A STUDY OF THE MINERALOGY OF ROOF AND FLOOR

STRATA ASSOCIATED WITH COAL MINES

by

Frank Tasman Fisher.

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INTRODUCTION

Of all the factors which affect the weathering of mine strata, none is subject to more speculation than that of the mineral content of the strata and to its effect upon the condition of the strata after long periods of standing.

Price and Headlee (1942) published a list of minerals which could be expected to occur in mine roof samples and this was modified and expressed quantitatively by Meyertons (1956). Such studies have, however, been confined to a limited number of roof shales and are in need of futher study, investigation and expansion. Similar studies, on a smaller scale, have been have been made for floor strata and here the knowledge of the mineral content is very slight, the need for a comprehensive study being no less apparent. White (1949) investigated the plastic properties of clay minerals, expanding his findings and relating them to the behaviour of mine floors in 1954.

The weathering action of roof and floor material is becoming increasingly important as mine mechanization progresses, which while increasing output and efficiency and reducing the physical labour involved, also increases the need for precision in mining techniques. Heavy machinery is constantly moving to and fro across fireclay floors, sometimes in the presence of large quantities of water. Some of these floors stand up to this treatment fairly well, while others rapidly degenerate into a quagmire. Investigation into the mineralogy of these floors may

well aid in formulating some methods of combating such conditions, which may even become so severe as to close down sections of the mine.

Likewise the study of roof behaviour, the very essence of mining practice, is increasing in detail so as to facilitate the use of mechanized support systems and to obtain less empirical support rules. Much of present day mining practice is still based on experience and rule of thumb methods and it is quite obvious that these must be superceded by a real knowledge of the factors involved if the Coal Mining Industry is to be competitive with other sources of energy.

With this in mined the composition of some 56 samples taken from the roof and floor of 28 mines varied both in location and throughout the Pennsylvanian sequence, has been investigated. Each mine investigated, supplied in addition to the rock samples, a detailed report of the actual physical conditions prevailing at the sampling stations and details of the behaviour of this strata material after weathering. These reports are compared with the results of the strata analysis and evaluated to see if any significant correlation can be found.

The analysis will supplement the present knowledge about the strata associated with coal mines and the comparison of these analyses and the mine reports may well lead to a better understanding of the way in which mine strata weathers.

REVIEW OF LITERATURE

Clay Minerals and their properties relating to Coal Mining.

Clay minerals are an important constituent in the materials
which form the roof and floor of coal mines in coals of the
Pennsylvanian age. Underclays commonly form the mine floor,
and the mine roof is usually composed of shale and other
argillaceous sediments. The properties of these clay minerals
may well determine whether a mine will be a success or failure.

It is first necessary to define what a clay mineral is. In
general clays are aggregates of minute flake shaped crystals.
These may be classified on the basis of their structure and
composition into a few groups known as clay minerals. Some
clays contain only one clay mineral, while others may contain
quite a complex mixture of various clay minerals and other
material. (Grim and Cuthbert 1945)

The different clay mineral types are built up of two basic
units. Figure 1 shows the silica or tetrahedral layer together
with the alumina or octahedral layer. These layers may extend
indefinitely in two directions but have a definite fixed thick-
ness. These two layers are capable of being bonded together in
different ways to give the various clay mineral groups.

The mechanism by which these layers combine depends upon the
atomic structure of the constituent parts. This is a study in
itself and is beyond the scope of this review. Those interested

should consult a suitable textbook on this subject. (Grim 1953)

Kaolinite.

The basic unit of the kaolinite group is formed by the bonding of one silica layer and one alumina layer as shown in Figure 2. These units are stacked one on top of the other and tied together by hydrogen bonds. The thickness of each unit so formed, is found to be approximately 10 A. (Note 1 A. is one Angstrom unit which is 10^{-8} cm.)

Montmorillonite.

The basic unit of montmorillonite is shown in Figure 3. This consists of two silica sheets and one alumina sheet bonded to-gether as shown. The basic units which are found to be 14 A. thick are stacked as before but may be separated by layers of water which can increase the interlayer spacing up to 17.5 A. or even 20 A. The basic unit spacing of 14 A. is found to be the spacing with two layers of water and this is the usual form. The completely dehydrated form with a thickness of 10 A. is seldom found. Magnesium and iron may be substituted for aluminium in the alumina layer and aluminium for silicon in the silica layer. The charges resulting from these substitut-ions of lesser valence are counterbalanced by surface adsorbtion of cations such as calcium or sodium, known as exchangeable ions.

Illite.

The basic unit of illite, Figure 4, is similar to that of montmorillonite. In this case some of the silicon of the silica layer is always replaced by aluminium. The charges produced are neutralised by potassium ions. These ions are, however, too large to fit in the interstices of the silica sheet so they form a double wedge between the silica layers of two basic units and hold them together. In this way a crystal is built up of basic units stacked one above the other and tied together with potassium ions. This structure has an interlayer spacing of 10 A. Like montmorillonite, illite has substitutions of magnesium and iron for aluminium in the alumina layer.

Chlorite.

Chlorite also has a basic structure similar to that of montmorillonite. This structure, however, is formed with the basic units held together with Brucite layers (Mg_3OH_6). The bond is either hydrogen bonding as for kaolinite or by the action of electrostatic attraction. A cation of higher valence substitutes in the Brucite layer for magnesium and the consequent positive charge neutralised by a similar negative charge on the silica sheets due to the substitution of lower valence aluminium for silicon, holds the units together. In a number of chlorites aluminium in the alumina sheet is replaced by magnesium in the

SiO_2

Al_2O_3
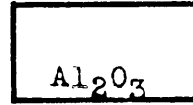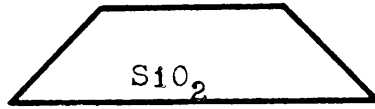
Figure 1.   The silica sheet   The alumina sheet
             Tetrahedral.   Octahedral.
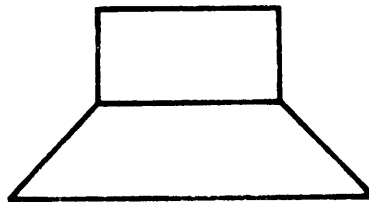
Figure 2.   Kaolinite Type Minerals.

(Water)
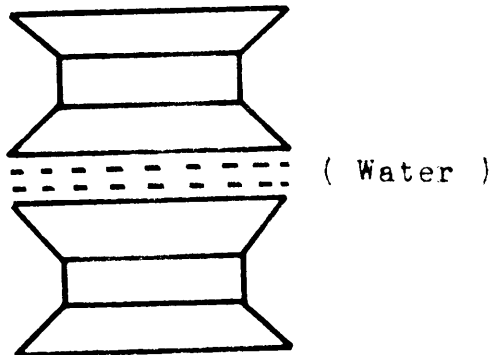
Figure 3.   Montmorillonite Type Minerals.

ratio 2 atoms of aluminium replaced by 3 atoms of magnesium or iron. This structure is found to have a basic unit spacing of 14 A. as Figure 5 shows.

Mixed layer minerals.

Montmorillonite, illite and chlorite may occur mixed in any one crystal. The mixing may or may not be present in a fixed sequence, and the ratio of the components is likewise arbitary. Regular mixed layer minerals are those with a constant repeating pattern of layers and can be distinguished by the large block which may be considered as the basic unit of the mineral. Random layer mixtures have no such regularity. Figure 6 shows both types of mineral.

The properties of clay minerals.

In this discussion we shall confine ourselves to those properties of clay minerals which contribute some understanding to the behaviour of clay materials in mines.

Ion exchange.

Ion exchange is the ability of clays to adsorb certain cations and some anions (Stout 1939) and to retain them in an exchangeable condition. The exchange usually takes place in aqueous solution although this is not essential (Grim 1953). Cations which are commonly adsorbed are Ca^{++}, Mg^{++}, H^+, Na^+, K^+, and NH_4^+. Anions are more restricted and are usually confined to the
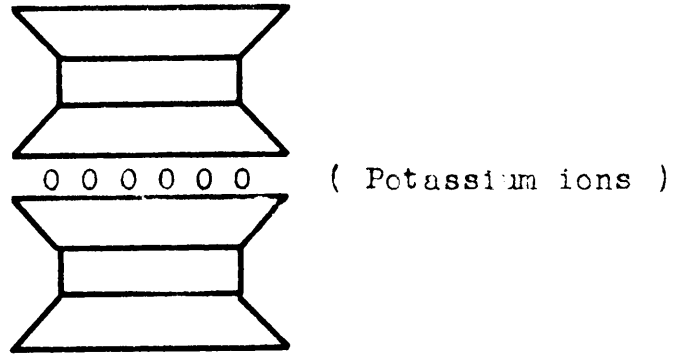
Figure 4.   Illite Type Minerals.

(Potassium ions)

(Brucite Mg_3OH_6)
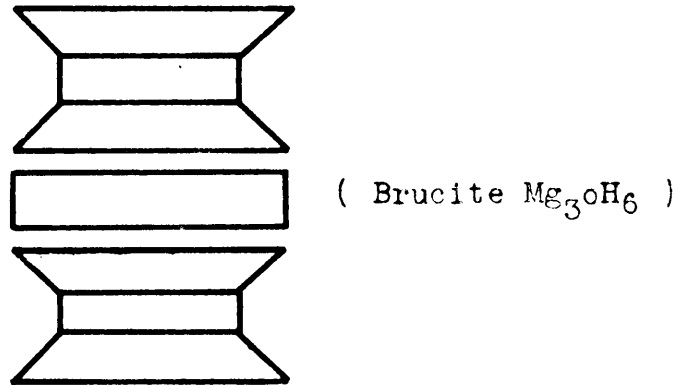
Figure 5.   Chlorite Type Minerals.

(a)   (b)
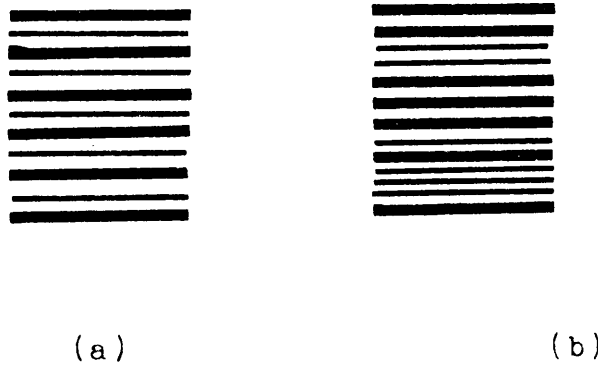
Figure 6.   Mixed Layer Minerals.

(a) Regular Mixed Layer.
(b) Random Mixed Layer.

phosphate and arsenate ions. The exchange capacity for both
cations and anions was shown to be the same by Dean and Rubin
(1940), who showed that the adsorption was due to the replacem-
ent of hydroxyl groups in the surface of the clay. Both anions
are tetrahedral in form like silica and can thus attach them-
selves to the edge of the silica sheet. Cations are adsorbed
either by broken bonds at the edge of the crystal (Kelly and
Jenny 1936) or inorder to neutralise any excess negative charges
due to the substitution of Al^{+++} for Si^{++++} in the silica sheets
(Brindley and Mac Ewan)(1953).

Ion exchange capacities differ greatly between the clay
minerals. Grim (1953) gives the following values in milliequi-
valents per 100 grams: kaolinite 3-15, illite 10-40, chlorite
10-40, montmorillonite 80-150, mixed layer minerals are usually
between illite and montmorillonite. In all these minerals both
of the above mechanisms are thought to contribute to the ion
exchange capacity (Grim 1953; Brindley and Mac Ewan 1953;
Hendricks et al. 1940). Organic cations may also be adsorbed
by clay minerals (Grim, Allaway and Cuthbert 1947), often in
excess of the exchange capacity, probably under the influence
of van de Waal's forces. After such adsorption of organic
ions, water adsorption is considerably reduced (Davidson 1949).

This exchange of ions influences many of the properties of
clay material; the type of ion adsorbed may influence the
amount of water adsorbed and unfavourable ions may well occur

unnoticed in rock dusts, delequescent salts or paints used in mining practice (Holland 1956).

Plastic properties.

The plastic properties of clay material has been shown to depend upon the following factors:-

1. The clay mineral present.

2. The size of the particles.

3. The shape of the particles.

4. The particular cation adsorbed on the minerals.

Grim's theory of plasticity (1953) is that the crystals adsorb water on their surfaces which takes on a solid or oriented (Hendricks and Jefferson 1938, Macey 1942) structure similar to that of ice. This water serves as a bond to hold the clay mineral units rigidly in place. As the layer increases in thickness the degree of orientation becomes less perfect and eventually becomes zero with subsequent water having truly fluid properties (Grim 1948). Thus in this concept, the plastic nature of clay becomes apparent when enough water has been adsorbed to fill all the requirements for "rigid" water. Subsequent water then acts as a lubricant between the flakes and plastic flow takes place.

Kaolinite is the most equidimensioned of all the clay minerals and shows little plasticity. Having large grains the surface area is relatively small and Whittaker (1939) showed that kaolinite was not plastic until the surface area exceeded 1.8×10^{4}

sq. cms. per gram of clay. Compared with kaolinite montmorillonite has a large surface area. Its crystals are very flate plate shaped. These make for easy orientation and slide easily when lubricated. The thinness of the crystals has a less wedging effect than does the thicker kaolinite crystal. Hendricks et al. (1940) have estimated that the surface area of montmorillonite reaches 8×10^6 sq. cms. per gram.

It has been found that when sodium is the exchangeable ion, montmorillonite has a rigid water layer of three molecules thickness (Grim and Cuthbert 1945). Calcium produces a layer four molecules thick. Thus it is seen that sodium (or lithium) ions give a greater plastic effect than calcium (or magnesium) ions. Chlorite and illite are intermediate between kaolinite and montmorillonite and exhibit intermediate plastic properties. Here the type of sation plays a lesser part than does the particle size which controls the plastic limits. White (1949) found halloysite and allophane to be non plastic but grim (1949) reports high plastic properties for halloysite in transition between the fully hydrated ($4H_2O$) and the partially hydrated ($2H_2O$) forms.

Grim (1950) points out that the transition from solid to plastic conditions may occur very suddenly when just enough water is added to fulfill the oriented requirements. Holland (1956) shows how this phenomenon will cause sudden deterioration in roof and floor strata in mines.

Water exchange.

Water is present in all mine strata whether as inherent non exchangeable moisture or as that water which is exchangeable with the atmosphere as the relative humidity changes. This latter water comes from two main sources (Holland 1956). Firstly there is the water which exists as free liquid in the pores of the shale or clay material and on the surface of clay particles. Secondly there is the water which exists between the layers of certain clay minerals and thus is more difficult to exchange. Such minerals are montmorillonite and halloysite and it is this water which increases the interunit spacing of the minerals and causes considerable volume change when exchanged, even only partially.

Expansion and shrinkage.

Expansion and shrinkage cause considerable damage to the strata and reduce its strength by quite a factor. Hydration of a clay varies in its swelling effect, depending upon; the clay minerals present, their exchangeable ions, the electrolyte content of the aqueous phase, particle size and distribution and internal structure and superimposed load.(Mielenz and King 1955)

Expansion takes place by two mechanisms:-

1. A relaxation of effective compressive stresses related to the enlargement of capilliary films.

2. Osmotic imbibition of water by expanding lattice clays.

Shrinkage is the reverse procedure. Montmorillonite and other mixed layer expanding structures exhibit the greatest expansion with the adsorbing of water, not only on account of adsorption into the expanding lattice but also because the capillary forces increase inversely as the radius of the capillary. Thus due to the smaller size of the montmorillonite crystals the compressive stresses are larger and their relaxation will produce the greater expansion.

The degree of expansion of the clay minerals is given by Mielenz and King (1955) as:- montmorillonite upto 2000/o, mixed layer minerals 150°/o, illite 100°/o, halloysite 70°/o and kaolinite 30°/o. The presence of certain cations was found to decrease the expansion of montmorillonite, whose expansion is derived mainly from the second mechanism. Kaolinite, chlorite and illite are less affected by the cation present and are thought to expand by means of the first mechanism.

Actual tests on shale material (Landsberg 1938, Hartman and Greenwald 1941) from coal mine roofs show that there is considerable expansion of these materials with an increase in water content and that repeated change in water content causes considerable slaking of the roof.

Slaking.

Slaking is the disintegration of a strata material due to constant changes in the water content. Mielenz and King (1955) give the following mechanism:-

1. With initial drying the material shrinks and due to the different sized capillaries, differential compressive stresses are set up which cause the material to crack.

2. These cracks break up the shale, admitting air to the capillaries and facilitating the reentry of water.

3. Rewetting causes air to be trapped within the capillaries, setting up tensile stresses which further break up the shale.

4. Expanding lattice materials on expansion also set up differential stresses which aid the slaking process.

Other forces may also be at play. The shale particles are held together with electrostatic forces as well as by the tension of binding water films. The entry of water tends to reduce these forces especially if the dielectric constant of the aqueous fluid is high. Slaking may be reduced by coating the material with an impervious layer of paint or asphalt (Holland 1954). Mielenz and King (1955) also recommend electro-chemical and electro-osmotic treatments, while the use of organic cations which set up hydrophobic qualities in the shale material is noted by Davidson (1949) and Glab (1949).

Conclusions.

Clay minerals such as, kaolinite, illite, and chlorite are
thought to produce good mine roofs and floors in general,
especially when they occur in a well crysallised form. On
the other hand montmorillonite is a very unstable mineral and
produces conditions of plastic and weak strata. Mixed layer
expanding minerals are also associated with unsatisfactory
strata conditions.

Similarly, size plays a part in the behaviour of the strata.
Material with the major part consisting of sand sized particles
can be expected to result in good mining conditions, while a
large quantity of clay or silt sized material points to some
difficulties.

White (1954) points out that under sufficient stress all
roof materials will crack and all floor clays will flow
plasticly. Thus although montmorillonite and other expanding
minerals produce effects far exceeding their proportion in
the material, because of the large surface area contributed,
it does not follow that a bad roof or floor must contain
montmorillonite. In fact Holland (1956) reports that in
extensive tests on shales overlying coal beds in Pennsylvanian
strata in Southwest Virginia, Illinois and Indiana only one
sample showed any traces of montmorillonite.

Further research is obviously needed to disclose the nature
of these phenomenon more completely.

Identification of clay minerals by X-ray Diffraction Analysis.

The method of X-ray diffraction analysis is based on the
fact that X-rays when directed in a beam onto a crystalline
material, give resulting peak reflections at certain angles
of incidence, which are related to the basic crystal struct-
ure. This phenomenon was first explained by Bragg (1933)
who showed that it was related to the distance between succ-
essive layers of atoms in the crystal structure.

Consider a beam of X-rays striking a row of atoms at an
angle of incidence $\theta°$ having a wave front 'oa'. Figure 7.
After reflection the wave front is 'oc' and for a maximum
intensity of the reflected beam the distance 'abc' must be
an exact number of wavelengths, inorder that reinforcement
might take place along the wave front. If 'λ' is the X-ray
wavelength then:-

$$abc = n \lambda \qquad \text{where 'n' is any integer.}$$

If 'd' is the interlayer distance then:-

$$abc = 2ab = 2d \sin \theta°$$

$$\text{i.e.} \quad n\lambda = 2d \sin \theta° \qquad \text{for an intense reflection.}$$

Thus if an intense reflection occurs at an angle of incidence
of $\theta°$, then there is a structurally repeating pattern with a
basic spacing of:-

$$d = n\lambda/2 \sin \theta°$$
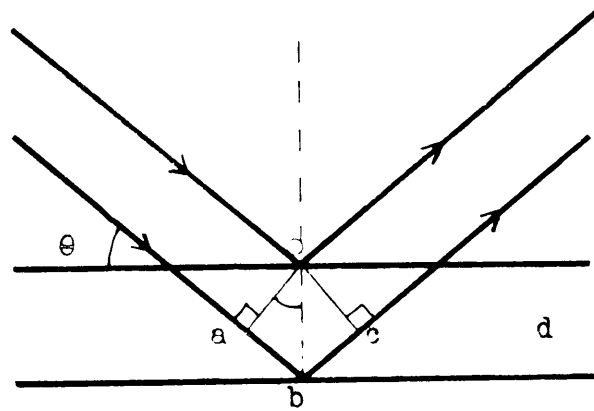
This forms the basis of this type of X-ray analysis.

Figure 7. X-ray diffraction according to Bragg.

Relative

Intensities.
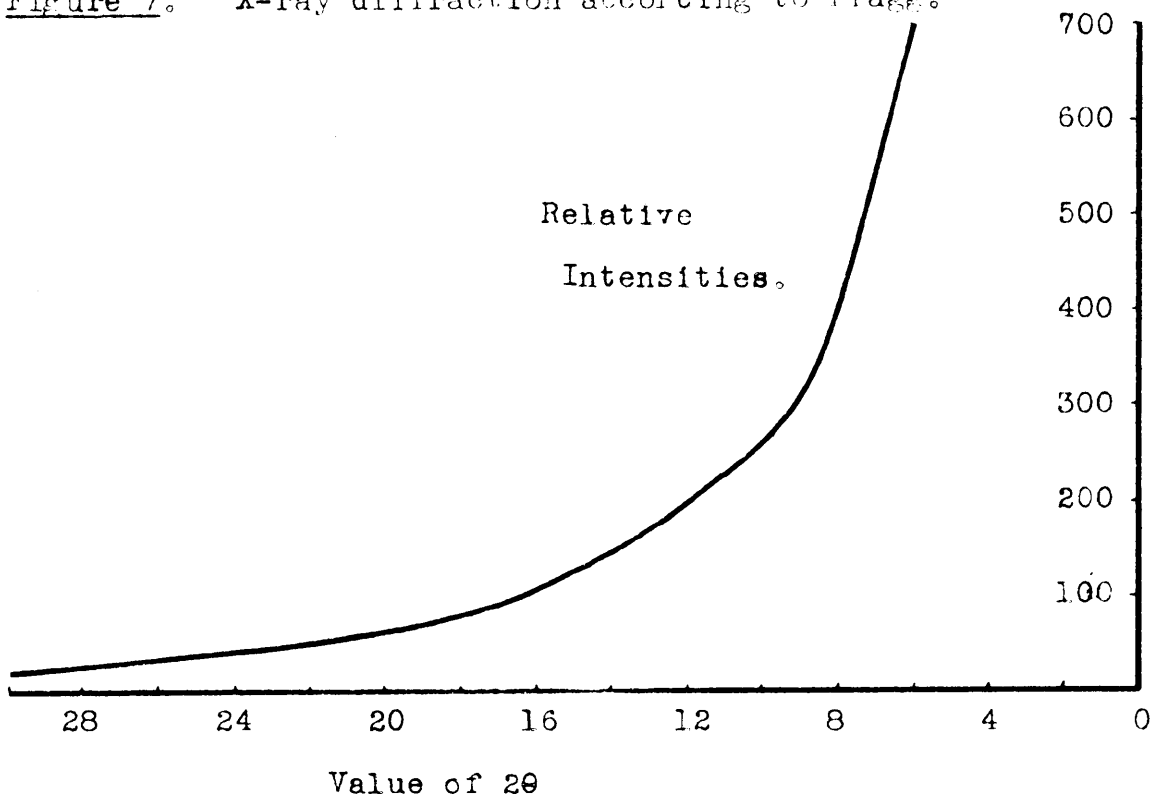
Value of 2θ

Figure 8. Optical factor in X-ray intensity according

to Bradley.

The crystal structure is scanned by a beam of X-rays, with θ° increasing. The intense peaks which occur in the reflected beam at angles corresponding to the value of 'd' and at n = 1,2, 3, etc. Noting the value of θ° for the first reflected peak, i.e. at 'n' = 1, the value of the interlayer spacing 'd' can be calculated. Charts are provided to ease these computations.

This interlayer spacing is a unique value according to the structure of the clay mineral examined and by further analysis after treating the specimen, small differences in clay mineral type can be detected.

The minerals may be examined in the oriented or unoriented condition. For most purposes of identification the former is prefered as this eliminates many unwanted and distracting peaks. The oriented samples are made from a suspension of the minus four micron fraction of the clay material, which contains most of the clay minerals. A small quantity is placed on a glass slide and allowed to dry out to give the orientated deposit. Reflections from the oriented slides are called basal reflections and are designated, 001,002,003, etc. according as 'n' = 1,2,3.

Layer spacings of about 7 A, 10 A, and 14 A are the ones most frequently observed and these are characteristic of different kinds of layers. Their interpretation is not without its ambiguity but the application of auxilliary techniques such as characteristic chemical and heat treatment in conjunction with the X-ray analysis usually resolves these difficulties.

Interpretation of a 10 A spacing.

Ten-A spacings are due to unexpanded mica-type layers i.e.
illite, or to hydrated forms of halloysite. Halloysite shows
no real orientation and gives diffuse peaks, while illite
gives good orientation and strong sharp peaks. Further
evidence, if necessary upon which to base the choice between
the two, can be achieved by noting the collapse of halloysite
back to the 7 A spacing of the dehydrated form on heating to
about 100°C.

Interpretation of a 14 A spacing.

Forteen-A spacings are generally due to chlorites, vermiculi-
tes, or montmorillonites. Heat treatment to 500°C causes
vermiculites and montmorillonites to collapse to about 10 A
whereas chlorites are unaffected. In fact heat treatment to
600°C enhances the 14 A peak of the chlorites, particularly
those containing iron. It must be noted, however, that the
heat treatment to 500°C causes the second and fourth order
peaks of chlorite to disappear. (Note the heat treatment 500°C
to 600°C effectively removes any kaolinite and makes the
presence of chlorite even clearer.) The swelling action with
organic reagents and montmorillonites also gives a good positive
test for this mineral. After saturation with glycol the 14 A
spacing increases to 17.7 A and is very strong, making the
detection of even small amounts rather easy. Vermiculite can
be positively identified according to Walker (1949) by leaching

with a solution of an ammonium salt. This reduces the 14 A
spacing to 11 A which remains even when treated with glycol.
Walker gives a three way test which consists of leaching with
ammonia, then treating with glycol. Lines at 11 A, 14 A, and
17.7 A indicate vermiculite, chlorite and montmorillonite
respectively. It is recommended, however, that if chlorite
is found, its presence should be checked with the appropriate
heat treatment.

Interpretation of a 7 A spacing.

True seven-A spacings, as distinct from a second order
reflection from a 14 A spacing, indicates the presence of
kaolinite. Difficulty is likely to arise when a 14 A mineral
is also present. Treatment to modify the 14 A and thus the 7 A
second order reflection should be made, thus leaving the
kaolinite peak on its own unless it too is modified by the
treatment. Alternatively heat treatment from 500°C to 600°C
causes the kaolinite to disintegrate and a decrease in the
intensity of the 7 A line after such treatment may be due to
this component. Any final analysis of the kaolinite content
can only be made taking into consideration all the other
minerals present and evaluating the contribution of each to
the 7 A line.

Quantitative analysis using X-ray diffraction traces.

The estimation of the relative abundance of the clay minerals
in a complex mixture is extremely difficult and is only in the

infancy of its development. Johns, Grim, and Bradley (1954) and Schultz (1955) have investigated the possibilities of using the relative peak intensities to give an indication of the percentage composition of a clay mineral mixture and have evolved some broadly successful techniques.

Factors which are found to affect the intensity of the characteristic peaks of the clay minerals are as follows:-

1. The relative abundance of the particular mineral. This is the factor we wish to measure.

2. The reflective efficiency of the mineral. Some minerals with atoms having high atomic numbers absorb X-rays to the detriment of the reflected intensity.

3. The general reflective properties of the matrix in which the minerals are found. This is usually not known and makes direct quantitative estimates impossible. This is overcome by refering all estimates to an internal standard within the material. This is usually illite and may be artificially introduced into the sample if necessary.

4. The intensity is also influenced by any lack of crystallinity or by a condition of nonparallelism between the layers. Lack of material on the slide will also reduce the intensity.

5. Position of the peak also has a profound effect upon the recorded intensity. Due to the optical nature

of the method, the reflected beam is subject to an increase in
scattering as the angle of incidence $\theta°$ increases. Thus peaks
at low values of θ are naturally more intense than those at
higher angles even though the other factors may be equal.
Bradley (1953) gives the relative values as shown in Figure 8.
on page 21. Before comparison the intensities of the peaks
must be divided by the corresponding "optical factor". For
example the intensity of a 17 A peak is four times that of a
10 A peak; an optical factor of 1048 compared with 322.

Johns, Grim and Bradley (1954) suggest that the 3.3 A peak
of the third order of illite may be compared with the 3.5 A
peak of the second order of kaolinite and the fourth order of
chlorite, directly to give good results. They assume equal
reflective efficiency for all the minerals and note that the
peaks are so close at a large value of θ that the optical
factor can be neglected. Before comparison they suggest that
the illite peak should be corrected for quartz by an amount
1 to $1\frac{1}{8}$ times the 4.3 A quartz peak. Heat treatment at 450°C
removes the contribution of chlorite to the 3.5 A and 7 A peaks
which can now be considered to be due to kaolinite alone.
The montmorillonite peak at 17.7 A after glycolation may be
compared with the 10 A peak of illite after dividing the 17,7 A
peak by four to allow for the optical factor.

Schultz (1955) found that the area of the peaks for mixed
layer minerals correlated better with their percentages in the

mixture than did the actual peak heights. He thus investigated
the composition of kaolinite and illite in underclays and
concluded from his study that the amount of kaolinite and illite
in a mixture is best evaluated on the basis of a 1/1 ratio of
the areas of the 001 peaks i.e. the 7 A and the 10 A lines.
He emphasised that this may well only apply to plastic under-
clays for he assumes that the optical factor difference between
7 A and 10 A is balanced by a better reflectivity in the
kaolinite component. Using the peak areas instead of the peak
heights eliminates difficulties due to preferential orientation,
differential adsorbing power and mixed layering.

Size Analysis and Choice of a Grade Scale.

In sedimentary analysis the date are arranged on a size scale (diameter, area or volume) so as to facilitate correlation of the data and the phenomenon which is being investigated. The first true geometric scale for soils or sediments was introduced by Udden (1898). In choosing his grade limits he changed the values of $1, \frac{1}{2}, \frac{1}{4}$, and 1/10 mm. of the older soil scientists to $1, \frac{1}{2}, \frac{1}{4}$, and 1/8 mm. using a constant ratio of two between each grade. Later he extended his scale to include larger and smaller sizes. (Udden 1914)

Hopkins (1899) made a plea for a scientific soils classification based on a geometric scale using a factor of $\sqrt{10}$. This was, however, rejected by the United States Bureau of Soils who continued to use the grade scale shown in table one.

Atterberg (1905) sought to advance the subject by seeking some physical basis for his scale. He eventually chose a unit value of 2 mm. and a geometric scale based on a factor of 10. See table two. In choosing this scale Atterberg points out that sand above 2mm. diameter does not hold water while that with a smaller diameter does. Similarly a division at 0.2mm. can be made between truly wet sand and relatively dry sand. Further at 0.02mm. the grains become invisible to the naked eye and root hairs can nolonger penetrate the pores between the grains. At 0.002mm. Atterberg draws attention to the fact that at this size

Brownian movement begins to take place. In 1927 this scale was adopted by the International Commission on Soils but was rejected by the United States Bureau of Soils.

In America, sedimentary petrologists favour Wentworth's modification of Udden's grade scale. Retaining Udden's factor of two, Wentworth (1922) modified and extended the scale to produce the size classification shown in table three. Later Wentworth (1933) examined the class limits of his grade scale and found that far from being arbitary, they agreed well with certain distinctions between suspension and traction loads.

With the above factors in mind and knowing that petrologists favour Wentworth's scale in general, it was decided to consider three size fractions for the purpose of this analysis.

1. Sand size   + 1/16 mm.
2. Silt size   - 1/16 mm.   + 1/256 mm.
3. Clay size   - 1/256 mm.

While defining the above size ranges for the purposes of this analysis, it should be noted that clay sized material is considered to be less than 1/512 mm. or approximately two microns in diameter, by most agriculturalists and this view is supported by Grim (1953) who states that there is a natural break in the mineral type at this size. He maintains that below two microns the material is almost 100°/o clay minerals, while above the two micron limit very little clay mineral material is present.

Table one.   United States Bureau of Soils Size Classification.

1. Gravel	− 2 mm.	+ 1 mm.
2. Coarse sand	− 1 mm.	+ $\frac{1}{2}$ mm.
3. Medium sand	− $\frac{1}{2}$ mm.	+ $\frac{1}{4}$ mm.
4. Fine sand	− $\frac{1}{4}$ mm.	+ 1/10 mm.
5. Very fine sand	− 1/10 mm.	+ 1/20 mm.
6. Silt	− 1/20 mm.	+ 1/200 mm.
7. Clay	− 1/200 mm.	

Table two.   Atterberg's Size Classification.

1. Blocks	− 2000 mm.	+ 200 mm.
2. Cobbles	− 200 mm.	+ 20 mm.
3. Pebbles	− 20 mm.	+ 2 mm.
4. Coarse sand	− 2 mm.	+ 0.2 mm.
5. Fine sand	− 0.2 mm.	+ 0.02 mm.
6. Silt	− 0.02 mm.	+ 0.002 mm.
7. Clay	− 0.002 mm.	

Table three.   Wentworth's Size Classification.

1. Boulder		+ 256 mm.
2. Cobble	− 256 mm.	+ 64 mm.
3. Pebble	− 64 mm.	+ 4 mm.
4. Granule	− 4 mm.	+ 2 mm.
5. Very coarse sand	− 2 mm.	+ 1 mm.
6. Coarse sand	− 1 mm.	+ $\frac{1}{2}$ mm.
7. Medium sand	− $\frac{1}{2}$ mm.	+ $\frac{1}{4}$ mm.
8. Fine sand	− $\frac{1}{4}$ mm.	+ 1/8 mm.
9. Very fine sand	− 1/8 mm.	+ 1/16 mm.
10. Silt	− 1/16 mm.	+ 1/256 mm.
11. Clay	− 1/256 mm.	

Principles of Sedimentary Analysis.

The fundamental principle which underlies sedimentary techni-
ques for separation is that small particles will settle with a
constant velocity in a fluid. It is universally true that small
particles will reach this terminal velocity when the resistance
of the fluid equals the downward forces of gravity. In general
the terminal velocity depends upon; the size, shape, density
and surface texture of the small body and the density and
viscosity of the fluid. A number of mathematical expressions
have been developed to cover this phenomenon and these are
discussed below.

Stokes' Law.

Stokes first formulated the resistance offered to the movement
of a sphere in a viscous fluid.

$$R = 6\pi r \eta v$$

where R is the resistance in gram cm. / sec^2.
r is the radius of the sphere in cm.
η is the viscosity of the fluid.
v is the velocity of the sphere in cm./sec.

When a small body settles in a fluid the force of gravity is:-

$$F = 4/3\pi r^3 d_1 g$$

and the buoyant force of the fluid is given by Archemedies:-

$$B = 4/3\pi r^3 d_2 g$$

Where d_1 is the density of the body.

d_2 is the density of the fluid.

g is the acceleration due to gravity.

Thus in the state of equilibrium when the terminal velocity
is reached:-

$$R = F - B$$

$$6\pi r\eta v = 4/3\, \pi\, r^3(d_1-d_2)g$$

Solving for 'v' we obtain:-

$$v = \frac{2\,(d_1-d_2)gr^2}{9\quad\eta}$$

which is Stokes' Law.

For a constant temperature; ,Density of the body d_1,Density of
the fluid d_2, and the viscosity , are all constant and thus

$$v = Cr^2$$

This law is closely followed in practice and Figure 9. shows
the calculated results for quartz particles settling in water
at 15°C. This curve is shown together with the recorded
observations of Schone (1868), Hilgard (1873), Owens (1911),
Atterberg (1912), Boswell (1918), and Richards (1925). Close
agreement occurs upto about 0.05 mm. when the results begin
to deviate from the mathematically predicted values. Error
above this point is probably due to the irregularity of the
particles and their deviation from a true spherical shape
upon which the law is based.

It should be noted here that temperature plays an important
part in determining the settling velocity. Although the
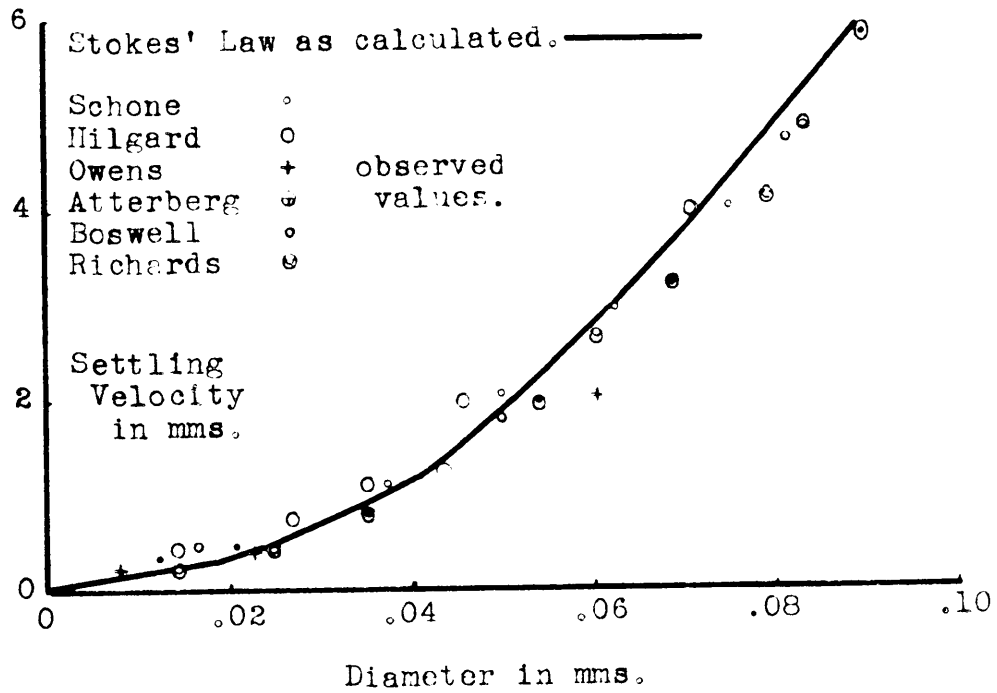densities involved do not alter much for small temperature

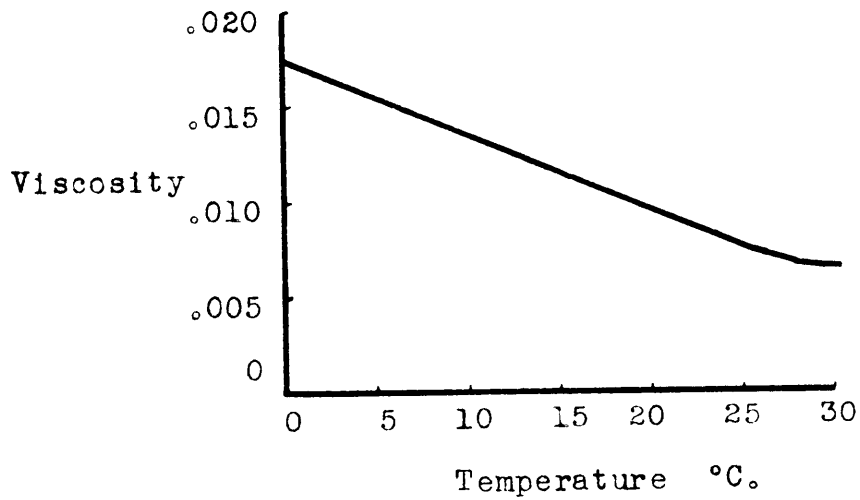Figure 9. Comparison of Stokes' Law and some observations.

Figure 10. Viscosity of water as a function of temperature.

changes, the viscosity may change considerably. Figure 10.
shows the viscosity of water as a function of temperature.

<u>Rubey's formula.</u>

Rubey (1933) developed a formula which agrees with the
practical observations over a wider size range than does Stokes'
Law. This he did by introducing the concept of an impact of
the fluid force which assists the viscous drag of the liguid at
high velocities.   Thus the equations become:-

$$4/3\pi r^3(d_1-d_2)g = 6\pi r \eta v + \pi r^2 v^2 d_2$$

and solving this for 'v' as before:-

$$v = \left\{ 4/3 g d_2(d_1-d_2)r^3 + 9\eta^2 + 3\eta \right\}^{\frac{1}{2}} / d_2 r$$

Figure 11. shows the theoretical curves and the transition
from viscous drag to impact resistance. This line agrees well
with observed results for quartz and galena.

Note that for small velocities the impact term may be
neglected and the formula reverts to Stokes' Law.

<u>Wadell's formula.</u>

Wadell (1934,1936) approached the problem by introducing the
concept of a coefficient of resistance, C_r. This is defined as
the ratio of the force producing motion to the dynamic pressure
acting on the cross-sectional area of the particle at right
angles to the flow.

$$\text{i.e.}\quad C_r = 4/3\pi r^3(d_1-d_2)g / \frac{1}{2}\pi r^2 v^2 d_2$$
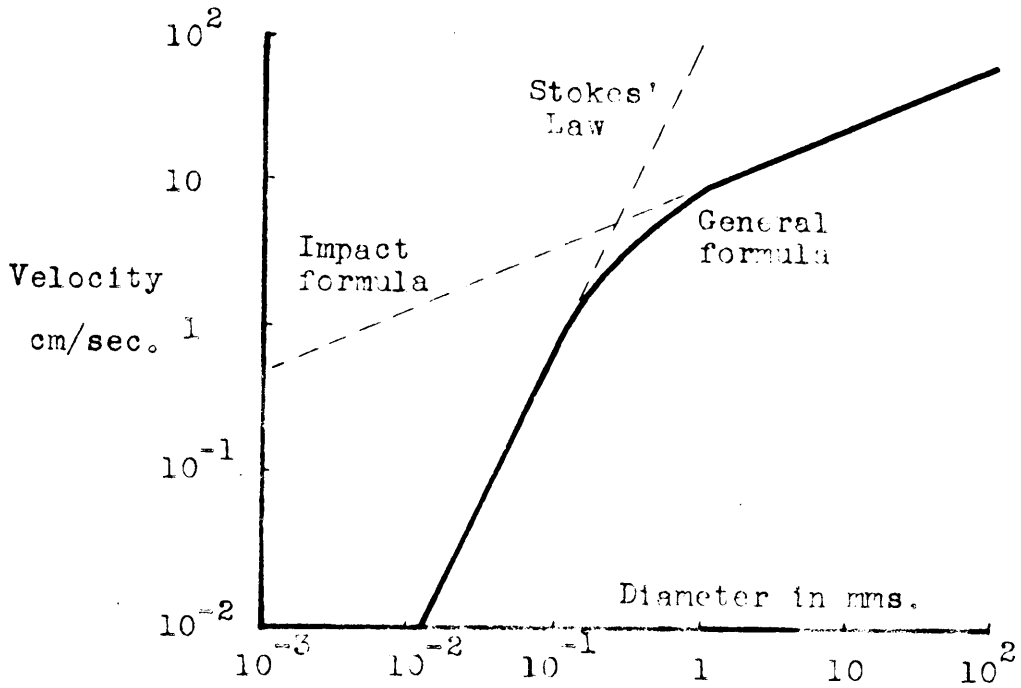
$$\text{or}\quad C_r = 8g(d_1-d_2)r / 3 d_2 v^2$$

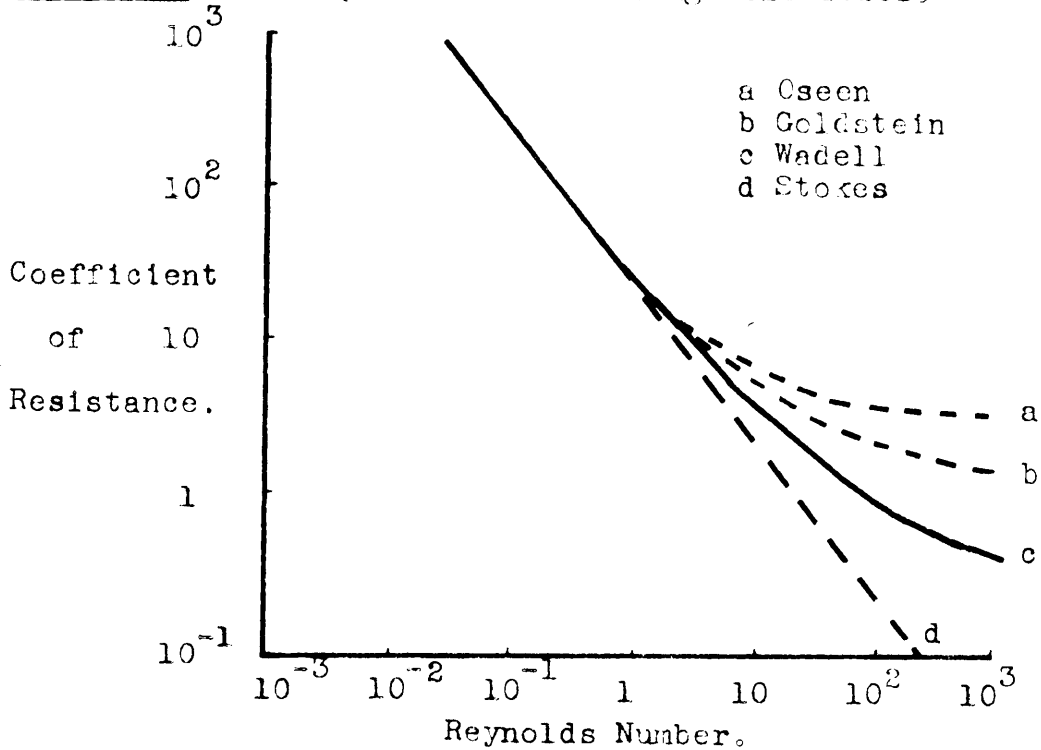Figure 11. Rubey's Law of settling velocities.

Figure 12. Comparison of the Settling velocity laws.

Wadell examined the relationship between C_r and Reynolds number, Re, $2rvd_1/\eta$. Starting with the assumption that C_r was a function of Re., he plotted the resulting line and developed the empirical relation for settling velocities, not only extending the range above that of Stokes' Law but also enabling him to elucidate the influence of shape on the settling velocity.

Wadell's formular is expressed in the form of a correction to Stokes' radius:-

$$r_a = r_s \left\{ 1 + 0.08(2r_s v_a d_2/\eta)^{0.69897001} \right\}$$

where r_a is the actual radius.

r_s is the radius from Stokes' Law.

v_a is the actual settling velocity.

Figure 12. shows Wadell's curve which agrees well with practical observations upto a value of 3000 for Reynolds number. The figure also shows Stokes', Oseen's and Goldstein's laws to indicate their departure from Wadell's curve in the upper range of diameters. Oseen's and Goldstein's Laws will be discussed later. Stokes' Law is valid upto Re. = 0.2, Oseen's and Goldstein's to Re. = 0.5, and Rubey's formula, according to Christiansen (1935) agrees with values obtained in experiments on quartz and galena upto Re. = 1000.

Wadell also modified Stokes' Law to allow for non spherical particles. Developing a resistance formula for particles half way between a disc and a sphere.

He proposed:-

$$R_w = 9.44 \, \Pi r \eta v$$

resulting in the formula:-

$$v_p = 1/7 \, (d_1-d_2) g r_p^2 / \eta$$

where v_p is the practical settling velocity.

r_p is the practical radius.

It will be noticed that this is Stokes' Law with a different constant and that:-

$$v_p/v_s = 1/7 \Big/ 2/9 = 0.64$$

Thus the practical settling velocity of a sedimentary body is 64°/o of the value for the corresponding sphere. Similarly for a given settling velocity the practical radius is 1.25 times the size of the theoretical sphere computed from Stokes' Law.

Oseen's formula.

Oseen (1910) developed the resistance formula:-

$$R = 6 \Pi r \eta v \left\{ 1 + 3 d_2 r/8 \eta \, |v| \right\}$$

Which gives

$$v = \frac{-3\eta/r + \sqrt{9 \eta^2/r^2 + 3 d_2(d_1-d_2)}}{9/4 \; d_2}$$

when v becomes much less than unity and v^2 can be neglected compared with v , This expression reduces to Stokes' Law. Figure 13. shows Stokes' and Oseen's laws and indicates their deviation above diameters of 0.1 mm. For smaller diameters

Stokes' or Wadell's laws are easier for computation and are
thus more generally useful.

Goldstein's formula.

Goldstein (1929) used Oseens equation solving in terms of a
series in Reynolds Number and a drag coefficient k_D.
Goldstein finally evolved this equation:-

$$k_D = \text{the drag} /Pd_2v^2r^2$$

$$k_D = 12/Re. \left(1 + 3/16 \ Re. - 19/1280 \ Re.^2 + 71.20480 \ Re.^3 \right)$$

In this series Stokes' Law is $\quad k_D = 12/Re.$

$$\text{Oseen's Law is} \quad k_D = 12/Re. \left(1 + 3/16 \ Re. \right)$$

$$\text{or} \quad k_D = 12/Re. + 2.25$$

Goldstein pointed out that below a value of Re. = 1.6 that
Oseen's formula is sufficiently accurate.

Summarising the Settling Laws.

The preceding discussion shows that for practical purposes
Stokes' Law and Wadell's formula are most easily applied to
sedimentary analysis and separation. Both laws extend to
values of Re. = 0.2 at least, giving a diameter of about 0.062
mm. or 1/16 mm. Thus we may use either laws in our analysis.
The choice between the two is one of degree. Stokes' being
for spherical particles and Wadell's for angular sedimentary
ones. In practice it is found that most clay technologists
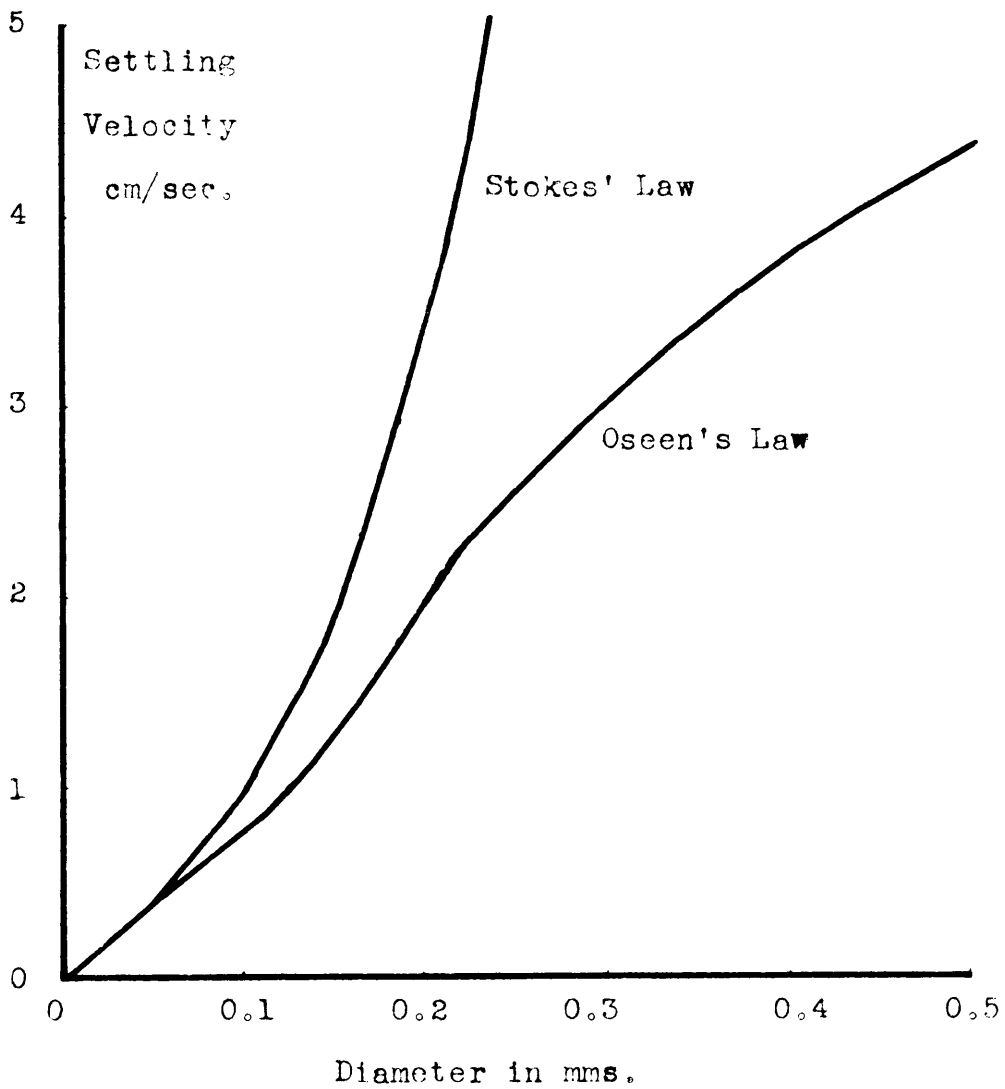
Figure 13.   Departure of Stokes' Law from Oseen's Law.

and investigators use Stoke's Law, making the assumption that
clay particles are nearer to the spherical shape. In general
this assumption is not justified but results with most clay
materials seem to indicate the validity of this treatment.
Table four shows the settling phenomenon based on Stokes' Law
for 1/16 mm. and 1/256 mm. particles.

Table four. Settling phenomenon based on Stokes' Law.

Temperature °C	15°C	20°C	25°C	30°C
Time for 1/16mm. particles to fall 25 cms. in secs.	78	69	62	56
Time for 1/256mm. particles to fall 10 cms. in mins.	139	123	109	99

INVESTIGATION

Object of the investigation.

The forgoing discussion of the effect of size and clay mineral content upon the weathering of the immediate strata associated with coal mines has indicated the sparcity of knowledge in this field. The object of this research is to increase this knowledge, providing additional information concerning the limits of clay mineral composition and size distribution of the particles within the roof and floor material. Then if possible it is hoped to correlate some of these factors with the performance of these materials under adverse weathering conditions.

Procedure and Experimental Techniques.

An outline of the experimental procedure is given below:-

1. A number of Coal Mining Companies were approached and their assistance in the collection of strata samples was obtained.

2. Instruction sheets and sampling jars were mailed to these companies, together with a questionnaire concerning the properties of their floor and roof material.

3. These questionnaires were completed and returned with the samples to V.P.I.

4. The samples were crushed and passed through a four mesh screen.

5. After splitting the sample, a 30 gram sample was weighed out and dried to constant weight in a 90°c steam heated oven. The sample was cooled and reweighed and the percentage loss due to moisture evaluated.

6. A 40 gram sample was weighed out and throughly mixed with 400 millilitres of water in an electric mixer for six minutes. This liberated the grains from the matrix.

7. The above mixture was made up to 1,000 millilitres in a large measuring cylinder and allowed to settle. Using the information from Table four on page 40, samples of 50 milli-litres first of the clay and silt size were taken with a pipette from a depth of 25 cms. followed later by a sample of the clay size only taken at a depth of 10 cms. These samples were evaporated to dryness in the 90°C oven. Thus the weight of material in each sample was one twentieth of the particular size fraction in the total 40 gram sample. Subtraction of the two determinations gave the silt size alone.

8. A further Clay sized fraction was taken and used to prepare orientated slides for X-ray analysis, as described on page 22.

9. The remainder of the mixture was wet sieved through a 250 mesh screen to retain all the sand size material. This was then dried and weighed to obtain the percentage sand size.

10. The percentages of water, sand, silt and clay fractions were added together and if the difference from 100 percent exceded 2 Or 3 percent then the test was thought to be in error and was repeated.

11. The slides were then tested in a General Electric XRD-5 X-ray spectroscope using secondary copper radiation with a wave length of 1.5418 Angstrom units.

12. The X-ray traces were analysed using the techniques of Johns, Grim and Bradley and of Schultz. This enabled the approximate mineral composition of the clay fraction to be estimated.

13. The results of the above tests were tabulated and evaluated for any significant correlation between the laboratory tests and the behaviour of the material in the mines.

This outline of the experimental procedure is amplified in the following notes:-

Instructions for sampling.

Companies were instructed to obtain the samples from strata which had been exposed nolonger than one week. Cuttings from several holes were to be collected from the first six inches of the strata and sealed in the air tight jars provided. Both the roof and the floor were to be sampled in the same way. Copies of these instructions and questionnaire are shown in

the appendix.   Tables five and six give a list of the samples
and their location which is illustrated by the map, Figure 19.

Liberation of the particles from the matrix.

Inorder to separate the sized fractions, it is first necess-
ary to release the grains from their matrix. This was effect-
ed using a Waring electric blender. The 40 gram sample was
placed with 400 millilitres of water into the blender, together
with one millilitre of ammonium hydroxide solution to prevent
flocculation. The blender was kept at a constant 115 volts
and the mixture subjected to this agitation for six minutes.
This time was chosen as a result of an auxiliary experiment.

In this experiment, identical samples of the same material
were subjected to varying degrees of agitation by varying the
time that the mixture was blended at the constant voltage of
115 volts. Figure 14. page 45 , shows the results of this test.
From the graph it was thought that the position of the maximum
amount of silt sized material marked the point where the
disintegration of the matrix was complete and the breakage of
the individual grains had not yet begun. This point occured
after agitating about six minutes and it was decided to subject
all the samples to this same amount of agitation. This ensures
the complete release of the grains while not causing the break-
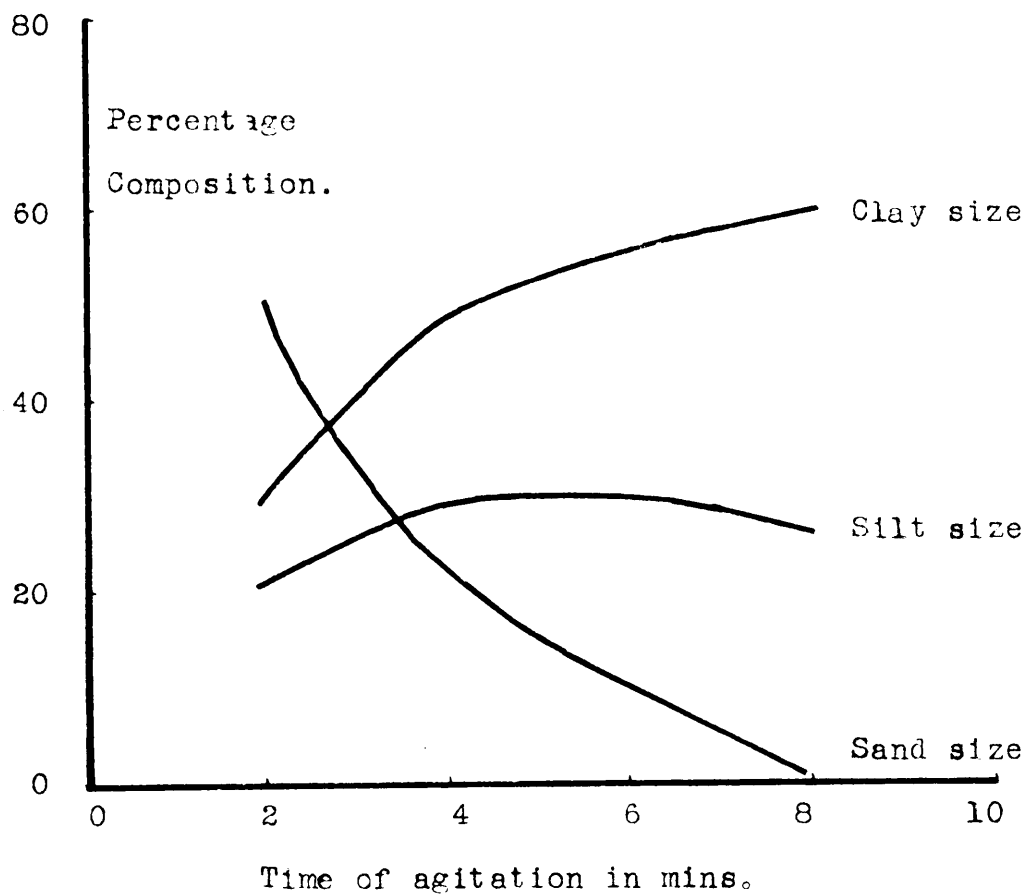age of the individual grains.

Figure 14.   Result of agitation on the size analysis.

Sedimentation.

In the sedimentary analysis, the combined clay and silt sized sample was removed at a depth of 25 cms. at a time given in Table four, page 40, this time is dependent upon the temperature which was measured before the settling period. The temperature was again taken after a two hour period and used as an average with the first temperature in determining the time at which to withdraw the clay only sample from a depth of 10 cms.

X-ray Analysis.

The slide is mounted in the spectrascope. This consists of a source of secondary copper radiation with a wave length of 1.5418 Angstrom units. These rays are concentrated into a beam which is stationary. The slide is rotated electrically at a constant speed of one degree per minute in the path of this beam and a recording device rotates at a speed of two degrees per minute recording the reflected intensities. The recording device was set with a sensitivity of such a magnitude that it took one second to reach 63 percent of the full deflection. The resulting intensity pattern was plotted as a graph of the intensity against the value of $2\theta°$ the reflected angle corresponding to the angle of incidence $\theta°$ of the X-ray beam. Four slides for each sample were tested; one untreated, one treated with glycol, one heated to 500°C and one heated to 600°C. These enabled the various peaks to be identified and the mineral content of the sample estimated.

Analysis of the X-ray diffraction patterns.

The quantity of chlorite and kaolinite together compared
with the quantity of illite was found using the 1/1 ratio of
the areas of the 3.5 A and the 3.3 A peaks, after first
correcting the 3.3 A illite peak for quartz. This involves
subtracting one and a half times the area of the 4.3 A quartz
peak from the illite peak area. This is the method advised
by Johns, Grim and Bradley. This was checked by a comparison
of the 7 A and the 10 A peaks on a straight 1/1 ratio of the
areas, as suggested by Schultz. Very close agreement between
the two methods was obtained.

Montmorillonite was checked for using the glycolated slides
and observing if any lattice expansion took place. This also
checks for mixed layer expanding material.

After heating the slides to 500°C, the traces were evaluat-
ed as in the first paragraph once again. Johns, Grim and
Bradley maintain that the 3.5 A and 7 A peaks are now due to
the kaolinite component only and any loss in intensity can
be atributed to chlorite. These values for chlorite were
checked by comparing the 4.7 A chlorite and 5 A illite peaks
on a 1/1 area basis and also by the comparison of the 14 A
and 10 A peaks after heating to 600°C. Neither of these
last two methods is recommended for general use in the evalu-
ation of chlorite, but are used here as confirming evidence.
Throughout these tests all three determinations of chlorite
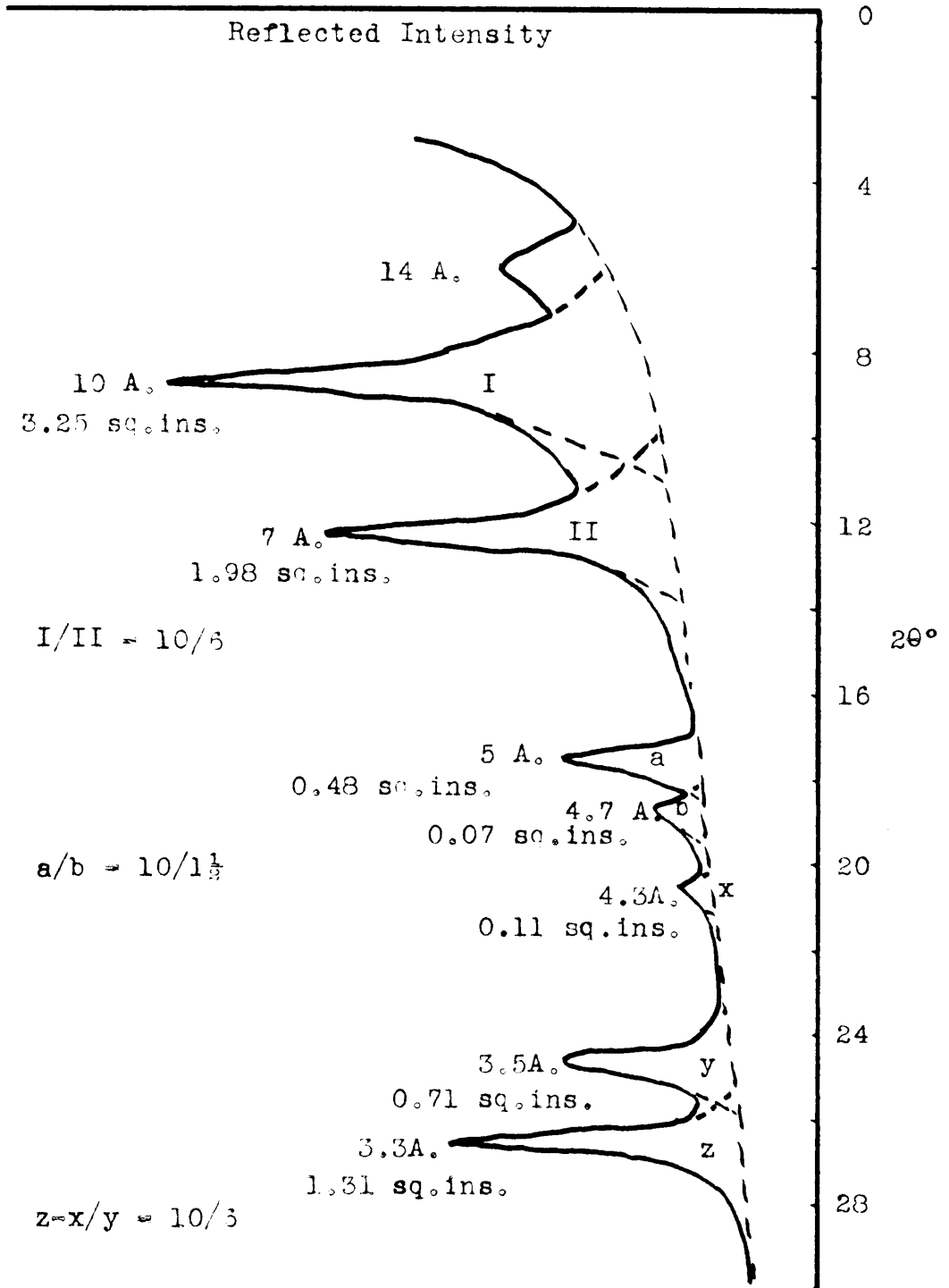
Figure 15. X-ray reflection intensities for Specimen #1.

(Untreated)

Reflected Intensities

0

4

8

12

2θ°

16

20

24

28

Note:- This is the same as
the untreated trace
and indicates the
absence of any
expanding lattice
material.
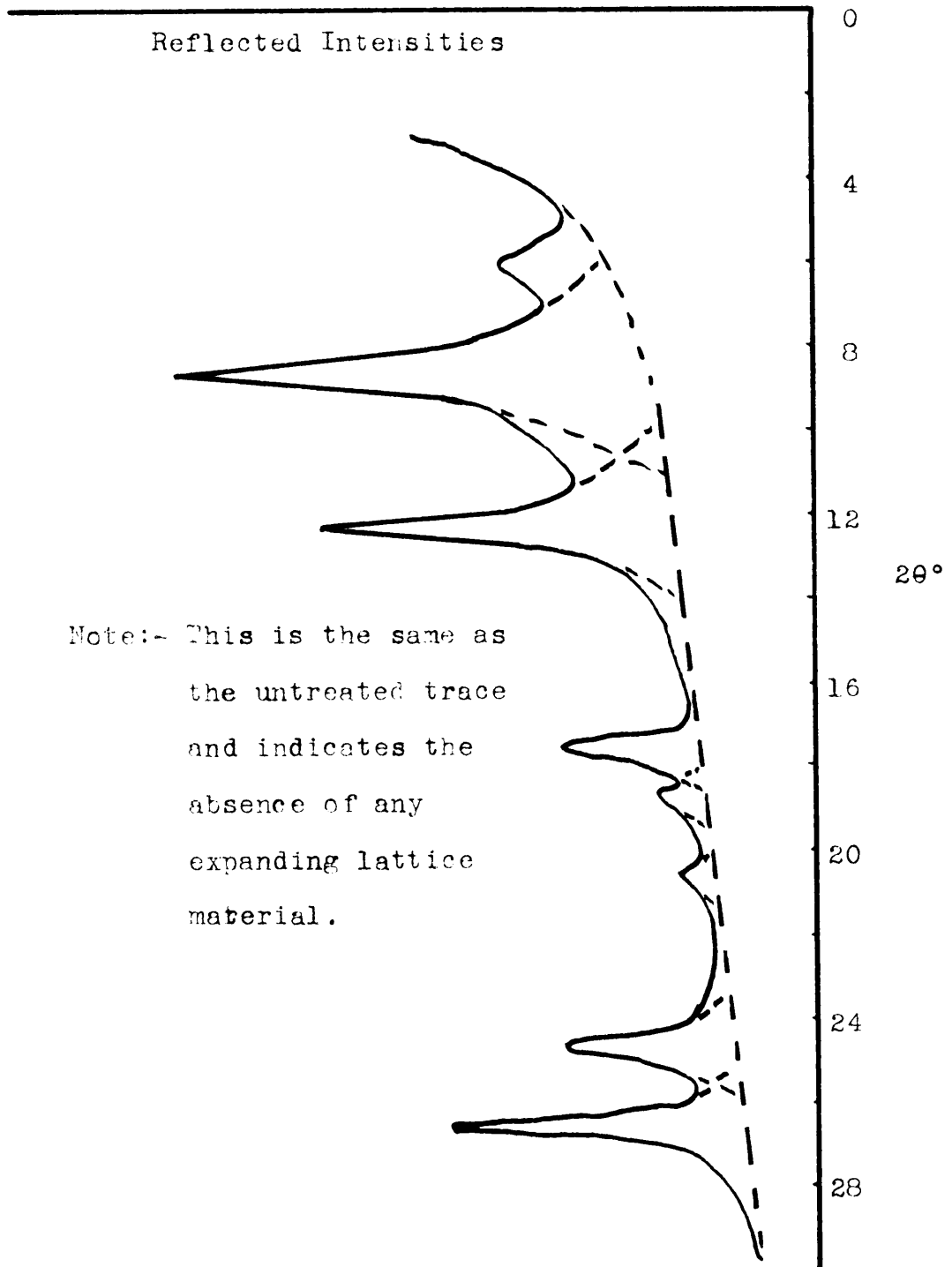
Figure 16. X-ray reflected intensities for Specimen #1.
(Glycolated)

Reflected Intensities.

0

4

8

I

2.80 sq.ins.

1.30 sq.ins

II

12

$2\theta°$

I/II = 10/4⅓

16

20

x

0.09 sq.in.

24

0.35 sq.ins.

y

0.37 sq.ins.

z

28

z-x/y = 10/4⅓
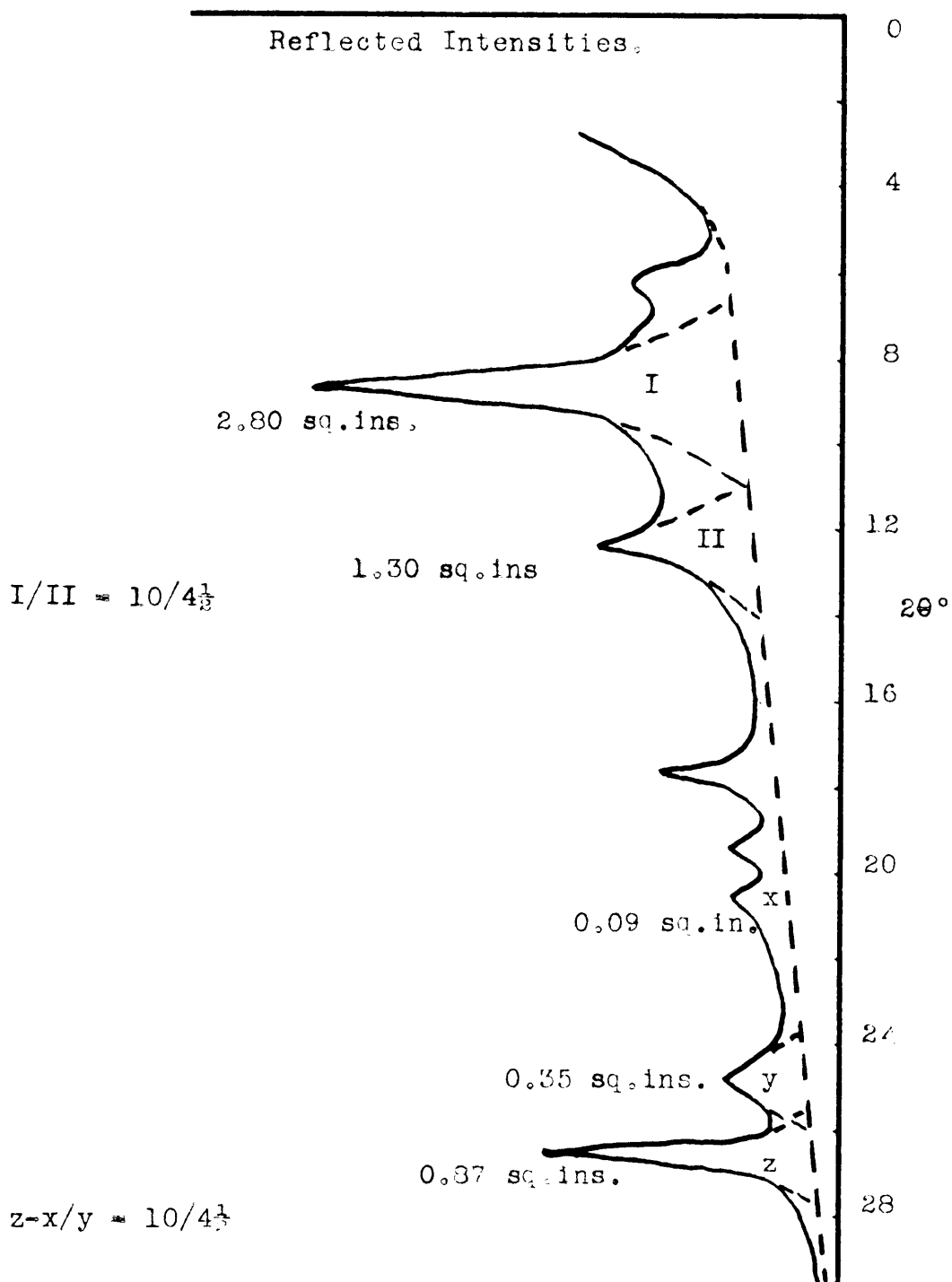
Figure 17. X-ray reflected intensities for Specimen #1.

(Heated to 500°C)

Reflected Intensities.

0.90 sq.ins.

3.15 sq.ins.

2q/p = 10/1½

p

q

0

4

8

12

2θ°

16

20

24

28
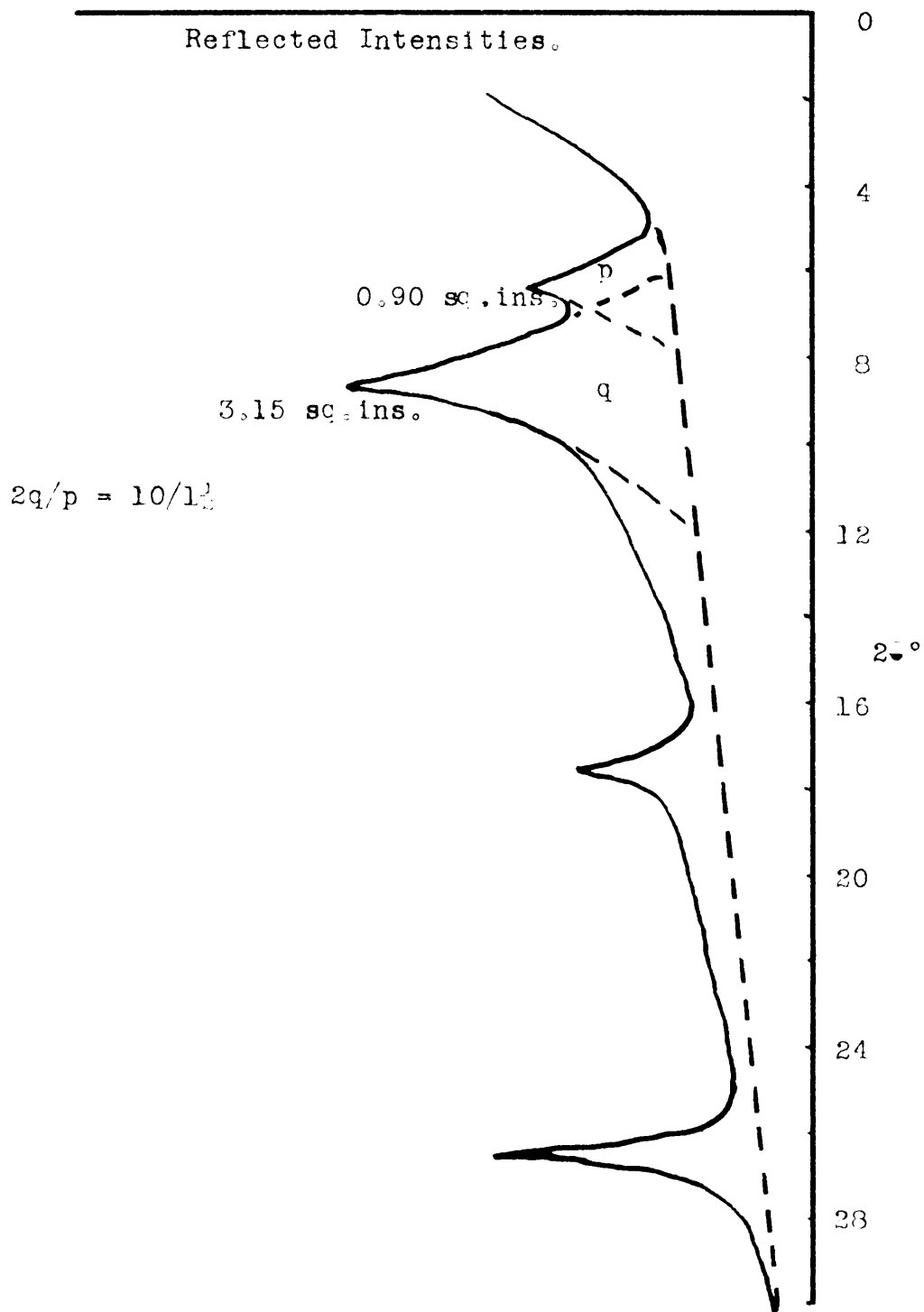
Figure 18. X-ray reflected intensities for Specimen #1.

(Heated to 600°C)

gave very close results.

For these determinations the areas were measured with a planimeter, making two determinations for each area and using the average. Figures; 15, 16, 17, and 18, show a typical set of these traces and the computations for the analysis of Sample number one.

RESULTS

Tables five and six show the origin of each of the samples
of roof shale and floor clay. This information is also shown
in map form, Figure 19, page 56.

Tables seven and eight show the results of the size and the
mineral analyses, together with the reported characteristics
of the shales and clays sent by the mines.

These characteristics were judged from the answers to the
questionnaires which were returned with each sample.

In tables seven and eight, column A shows the answer to
question A etc.   These questions were:-

A. Is the top sampled classed as slate or draw-slate?

B. Does the roof deteriorate when it comes into contact with
   air?

C. Where does the roof stand best?   a) Intake.
                                     b) Return.
                                     c) Same in both.

D. Does the floor heave in solid work?

E. Does the floor heave in rooms?

F. Does the floor heave on pillar lines?

G. Does the floor get soft when it stands under water?

H. Does the floor get soft when water is present from normal
   mining operations?

I. Does the floor get soft when shuttle cars run over it and
   water is present.

Table five. **Location, sample number and symbol of the**

Specimens of roof shale.

Specimen number.	Name of coal bed.	Symbol and Location of the mine.
2	High Splint	a Glenbrook, Harlan Co, Ky.
4	Imboden	b Crossbrook, Wise Co, Va.
5	Thick Tiller	c Moss#3, Duty, Va.
7	Splashdam	d Splashdam, Va.
10	Clintwood	e Moss#1, Lick Fork, Va.
11	Tiller	f Moss#2, South Clinchfield, Va.
14	Upper Banner	g #9 Mine, Clincho, Va.
15	Pocahontas #5	h #34 Mine, Bishop, Va.
17	Sogomore #6	i Punch, Mercer Co, Va.
20	Pocahontas #3	j #35 Mine, Bishop, Va.
22	Pocahontas #4	k #34 Mine, Amonate, Va.
24	Fire Creek	l Layland, Fayette Co, W.Va.
25	Lower Douglas	m #2 Mine, Jewell, Va.
28	Pardee	n Critical Fork, Norton, Va.
31	Island Creek	o #7 Mine, Holden, W.Va.
32	Draper	p Truck, Verdunville, W.Va.
34	Eagle	q #28 Mine, Verdunville, W.Va.
36	Chilton	r Chilton, Coal Mountain, W.Va.
39	Upper Thacker	s Junior #10, Red Jacket, W.Va.
40	Lower Thacker	t #17 Mine, Red Jacket, W.Va.
42	Coalburg	u Coalburg #2, Red Jacket, W.Va.
45	Beckley	v #2 Mine, Stanaford, W.Va.
46	Sewell	w Lochgelly, Fayette Co, W.Va.
49	Five Block	x #11 Mine, Kayford, W.Va.
51	Five Block	x #11 Mine, Kayford, W.Va.
52	Dorothy	y Marfork, Raleigh Co, W.Va.
54	#2 Gas	z #6 Mine, Kayford, W.Va.
56	Pocahontas	# Gary, Welch, W.Va.

Table six. Location, sample number and symbol of the

Specimens of floor clay.

| Specimen number.	Name of coal bed.	Symbol and Location of the mine.	
1	High Splint	a	Glenbrook, Harlan Co, Ky.
3	Imboden	b	Crossbrook, Wise Co, Va.
6	Thick Tiller	c	Moss#3, Duty, Va.
8	Splashdam	d	Splashdam, Va.
9	Clintwood	e	Moss#1, Lick Fork, Va.
12	Tiller	f	Moss#2, South Clinchfield, Va.
13	Upper Banner	g	#9 Mine, Clincho, Va.
16	Pocahontas #5	h	#34 Mine, Bishop, Va.
18	Sogomore #6	i	Punch, Mercer Co, W.Va.
19	Pocahontas #3	j	#35 Mine, Bishop, Va.
21	Pocahontas #4	k	#31 Mine, Amonate, Va.
23	Fire Creek	l	Layland, Fayette Co, W.Va.
26	Lower Douglas	m	#2 Mine, Jewell, Va.
27	Pardee	n	Critical Fork, Norton, Va.
29	Pardee	n	Critical Fork, Norton, Va.
30	Island Creek	o	#7 Mine, Holden, W.Va.
33	Draper	p	Truck, Verdunville, W.Va.
35	Eagle	q	#28 Mine, Verdunville, W.Va.
37	Chilton	r	Chilton, Coal Mountain, W.Va.
38	Upper Thacker	s	Junior #10, Red Jacket, W.Va.
41	Lower Thacker	t	#17 Mine, Red Jacket, W.Va.
43	Coalburg	u	Coalburg #2, Red Jacket, W.Va.
44	Beckley	v	#2 Mine, Stanaford, W.Va.
47	Sewell	w	Lochgelly, Fayette Co, W.Va.
48	Five Block	x	#11 Mine, Kayford, W.Va.
50	Five Block	x	#11 Mine, Kayford, W.Va.
53	Dorothy	y	Marfork, Raleigh Co, W.Va.
55	#2 Gas	z	#6 Mine, Kayford, W.Va.
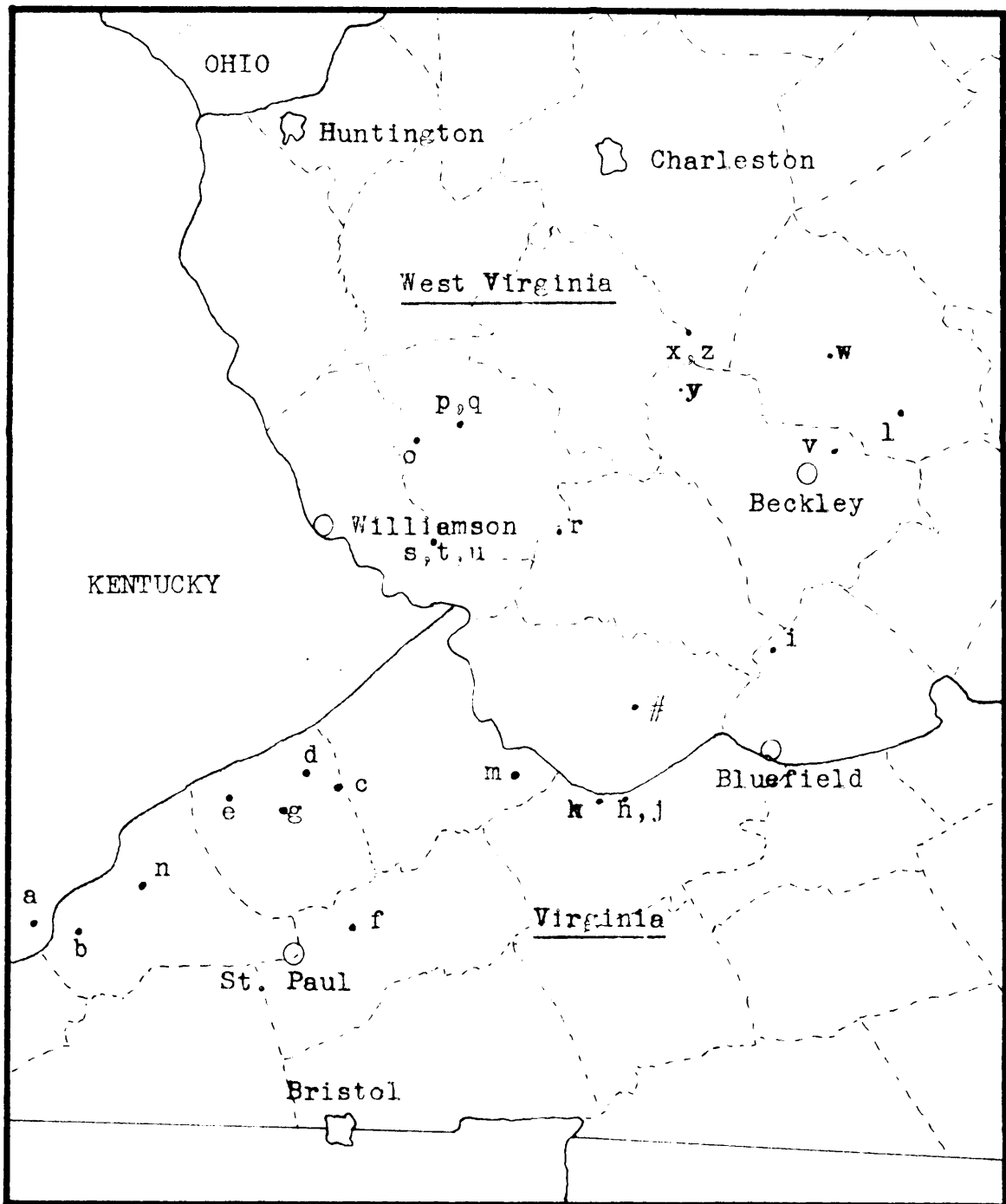
Figure 19. Location of the mines from which the samples were obtained. For the symbols see Tables 5&6.

Table seven. **Results of the analyses on Roof Shales.**

Specimen number.	Answers to the Questionnaire. Questions, A , B & C.			Percentage Composition. a=Water, b=Sand, c=Silt, d=Clay, e=Illite, f=Kaolinite, and g=Chlorite.						
	A.	B.	C.	a.	b.	c.	d.	e.	f.	g.
2	S	Y	S	2	2	60	36	22	10	4
4	S	Y	S	2	30	41	35	26	4	5
5	S	Y	S	1	11	56	30	22	4	4
7	S	N	S	3	20	50	27	18	4	5
10	S	Y	I	2	2	52	44	32	8	4
11	D	Y	S	1	26	46	27	21	3	3
14	D	M	S	1	12	53	34	26	4	4
15	S	N	S	1	35	41	24	20	0	4
17	D	Y	S	3	6	53	38	28	6	4
20	S	N	S	2	23	43	32	29	3	0
22	S	N	S	2	27	52	18	16	2	0
24	S	Y	S	2	21	35	42	26	12	4
25	D	Y	S	2	4	54	40	31	8	1
28	S	M	S	7	1	25	68	48	3	17
31	S	Y	R	1	29	40	30	23	3	4
32	S	M	R	5	1	72	22	14	4	4
34	S	M	S	2	12	60	25	17	5	3
36	D	Y	S	5	3	64	30	24	5	1
39	S	Y	S	2	33	35	29	21	2	6
40	S	Y	S	1	45	37	17	13	2	2
42	S	Y	S	2	16	3	80	59	6	15
45	S	Y	S	1	64	21	15	13	0	2
46	D	N	S	1	38	36	25	20	2	3
49	S	N	S	3	22	51	25	13	6	6
51	S	N	S	3	3	47	46	27	12	7
52	S	N	S	2	12	55	22	10	10	2
54	S	Y	S	2	8	87	3	2	1	0
56	S	N	S	1	40	47	13	9	2	2

Notes:- In question A. 'S' denotes shale and 'D' denotes draw-slate. For question B. 'Y'= yes, 'N'= no, and 'M' is moderately. Similarly for question C. 'I'is the intake, 'R' is the return and 'S' means "Same in both".

Table eight. Results of the analyses on Floor Clays.

Specimen number.	Answers to the Questionnaire. Questions, D,E,F,G,H&I.						Percentage Composition. a=Water, b=Sand, c=Silt, d=Clay, e=Illite, f=Kaolinite, g=Chlorite.						
	D.	E.	F.	G.	H.	I.	a.	b.	c.	d.	e.	f.	g.
1	N	N	Y	Y	Y	Y	2	11	61	26	16	8	2
3	N	N	M	Y	Y	Y	2	9	50	37	25	6	6
6	N	N	Y	Y	N	Y	1	20	65	14	9	3	2
8	N	N	Y	N	N	N	3	28	42	27	19	3	5
9	N	N	N	Y	Y	Y	1	8	68	23	13	9	1
12	Y	Y	Y	N	N	N	1	14	65	19	13	4	2
13	N	N	N	Y	N	N	1	4	65	30	21	3	6
16	N	N	N	N	N	N	1	33	48	18	13	2	3
18	N	N	N	Y	N	Y	5	3	42	50	22	27	1
19	N	N	N	N	N	N	2	15	47	36	25	11	0
21	N	N	N	N	N	N	2	28	51	19	10	9	0
23	N	N	N	M	N	N	2	5	48	45	26	18	1
26	N	N	M	Y	Y	Y	2	7	43	48	37	2	9
27	Y	Y	N	Y	Y	Y	0	83	7	10	5	5	0
29	Y	Y	N	Y	Y	Y	5	2	27	66	66	0	0
30	N	Y	Y	M	N	M	1	4	63	32	21	4	7
33	N	Y	Y	Y	Y	Y	4	1	69	25	18	3	4
35	N	M	M	M	N	M	2	15	62	22	15	4	3
37	N	N	N	N	M	Y	3	4	89	5	3	1	1
38	N	Y	Y	Y	Y	Y	2	17	75	8	6	1	1
41	N	Y	Y	Y	Y	Y	1	23	61	15	12	2	1
43	N	N	N	Y	Y	Y	3	4	59	34	27	0	7
44	Y	Y	Y	Y	Y	Y	2	49	27	22	15	6	1
47	N	Y	Y	Y	Y	Y	2	38	34	26	19	7	0
48	N	N	N	N	N	N	2	8	64	27	16	8	3
50	N	N	N	N	N	N	1	57	34	9	6	3	0
53	N	M	Y	Y	N	Y	2	13	44	41	30	5	6
55	N	M	Y	Y	N	Y	2	7	80	10	6	2	2

Notes:- For questions D,E,F,G,H and I, 'Y'= yes, 'N'= no, and 'M'= moderately.

DISCUSSION OF RESULTS AND CONCLUSIONS

The first conclusion that can be drawn from these results is the extreme variation in the size distribution of the particles of the material. Table nine shows the maximum, average and minimum percentes of each size found in the roof shales, and table ten shows the same factors for the floor clays. From the reported answers to question A we can also see the wide range of opinion concerning roof shales. Of those materials classed as slate, the sand size varied from 1 to 64 percent, while the material reported as draw-slate fell between these limits with a range of sand size from 3 to 38 percent.

The clay mineral analysis shows the same wide range in composition, although illite can be recognised as the major clay component in most of the samples. Tables eleven and twelve give the maximum, average and minimum percentages of illite in the roof and floor material respectively. In the same tables the same data is given for the Kaolinite and Chlorite components. A further conclusion which may be drawn from these results is in the absence of any montmorillonite or other expanding material in any of the specimens. The conclusion here is that there is a negligable amount of this mineral in the overshales and underclays of coal beds in the Pennsylvanian sequence. This confirms the findings of Holland (1956) who found, in extensive studies of the

literature pertaining to these materials only one sample
containing montmorillonite. This too agrees with White (1954)
who maintains that although montmorillonite may cause the
disintegration of some roof materials and the heave of some
floors, it is not essential for strata exhibiting these
phenomenon to contain this mineral, either in the single or
combined states.

Thus we have achieved the first purpose of these tests.
To give a more complete picture of the composition of the
roof shales and floor clays associated with coals of the
Pennsylvanian age. This expands the data brought forward by
Price and Headlee (1942) and Meyertons (1956).

The second purpose of the tests was to see if there was
any correlation between the analyses performed on the material
and their reported characteristics. From the results in
tables seven and eight it can be seen that no such correlat-
ion is present and that the size distribution and clay
mineral composition seem to have no direct bearing upon the
behaviour of the roof and floor material under conditions
of weathering.

It must be noted, however, that these tests have been
subject to severe limitations. The information for evaluating
the behaviour of these materials has of necessity come in the
form of answers to specific questions. This method of ind-
irect evaluation is subject to wide ranges of opinion

Table nine. The composition of roof shales.

Component.	Maximum percentage.	Average percentage.	Minimum percentage.
Water	5	2	0
Sand size	83	18	1
Silt size	89	55	7
Clay size	66	25	5

Table ten. The composition of floor clays.

Component.	Maximum percentage.	Average percentage.	Minimum percentage.
Water	7	2	1
Sand size	64	20	1
Silt size	87	47	3
Clay size	80	31	3

Table eleven. The clay mineral composition of the roof shales.

Component.	Maximum percentage.	Average percentage.	Minimum percentage.
Illite	66	18	3
Kaolinite	27	6	0
Chlorite	9	3	0

Table twelve. The clay mineral composition of the floor clays.

Component.	Maximum percentage.	Average percentage.	Minimum percentage.
Illite	59	23	2
Kaolinite	12	5	0
Chlorite	9	3	0

especially as each questionnaire has been completed by a
different observer. Unfortunately this arrangement was
necessary as a personal visit to each mine, for a duration
long enough to evaluate these factors adequately would take
a prohibitively long time.

These results based on the imperfect answers to the
questionnaire are, however, in the opinion of the author
sufficiently representative to suggest that these factors
are not the controlling ones in the weathering of mine strata.
The information is, however, not sufficiently precise to
state catagorically that they have no effect what so ever.

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APPENDIX

Sample Questionnaires sent to the mines.

Method of taking samples.

The sample shall be taken at a location where the roof shale is SLATE and has not been exposed to the atmosphere longer than one week.

The sample shall consist of a section of the mine roof 6" thick lying immediately on the coal. Using a 1¼ to 2" auger drill 6" holes into the roof and catch the cuttings to fill the sample jar. Where more than one hole is drilled all the holes should be not more than 6" apart.

After collecting the sample place it in the jar provided. Be sure to carefully tighten the lid on the jar so as to make an air tight seal.

Label the jar as follows:

Name of bed.
Name of mine.
Location of mine.
Location in mine.
State whether the sample is top or bottom rock.
Date.

Requested Information.

1. Is the top sampled classed as slate or draw-slate?
2. Does the roof deteriorate when it comes into contact with the air?
3. Where does the roof stand best?
                On intake airways?
                On return airways?
                About the same in both?
4. Name of bed sampled.
5. Is sample top rock or bottom rock.

Sample of Bottom Rock.

The sample shall be taken where the mine floor is slate and has not been exposed to the atmosphere for more than one week.

First thoroughly clean the mine floor and using a $1\frac{1}{2}$ to 2" auger, drill a vertical hole 6" deep. Place the cuttings from the hole into the jar provided. Where more than one hole is drilled, all the holes should be not more than 6" apart.

If a pick is used to obtain the sample, dig a hole approximately 5" in diameter and 6" deep. The diameter of the hole should be the same at the top and bottom when it is complete. Break the cuttings from this hole into pieces no bigger than $\frac{1}{2}$". Then thoroughly mix the cuttings and make into a pile about 8" in diameter. Fill the jar provided with handfuls of the material taken from various parts of the pile. Be sure to tighten the lid of the jar carefully so as to form an air tight seal.

Label the jar as follows:

Name of Coal Bed.
Name of Mine.
Location of Mine.
Location in Mine.
State whether the sample is bottom or top rock.
Date.

Requested Information.

1. Does the floor heave in solid work?
2. Does the floor heave in rooms?
3. Does the floor heave on pillar lines?
4. Does the floor get soft when it stands under water?
5. Does the floor get soft when water is present from ordinary mining operations (that is cutting and loading)?
6. Does the floor get soft when shuttle cars run over it and water is present?

A STUDY OF THE MINERALOGY OF ROOF AND FLOOR
STRATA ASSOCIATED WITH COAL MINES

by

Frank Tasman Fisher

AN ABSTRACT

The size distribution of the grains and the clay mineral composition of the clay material which occurs in the roof and floor strata of coal seams is of interest to the Mining Engineer so that he may realistically judge the effect that weathering of the strata may have upon the extraction process. Many hypotheses and ideas have been put forward to explain the phenomenon of weathering in coal mine workings. Among them is the idea that expanding clay minerals contribute a great deal to the disintegration of the strata. The results of this study, however, show that these minerals are not present to any great extent in the rocks associated with coal seams of the Pennsylvanian age. This confirms the findings of other observers in this field. The results also suggest that neither of the above factors controls the weathering process.