGRESSION LINE      RES.MS.
X   32.735    15.484   X= .11229*Y+ 22.426    251.60
Y   91.800    55.242   Y= 1.4293*X+ 45.012    3202.3

VARIABLE  11 PINDEX   VERSUS VARIABLE    1 CUTTEST
```

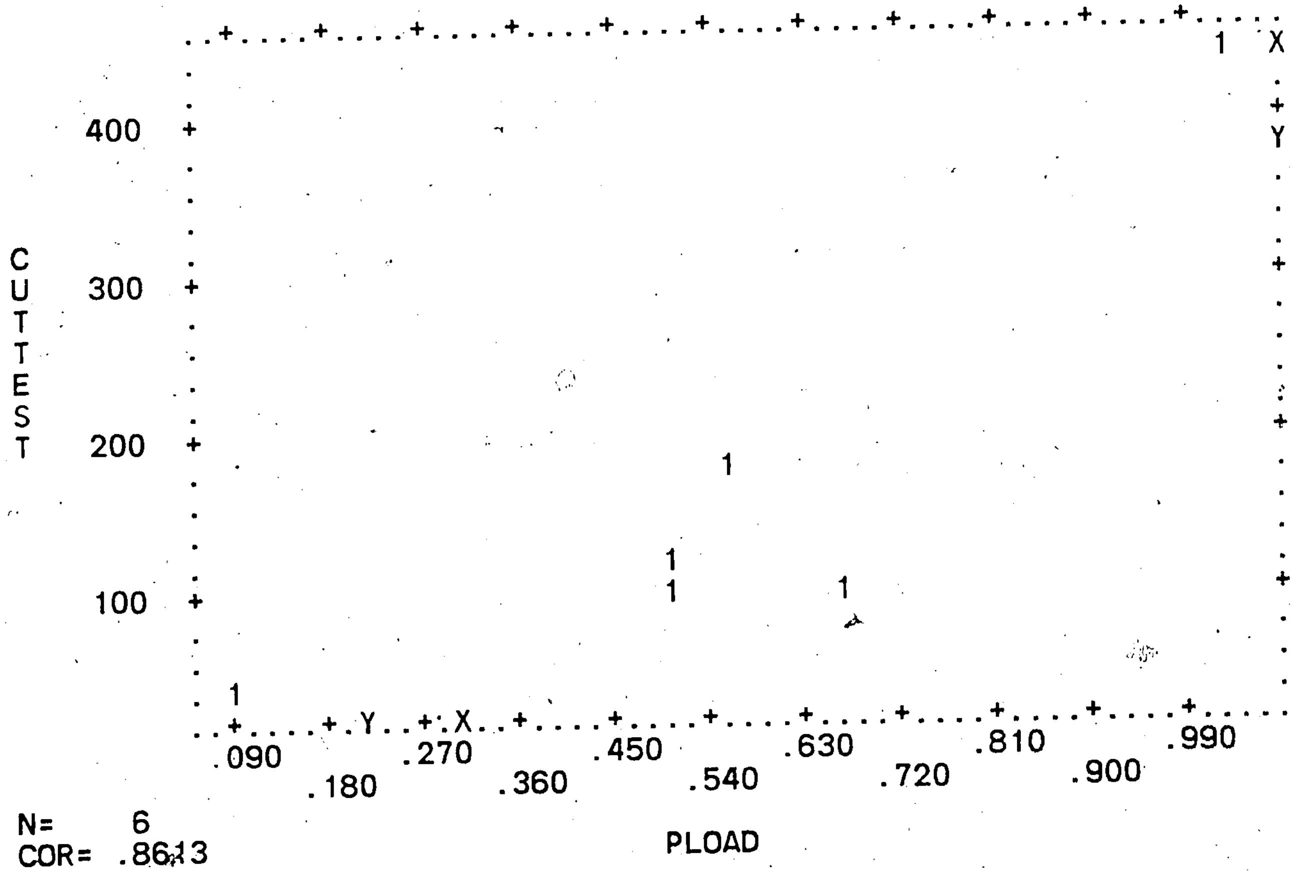
```
PAGE  14  BMDP6D DATA DISPLAY



        ...+....+....+....+....+....+X...+....+....+....+....+....
        .                         1                              .
    700 +                                                        +
        .                                                        .
        .                                                        .
        .                                                        .
        .                                                        .
C   525 +                                                        +
U       .                                                        .
T       .                                                        .
T       .                                1                       .
E       .                                                        .
S   350 +                                                        +
T       .                                                        .
        .                                                        .
        .                                                        .
        Y                                                        Y
    175 +                         1                              +
        .                                  1                     .
        .         1                       1                      .
        .                                                        .
        .  1                                                  1  .
        ...+....+....+....+....+...X+....+....+....+....+....+....
               13.5      16.5      19.5      22.5      25.5
          12.0      15.0      18.0      21.0      24.0      27.0
N=     8
COR= .0261                                  PORS

    MEAN     ST.DEV.     REGRESSION LINE     RES.MS.
X   19.450   4.7153   X= 507E-6*Y+ 19.342    25.922
Y   213.17   242.46   Y= 1.3408*X+ 187.10    68539.

VARIABLE   12 PORS      VERSUS VARIABLE    1 CUTTEST
```

```
PAGE  15  BMDP6D DATA DISPLAY

         ...+....+....+....+....+....+....+....+....+....+....+....
         .                                                        *
    700  +                                                        +
         .                                                        .
         .                                                        .
         .                                                        .
         .                                                        .
C   525  +                                                        +
U        .                                                        .
T        .                                                        .
T        .                                                        *
E        .                                                        .
S   350  +                                                        +
T        .                                                        .
         .                                                        .
         .                                                        .
         .                                                        X
    175  +                                             1          +
         .                                      1                 Y
         .                                1                 1     .
         .                                                        .
         .     1                      1                           .
         Y..+....+....+.X..+....+....+....+....+....+....+....+....
          .3750     .6250     .8750     1.125     1.375     1.625
               .5000     .7500     1.000     1.250     1.500
N=    6
COR= .7294                       ACTIV

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   1.1567   .39712  X= .00524*Y+ .67533   .09226
Y   91.800   55.242  Y= 101.46*X-25.554     1785.3

VARIABLE  13 ACTIV    VERSUS VARIABLE    1 CUTTEST
CPU TIME USED      0.543 SECONDS
```

```
PAGE    3  BMDP6D DATA DISPLAY

  TABLE OF CONTENTS

  HORIZONTAL        VERTICAL
  VARIABLE          VARIABLE          GROUP       PLOT                                PAGE
  NO. NAME          NO. NAME          NAME        SYMBOL                               NO.

    2  PLOAD          1  CUTTEST                               . . . . . . . . .       4

    3  NCBCON         1  CUTTEST                               . . . . . . . . .       5

    4  BULKDEN        1  CUTTEST                               . . . . . . . . .       6

    5  SPGRAV         1  CUTTEST                               . . . . . . . . .       7

    6  MOIST          1  CUTTEST                               . . . . . . . . .       8

    7  SLDUR          1  CUTTEST                               . . . . . . . . .       9

    8  LLIM           1  CUTTEST                               . . . . . . . . .      10

    9  PLIM           1  CUTTEST                               . . . . . . . . .      11

   10  CLAY           1  CUTTEST                               . . . . . . . . .      12

   11  PINDEX         1  CUTTEST                               . . . . . . . . .      13

   12  PORS           1  CUTTEST                               . . . . . . . . .      14

   13  ACTIV          1  CUTTEST                               . . . . . . . . .      15
```

SET IV

```
PAGE    4  BMDP6D DATA DISPLAY
```



```
N=       6
COR=  .8613

      MEAN     ST.DEV.    REGRESSION LINE    RES.MS.
X    .55800    .29868   X= .00181*Y+ .27142   .02878
Y    158.08    141.91   Y= 409.23*X-70.270    6497.3

VARIABLE   2 PLOAD     VERSUS VARIABLE   1 CUTTEST
```

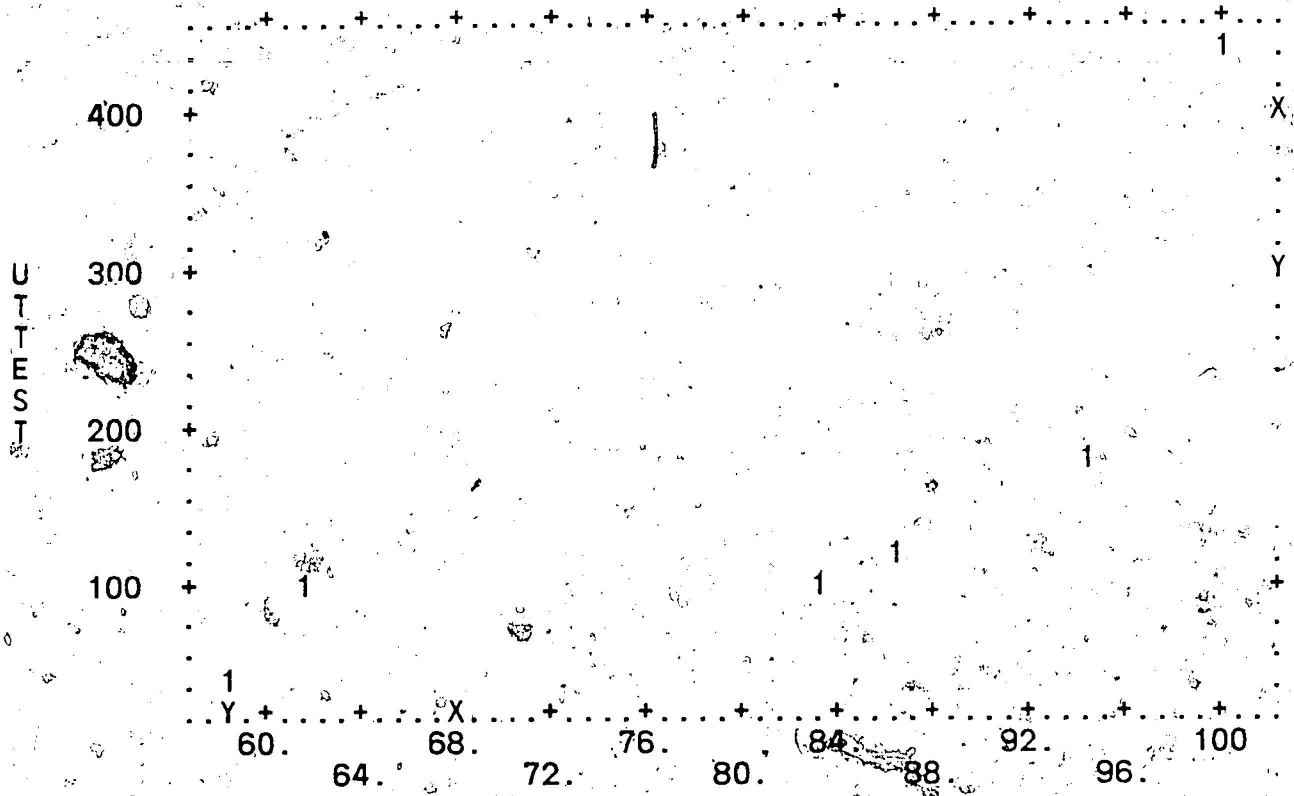
```
PAGE    5  BMDP6D DATA DISPLAY




        .....+....+....+....+....+....+....+....+....+....+....+XY
        .                                                    1   .
        .                                                        .
    400 +                                                        +
        .                                                        .
        .                                                        .
        .                                                        .
C       .                                                        .
U   300 +                                                        +
T       .                                                        .
T       .                                                        .
E       .                                                        .
S       .                                                        .
T   200 +                                                        +
        .                      1                                 .
        .                                                        .
        .                                                        .
        .                                                        .
        .             1                                          .
    100 +           1       1                                    +
        .                                                        .
        .                                                        .
        .  1                                                     .
        ....YX....+....+....+....+....+....+....+....+....+....+..
            .150      .450      .750      1.05      1.35      1.65
                 .300      .600      .900      1.20      1.50
N=    6
COR= .9770                      NCBCON

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   .62333   .51059  X= .00352*Y+ .06760   .01479
Y   158.08   141.91  Y= 271.55*X-11.183    1142.3

VARIABLE   3 NCBCON   VERSUS VARIABLE   1 CUTTEST
```

```
PAGE   6  BMDP6D DATA DISPLAY




         .....+....+....+....+....+....+....+....+..X.+....+....+..
         .                               1                        .
         .                                                        .
    400  +                                                        +
         .                                                        .
         .                                                        .
         .                                                        .
C        .                                                        .
U   300  +                                                        +
T        .                                                        .
T        .                                                        .
E        .                                                        .
S        .                                                        .
T   200  +                                                        Y
         .                                                        .
         .                                                        .
         .                                                        .
         .                                 1                      .
    100  Y                         1                           1  +
         .                                                        .
         .                                                        .
         . 1                                                      .
         .....+....+....+....+....+...X+....+....+....+....+....+..
            1.925     1.975     2.025     2.075     2.125     2.175
                 1.950     2.000     2.050     2.100     2.150
N=    6
COR= .2289                        BULKDEN

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   2.0667   .09522  X= 154E-6*Y+ 2.0424   .01074
Y   158.08   141.91  Y= 341.12*X-546.89    23854.

VARIABLE   4 BULKDEN  VERSUS VARIABLE   1 CUTTEST
```

```
PAGE    7  BMDP6D DATA DISPLAY


         .+....+....+....+....+....+....+....+X...+....+....+....+.
         .                                        1               .
         .                                                        .
     400 +                                                        +
         .                                                        .
         .                                                        .
         .                                                        .
C        .                                                        .
U    300 +                                                        +
T        .                                                        .
T        .                                                        .
E        .                                                        .
S        .                                                        .
T    200 +                                                        +
         .                    1                                   Y
         .                                                        .
         Y                                                        .
         .                                                       1.
     100 +1                        1                              +
         .                                                        .
         .                                                        .
         .                                                  1     .
         .+....+....+....+....+....+....X....+....+....+....+....+.
         2.53      2.55      2.57      2.59      2.61      2.63
              2.54      2.56      2.58      2.60      2.62      2.64
N=     6
COR= .0958                              SPGRAV

    MEAN      ST.DEV.     REGRESSION LINE     RES.MS.
X   2.5933    .04131   X= 279E-7*Y+ 2.5889    .00211
Y   158.08    141.91   Y= 328.91*X-694.89     24942.

VARIABLE    5 SPGRAV    VERSUS VARIABLE    1 CUTTEST
```

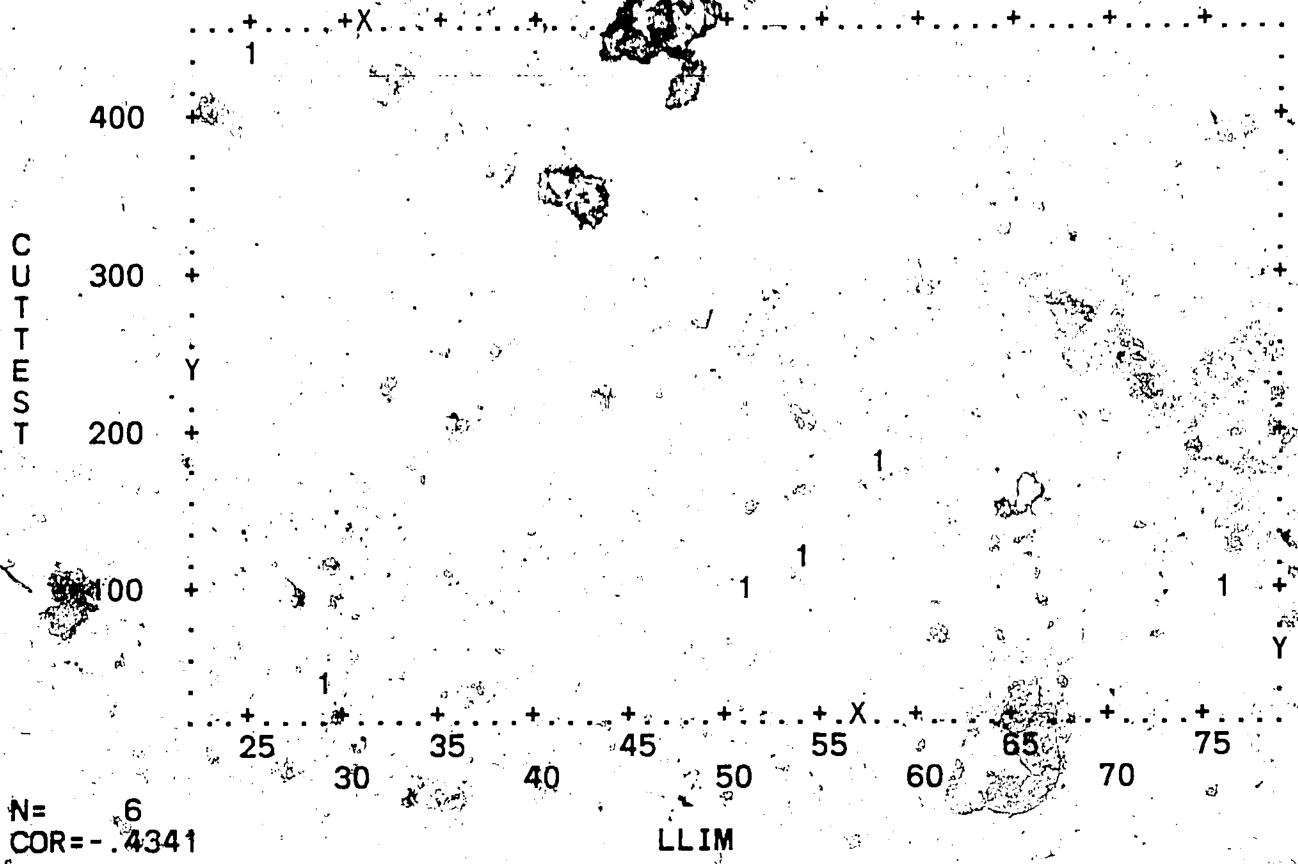
```
PAGE   8  BMDP6D DATA DISPLAY

         X+....+....+....+....+....+....+....+....+....+....+....+....+.
         . 1                                                      .
         .                                                        .
    400  +                                                        +
         .                                                        .
         .                                                        .
         .                                                        .
C        .                                                        .
U   300  +                                                        +
T        .                                                        .
T        .                                                        .
E        Y                                                        .
S        .                                                        .
T   200  +                                                        +
         .1                                                       .
         .                                                        .
         .                                                        .
         .                                                       1.
    100  +                                               1     1  +
         .                                                        Y
         .                                                        .
         .              1                                         .
         .+....+....+....+....+....+....+....+....+.X..+....+....+.
         5.7       6.3       6.9       7.5       8.1       8.7
              6.0       6.6       7.2       7.8       8.4       9.0
N=    6
COR=-.5383                                 MOIST

    MEAN     ST.DEV.     REGRESSION LINE     RES.MS.
    7.4000    1.5690  X=-.00595*Y+ 8.3409    2.1857
    158.08    141.91  Y=-48.684*X+ 518.35    17879.

VARIABLE   6 MOIST    VERSUS VARIABLE   1 CUTTEST
```

```
PAGE   9  BMDP6D DATA DISPLAY
```



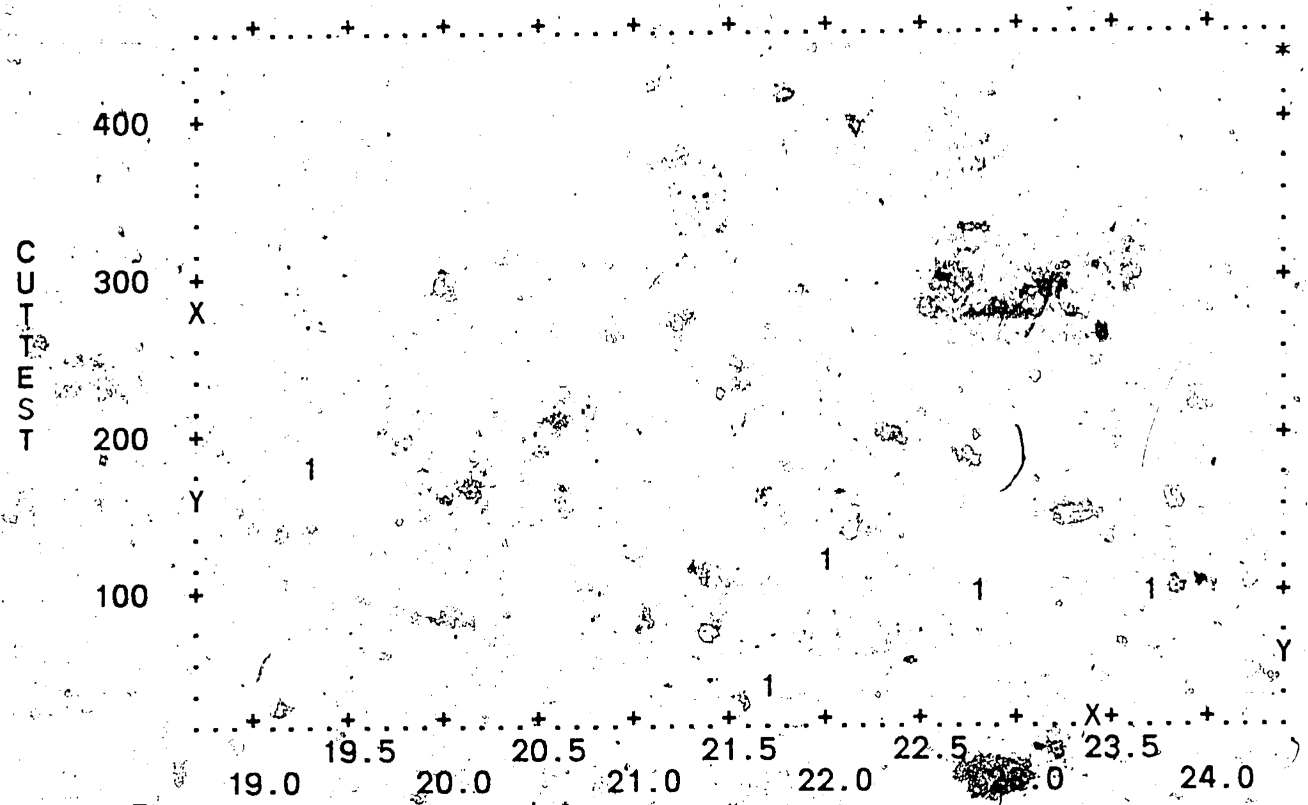
```
N=      6
COR=  .7555                              SLDUR

      MEAN      ST.DEV.     REGRESSION LINE       RES.MS.
X    80.662     17.206    X= .09160*Y+ 66.181      158.85
Y    158.08     141.91    Y= 6.2309*X-344.51       10805.

VARIABLE    7 SLDUR     VERSUS VARIABLE     1 CU.TEST
```

```
PAGE  10  BMDP6D DATA DISPLAY
```



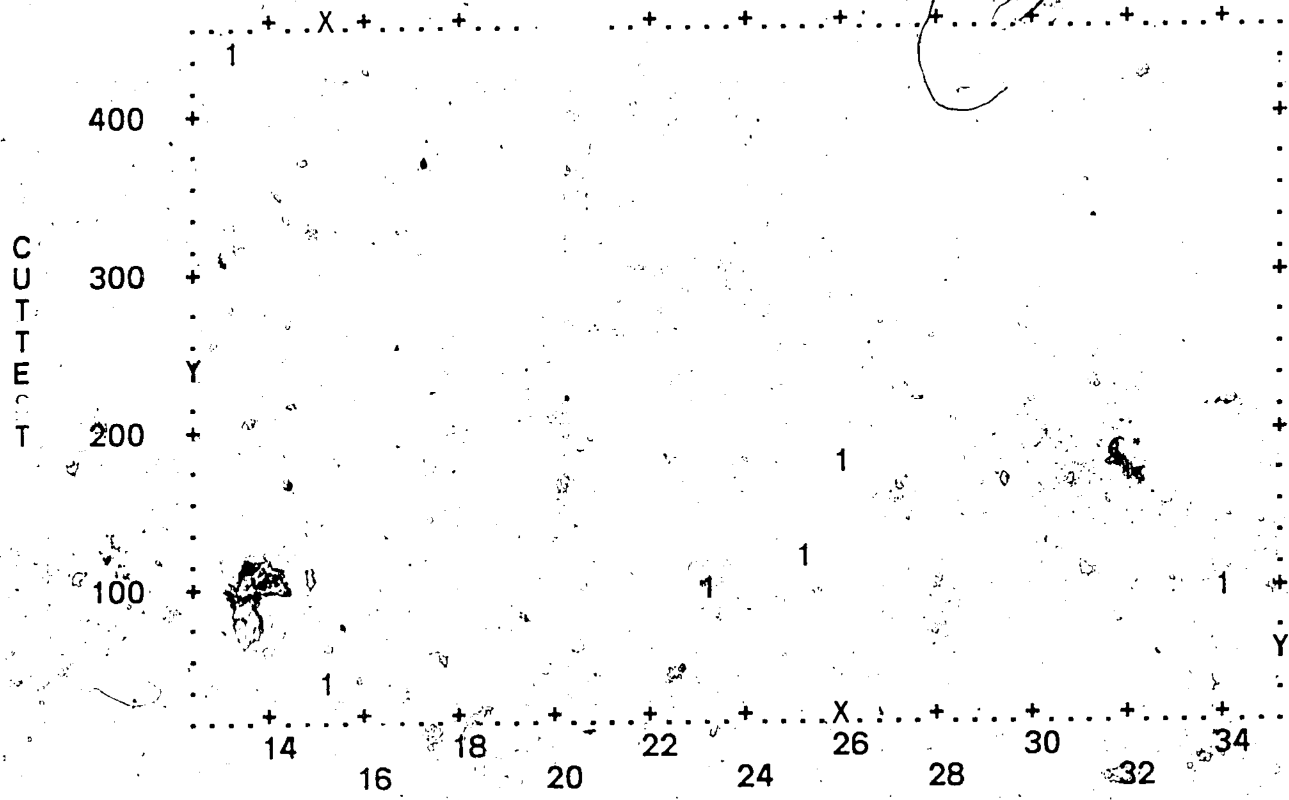
```
N=     6
COR=-.4341

       MEAN     ST.DEV.     REGRESSION LINE      RES.MS.
X    48.637     19.198   X=-.05873*Y+ 57.921     373.85
Y    158.08     141.91   Y=-3.2092*X+ 314.17     20428.

VARIABLE   8 LLIM       VERSUS VARIABLE   1 CUTTEST
```

```
PAGE  11  BMDP6D DATA DISPLAY
```



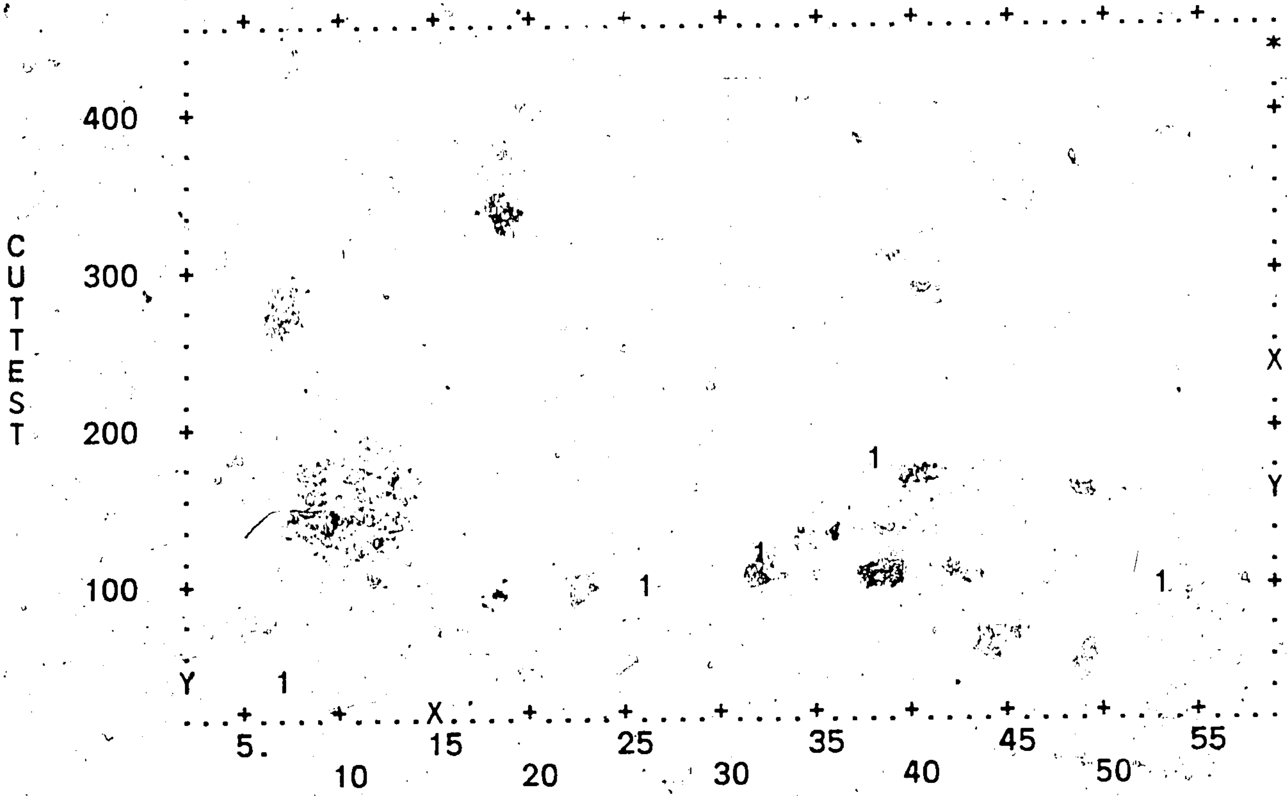
```
N=     5
COR=-.5815

     MEAN     ST.DEV.     REGRESSION LINE      RES.MS.
X   21.888    1.6806    X=-.01849*Y+ 23.800    2.4926
Y   103.46    52.867    Y=-18.292*X+ 503.83    2466.5

VARIABLE    9 PLIM       VERSUS VARIABLE    1 CUTTEST
```

```
PAGE  12  BMDP6D DATA DISPLAY
```



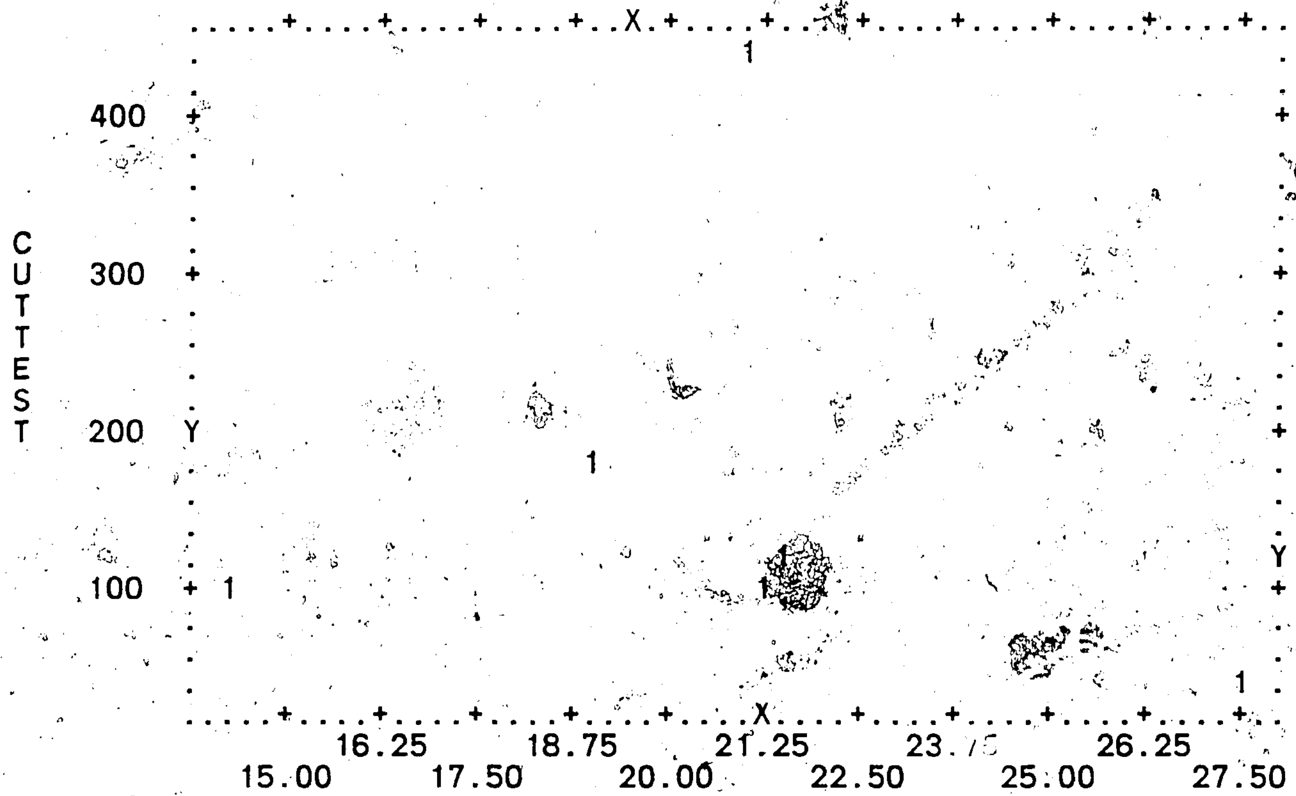
```
N=     6
COR=-.4452                                  CLAY

      MEAN     ST.DEV.    REGRESSION LINE     RES.MS.
X    22.667    7.7114   X=-.02419*Y+ 26.491    59.598
Y    158.08    141.91   Y=-8.1933*X+ 343.80    20183.

VARIABLE  10 CLAY    VERSUS VARIABLE   1 CUTTEST
```

```
PAGE   13  BMDP6D DATA DISPLAY
```



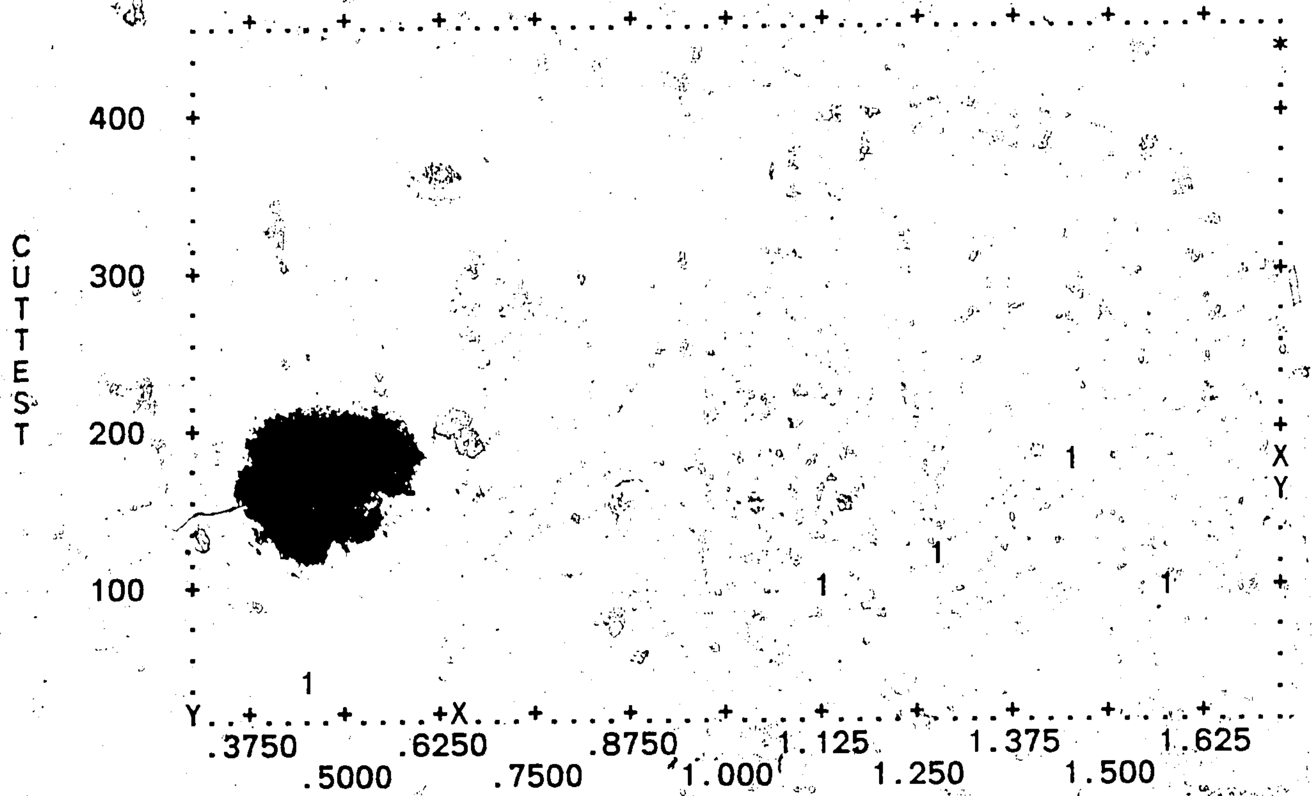
```
N=      5
COR= .5997                                  PINDEX

      MEAN      ST.DEV      REGRESSION LINE      RES.MS.
X    31.482     16.968  X= .19247*Y+ 11.569      245.85
Y    103.46     52.867  Y= 1.8683*X+ 44.642      2386.5

VARIABLE  11 PINDEX   VERSUS VARIABLE   1 CUTTEST
```

```
PAGE  14  BMDP6D DATA DISPLAY
```



```
N=     6
COR=-.1493                              PORS

    MEAN     ST.DEV.    REGRESSION LINE     RES.MS.
X   20.750    4.2726   X=-.00450*Y+ 21.461   22.310
Y   158.08    141.91   Y=-4.9589*X+ 260.98   24612.

VARIABLE  12 PORS      VERSUS VARIABLE    1 CUTTEST
```

```
PAGE  15  BMDP6D DATA DISPLAY
```

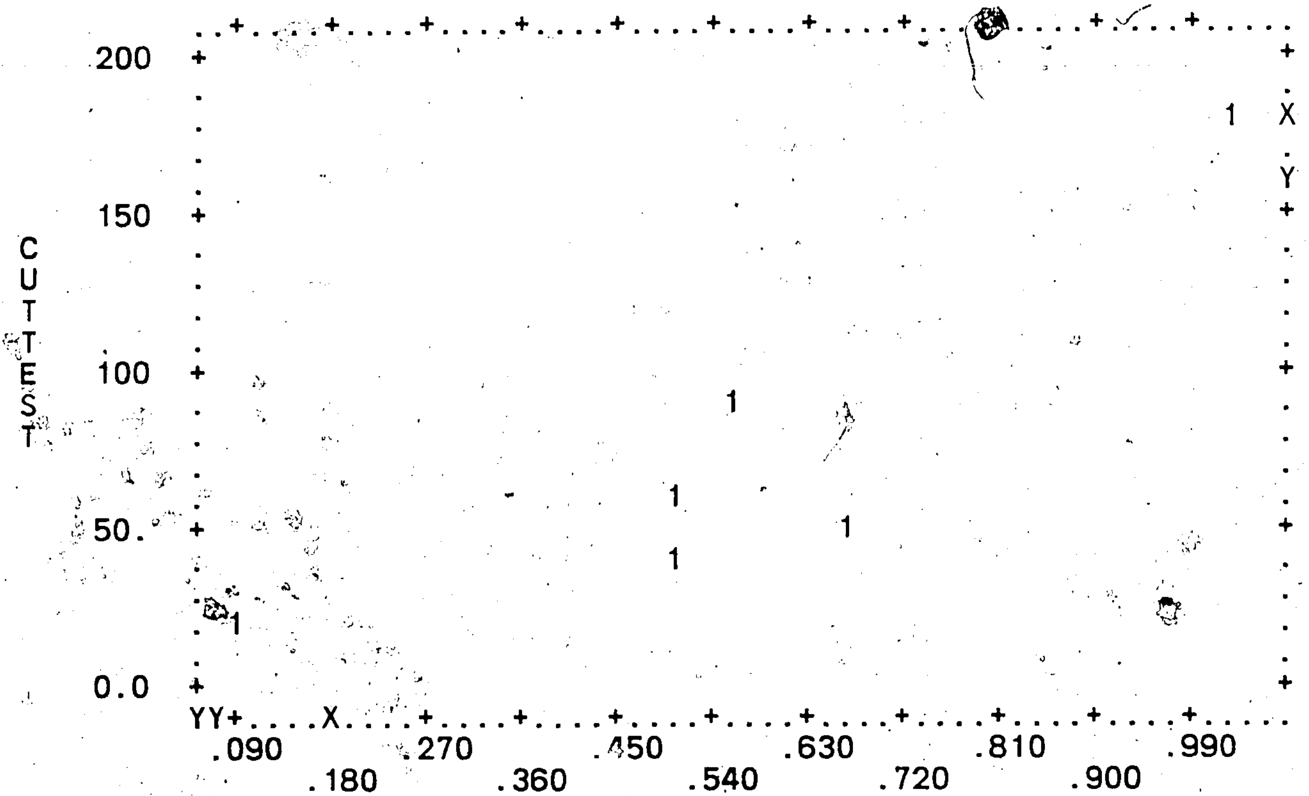


```
N=     5
COR= .7671                               ACTIV

     MEAN     ST.DEV.    REGRESSION LINE     RES.MS.
X   1.1820    .43854  X= .00636*Y+ .52363    .10552
Y   103.46    52.867  Y= 92.479*X-5.8504     1533.5

VARIABLE  13 ACTIV    VERSUS VARIABLE   1 CUTTEST
CPU TIME USED      0.550 SECONDS
```

```
PAGE   3   BMDP6D DATA DISPLAY

TABLE OF CONTENTS

HORIZONTAL      VERTICAL
VARIABLE        VARIABLE        GROUP      PLOT                  PAGE
NO.  NAME       NO.  NAME       NAME       SYMBOL                NO.

  2  PLOAD        1  CUTTEST                         . . . . . . .    4
  3  NCBCON       1  CUTTEST                         . . . . . . .    5
  4  BULKDEN      1  CUTTEST                         . . . . . . .    6
  5  SPGRAV       1  CUTTEST                         . . . . . . .    7
  6  MOIST        1  CUTTEST                         . . . . . . .    8
  7  SLDUR        1  CUTTEST                         . . . . . . .    9
  8  LLIM         1  CUTTEST                         . . . . . . .   10
  9  PLIM         1  CUTTEST                         . . . . . . .   11
 10  CLAY         1  CUTTEST                         . . . . . . .   12
 11  PINDEX       1  CUTTEST                         . . . . . . .   13
 12  PORS         1  CUTTEST                         . . . . . . .   14
 13  ACTIV        1  CUTTEST                         . . . . . . .   15
```

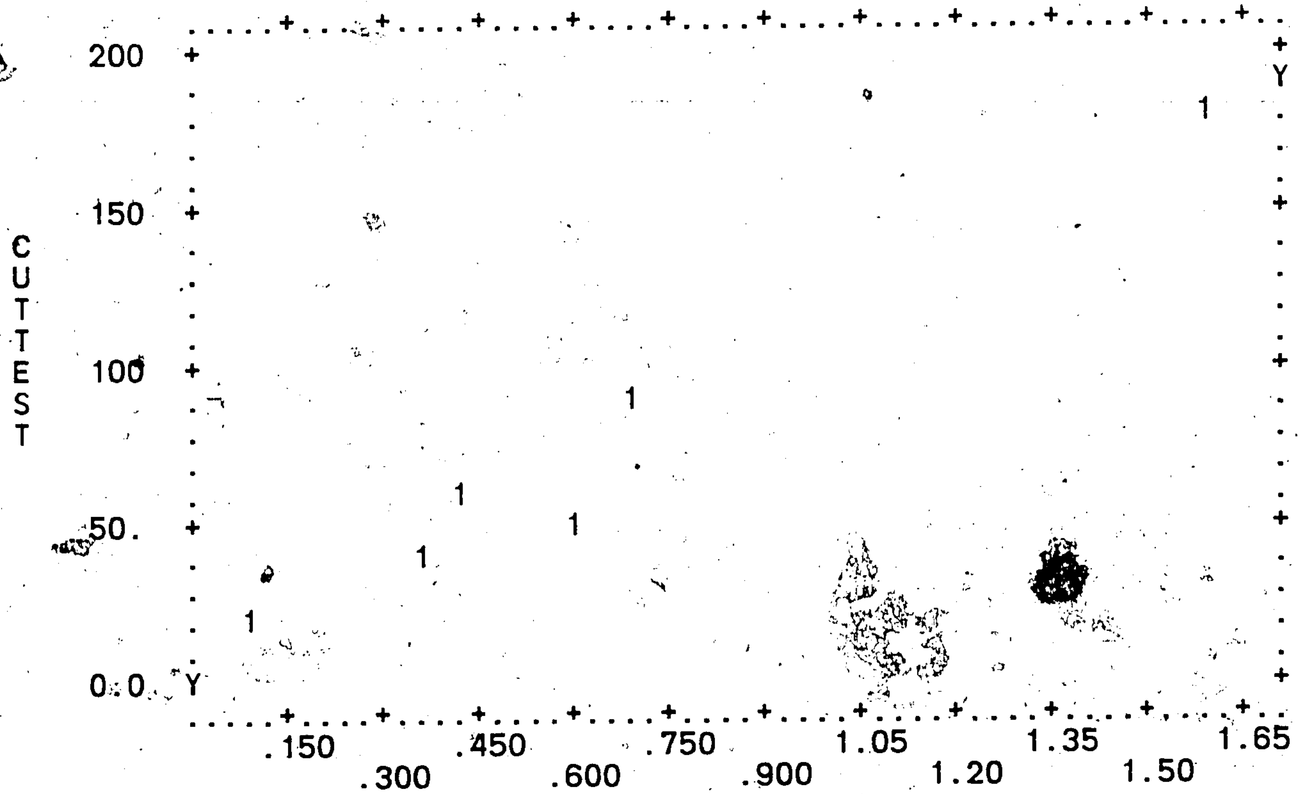
SET V

```
PAGE   4  BMDP6D DATA DISPLAY
```



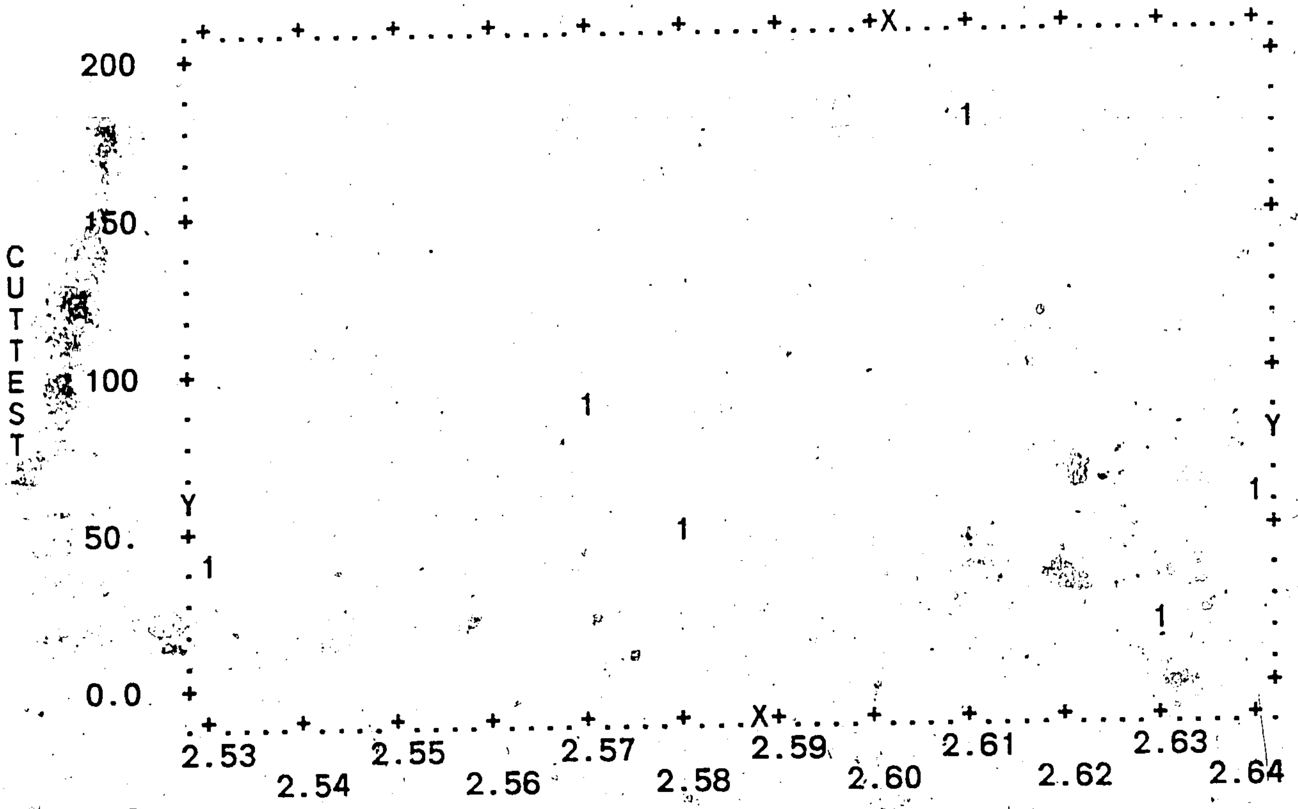
```
N=     6
COR= .8799

    MEAN     ST.DEV.     REGRESSION LINE     RES.MS.
X   .55800    .29868   X= .00466*Y+ .22904   .02517
Y   70.600    56.404   Y= 166.17*X-22.122    897.72

VARIABLE    2 PLOAD     VERSUS VARIABLE    1 CUTTEST
```

```
PAGE    5  BMDP6D DATA DISPLAY
```



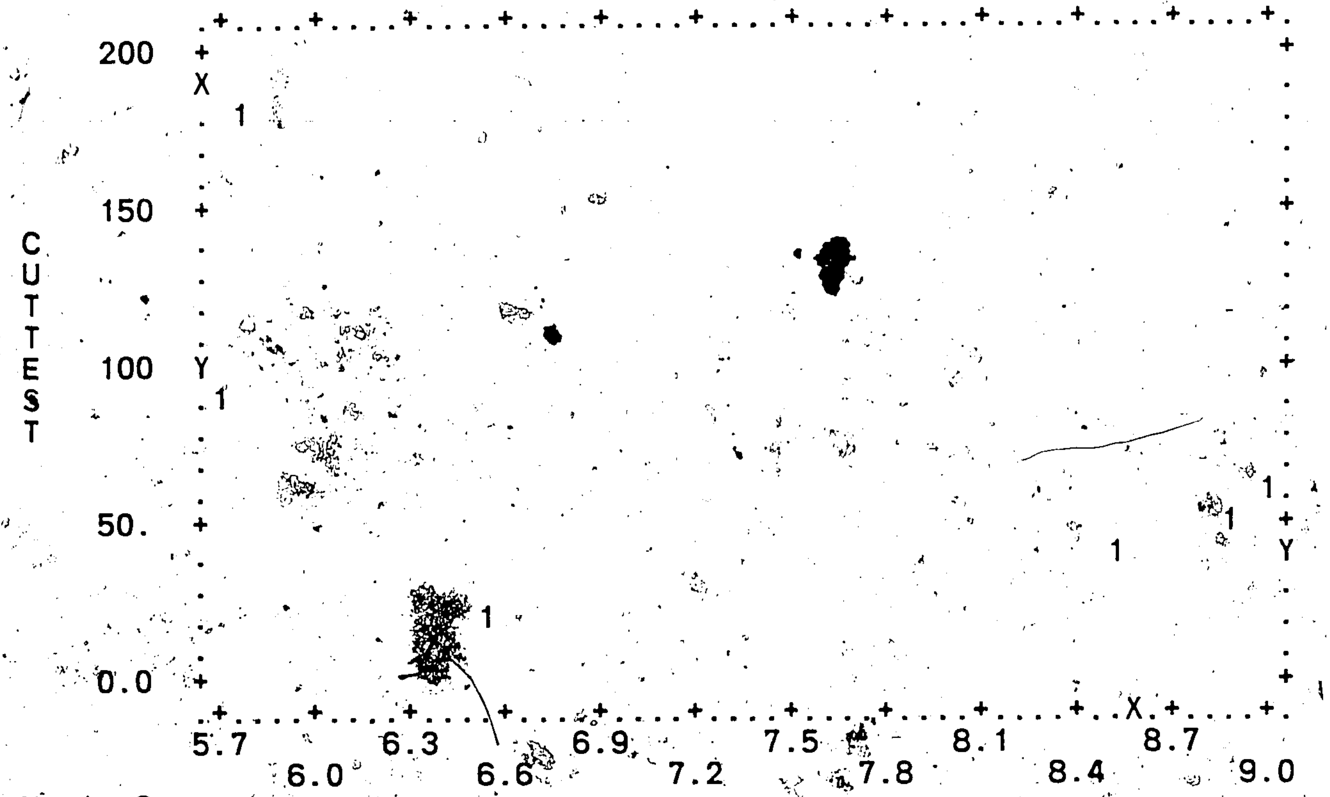
```
N=      6
COR=  .9830                                     NCBCON

    MEAN      ST.DEV.      REGRESSION LINE      RES.MS.
X   .62333    .51059    X= .00890*Y-.00493      .01095
Y   70.600    56.404    Y= 108.60*X+ 2.9086     133.68

VARIABLE    3 NCBCON   VERSUS VARIABLE   1 CUTTEST
```

```
PAGE   6  BMDP6D DATA DISPLAY



        .....+....+....+....+....+....+....+....+....X....+....+..
    200 +                                                        +
        .                                                        .
        .                               1                        .
        .                                                        .
        .                                                        .
    150 +                                                        +
C       .                                                        .
U       .                                                        .
T       .                                                        .
T       .                                                        .
E   100 +                                                        +
S       .                                                   1    Y
T       .                                                        .
        .                                                        .
        .                                 1                      .
    50. Y                         1                              +
        .                                                     1  .
        .                                                        .
        .  1                                                     .
        .                                                        .
    0.0 +                                                        +
        .....+....+....+....+....+X...+....+....+....+....+....+..
           1.925     1.975     2.025     2.075     2.125     2.175
                1.950     2.000     2.050     2.100     2.150
N=     6
COR= .2543                        BULKDEN

    MEAN     ST.DEV.    REGRESSION LINE     RES.MS.
X  2.0667    .09522   X= 429E-6*Y+ 2.0364    .01060
Y  70.600    56.404   Y= 150.62*X-240.68     3719.7

VARIABLE   4 BULKDEN  VERSUS VARIABLE   1 CUTTEST
```

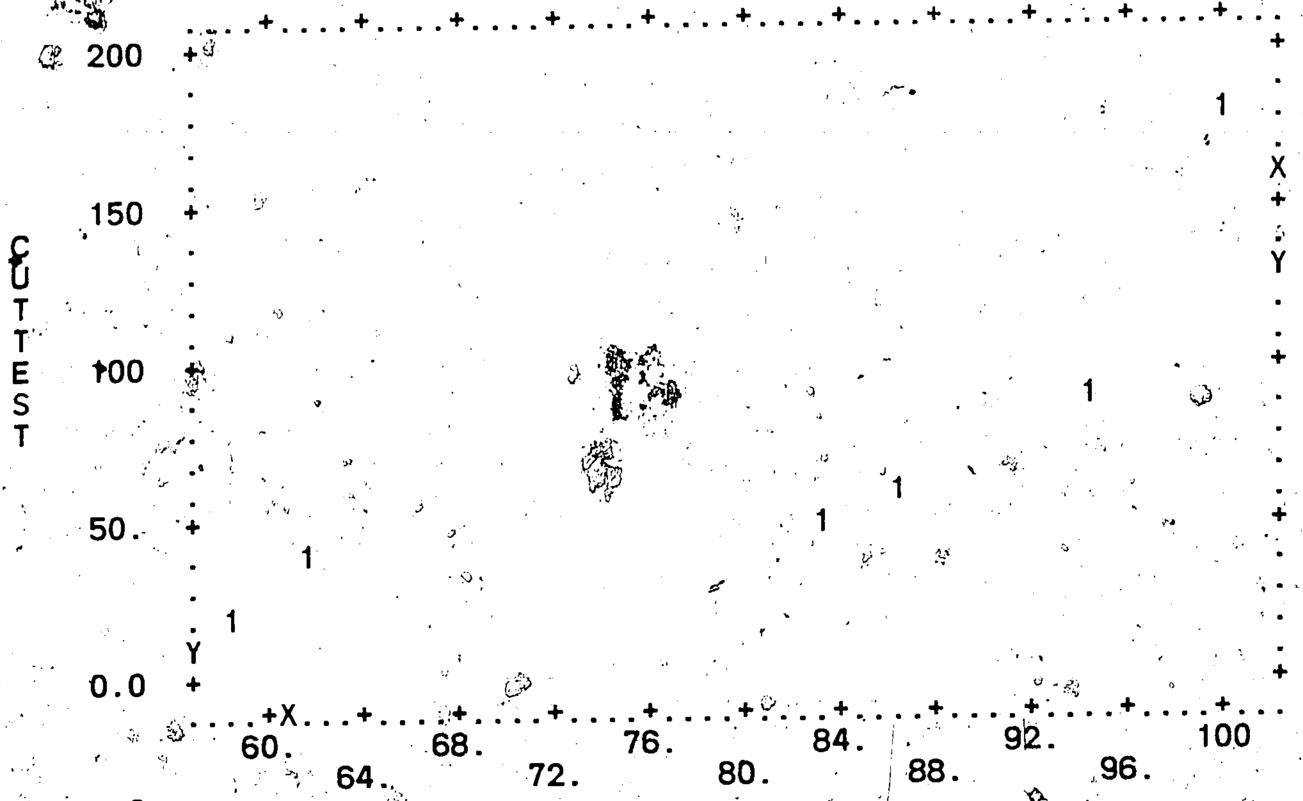


```
N=     6
COR= .0946                                   SPGRAV

     MEAN      ST.DEV.     REGRESSION LINE      RES.MS.
X   2.5933     .04131   X= 693E-7*Y+ 2.5884     .00211
Y   70.600     56.404   Y= 129.16*X-264.35      3941.2

VARIABLE    5 SPGRAV    VERSUS VARIABLE    1 CUTTEST
```

```
PAGE    8  BMDP6D DATA DISPLAY
```



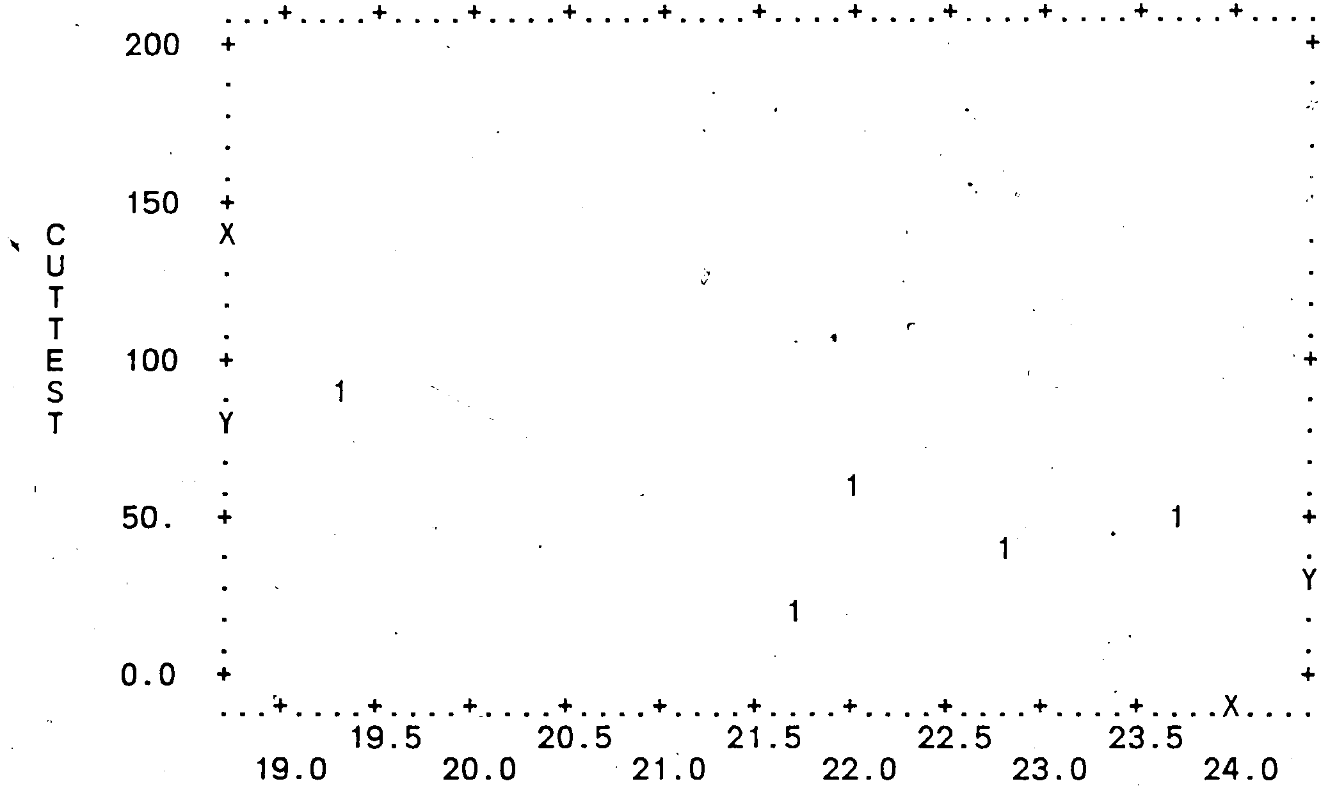
```
N=      6
COR=-.5377                                  MOIST

     MEAN    ST.DEV.      REGRESSION LINE     RES.MS.
X    7[illegible]5690   X=-.01496*Y+ 8.4560    2.1877
Y    70[illegible].404   Y=-19.329*X+ 213.64    2827.1

VARIABLE   6 MOIST     VERSUS VARIABLE    1 CUTTEST
```



```
N=     6
COR= .8198                                 SLDUR

     MEAN     ST.DEV.    REGRESSION LINE      RES.MS.
X   80.662     17.206   X= .25007*Y+ 63.007    121.38
Y   70.600     56.404   Y= 2.6873*X-146.16     1304.3

VARIABLE    7 SLDUR     VERSUS VARIABLE    1 CUTTEST
```

```
PAGE  10  BMDP6D DATA DISPLAY

         ...+...X+....+....+....+....+....+....+....+....+....+....
    200  +                                                        +
         .                                                        .
         .  1                                                     .
         .                                                        .
         .                                                        .
    150  +                                                        +
C        .                                                        .
U        .                                                        .
T        .                                                        .
T        .                                                        .
E   100  Y                                                        +
S        .                                             1          .
T        .                                                        .
         .                                                        .
         .                                         1              .
    50.  +                                      1                 +
         .                                                     1  .
         .                                                        Y
         .      1                                                 .
         .                                                        .
    0.0  +                                                        +
         ...+....+....+....+....+....+....+....X....+....+....+....
            25        35        45        55        65        75
                 30        40        50        60        70
N=    6
COR=-.4152                        LLIM

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   48.637   19.198  X=-.14131*Y+ 58.613   381.27
Y   70.600   56.404  Y=-1.2199*X+ 129.93   3291.3

VARIABLE   8 LLIM     VERSUS VARIABLE   1 CUTTEST
```

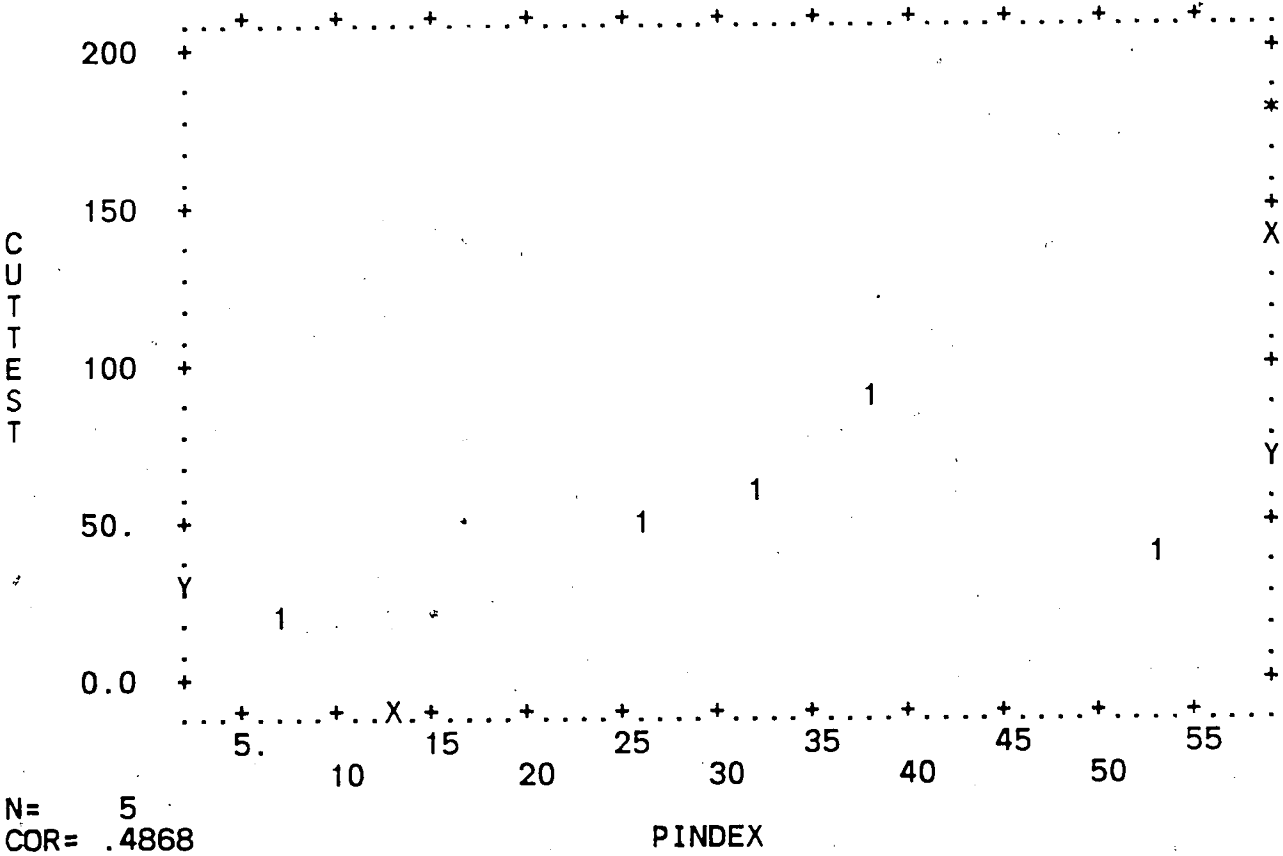
```
PAGE  11  BMDP6D DATA DISPLAY
```



```
N=     5
COR=-.5581                        PLIM

    MEAN      ST.DEV.     REGRESSION LINE     RES.MS.
X   21.888     1.6806   X=-.03592*Y+ 23.671    2.5929
Y   49.640    26.113    Y=-8.6719*X+ 239.45    626.00

VARIABLE   9 PLIM      VERSUS VARIABLE    1 CUTTEST
```

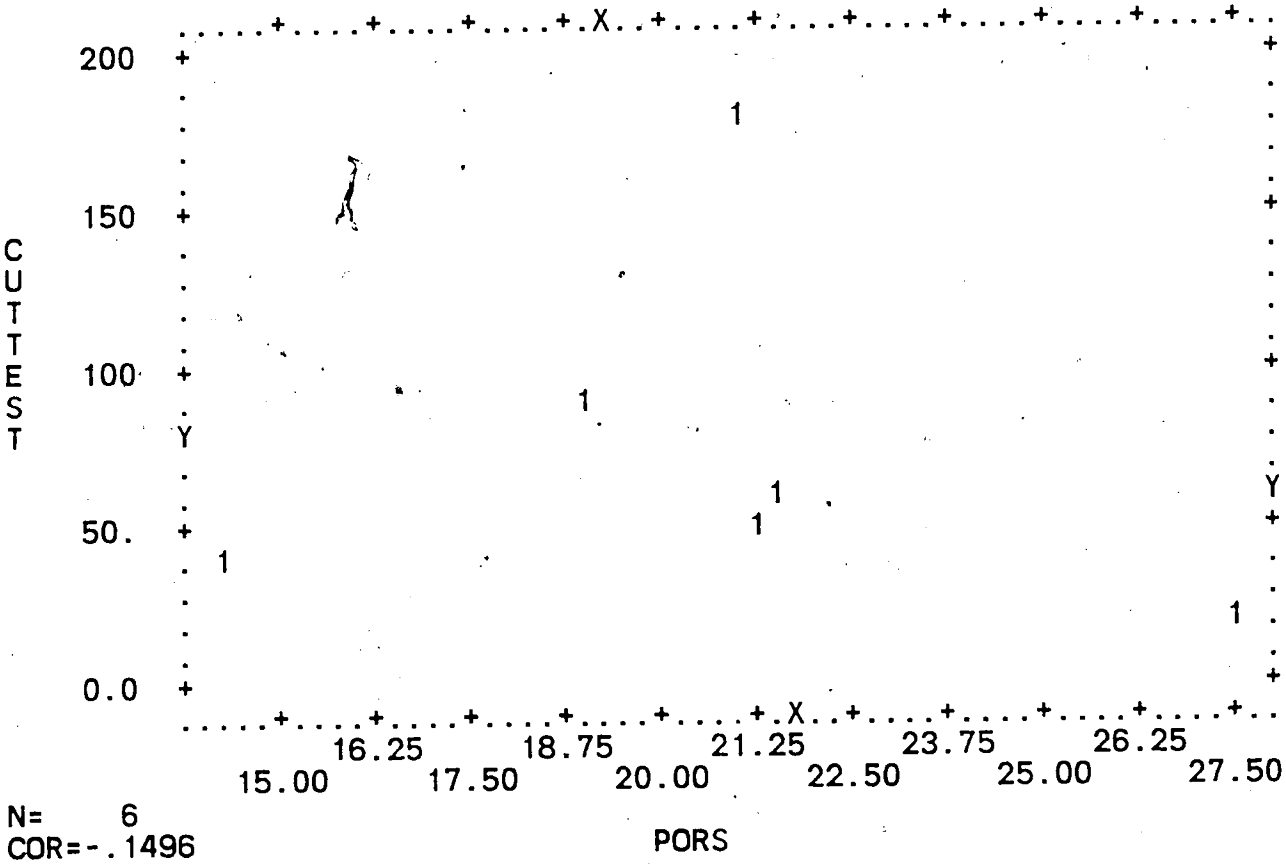
```
PAGE  12  BMDP6D DATA DISPLAY

      ....+X...+....+....+....+....+....+....+....+....+....+...
  200 +                                                        +
      .                                                        .
      . 1                                                      .
      .                                                        .
      .                                                        .
  150 +                                                        +
C     .                                                        .
U     .                                                        .
T     .                                                        .
T     .                                                        .
E 100 Y                                                        +
S     .                                 1                      .
T     .                                                        .
      .                                                        .
      .                               1                        .
  50. +                          1                             +
      .                                                     1  .
      .                                                        Y
      .      1                                                 .
      .                                                        .
  0.0 +                                                        +
      ....+....+....+....+....+....+....+...X+....+....+....+...
          14        18        22        26        30        34
               16        20        24        28        32
N=     6
COR=-.4306                            CLAY

    MEAN     ST.DEV.     REGRESSION LINE     RES.MS.
X   22.667    7.7114   X=-.05887*Y+ 26.823    60.553
Y   70.600   56.404    Y=-3.1493*X+ 141.98    3239.6

VARIABLE  10 CLAY       VERSUS VARIABLE    1 CUTTEST
```

```
PAGE  13  BMDP6D DATA DISPLAY
```



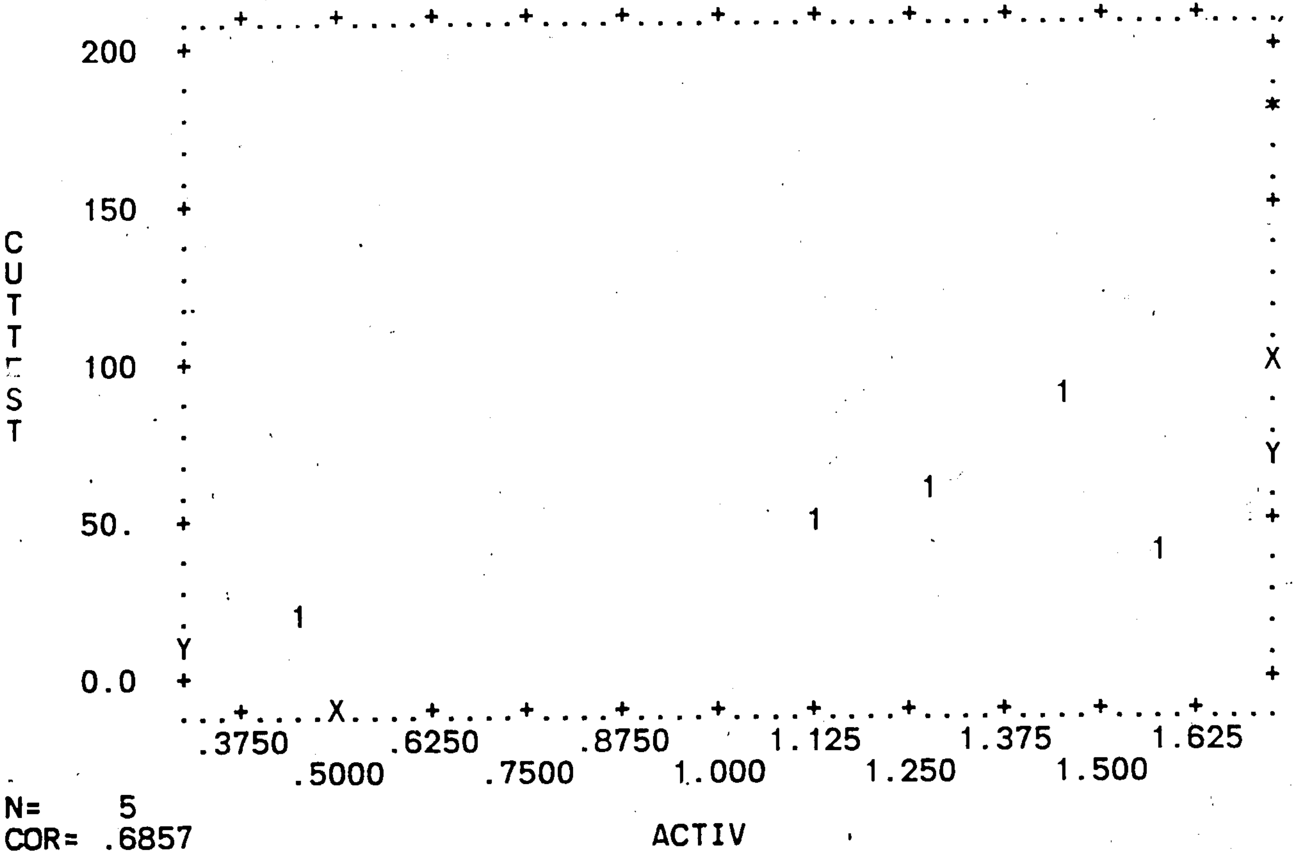
```
N=     5
COR= .4868

    MEAN      ST.DEV.    REGRESSION LINE     RES.MS.
X   31.482    16.968   X= .31634*Y+ 15.779   292.91
Y   49.640    26.113   Y= .74922*X+ 26.053   693.72

VARIABLE  11 PINDEX   VERSUS VARIABLE   1 CUTTEST
```

```
PAGE  14  BMDP6D DATA DISPLAY
```



```
N=     6
COR=-.1496

    MEAN     ST.DEV.     REGRESSION LINE     RES.MS.
X   20.750    4.2726   X=-.01133*Y+ 21.550    22.308
Y   70.600   56.404    Y=-1.9750*X+ 111.58    3887.8

VARIABLE  12 PORS      VERSUS VARIABLE    1 CUTTEST
```

```
PAGE  15  BMDP6D DATA DISPLAY
```



```
N=     5
COR= .6857

    MEAN      ST.DEV.     REGRESSION LINE     RES.MS.
X   1.1820    .43854   X= .01152*Y+ .61036    .13586
Y   49.640    26.113   Y= 40.831*X+ 1.3776    481.71

VARIABLE  13 ACTIV    VERSUS VARIABLE    1 CUTTEST
CPU TIME USED       0.561 SECONDS
```

```
PAGE   3  BMDP6D DATA DISPLAY

  TABLE OF CONTENTS

  HORIZONTAL         VERTICAL
  VARIABLE           VARIABLE         GROUP      PLOT                          PAGE
  NO. NAME           NO. NAME         NAME       SYMBOL                        NO.

   2  PLOAD           1  CUTTEST                            . . . . . . . .    4
   3  NCBCON          1  CUTTEST                            . . . . . . . .    5
   4  BULKDEN         1  CUTTEST                            . . . . . . . .    6
   5  SPGRAV          1  CUTTEST                            . . . . . . . .    7
   6  MOIST           1  CUTTEST                            . . . . . . . .    8
   7  SLDUR           1  CUTTEST                            . . . . . . . .    9
   8  LLIM            1  CUTTEST                            . . . . . . . .   10
   9  PLIM            1  CUTTEST                            . . . . . . . .   11
  10  CLAY            1  CUTTEST                            . . . . . . . .   12
  11  PINDEX          1  CUTTEST                            . . . . . . . .   13
  12  PORS            1  CUTTEST                            . . . . . . . .   14
  13  ACTIV           1  CUTTEST                            . . . . . . . .   15
```

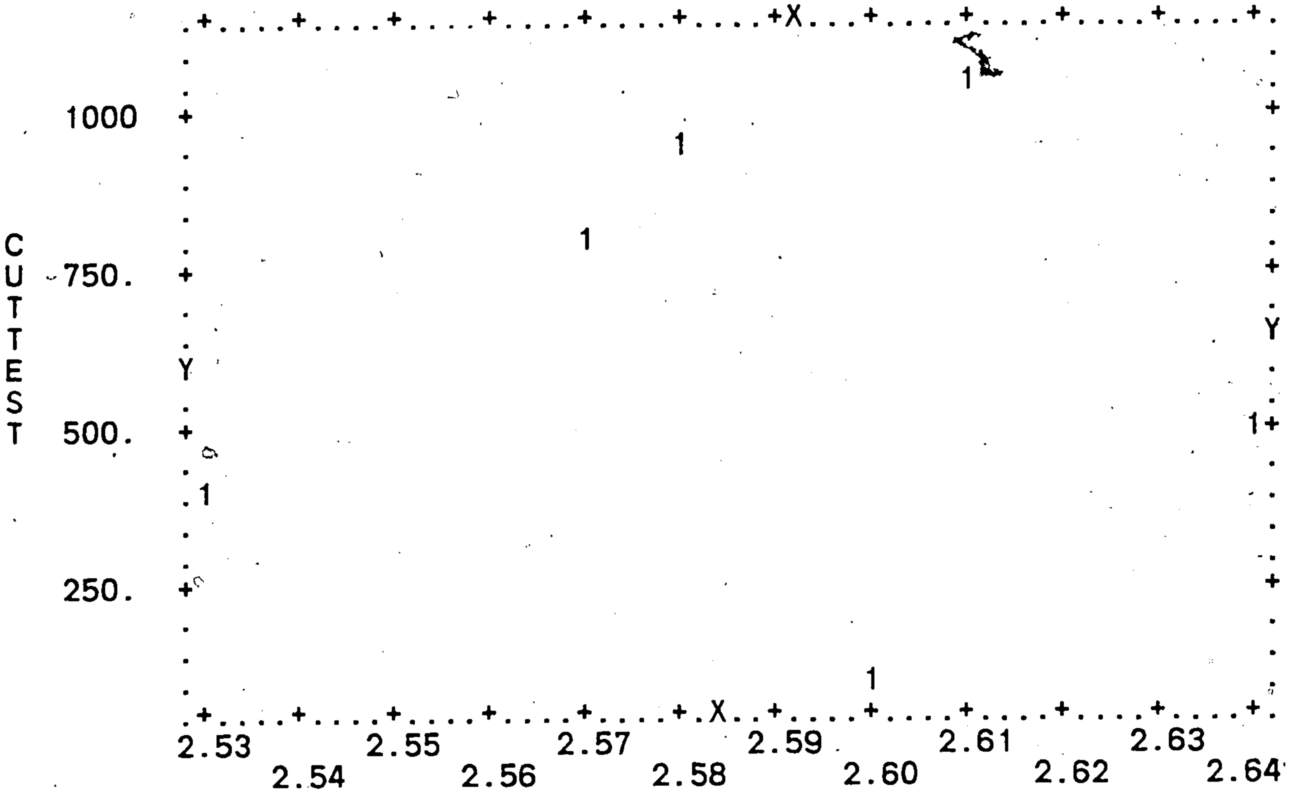
S E T   V I

```
PAGE    4  BMDP6D DATA DISPLAY




         ..+....+....+....+....+....+....+....+....+....+.X..+.Y...
         .                                                        .
         .                                                     1  .
    1000 +                                                        +
         .                                 1                      .
         .                                                        .
         .                                                        .
C        .                           1                            .
U   750. +                                                        +
T        .                                                        .
T        .                                                        .
E        .                                                        .
S        .                                                        .
T   500. +                        1                               +
         .                                                        .
         .                        1                               .
         .                                                        .
         .                                                        .
    250. +                                                        +
         .                                                        .
         .                                                        .
         Y 1                                                      .
         ..+.X..+....+....+....+....+....+....+....+....+....+.....
          .090      .270      .450      .630      .810      .990
               .180      .360      .540      .720      .900
N=      6
COR= .9008                                PLOAD

    MEAN      ST.DEV.     REGRESSION LINE     RES.MS.
X   .55800     .29868   X= 737E-6*Y+ .08983    .02103
Y   635.17     365.01   Y= 1100.8*X+ 20.914    31411.

VARIABLE    2 PLOAD     VERSUS VARIABLE    1 CUTTEST
```

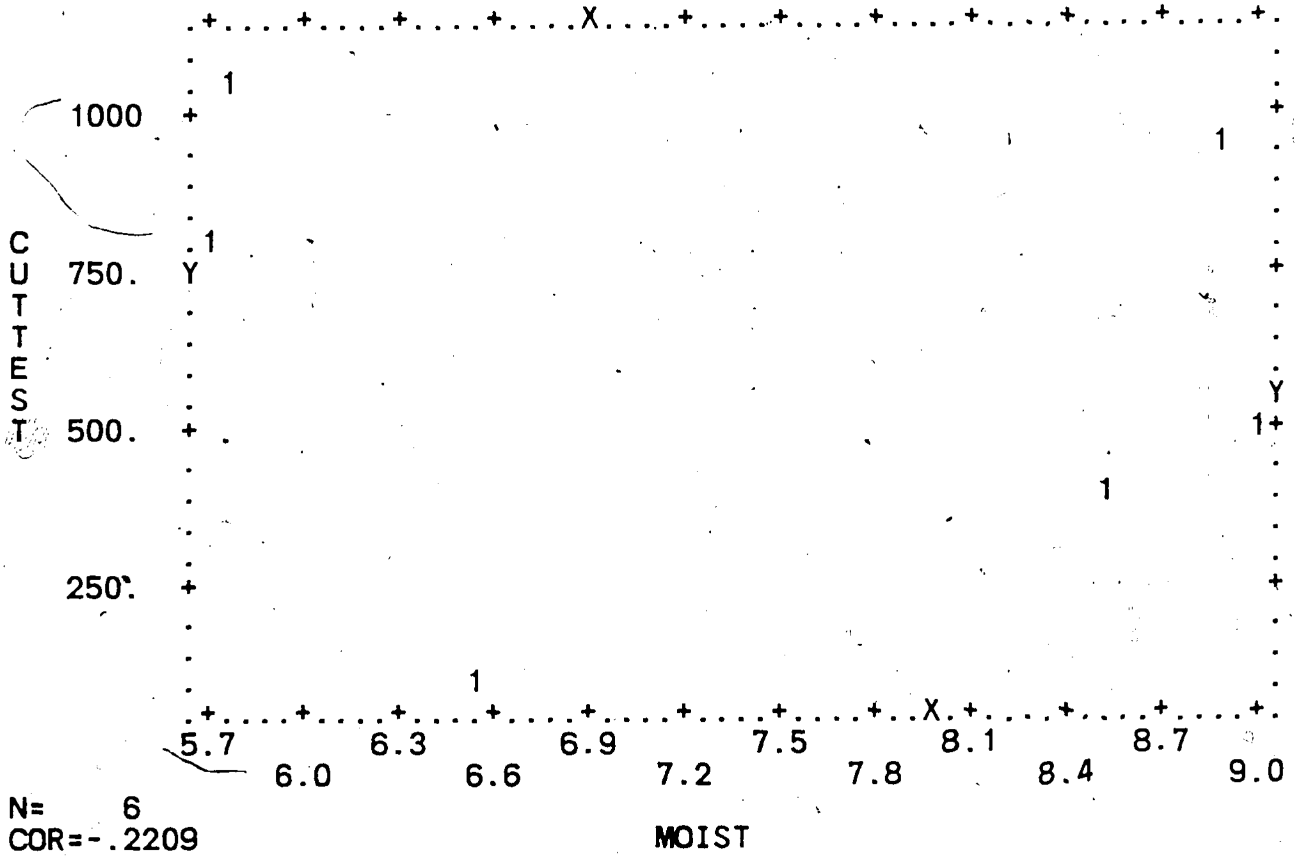
```
PAGE    5  BMDP6D DATA DISPLAY





          .....+....+....+....+....+....+....+....+X...+....Y....+..
          .                                                        .
          .                                                    1   .
    1000  +                                                        +
          .                   1                                    .
          .                                                        .
          .                                                        .
 C        .                      1                                 .
 U  750.  +                                                        +
 T        .                                                        .
 T        .                                                        .
 E        .                                                        .
 S        .                                                        .
 T  500.  +             1                                          +
          .                                                        .
          .           1                                            .
          .                                                        .
          .                                                        .
    250.  Y                                                        +
          .                                                        .
          .                                                        .
          X  1                                                     .
          .....+....+....+....+....+....+....+....+....+....+....+..
             .150      .450      .750      1.05      1.35      1.65
                  .300      .600      .900      1.20      1.50
N=     6
COR= .8317                               NCBCON

    MEAN     ST.DEV.     REGRESSION LINE     RES.MS.
X    .62333   .51059   X= .00116*Y-.11560     .10048
Y   635.17    365.01   Y= 594.54*X+ 264.57    51350.

VARIABLE    3 NCBCON   VERSUS VARIABLE    1 CUTTEST
```

```
PAGE    6  BMDP6D DATA DISPLAY

           .....+....+....+....+....+....+....+....+.X..+....+....+..
           .                                                        .
           .                               1                        .
   1000    +                                                        +
           .                         1                              .
           .                                                        .
           .                                                        .
C          .                                                        Y
U  750.    +                                                        +
T          .                                                        .
T          .                                                        .
E          .                                                        .
S          .                                                        .
T  500.    +                                 1                      +
           .                                                        .
           Y                                                     1  .
           .                                                        .
           .                                                        .
   250.    +                                                        +
           .                                                        .
           .                                                        .
           . 1                                                      .
           .....+....+....+....+..X.+....+....+....+....+....+....+..
              1.925     1.975     2.025     2.075     2.125     2.175
                   1.950     2.000     2.050     2.100     2.150
N=     6
COR= .3310                                   BULKDEN

     MEAN      ST.DEV.     REGRESSION LINE     RES.MS.
X   2.0667     .09522   X= 863E-7*Y+ 2.0118    .01009
Y   635.17     365.01   Y= 1268.7*X-1986.8     148299

VARIABLE    4 BULKDEN   VERSUS VARIABLE    1 CUTTEST
```

```
PAGE    7  BMDP6D DATA DISPLAY
```



```
N=     6
COR= .0580                                   SPGRAV

    MEAN      ST.DEV.     REGRESSION LINE     RES.MS.
X   2.5883     .03764   X= 598E-8*Y+ 2.5845    .00176
Y   635.17     365.01   Y= 562.20*X-820.01     165981

VARIABLE    5 SPGRAV    VERSUS VARIABLE    1 CUTTEST
```

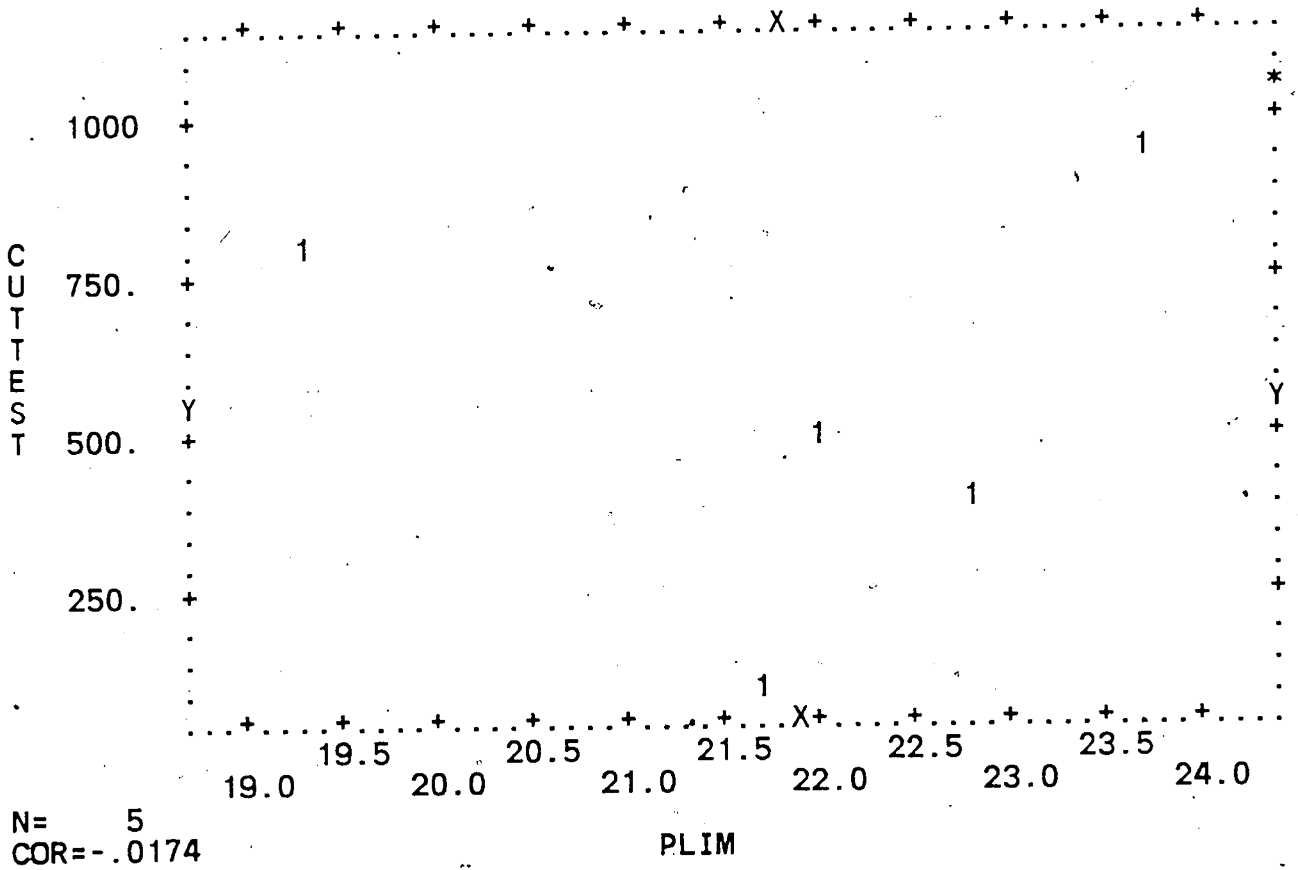


```
N=     6
COR=-.2209

    MEAN      ST.DEV.     REGRESSION LINE    RES.MS.
X   7.4000     1.5690    X=-949E-6*Y+ 8.0030   2.9272
Y   635.17     365.01    Y=-51.380*X+ 1015.4   158417

VARIABLE   6 MOIST    VERSUS VARIABLE   1 CUTTEST
```

```
PAGE   9  BMDP6D DATA DISPLAY

       ...+...+...+...+...+...+...+...+...+...+...+.XX
       .                                            .
       .                                          1 Y
  1000 +                                            +
       .                         1                  .
       .                                            .
       .                                            .
C      .                                     1      .
U 750. +                                            +
T      .                                            .
T      .                                            .
E      .                                            .
S      .                                            .
T 500. +                            1               +
       .                                            .
       .    1                                       .
       .                                            .
       .                                            .
  250. +                                            +
       Y                                            .
       .                                            .
       . 1                                          .
       X..+...+...+...+...+...+...+...+...+...+...+...
         60.     68.     76.     84.     92.     100
             64.     72.     80.     88.     96.
N=     6
COR=  .8687                            SLDUR

    MEAN     ST.DEV.     REGRESSION LINE     RES.MS.
X   80.662    17.206   X= .04095*Y+ 54.653    90.823
Y   635.17    365.01   Y= 18.428*X-851.24     40872.

VARIABLE   7 SLDUR     VERSUS VARIABLE    1 CUTTEST
```

```
PAGE   10  BMDP6D DATA DISPLAY



         ...+....+....+....+....X....+....+....+....+....+....+....
         .                                                        .
         .  1                                                     .
   1000  +                                                        +
         .                            1                           .
         .                                                        .
         .                                                        .
C        .                                   1                    .
U  750.  +                                                        +
T        Y                                                        .
T        .                                                        .
E        .                                                        .
S        .                                                        Y
T  500.  +                               1                        +
         .                                                        .
         .                                                     1  .
         .                                                        .
         .                                                        .
   250.  +                                                        +
         .                                                        .
         .                                                        .
         .      1                                                 .
         ...+....+....+....+....+....+..X.+....+....+....+....+....
            25        35        45        55        65        75
                 30        40        50        60        70
N=     6
COR=-.1479                        LLIM

    MEAN    ST.DEV.    REGRESSION LINE    RES.MS.
X   48.637    19.198  X=-.00778*Y+ 53.576   450.61
Y   635.17    365.01  Y=-2.8114*X+ 771.90   162899

VARIABLE   8 LLIM     VERSUS VARIABLE   1 CUTTEST
```

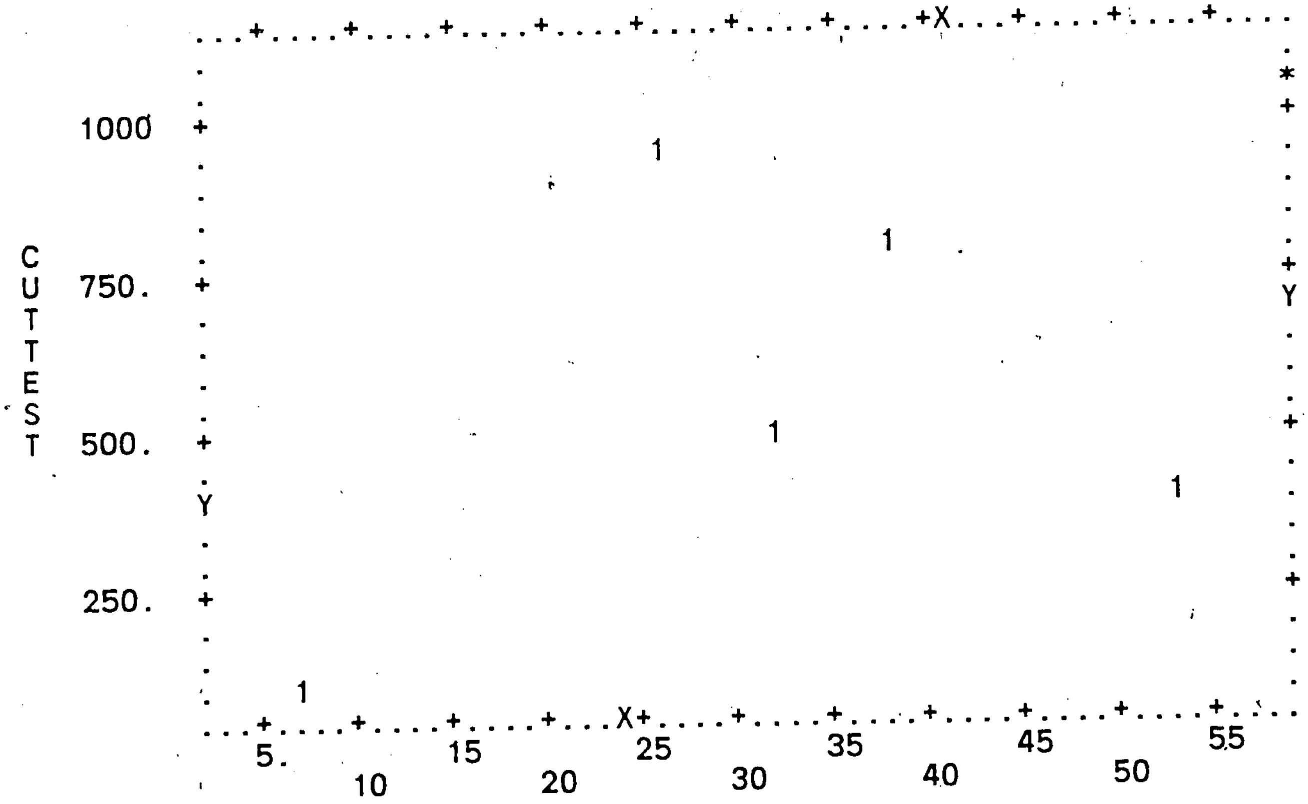
```
PAGE   11   BMDP6D DATA DISPLAY
```



```
N=     5
COR=-.0174

      MEAN     ST.DEV.    REGRESSION LINE     RES.MS.
X    21.888    1.6806  X=-872E-7*Y+ 21.936    3.7648
Y    550.80    336.39  Y=-3.4925*X+ 627.24    150831

VARIABLE    9 PLIM      VERSUS VARIABLE    1 CUTTEST
```

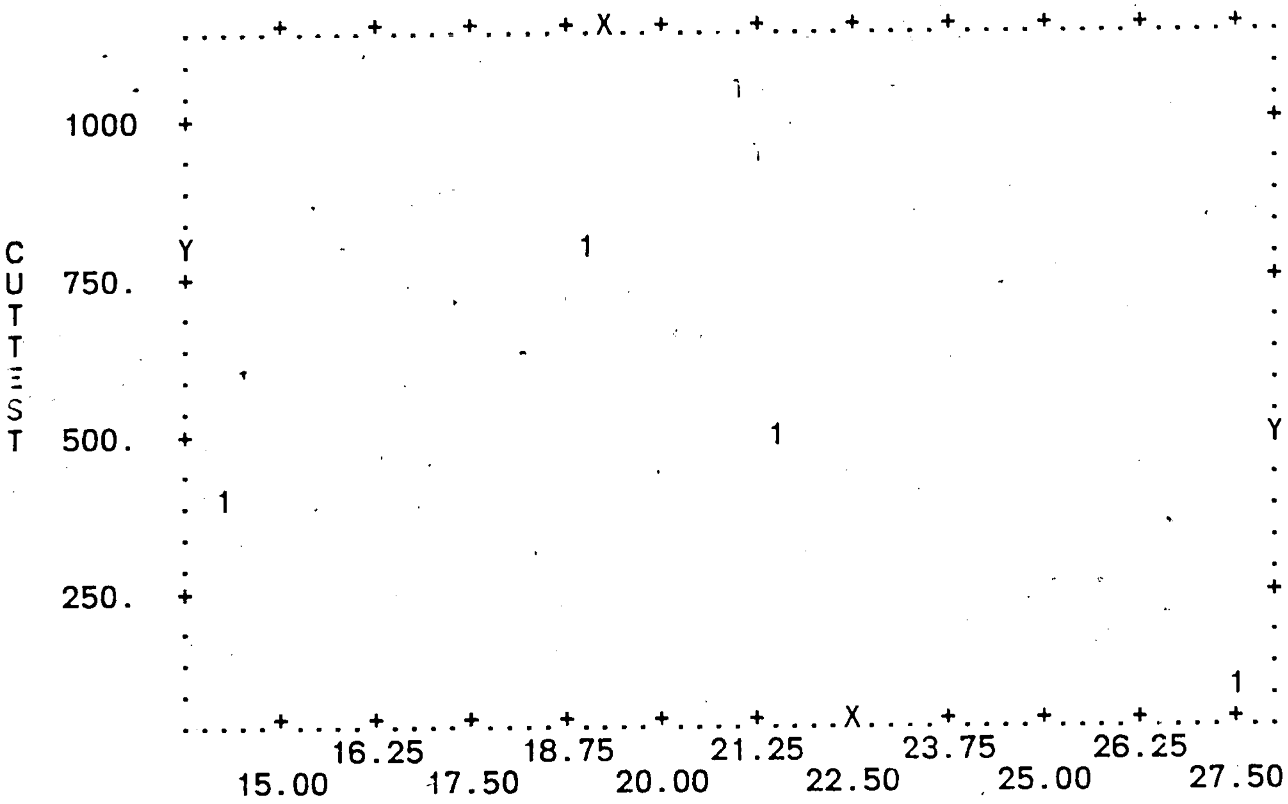
```
PAGE  12  BMDP6D DATA DISPLAY





        ....+....+....+....+.X..+....+....+....+....+....+....+...
        .                                                        .
        . 1                                                      .
   1000 +                                                        +
        .                          1                             .
        .                                                        .
        .                                                        .
C       .                                  1                     .
U  750. +                                                        +
T       Y                                                        .
T       .                                                        .
E       .                                                        .
S       .                                                        Y
T  500. +                               1                        +
        .                                                        .
        .                                                     1  .
        .                                                        .
        .                                                        .
   250. +                                                        +
        .                                                        .
        .                                                        .
        .      1                                                 .
        ....+....+....+....+....+....+.X..+....+....+....+....+...
            14        18        22        26        30        34
                 16        20        24        28        32
N=     6
COR=-.1844                       CLAY

    MEAN     ST.DEV.    REGRESSION LINE    RES.MS.
X   22.667   7.7114   X=-.00389*Y+ 25.141   71.807
Y   635.17   365.01   Y=-8.7265*X+ 832.97   160880

VARIABLE  10 CLAY     VERSUS VARIABLE   1 CUTTEST
```

PAGE 13 BMDP6D DATA DISPLAY



```
N=     5
COR= .2985                                  PINDEX

     MEAN     ST.DEV.     REGRESSION LINE     RES.MS.
X   31.482    16.968   X= .01505*Y+ 23.190    349.70
Y   550.80    336.39   Y= 5.9167*X+ 364.53    137438

VARIABLE  11 PINDEX   VERSUS VARIABLE   1 CUTTEST
```

```
PAGE  14  BMDP6D DATA DISPLAY
```



```
N=     6
COR=-.2523                                 PORS

     MEAN     ST.DEV.     REGRESSION LINE     RES.MS.
X   20.750    4.2726   X=-.00295*Y+ 22.626    21.366
Y   635.17    365.01   Y=-21.555*X+ 1082.4    155939

VARIABLE  12 PORS       VERSUS VARIABLE    1 CUTTEST
```

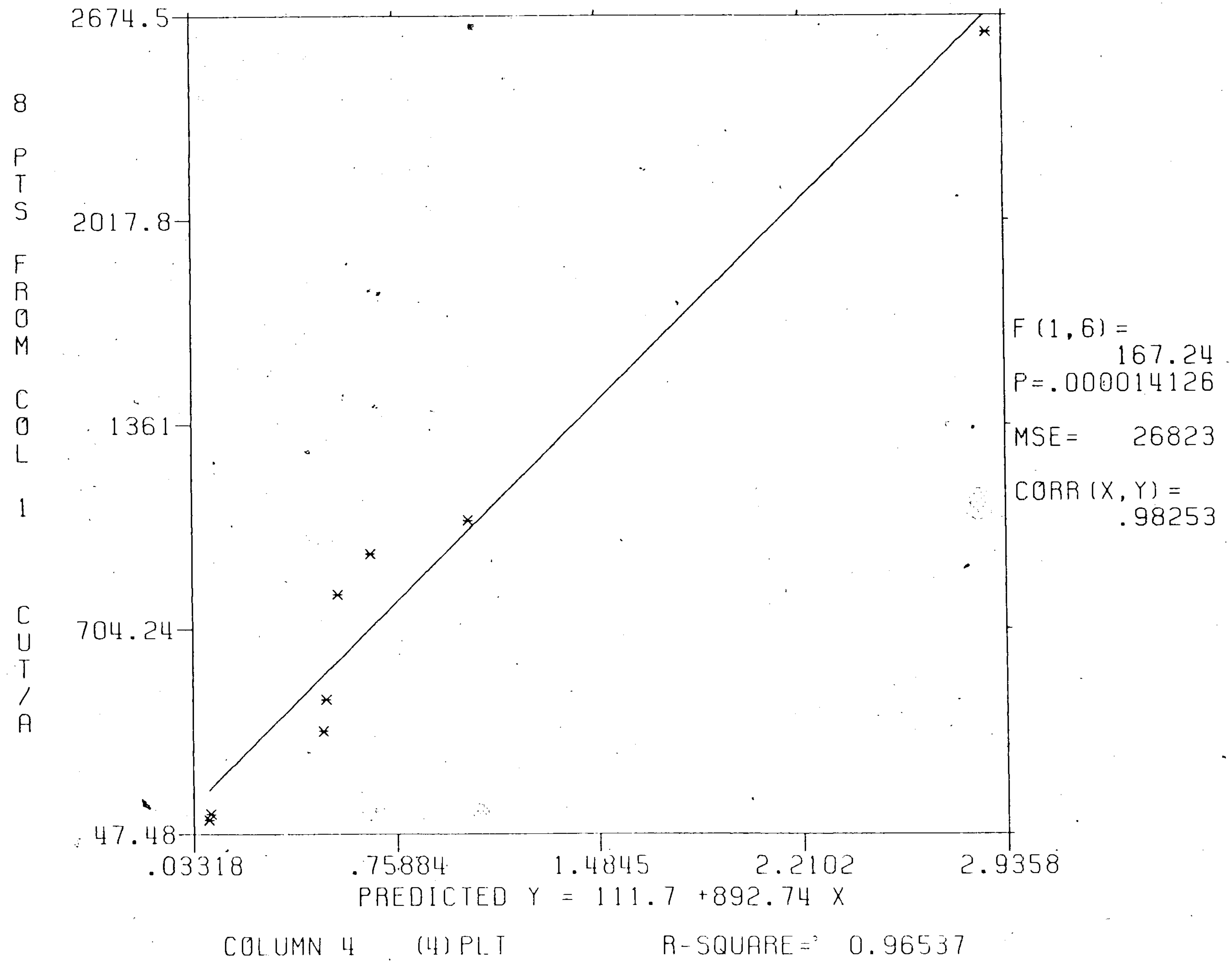
```
PAGE  15  BMDP6D DATA DISPLAY



          ...+....+....+....+....+....+....+....+....+....+..X.+....
          .                                                        .
          .                                                        *
    1000  +                                                        +
          .                                1                       .
          .                                                        .
          .                                                        .
 C        .                                             1          .
 U  750.  +                                                        Y
 T        .                                                        .
 T        .                                                        .
 E        .                                                        .
 S        .                                                        .
 T  500.  +                                      1                 +
          .                                                        .
          .                                                  1     .
          .                                                        .
          .                                                        .
    250.  +                                                        +
          Y                                                        .
          .                                                        .
          .     1                                                  .
          ...+....+....+....+...X+....+....+....+....+....+....+....
           .3750     .6250     .8750     1.125     1.375     1.625
                .5000     .7500     1.000     1.250     1.500
N=    5
COR= .4982                                 ACTIV

    MEAN     ST.DEV.    REGRESSION LINE    RES.MS.
X   1.1820    .43854   X= 649E-6*Y+ .82429     .19279
Y   550.80    336.39   Y= 382.11*X+ 99.143     113436

VARIABLE  13 ACTIV    VERSUS VARIABLE   1 CUTTEST
CPU TIME USED       0.564 SECONDS
```

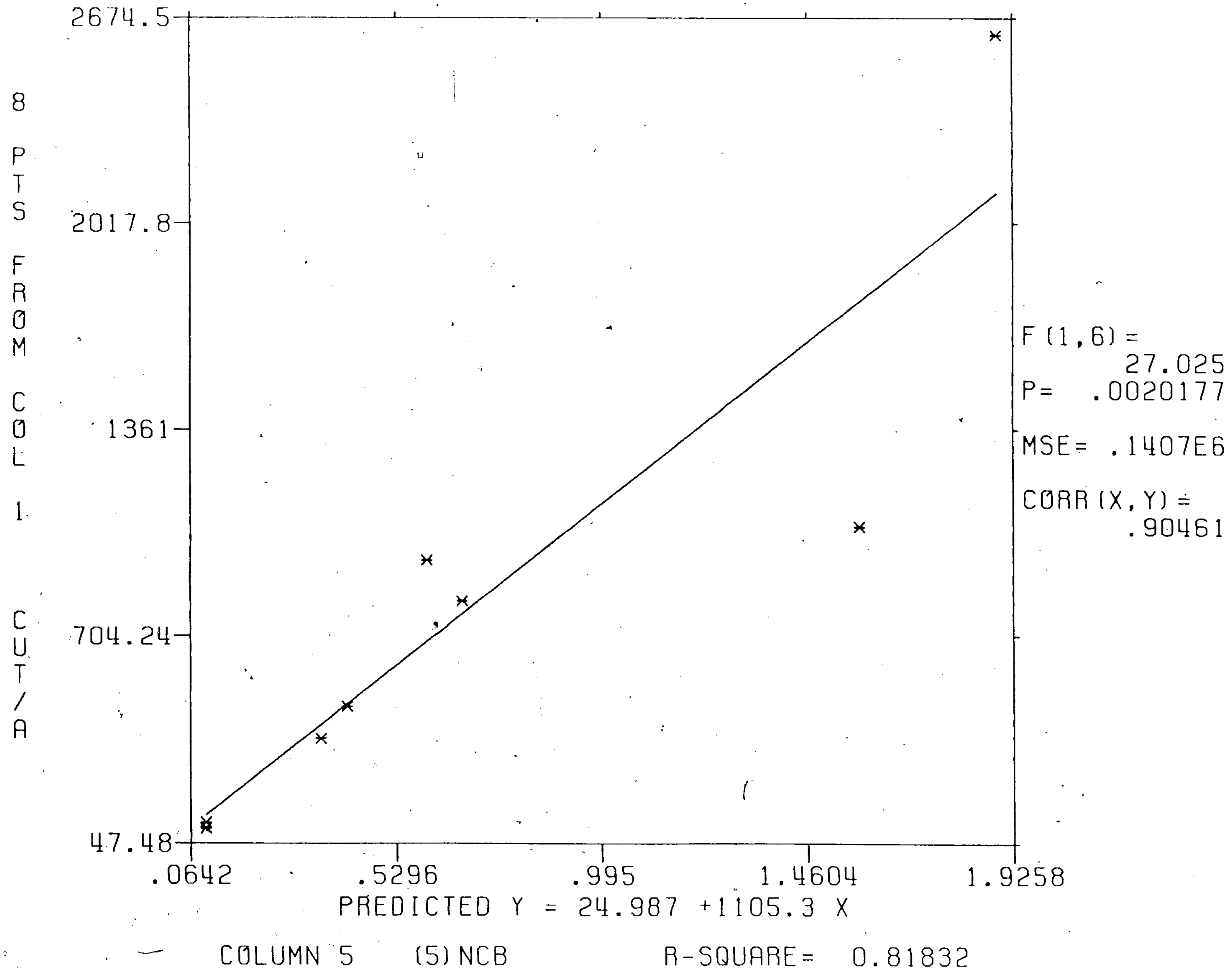
# APPENDIX D

## SCATTER PLOTS OF HIGHLY CORRELATED TEST RESULTS

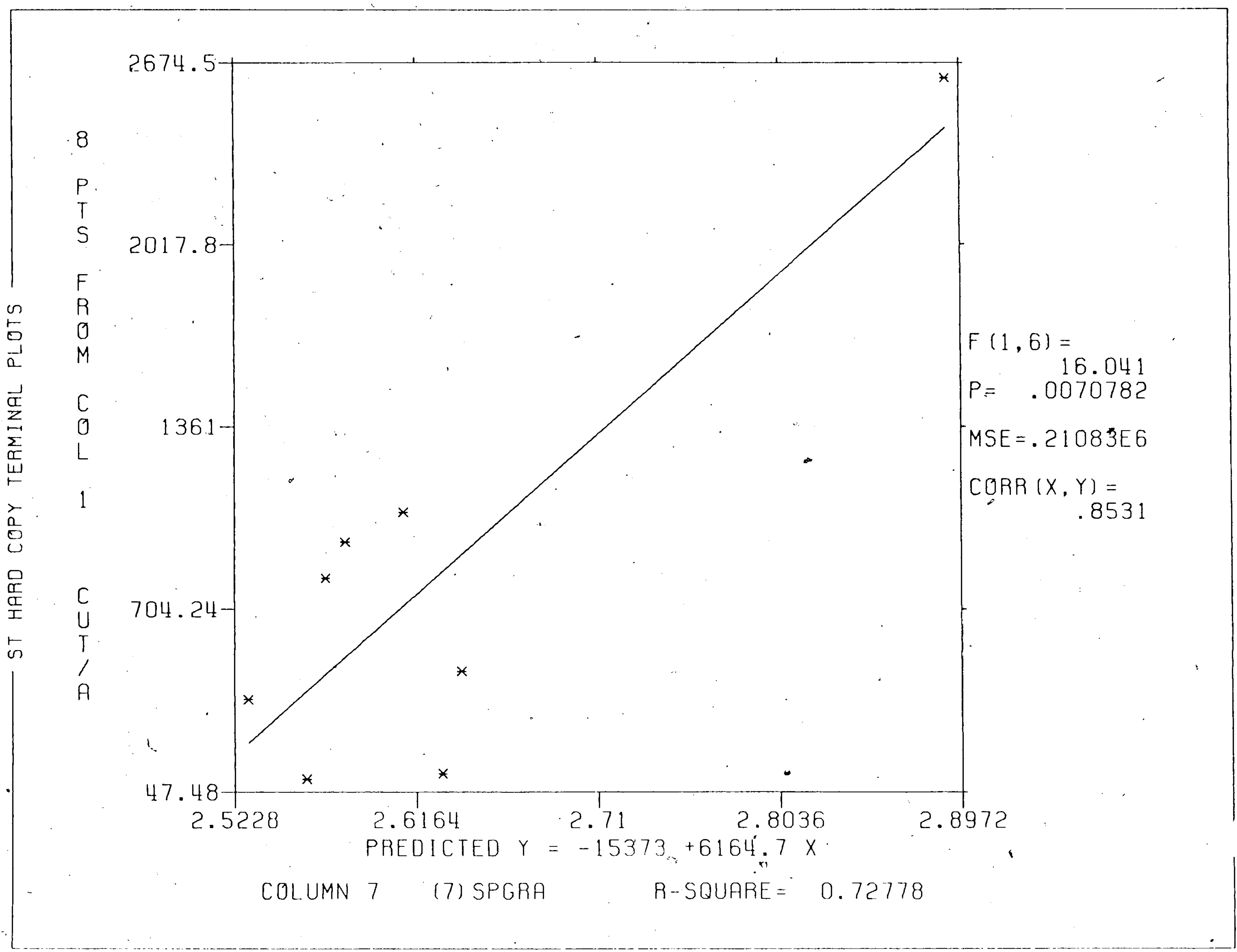
Each figure gives the following information about analysed variables: F- ration ,P- tail probabily , mean square error,correlation coeficient and fitted linear equasion.

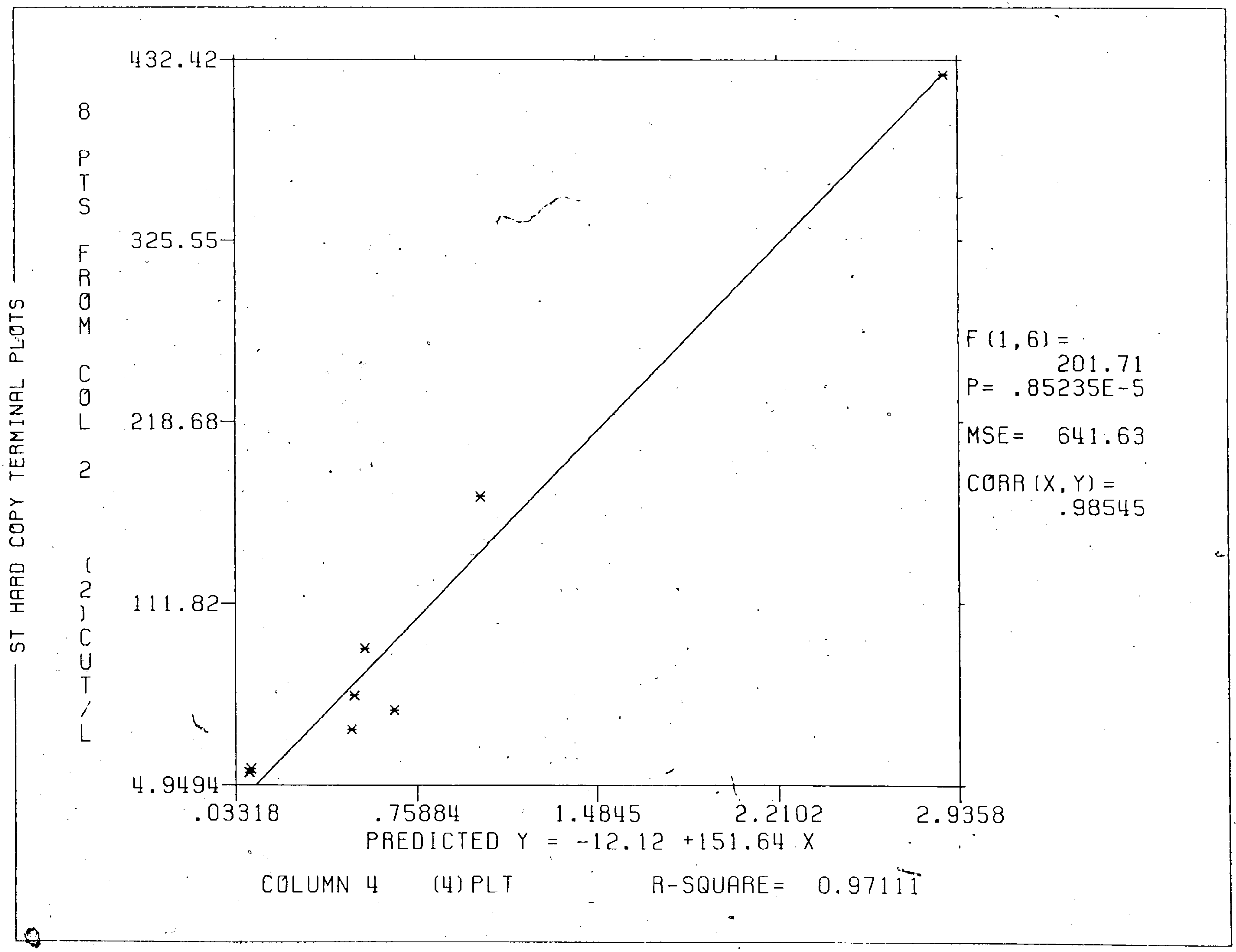
ST HARD COPY TERMINAL PLOTS

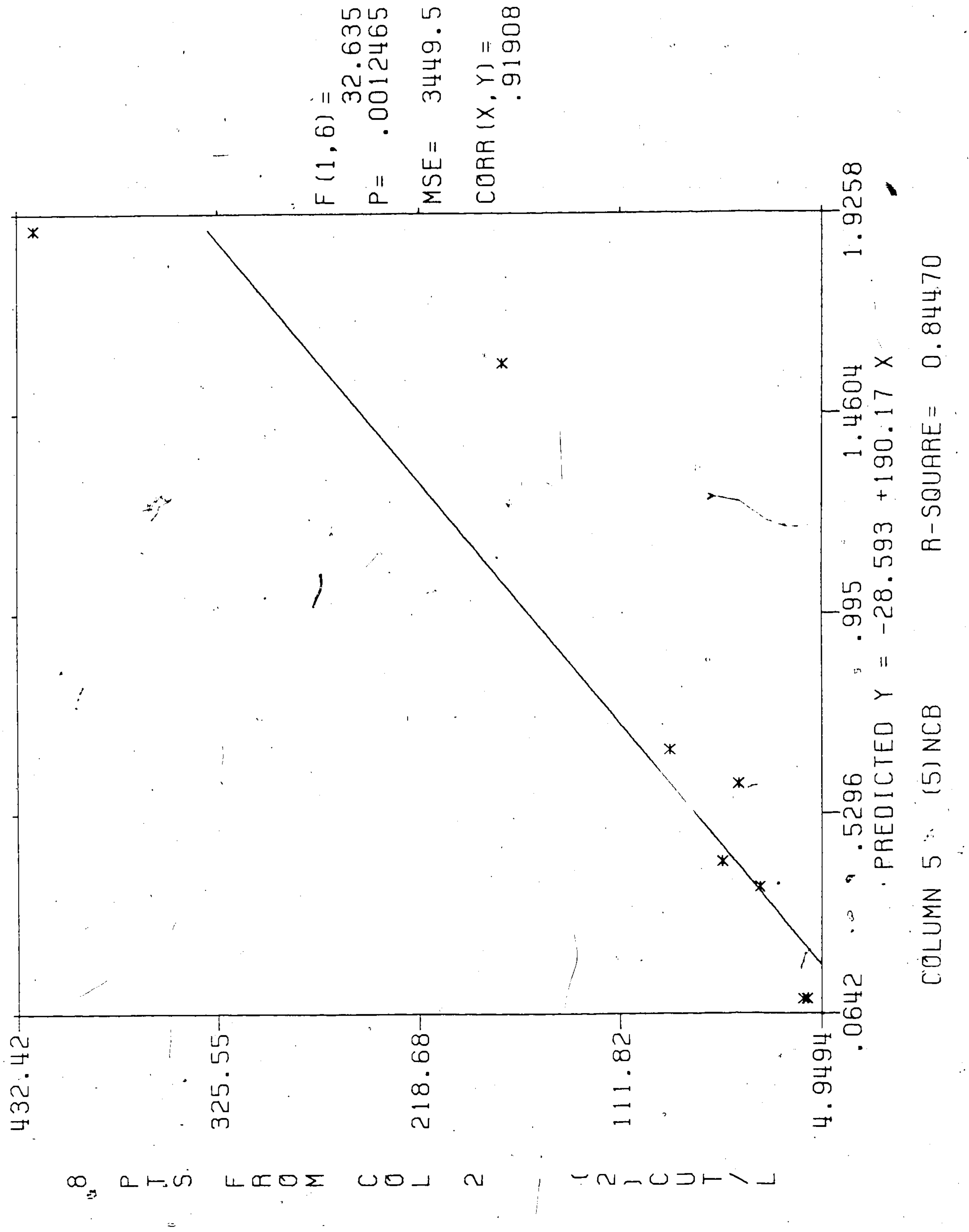




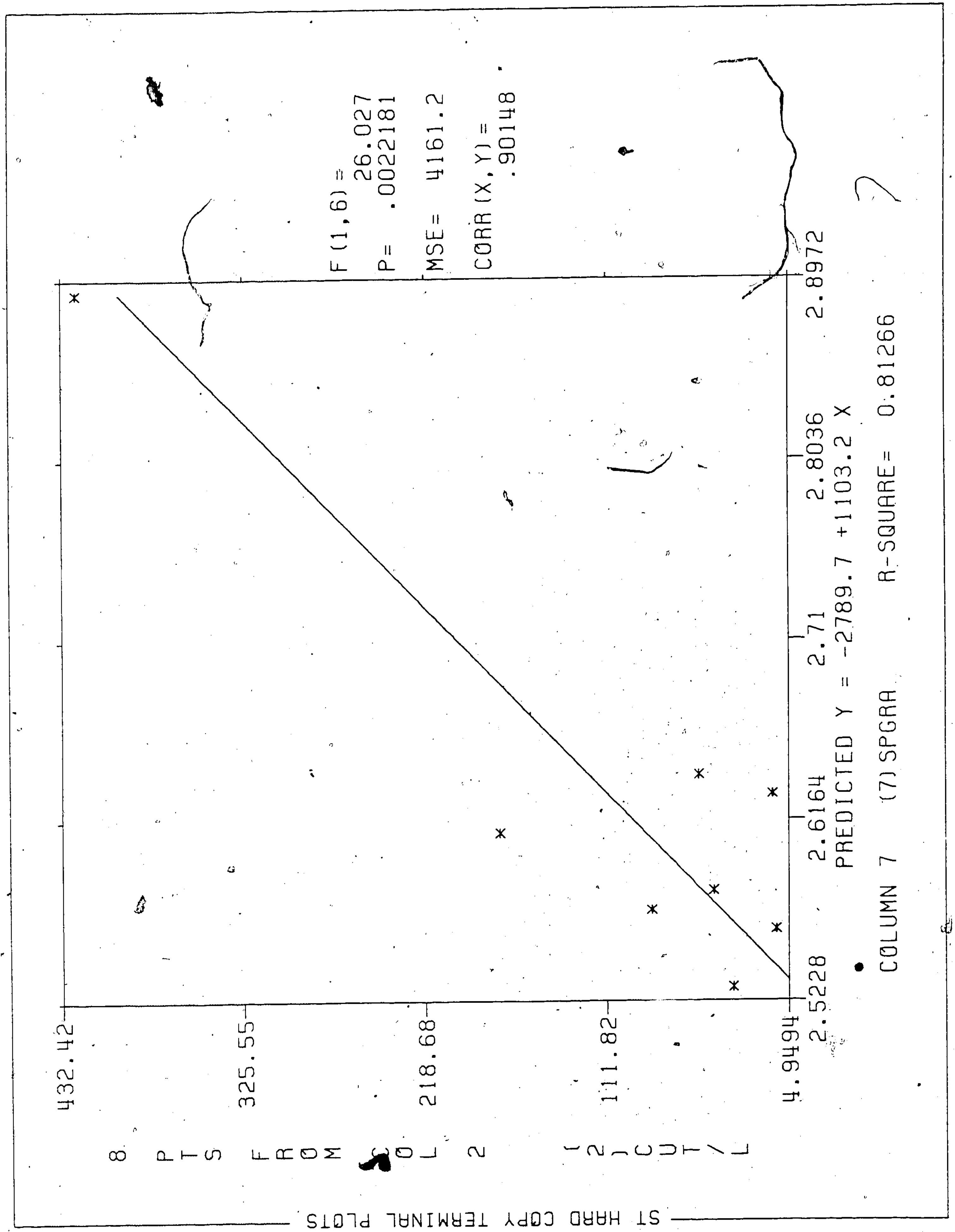
ST HARD COPY TERMINAL PLOTS

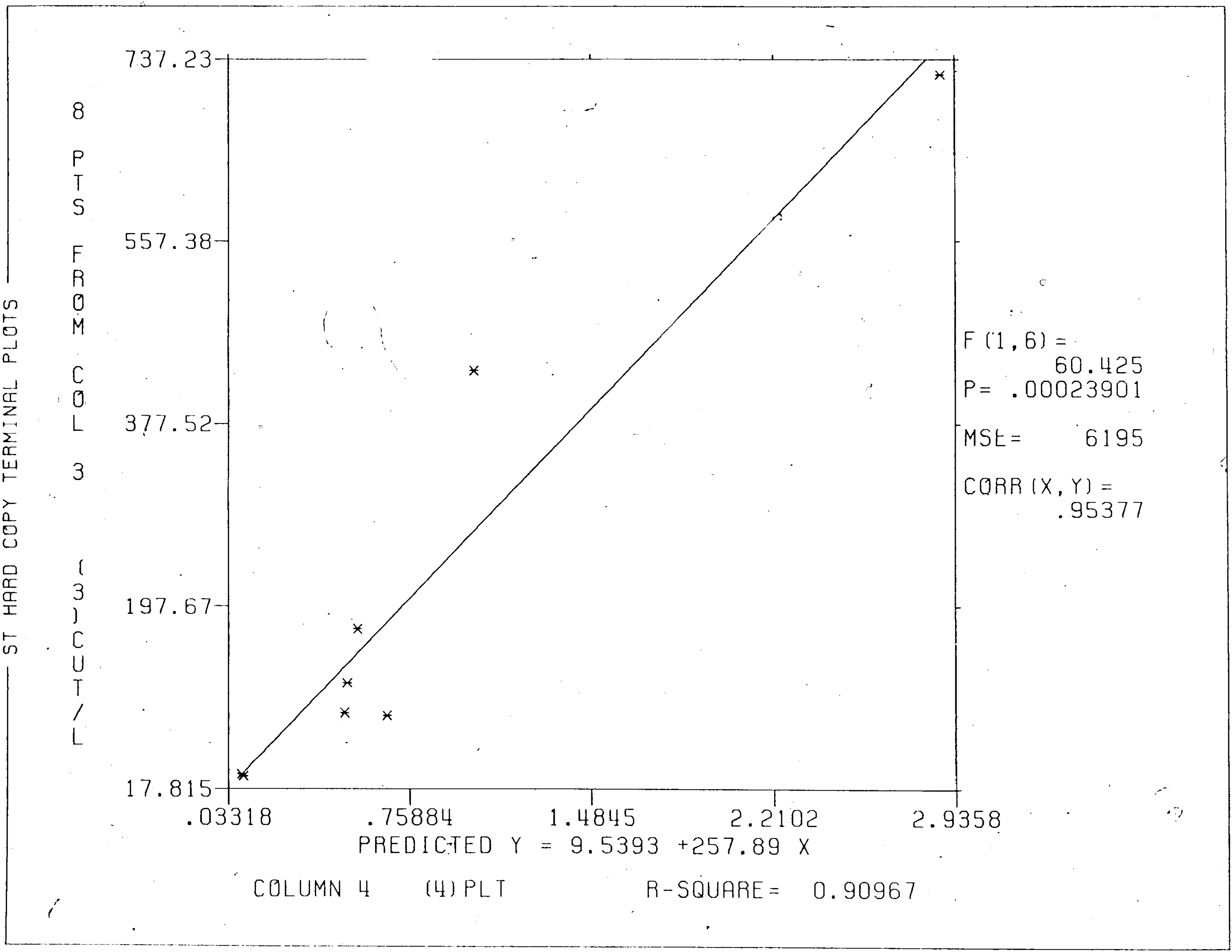

ST HARD COPY TERMINAL PLOTS
8 PTS FRØM CØL 1 CUT/A
2674.5
2017.8
1361
704.24
47.48
2.5228
2.6164
2.71
2.8036
2.8972
F (1,6) = 16.041
P= .0070782
MSE=.21083E6
CØRR (X,Y) = .8531
PREDICTED Y = -15373 +6164.7 X
COLUMN 7 (7) SPGRA
R-SQUARE= 0.72778

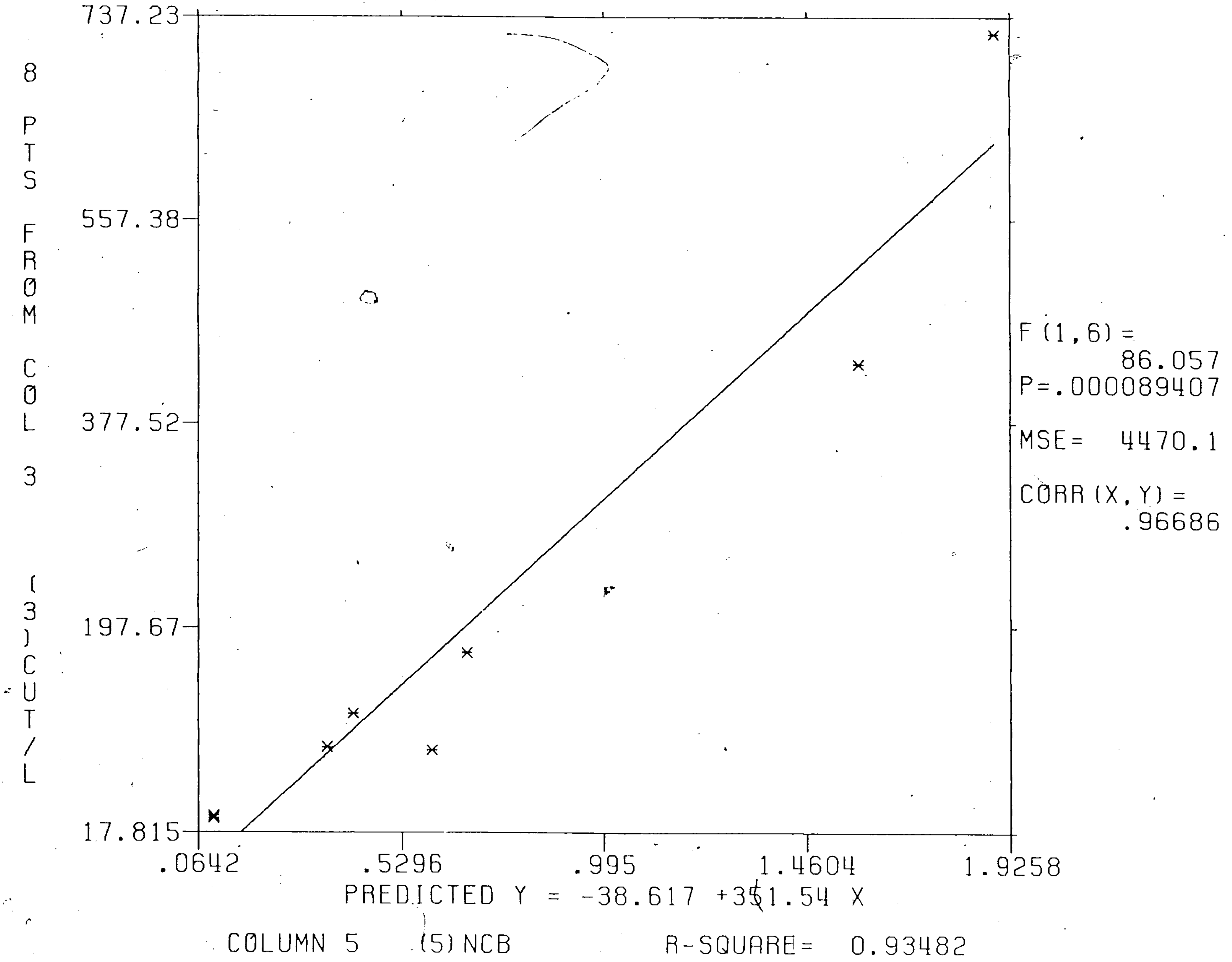

ST HARD COPY TERMINAL PLOTS
8 PTS FROM COL 2 (2)CUT/L
432.42
325.55
218.68
111.82
4.9494
.03318
.75884
1.4845
2.2102
2.9358
PREDICTED Y = -12.12 +151.64 X
COLUMN 4 (4)PLT
R-SQUARE= 0.97111
F(1,6)= 201.71
P= .85235E-5
MSE= 641.63
CORR(X,Y)= .98545

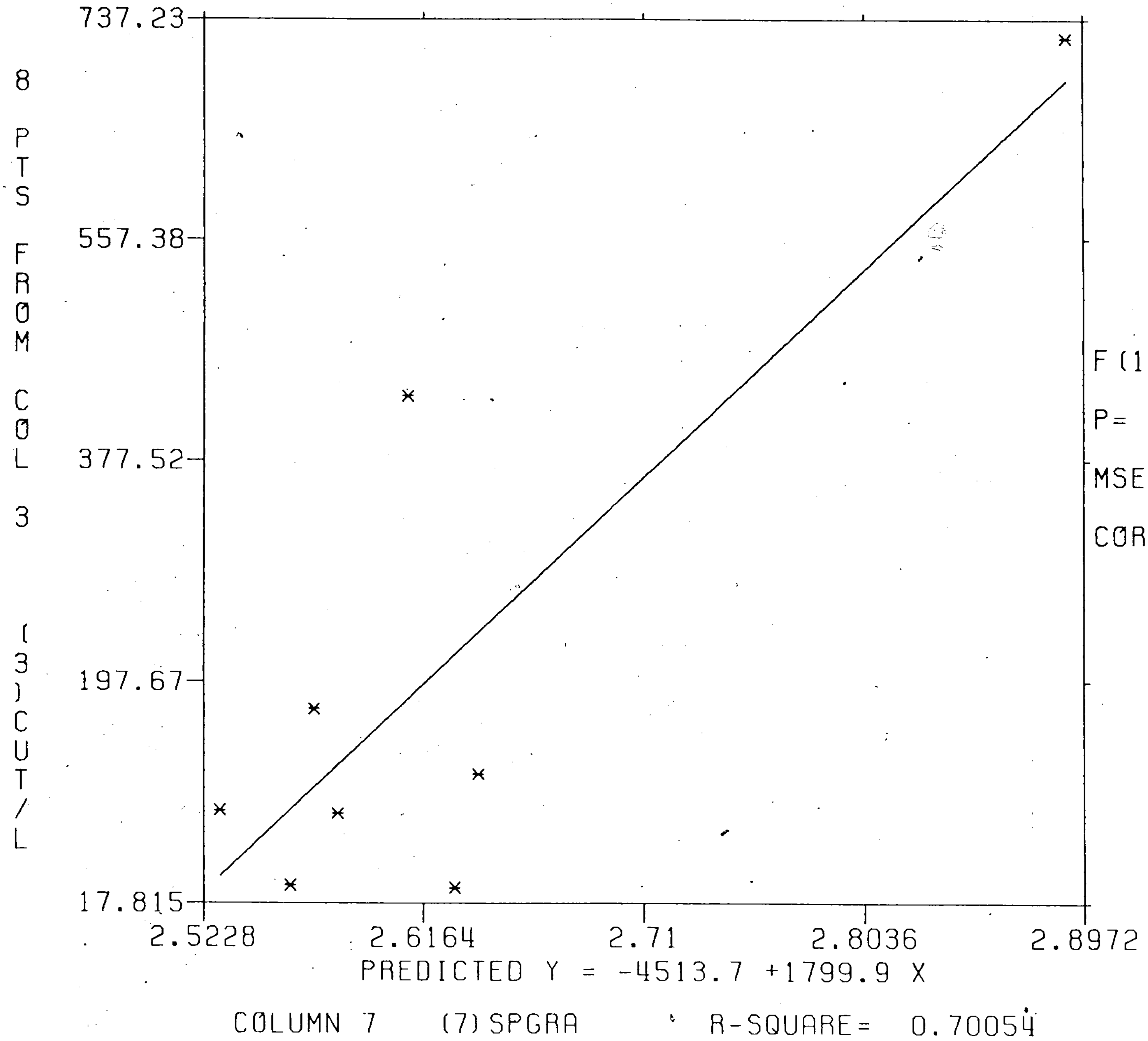


ST HARD COPY TERMINAL PLOTS

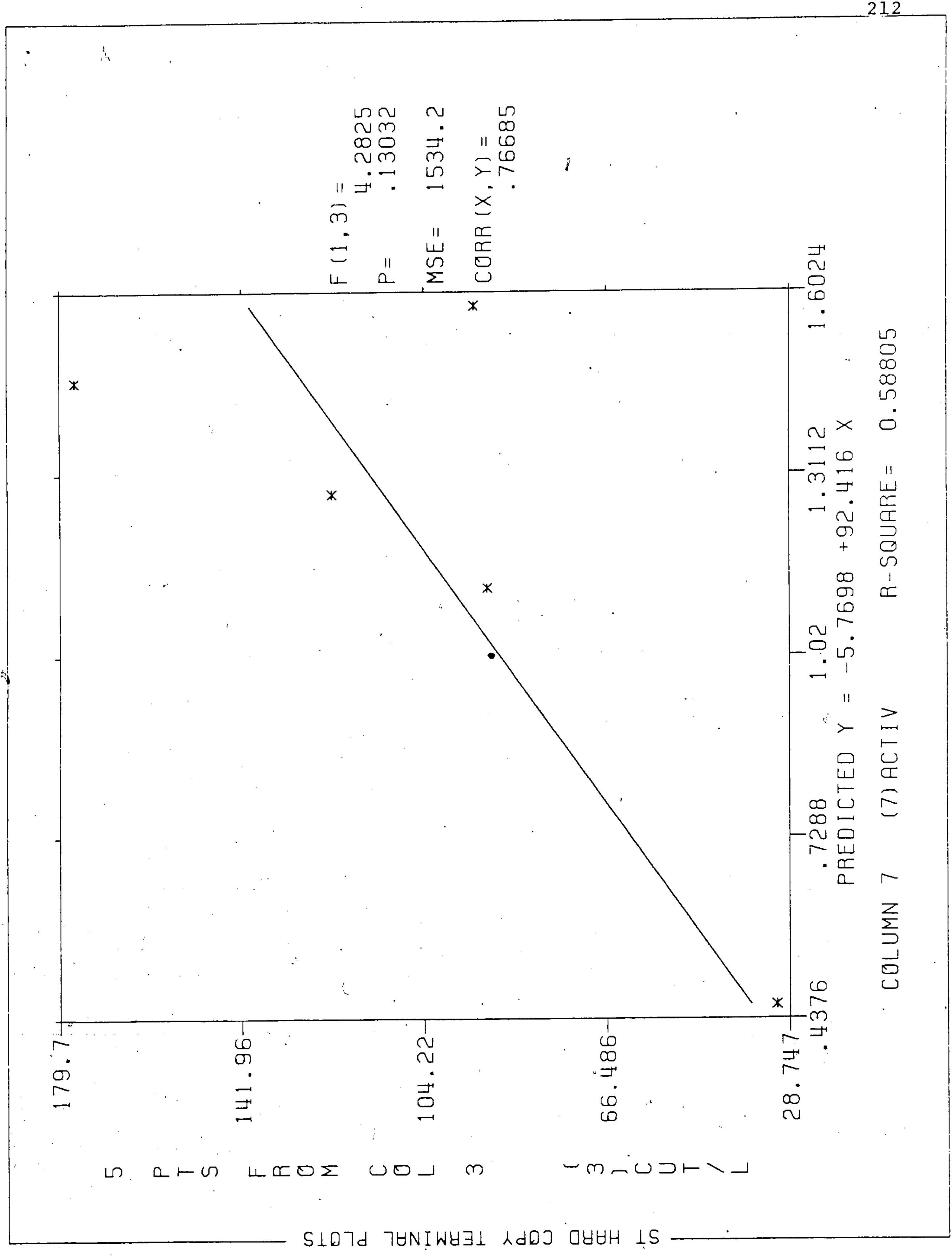

8 PTS FROM COL 2 (2)CUT/L
432.42
325.55
218.68
111.82
4.9494
2.5228
2.6164
2.71
2.8036
2.8972
F(1,6)= 26.027
P= .0022181
MSE= 4161.2
CORR(X,Y)= .90148
PREDICTED Y = -2789.7 +1103.2 X
COLUMN 7 (7)SPGRA R-SQUARE= 0.81266
ST HARD COPY TERMINAL PLOTS

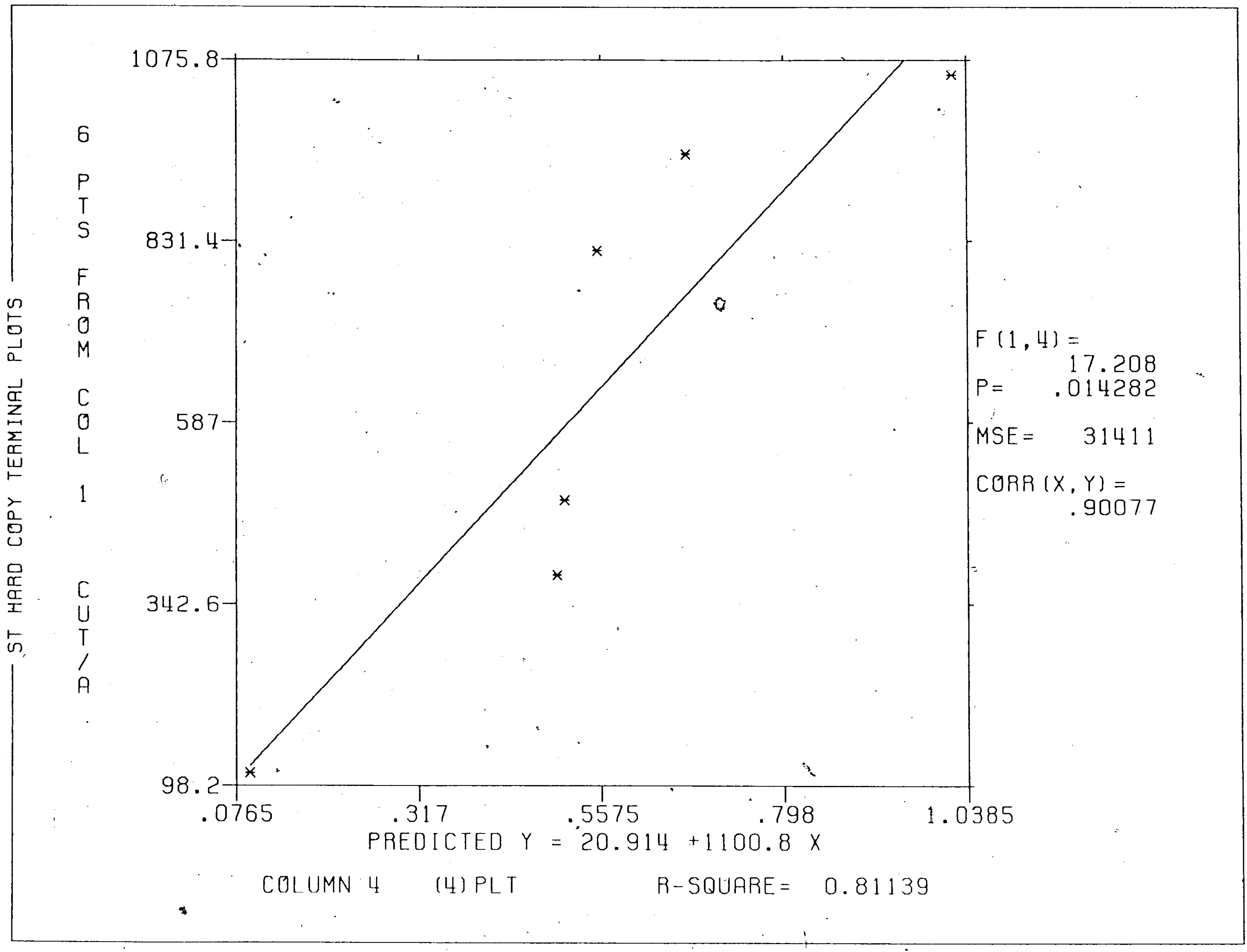

ST HARD COPY TERMINAL PLOTS
8 PTS FROM COL 3
(3)CUT/L
737.23
557.38
377.52
197.67
17.815
.03318
.75884
1.4845
2.2102
2.9358
PREDICTED Y = 9.5393 +257.89 X
COLUMN 4 (4)PLT
R-SQUARE= 0.90967
F(1,6) = 60.425
P= .00023901
MSE= 6195
CORR(X,Y) = .95377

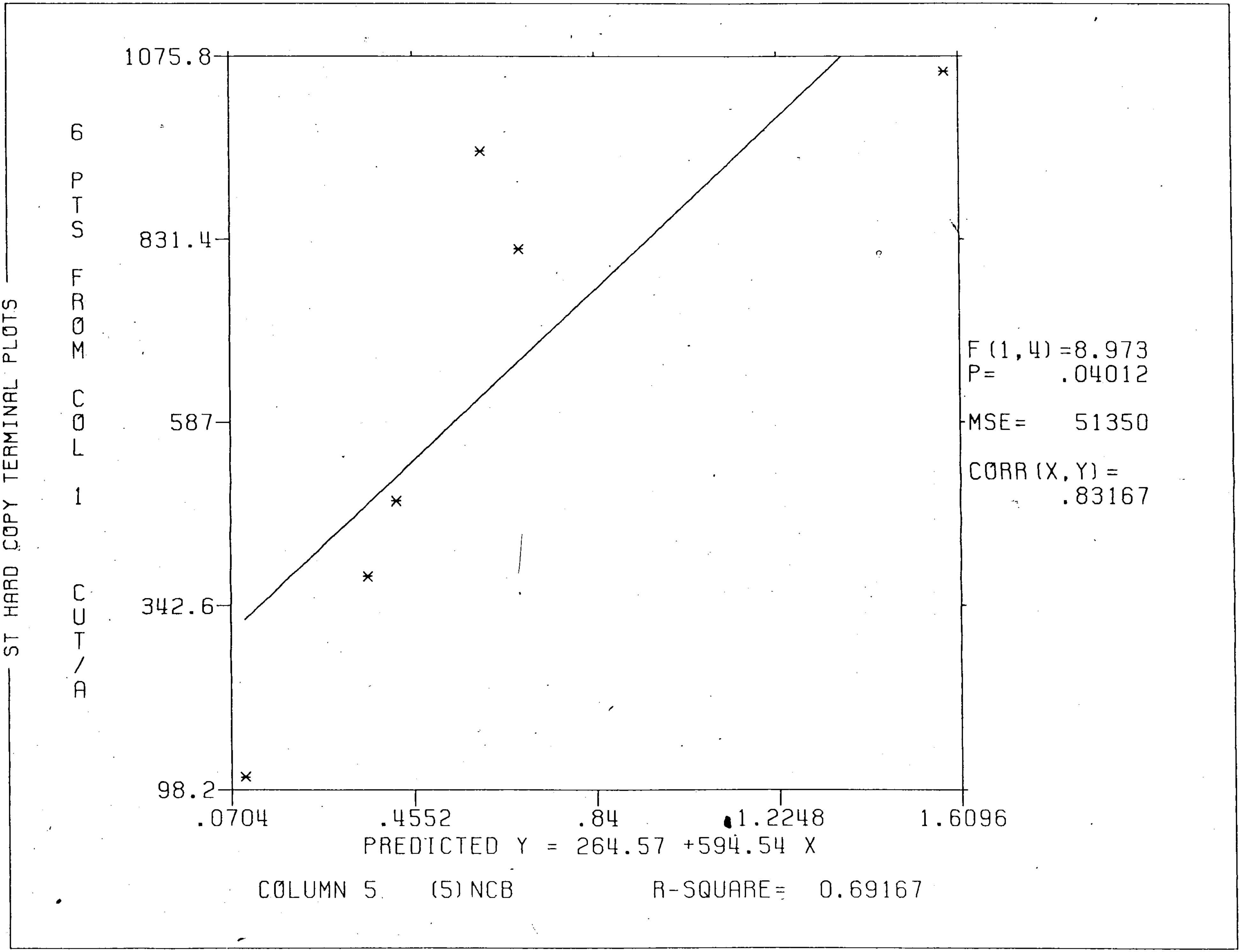

8 PTS FROM COL 3 (3)CUT/L
737.23
557.38
377.52
197.67
17.815
.0642
.5296
.995
1.4604
1.9258
PREDICTED Y = -38.617 +351.54 X
COLUMN 5 (5)NCB
R-SQUARE= 0.93482
F(1,6) = 86.057
P=.000089407
MSE= 4470.1
CORR(X,Y) = .96686

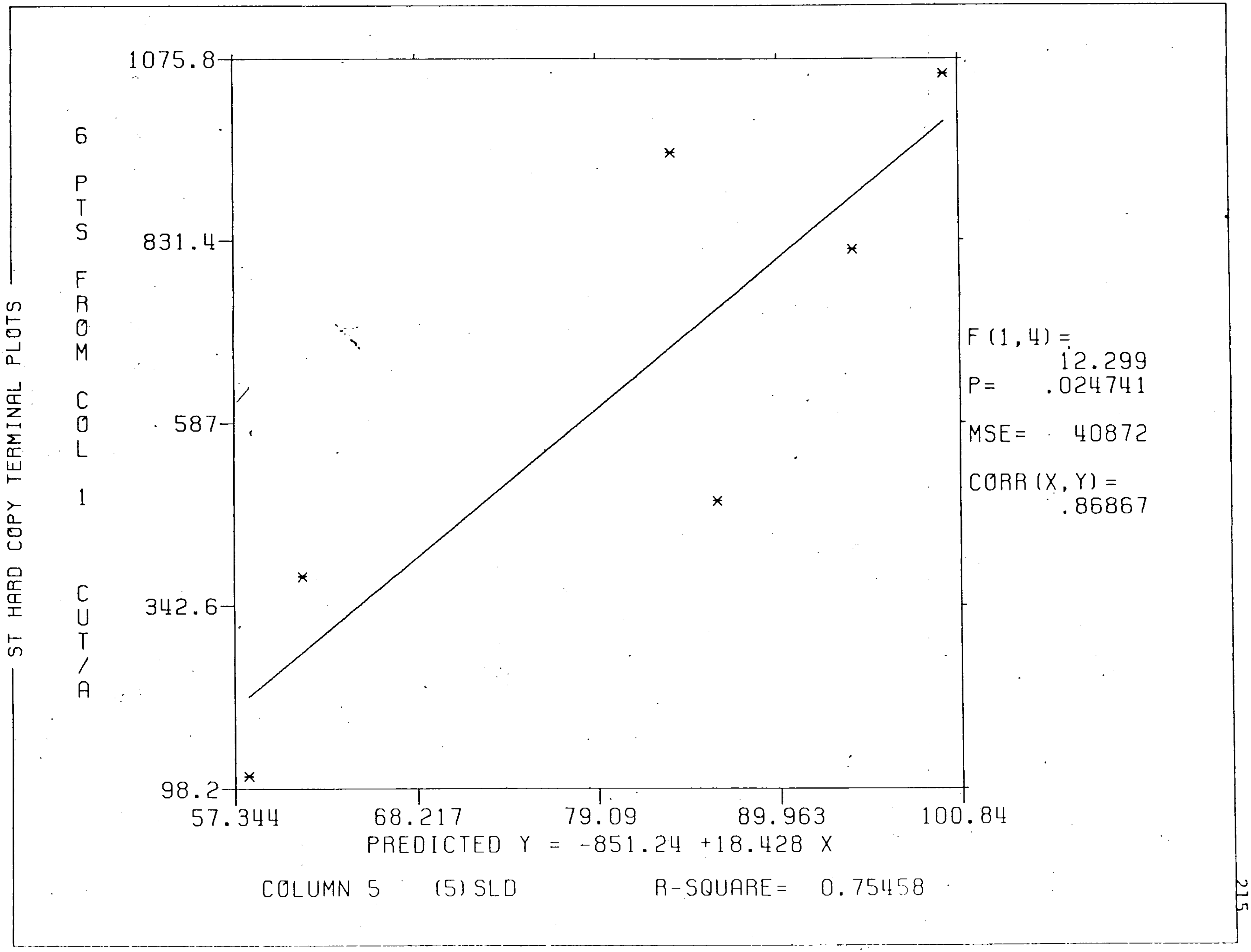


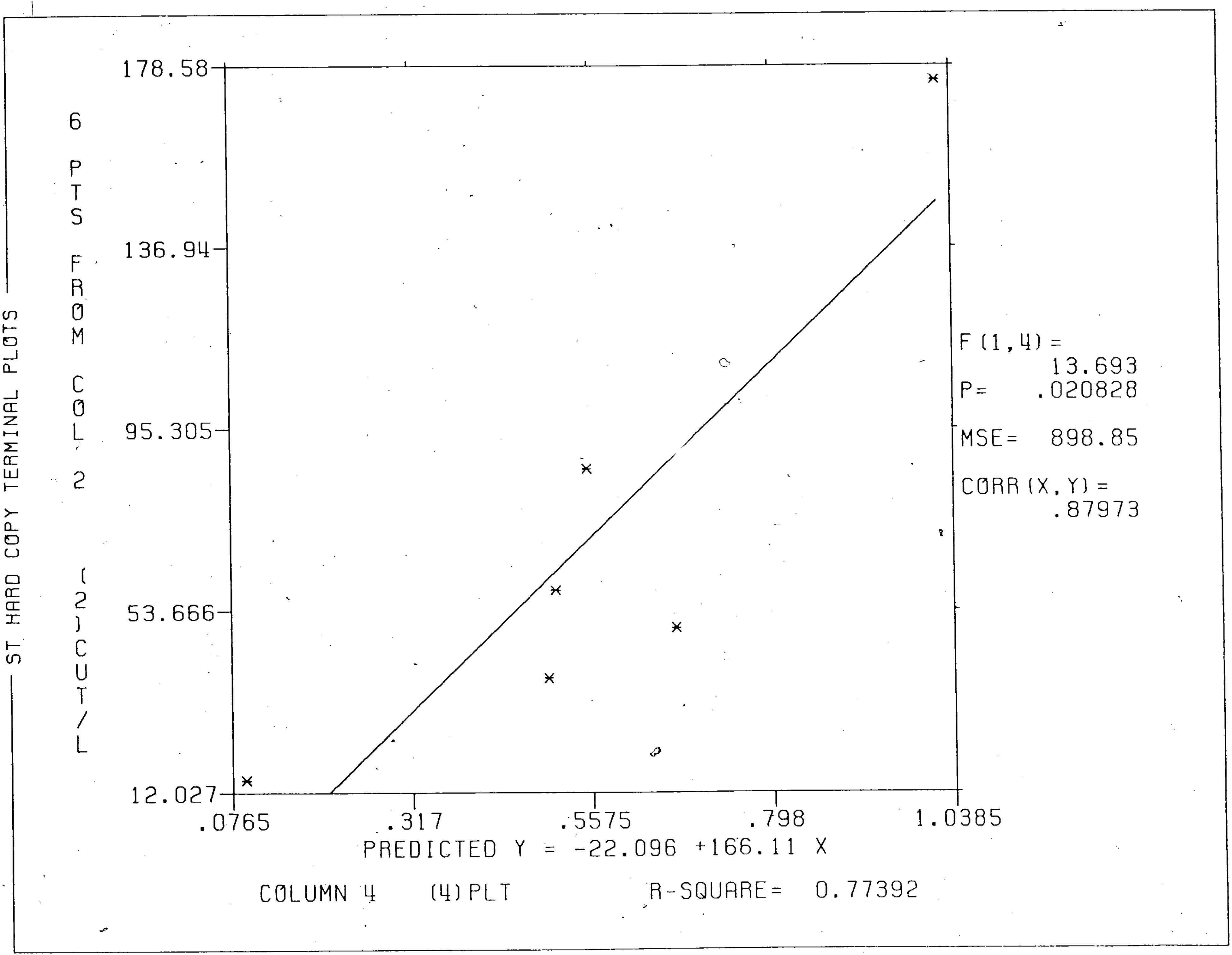
```
F(1,6) =
        14.036
P=   .0095499

MSE=    20538

CØRR(X,Y) =
        .83698
```


F(1,3)= 4.2825
P= .13032
MSE= 1534.2
CØRR(X,Y)= .76685
179.7
141.96
104.22
66.486
28.747
.4376
.7288
1.02
1.3112
1.6024
PREDICTED Y = -5.7698 +92.416 X
COLUMN 7 (7)ACTIV R-SQUARE= 0.58805
5 PTS FROM COL 3 (3)CUT/L
ST HARD CØPY TERMINAL PLØTS

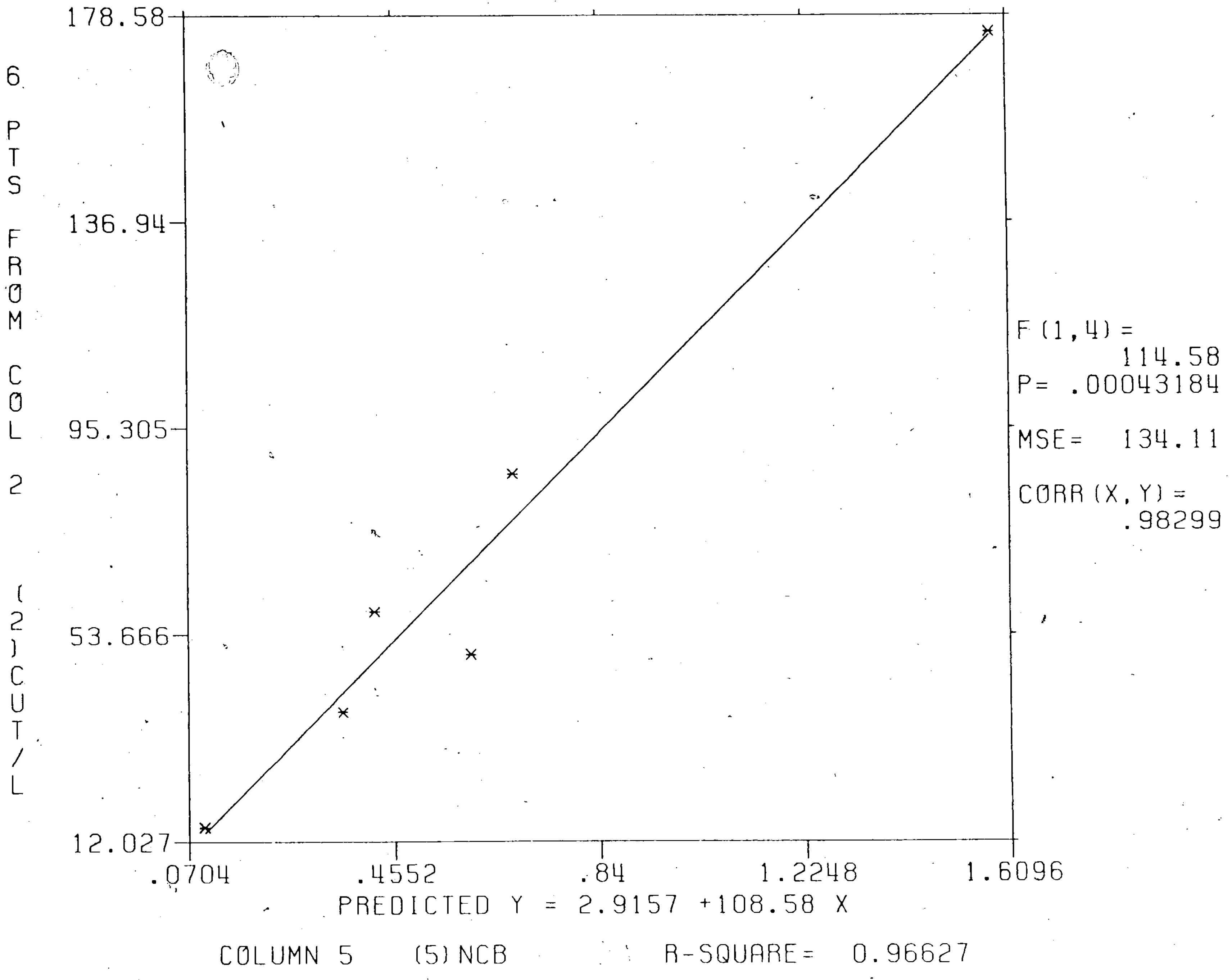

ST HARD COPY TERMINAL PLOTS
6 PTS FROM COL 1 CUT/A
1075.8
831.4
587
342.6
98.2
.0765
.317
.5575
.798
1.0385
PREDICTED Y = 20.914 +1100.8 X
COLUMN 4 (4)PLT
R-SQUARE= 0.81139
F(1,4)= 17.208
P= .014282
MSE= 31411
CORR(X,Y)= .90077

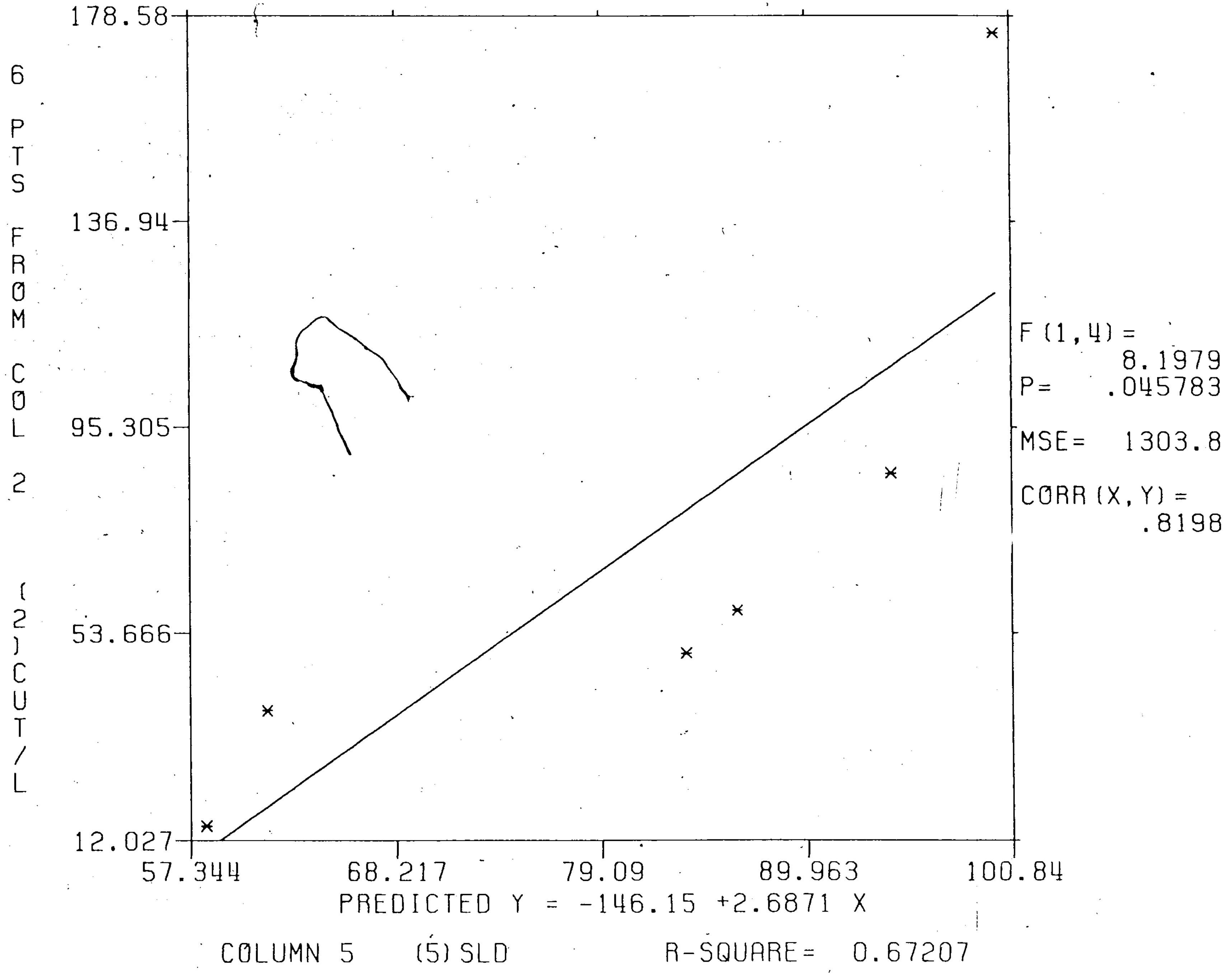

ST HARD COPY TERMINAL PLOTS
6 PTS FROM COL 1 CUT/A
1075.8
831.4
587
342.6
98.2
.0704
.4552
.84
1.2248
1.6096
F (1,4) =8.973
P= .04012
MSE= 51350
CORR (X,Y) = .83167
PREDICTED Y = 264.57 +594.54 X
COLUMN 5 (5) NCB
R-SQUARE= 0.69167


ST HARD COPY TERMINAL PLOTS
6 PTS FROM COL 1 CUT/A
1075.8
831.4
587
342.6
98.2
57.344
68.217
79.09
89.963
100.84
F(1,4) = 12.299
P= .024741
MSE= 40872
CORR(X,Y) = .86867
PREDICTED Y = -851.24 +18.428 X
COLUMN 5 (5)SLD
R-SQUARE= 0.75458


ST HARD COPY TERMINAL PLOTS
6 PTS FROM COL 2 (2)CUT/L
178.58
136.94
95.305
53.666
12.027
.0765
.317
.5575
.798
1.0385
F(1,4) = 13.693
P= .020828
MSE= 898.85
CØRR(X,Y) = .87973
PREDICTED Y = -22.096 +166.11 X
CØLUMN 4 (4)PLT
R-SQUARE= 0.77392

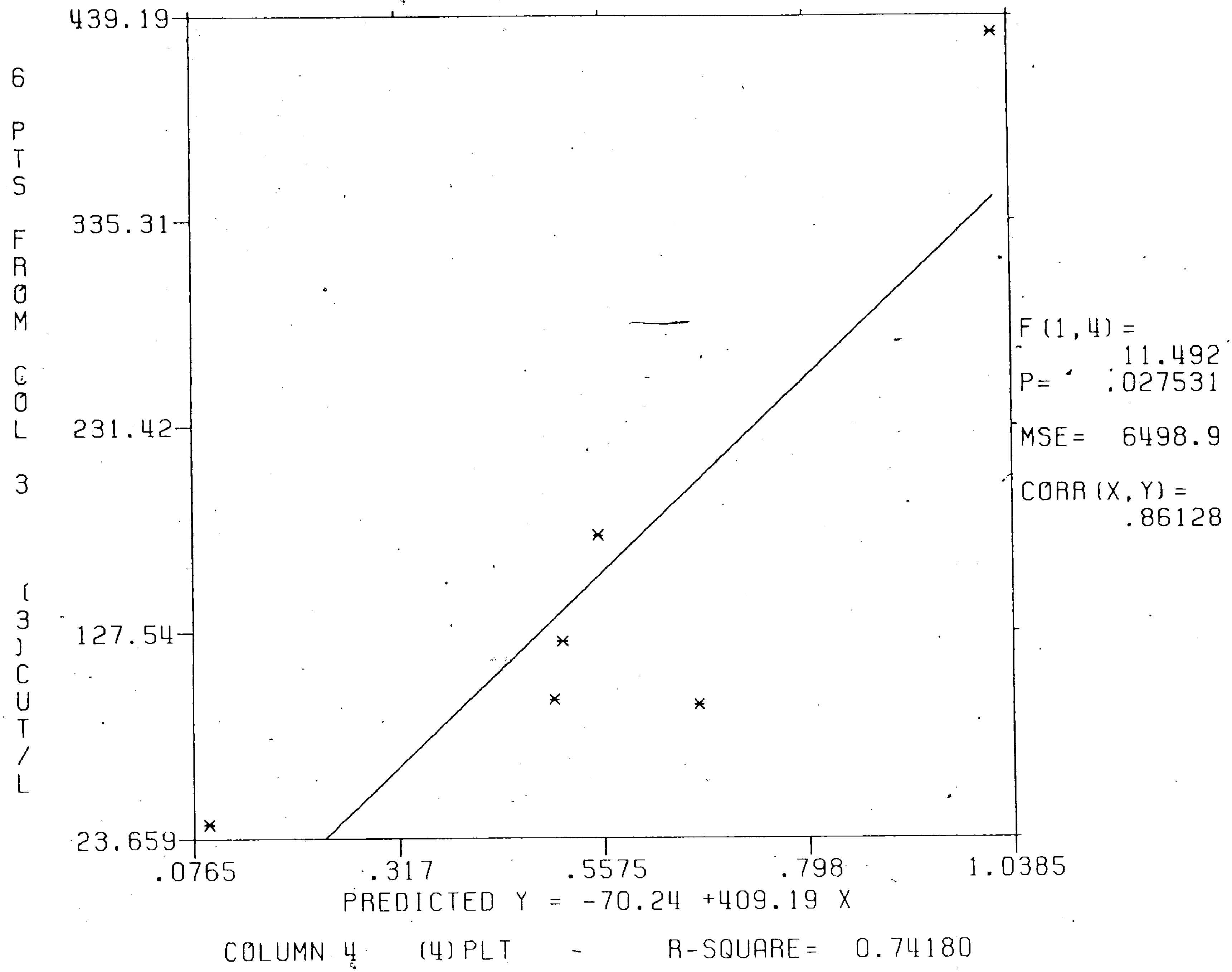
ST HARD COPY TERMINAL PLOTS





ST HARD COPY TERMINAL PLOTS

ST H D COPY TERMINAL PLOTS

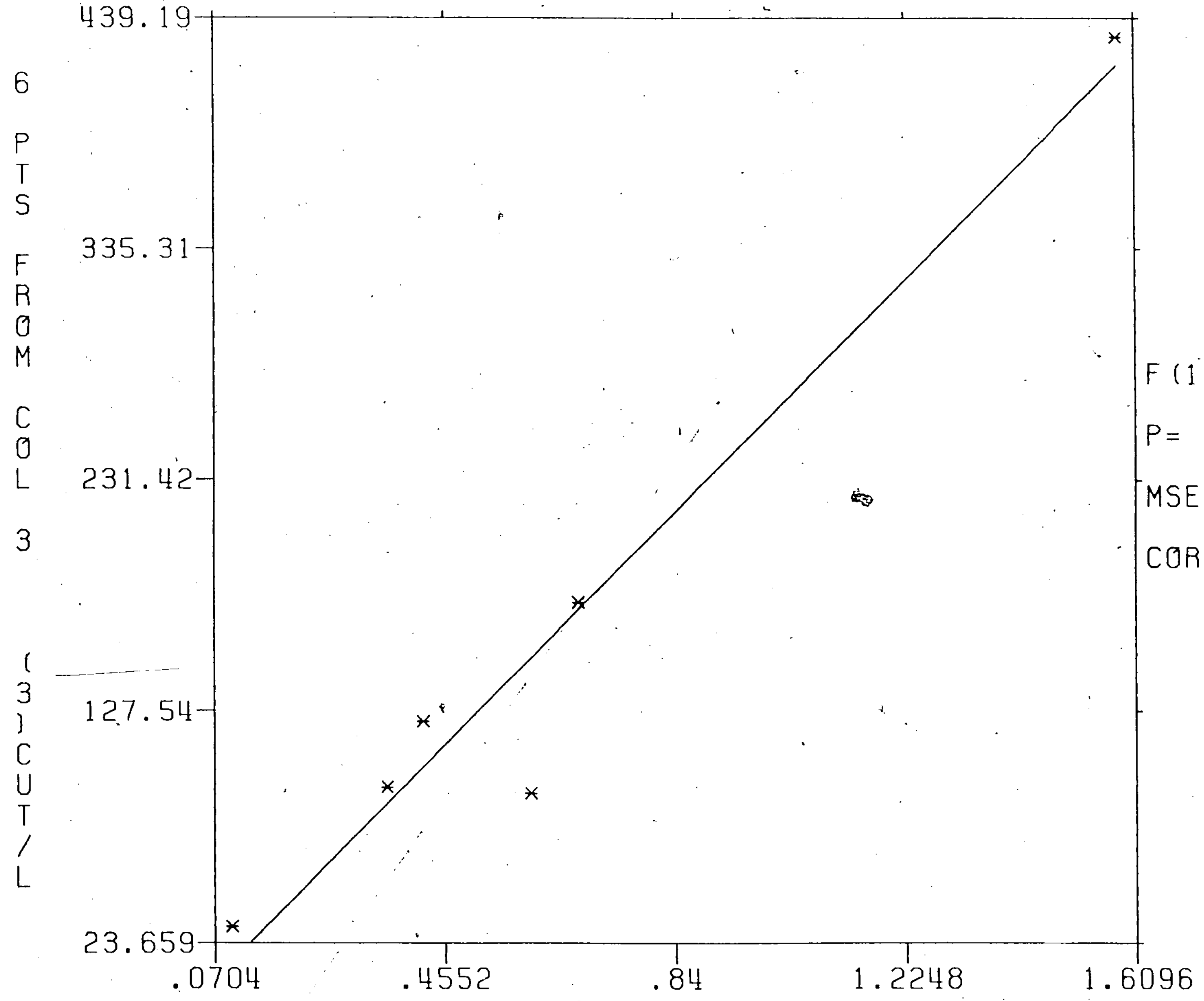


F(1,4) = 11.492
P= .027531
MSE= 6498.9
CORR(X,Y) = .86128

PREDICTED Y = -70.24 +409.19 X

COLUMN 4 (4)PLT - R-SQUARE= 0.74180

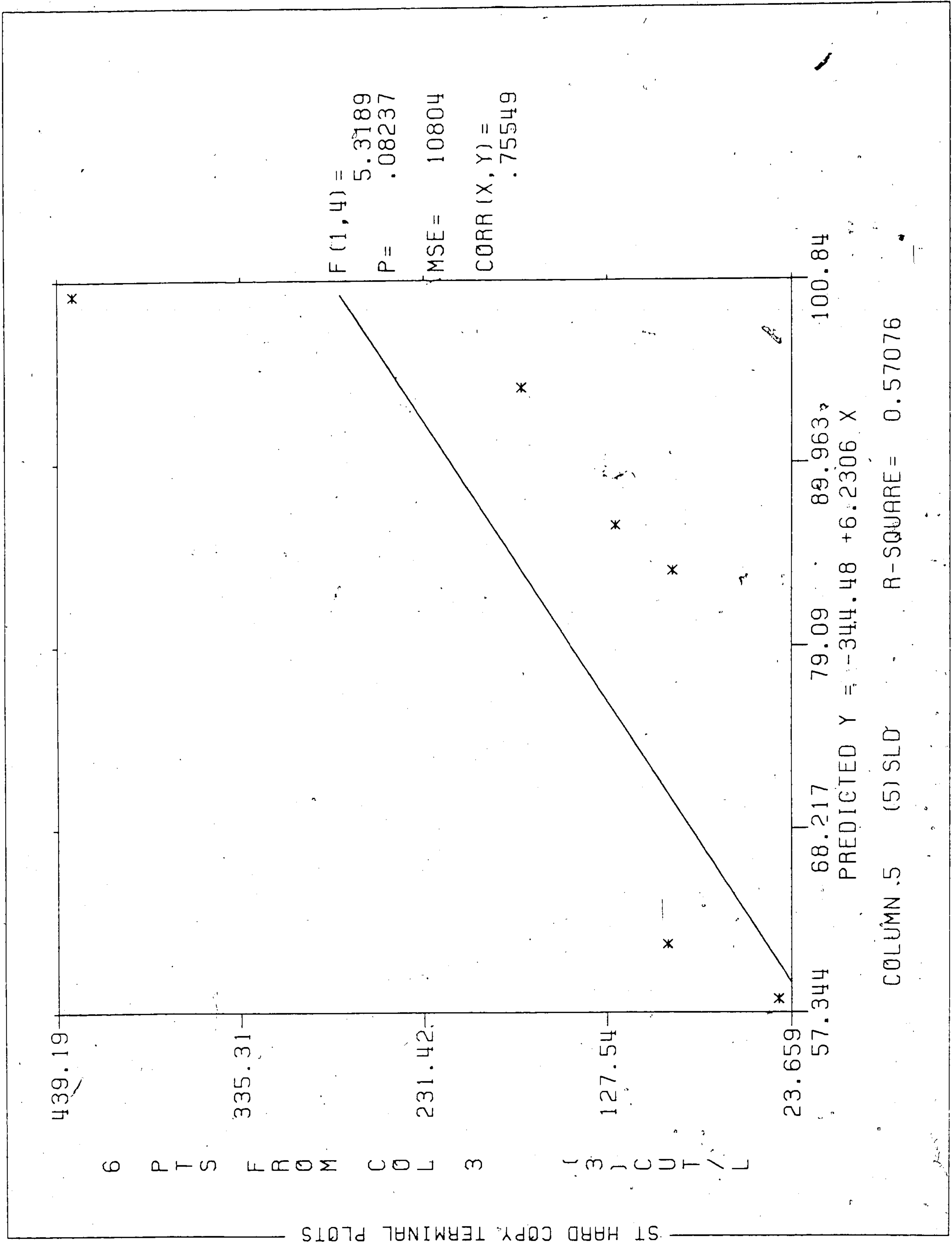
ST HARD COPY TERMINAL PLOTS

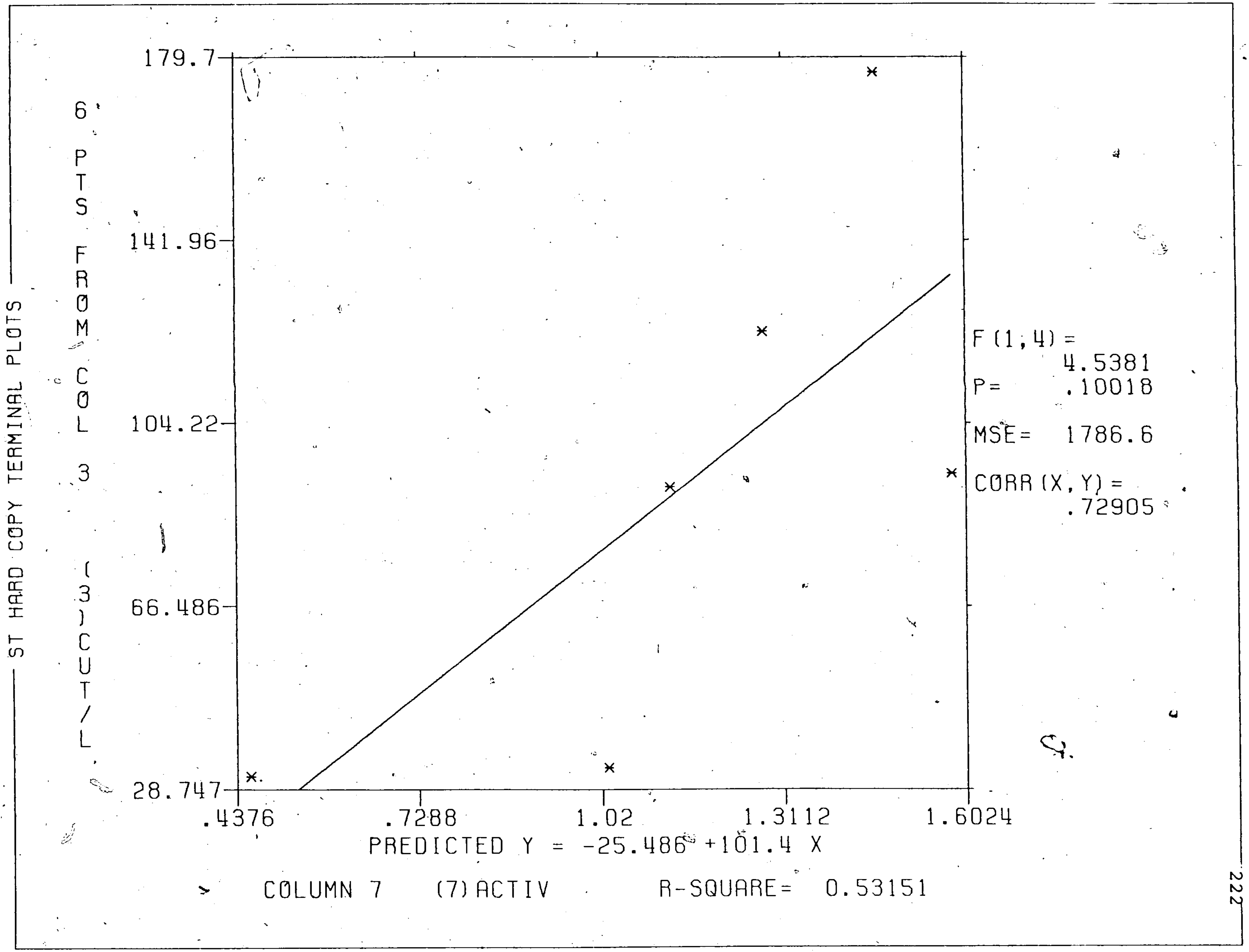


F(1,4) = 84.139
P= .00078487
MSE= 1142.3
CORR(X,Y) = .97705

PREDICTED Y = -11.169 +271.54 X

COLUMN 5 (5)NCB R-SQUARE= 0.95462


6 PTS FROM COL 3
(3)CUT/L
439.19
335.31
231.42
127.54
23.659
57.344
68.217
79.09
89.963
100.84
F(1,4)= 5.3189
P= .08237
MSE= 10804
CORR(X,Y)= .75549
PREDICTED Y = -344.48 +6.2306 X
COLUMN 5 (5)SLD
R-SQUARE= 0.57076
ST HARD COPY TERMINAL PLOTS


ST HARD COPY TERMINAL PLOTS
6 PTS FROM COL 3 (3)CUT/L
179.7
141.96
104.22
66.486
28.747
.4376
.7288
1.02
1.3112
1.6024
PREDICTED Y = -25.486 +101.4 X
COLUMN 7 (7)ACTIV
R-SQUARE= 0.53151
F(1,4) = 4.5381
P= .10018
MSE= 1786.6
CORR(X,Y) = .72905

# APPENDIX E

# GENERAL STRATIGRAPHY OF THE OIL SANDS REGION AND PLAN OF HIGHVALE MINE

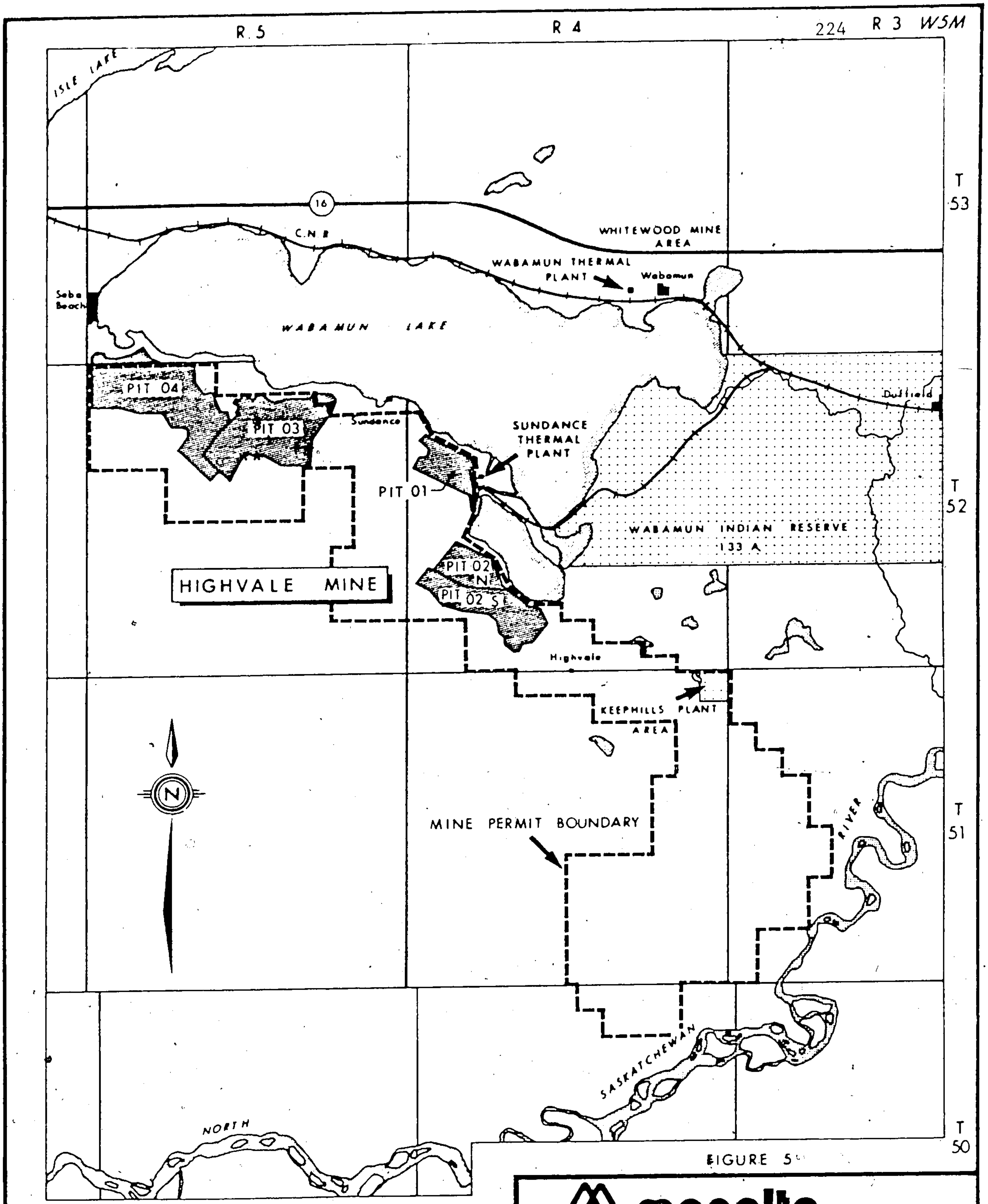


FIGURE 5

adapted by R.M.Krzanowski

* SAMPLE A,B,C,D

** SAMPLE F

++ SAMPLE G

0 1 2 3 4 5

KILOMETRES

**manalta coal ltd.**

HIGHVALE

MINES AND POWER PLANTS

| | | | |
|---|---|---|---|
| Dwn. by: | P.J.S. | Date: | AUGUST, 1982 |
| Chk'd. by: | J.G.H.J | File no.: | 3984 |

| | | |
|---|---|---|
| PLEISTOCENE and RECENT | Glacial till; silts, sands and gravels. | (sample K) |
| unconformity | | |
| CRETACEOUS | | |
| La Bich Formation | Shale | |
| Pelican Formation | Sandstone | |
| Joli Fou Formation | Shale | |
| Grand Rapids Formation | Lithic sand and sandstone | |
| Clearwater Formation (with basal Wabiskaw Member) | Shale, siltstone (glauconitic sandstone) | (sample L) |
| McMurray Formation | Quartz sand with bitumen; silty and clayey lenses | |
| unconformity | | |
| UPPER DEVONIAN | | |
| Woodbend Group (with basal Cooking Lake Formation) | Reef limestone; shale, and argillaceous limestone | |
| Waterways Formation | Argillaceous lst, lst and shale | |
| Slave Point Formation | Limestone and dolomite | |
| MIDDLE DEVONIAN | | |
| Prairie Evaporite Fm. | Anhydrite, halite, gypsum and dolomite | |
| Methy Formation | Reefal dolomite | |
| Maclean River Formation | Dolomite, claystone and evaporites | |
| La Loche Formation | Basal "Granite Wash" sandstone | |
| erosional unconformity | | |
| PRECAMBRIAN | Metasedimentary rocks and granite | |

General Sratigraphy of The Oil Sands Region