# PETROLOGY AND PETROGRAPHY OF SAMPLES

# FROM TWO ALGOA BASIN CORES

by

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## 1. SUMMARY

Ninety-four samples from two cores drilled in the Uitenhage Group of the Algoa Basin were analysed. The group of sedimentary rocks comprises the Enon, Kirkwood and Sundays River Formations and consists of continental (Enon and Kirkwood Fms.) and marine (Sundays River Fm.) deposits typical of a transgression sequence into an intermontane valley. Only the Kirkwood and Sundays River Formations were intersected in the boreholes but in one - AD 1/68 - 'basement' of Bokkeveld Group is reached, while the other borehole, CO 1/67, did not reach 'basement'.

The Kirkwood Formation sediments are typically red shales interbedded with drab, fine sandstones (wackes) while the Sundays River Formation is typically drab fine to very fine silty sandstones and gray shales of a marine delta environment.

Grain size analyses utilizing wet sieving and pippeting methods showed that two populations of grains are dominant, namely fine to very fine silty sand and clay size material. From the granulometric analyses statistical parameters (e.g. mean, standard deviation, skewness, kurtosis) were calculated and plotted in various combinations. Distinctive trends are thus revealed indicating a mixing of the two sediment populations in varying proportions.

Compaction has resulted in an increase with depth in specific gravity (which varies from about 2,5 to +2,6 gm $cc^{-3}$). Studies of the heavy mineralogy reveals a dominance of garnet (two varieties, colourless and pink) with zircon, sphene, rutile and some others in considerably lesser amounts. Opaque grains are also present, sometimes in dominant amounts.

X-ray diffraction analyses of the <2 $\mu$m clay fraction showed that illite is dominant in both the marine and terrestrial deposits and that chlorite is abundant to infrequent, while montmorillonite is more prevalent in the continentally deposited rocks. Selected clay samples were photographed with both the Transmission and the Scanning Electron Microscopes.

Thin sections of the arenaceous samples reveal that those which are carbonate cemented are relatively free from matrix, while those which are uncemented are matrix-rich. This latter situation can be ascribed to the breakdown, after burial, of the commonly occurring rock fragments which frequently constitute about one-third of the sandstones.

The problem of red beds is considered, and the red pigmentation found in the Kirkwood Formation is believed to be due to oxidation of iron after deposition of the sediment. Intense weathering in the upland source area is not a suitable explanation for the formation of the Kirkwood Formation red beds.

The basin as a whole is considered with attention being focussed on the provenance areas (believed to be the Cape and Lower Karroo Supergroups), the dispersal, depositional environments and the lithification and diagenesis.

Finally, the economic potential is briefly considered and some suggestions for future research are put forward.

CONTENTS

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## 3. GEOLOGICAL SETTING

The Jurassic-Cretaceous rocks of the Algoa Bay Basin (the Uitenhage Group) are of the "molasse" type, with fanglomerates grading into variegated argillaceous and arenaceous sediments of a paralic environment. These latter rocks grade laterally and vertically into shales, siltstones and subordinate sandstones which are attributed to a marine transgression.

The initial coarse, clastic material (the Enon Formation) was derived from the long, E -W to SE - NW anticlines of the Cape Fold Belt. These large folds are often overturned and many are fault-bounded on their Northern boundaries, having downthrows to the South. The Zuurberg Fault which forms the Northern boundary of the Algoa Basin has a clearly defined fault-scarp. HILL, 1972, rejects the existence of a fault bounding the Algoa Basin although conceding faulting in the adjacent Cape and Karoo Supergroup rocks. The variegated sediments of the 'Kirkwood Formation' are mainly fine-grained, brightly coloured sediments deposited under lacustrine or paralic conditions. These are succeeded and overstepped by the marine sequence known as the 'Sundays River Formation', (WINTER, 1973 ; DINGLE, 1973).

The rocks forming the 'basement' of this basin belong to the Cape Supergroup (Table Mountain and Bokkeveld Groups) while immediately adjacent to the basin on the Northern, fault-bounded side are the Dwyka Group (Karoo Supergroup) sediments as well as Witteberg Group (Cape) quartzites. Further to the North, as possible provenance rocks, are the Ecca and Beaufort Groups (Karoo). The hard, brittle, quartzites of the Table Mountain Group under the Southern portion of the basin are also exposed as 'islands' sticking up through the younger sediments, e.g. Coega Kop. In the central and Northern portions the predominantly argillaceous Bokkeveld Group rocks underlie the Uitenhage Group. These older rocks are highly folded and foliated.

In the extreme West, North-west and North are volcanics which were associated with the Karoo volcanics (Du TOIT, 1954) but are now believed to be of upper Cretaceous age (see DINGLE, 1973, p. 39). HILL, 1972, on the other hand believes these extrusives to be conformably below the Enon Formation, which would result in the volcanics being of Middle to Lower Jurassic age. Notwithstanding these findings, HILL, 1972, does report that a single radiometric dating of 80 - 90 my. has been obtained from the Zuurberg volcanics.

Large areas of the basin are covered by Tertiary and younger rocks and alluvium. (For a discussion of the Tertiary sequence see SIESSER, 1971; DINGLE, 1971).

Because the 'basement' of Cape Supergroup rocks was folded prior to deposition in the Algoa Basin, the Uitenhage Group is not uniformly distributed with respect to thickness. In fact, the basin as a whole can be divided into three sub-basins each separated by a 'basement high'. Deformation of the Uitenhage Group is, when compared with the underlying sediments, slight and although there has been open-type folding as well as faulting, all topographic expression of the faulting has been obscured by the Sundays River Formation and younger beds with but a few minor exceptions.

Economically, the Algoa Basin is considered to be a potential petroleum/natural gas producing area motivating exploration and research.

# 4. ANALYTICAL METHODS

## 4.1 Hand Specimen Descriptions

Upon receipt of the samples each was weighed to the nearest gram (the samples varied between 35 and 730 grams although most were between about 100 and 300 grams) and described as fully as possible, noting primary and secondary structures, nodules, concretions etc. The samples were allocated colours according to the Rock-Color Chart, 1963, and where there were inhomogenieties each was assigned a colour. Photographic records (black-and-white prints and a few colour transparencies) were made of all the samples with particular interest being taken in those which displayed primary sedimentary structures.

It is unfortunate that none of the samples had any orientation markings in order that they could be photographed the "right way up" with absolute certainty. This is particularly important when the sample is reasonably homogeneous. Geographical orientation of the samples is not at all possible.

## 4.2 Thin Sections

An attempt was made to have thin sections cut for all samples but this proved to be impossible due to the fact that many of the samples are not well indurated, and having large amounts of fine material are not suscectible to impregnation. The elaborate procedure necessary for dry thin sectioning was not considered to be justified. Whenever thin sections were made they were carefully examined under the photograph microscope.

A few selected, coarser grained samples were analysed in detail, using a mechanical stage and counting 1000 points to obtain a modal analysis. Diagram 3 shows the variation resulting from less than about 500 counted points. Over this value the uniformity is reasonable. However, in some cases the graph did not level off at >1000 points due to many of the feldspar grains being highly altered and rock fragments being numerous, making positive identification of these two phases, as well as 'matrix', uncertain and ambiguous.

An attempt was also made to do size analyses in thin section. But due to the fineness of the grain-size as well as the reasons adversely affecting the modal analysis mentioned above and the general uncertainty of the whole concept with relation to sieve analyses, this aspect was not pursued.

## 4.3 Size Analysis

### 4.3.1 Methods

To do a size analysis on the samples it was first necessary to disaggregate them, and in this respect it was found that remarkable variations in the degree of compaction, cementation or induration were present even in adjacent, lithologically similar samples. The first step in the disaggregation procedure was to place a sub-sample of about 20 - 25 grams in a clean plastic dish containing about 300 ml. of distilled water. This was enough to cause the complete breakdown of some of the samples. Stubborn cases needed more drastic treatment however, and either dilute HCl or dilute NaOH was used. In general, the scheme advocated by FOLK, 1968, (p. 17 - 18) was adhered to and proved to be reasonably satisfactory.

For the argillaceous samples, the disaggregated material was passed through a 230-mesh sieve (63 $\mu$m) and any material left on the screen was checked under the binocular microscope to ensure that it was not in aggregate form. All the material that did pass through the sieve was placed in a 1 litre measuring cylinder and a size analysis utilizing the pipette method was followed. The details involved in both the method and the calculation are fully described in FOLK, 1968, p. 37 - 40. As a dispersant, 5 grams of sodium hexametaphosphate (Calgon) was used and withdrawals were made at 1 Ø intervals. (Phi (Ø) = $-\log_2$ diameter in millimetres.) ROGERS, 1971, p. 84, (from Van Andel & Franklin, 1968) has a convenient chart of pipetting depth against time of withdrawals and temperature. He also has a scheme for analysing twelve samples simultaneously, as well as a more simplified calculation procedure (personal communication) than that of FOLK, 1968. An example of the calculation and the pipetting table (which had to be extended temperature-wise) is given in Appendix C.

For those samples which had more than 10 percent (by mass) of material remaining on the 63 µm sieve, as well as the arenaceous samples, recourse had to be made to wet-sieving. Quarter phi intervals were used. Due to the small amounts of sample available, it was not possible to use more than about 60 grams of sample although 10 to 30 grams were usually used. When more than 10 percent (by mass) of the material passed through the 63 µm screen this material was subjected to pipette size analysis as described above.

### 4.3.2 <u>Discussion</u>

It is of interest to note that the results of, and conclusions drawn from size analyses have been questioned, and numerous authors have warned of the difficulties involved in comparing analyses of recent, unconsolidated sediments with those of older sediments. SELLEY, 1970, cautions against errors and oversimplifications that can result while, concerning the size analysis itself SWIFT, et al., 1972, state that "one of the most difficult problems in any size analysis of fine-grained suspended sediment is the preservation of the naturally occurring size distribution throughout sampling and analysis. Ideally the particle size would be measured by means of an in situ analyser. ... The ultimate size distribution, which is obtained by dispersing the suspension by means of peptizing agents, has very little diagnostic value in the interpretation of the sedimentary processes. The practice of peptizing was initiated by students of ancient sediments who sought the 'ultimate' size distribution, since the size distribution at the time of deposition could not be recovered" (p. 123). Furthermore, "a clay floccule with a diameter of 500 microns may settle with a velocity of a quartz sphere of 20 microns" (Op. cit. p. 123).

From the work of VISHER, 1969; ROGERS, 1971, and others, material finer than about 4 phi is in one of two forms of suspension in the aqueous environment, namely graded or homogeneous, and "the structure of suspended sediment particles may be as variable as their composition" (SWIFT, et al, 1972, p. 123). These structures can never be duplicated during the size analysis process, let alone the physico-chemical conditions pertaining to the fluid in which the rock-forming material settled out of suspension.

CROSBY, 1972, also draws attention to the importance of "the physical and chemical conditions in the water overlying the site of deposition" (p. 8). Not having access to the conditions (physico-chemical) at the time of deposition of an 'ancient' sediment, one is forced when doing size analyses to adopt a standard procedure. Thus, samples from fresh water, paralic and marine environments have been analysed alike. In his review MOON, 1972, illustrates various structures or 'domains' envisaged by different authors and one can but wonder how closely these domains compare with those of the highly artificial environment of the size analysis cylinder.

WEAVER, 1967, (p. 38) states "expanded clay minerals... which are in contact with the formation brine are flocculated and unexpanded. ... When the cation concentration of the brine is decreased by the injection of fresh water, the clays deflocculate and expand". DUANE, 1964, goes further (p. 866) and "questions the validity of size analysis of the fine fraction obtained by pipette method. Whitehouse, et al. (1959) showed that when clay minerals settled out of saline waters they do so as aggregates, not as individual grains, adding that aggregation is a reversable process. Therefore, in the complete disaggregation of Recent sediments prior to pipetting or sieving the size characteristics of the original fine particles that settled out of suspension may be altered with the result that spurious data would be obtained leading to inaccurate conclusions".

The photomicrographs (Plate II) of thin sections of samples from the present study show that minerals are in all stages of alteration and that argillaceous rock fragments are present. During disaggregation it is highly likely that portions of what was a sand-sized clastic particle during transport and deposition can be substantially reduced in size to silt and clay sized material. This will affect the proportions of each grade, the size analysis and the resulting conclusions.

Notwithstanding these above mentioned difficulties and uncertainties, size analyses were carried out and the data obtained can be of value, particularly when combined with other data such as the geometry of the sedimentary body, it's lithology, sedimentary structures, palaeocurrent pattern and fossils (see SELLEY, 1970, p. 2).

## 4.4 Specific Gravity

The specific gravity of the samples as measured on the drill-site and recorded on the well-logs (kindly supplied by the Geological Survey of South Africa) show a range of values. As the depths at which the well-site S.G.'s were measured does not necessarily correspond to those of the present study, the author undertook to measure the specific gravity of those samples available to him.

Initially an attempt was made to do the measurements by means of a Jolly Balance but the results obtained were not reproducible. An alternative method was sought and the pycnometer bottle was utilized. This required the accurate weighing (to 2 significant decimal places of a gram) of:-

a) the sample when dry

b) the pycnometer bottle full of distilled water

c) the bottle plus water plus sample

The specific gravity was then calculated using the following formula:- $\frac{a}{(a + b) - c}$

i.e. dividing the weight of the sample by the weight of the water displaced by the sample.

The results were found to be reproducible and accurate to within $\pm$ 0,02 gram/cm$^3$. and are shown in Table I and Diagram 12.

## 4.5 Oriented Slides for X-ray Diffraction

### 4.5.1 Method

To examine the clay mineralogy, slides of the clay fraction were prepared in such a way as to get preferred orientation of these platy minerals, and therefore enhancement of basal reflections of the X-radiation.

Two methods were used to prepare these slides. Firstly, on completion of a size analysis by the pipette method the cylinders were restirred. After being allowed to resettle for about 20 minutes the top 6 centimetres of the suspension was syphoned off into flat bottomed vessels each containing 2 or more glass slides. This suspension was then allowed to evaporate to dryness. However this proved to be a very lengthy procedure and after personal discussion with Prof. A. Ruotsala, Mr. A.B. Simpson and others it was abandoned in preference to the method described below.

The second method is far more time-saving and gives equally good results. The cylinders were not stirred after completion of the pipette size analysis. A pipette or dropper was used to draw up some of the suspension from a depth of between 10 and 12 centimetres after at least 12 hours of settling from initial stirring at 20$^\circ$ C. This drawn-up suspension was then allowed to run onto 2 or more glass slides, and was evaporated to dryness. Due to the time saved by this method of preparation it was generally adopted.

## 4.6 X-ray Diffraction of Oriented Slides

### 4.6.1 Method

Once prepared the 'oriented slides' were X-rayed using a Philips P.W. 1051 X-ray Diffractometer. Nickel-filtered, Copper radiation (1,54178 A$^{o}$) was used and various chart and goniometer speeds as well as various voltage and amperage settings were made use of to obtain the best possible chart records (diffractograms). All slides were X-rayed in the 'untreated' and glycollated state, while selected slides were treated with HCl and also heated to 600$^{o}$C.

It should be noted that this particular machine gives an "escape peak" (PHILIPS, 1966) when run at a potential of greater than 35 Kv. and not strictly monochromatic radiation, e.g. by using a crystal monochromator. This peak will only disappear when the voltage is less than 34,5 Kv. To check that the "escape peak" is present, 'diffractograms' of a plain glass slide and an aluminium sample holder were run. These two are shown in Diagram 16b. It can be seen that the peak will mask the 001 peak of chlorite (at about 6,5$^{o}$ 2$\theta$, 14 A$^{o}$) to a certain degree .

### 4.6.2 Discussion

GIBBS, 1965, has criticised the above mentioned methods of preparation of the oriented slides as well as any other involving the settling of the particles onto the mount. He regards the smear-on glass, suction-on-tile and the powder press as the only methods which are acceptable. He bases his argument on the fact that various clay minerals have inherently different sizes (cf. GRIM, 1953) . Thus settling will cause mineralogical differences and therefore inaccurate quantitative results. To check this, the author prepared a sample using the sedimentation procedure and X-rayed both the top and the bottom of the sample. The diffractograms are shown in Diagram 16 and discussed in a later section. DANCHIN, 1970; HOFMEYER, 1971; and FESQ, personal communication, all favour the use of the pressed pellet method for clay mineral studies, but due to the paucity of sample this method could not be used.

From what has been stated above it can be seen that there is no consistency in the method of preparation between different laboratories (cf. PIERCE and SIEGEL, 1969) and any form of quantitative data obtained from X-ray studies of clay minerals must be treated with the greatest caution. DANCHIN, 1970, and HOFMEYER, 1971, have sounded clear words of warning on this subject and from the work of PIERCE and SIEGEL, 1969, it is clear that calculations from diffractograms might be precise but "accurate quantitative results are unobtainable" (p. 187). This is due to such problems as the degree of crystallinity and chemical uniformity within and between mineral species, particle size and the preferred orientation effects as well as the actual calculation procedure from the diffractograms themselves.

## 4.7 Heavy Minerals

### 4.7.1 Method

Disaggregated portions of the six selected samples were used to obtain the heavy mineral fraction. Separation of the minerals was done using bromoform (S.G.~2,8) in a separating funnel.

Once separated a portion of the heavy fraction was used for preparing slides of the crop, mounted in epoxy resin, while in two cases (AD 990 and CO 3540) where there was a distinct pink colouration due to garnet, single grains were recovered and further analysed. These grains were individually measured in high refractive index liquids, matching being done in monochromatic Na light, ($\lambda$ = 5890A$^{o}$). The R.I. of the matching liquid was measured in a Leitz-Jelley refractometer, again using Na light. Five readings of each grain were taken and averaged arithmetically. The precision was found to be $\pm$ 0,003.

A further portion of the heavy mineral crop was used for the production of an X-ray diffractogram. Once again Nickel-filtered, Copper radiation was used. Because of the small amount of sample available it was necessary to make a smear-on-glass mount. The machine conditions were as follows: 48 Kv, 20mA, 1$^{o}$ 2θ/min. goniometer speed and 1600 mm/hr. chart speed.

The grain mounts were subjected to point count and at least 500 grains on each slide were counted. The results of this count is presented in Table II.

## 5. DISCUSSION OF RESULTS

### 5.1 Grain-size Parameters

#### 5.1.1 Parameters Used

The following are the parameters that have been used in the statistical analysis of the grain-size distributions determined by either wet-sieving or pipette analysis or both. (Calculation of all these parameters was done manually while parameters 1 to 5 were checked utilizing a computer program (see Appendix IV) run on an I.C.L. 1904A computer).

1) Graphic Mean (Mz) :-

$$\frac{\phi 16 + \phi 50 + \phi 84}{3}$$

2) Inclusive Graphic Standard Deviation ($\sigma_I$) :-

$$\frac{\phi 16 - \phi 84}{4} + \frac{\phi 5 - \phi 95}{6,6}$$

3) Inclusive Graphic Skewness ($Sk_I$) :-

$$\frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

4) Graphic Kurtosis ($K_G$) :-

$$\frac{\phi 95 - \phi 5}{2{,}44(\phi 75 - \phi 25)}$$

5) Transformed Kurtosis ($K_G'$) :-

$K_G/1 + K_G$

6) Median Diameter (Md) :-

in millimetres

7) Arithmetic Quartile Deviation (QDa) :-

$(Q_3 - Q_1) / 2$

8) Arithmetic Quartile Skewness (Ska) :-

$(Q_3 + Q_1 - 2\ Md) / 2$

(16th and 84th percentile diameter substituted for $Q_3$ and $Q_1$)

Parameters 1) to 5) are from FOLK, 1968, p.45 - 48, while parameters 6) to 8) are from BULLER and Mc MANUS, 1972, p. 4.

### 5.1.2 Discussion

For many decades various workers have been applying statistical treatment to the frequency distributions obtained from grain size analysis which have been done using every conceivable method. Numerous formulae have been proposed and used for calculating the various statistical moments. FOLK, 1966, has reviewed the "many graphical and mathematical techniques that have been proposed for the statistical summary of grain-size data" (p. 73).

However, most of what has been written by so many authors concerns the application of the statistical treatment of grain size data to the problem of environments of deposition. FOLK and WARD, 1957, in their classic work on the Brazos River Bar used the third and fourth moments (skewness and kurtosis respectively) to show the mixing of two populations, and also derived their helical trend from the relationship existing between the first four moments, namely mean size, standard deviation, skewness and kurtosis. Championing the use of arithmetic probability paper for cumulative plots of grain size data these authors state that "it is a waste of time to plot analyses on any other type of paper" (Op. cit. p. 6).

MASON and FOLK, 1958, have used skewness and kurtosis for environmental separation (beach vs. dune vs. aeolian) and DUANE, 1964, found "that the sign of skewness is environmentally sensitive" (p. 864) and having skewness values ranging from -1,59 to + 1,60 showed that when plotted "in map form according to environments a trend can be seen to emerge" (p. 867).

On the other hand SOLOHUB and KLOVAN, 1970, have sounded a warning "that depositional environments cannot be recognised from the grain size data in lacustrine settings" (p. 100). In similar vein CRONAN, 1972, expresses the view "that the prime influence on skewness is the proportions in which the various grain-size populations in a sediment are mixed... (and) that caution should be exercised in attempting to use skewness in characterizing depositional environments of polymodal sediments and that in such characterizations the nature and degree of polymodality should be taken into account". (p. 105 - 106).

THOMAS, et al., 1972, has shown that in Lake Ontario "inshore coarser sediments are positively skewed whereas the offshore basin sediments are negatively skewed" (p. 76).

BULLER and McMANUS, 1972, have been able to show that the use of metric statistics are of value in defining depositional environments. They favour the measures Md, Qda and Ska (median diameter in millimetres, arithmetic quartile deviation and arithmetic skewness respectively) as defined on page 13 and they plot data on double-log paper. Although this is not advocated by FOLK and WARD, 1957, VISHER, 1969, and others, very definite trends are evident when various combinations of statistical parameters are plotted.

PASSEGA, 1964, has developed the "C M Pattern" in which values of the one percentile (in microns) are plotted against the median diameter (also in microns) on double-log paper. "Each sample should be a deposit of homogeneous sedimentation" (p. 831). PASSEGA also gives a diagram of the relationship between population and transport dynamics (Fig. 1, p. 831).

It is the present author's belief that PASSEGA's form of representation of data is not suitable for general acceptance in that so many samples of both Recent and "ancient" sediments are not "homogeneous sedimentation" units. Analytical difficulties would become too complex, particularly in the older sediments, if this method of representation of data were to be adopted. It is also felt that perception and comprehension of plots in the C M Pattern with respect to geological significance are far from easy.

There is however, no implication made that the arithmetic probability versus phi-diameter plots are easy to decipher and understand, but with a little practice the characteristics of the phi-notation become meaningful.

SELLEY, 1970, claims that while granulometric analyses of Recent sediment taken from known depositional environments may reveal patterns when treated statistically, the reverse procedure of analysing ancient sediments and trying to derive the environment of deposition from the "various statistical gymnastics" (p. 5) performed on the grain size data has largely proved unsatisfactory. Gross oversimplifications and/or complications as well as errors may also result. The reasons are several: first, that the previous history of the sediment will also affect it's characteristics, not just the depositional environment; second, the fine material may not have been deposited at the same time as the rest of the detritus. The work of CUMMINGS, 1962, in this respect is of interest and will be discussed more fully in a later section.

The difficulties and uncertainties mentioned in connection with the size analysis procedure for fine grained rocks are also pertinent to the above discussion. Obviously, if an analytical procedure is subject to uncertainties and frought with unanswered assumptions, the data obtained from such conditions are even less certain.

Notwithstanding these objections and difficulties the work of VISHER, 1969, is of interest. He granulometrically analysed samples from numerous environments of deposition and by plotting the results of these analyses on arithmetic probability paper he has been able to 'define' the various environments. Of more interest still however, is the relationship that VISHER has been able to show to exist between sediment transport dynamics and population and truncation points in the size distribution. Unfortunately the work is restricted to sediment of the sand size range and is not carried into the finer grades.

5.2 Size Analyses

The raw data obtained from the granulometric analyses was plotted on arithmetic probability paper with cumulative per cent versus phi (Ø) diameter. The first four statistical moments were calculated by one or more of the formulae given earlier (p. 12, 13) and the results are given in TABLE I. Various moments have been plotted one against each other in an attempt to arrive at some meaningful diagnostics, and these are shown in Diagrams 4 to 11.

The Mean size ($M_z$) shows variations between 1,9 Ø and 9,8 Ø with the mean of the Means being 5,1Ø ± 1,9 Ø (i.e. about 0,03 mm ranging from 0,12 to 0,008 mm). However the significance of these values must be interpreted with the utmost caution. Should a sample consist of say two logarithmetically normally distributed populations (it is believed that this is the case as many of the plots have straight line segments, cf. Diagram 13) a simple mean does not take this into account and the mean will fall closer to the dominant population. Furthermore, as pointed out by SPENCER, 1963, SELLEY, 1970, and others, it is unwise to make dogmatic associations between the mean size and the velocity of the transportation medium. Under high energy conditions there will be very little deposition of whatever fine material is being transported and any material that is deposited will be a fair indication of the environment. But under low energy conditions, when fine material is deposited, the nature of the source is of the utmost importance. From the data supplied by PETTIJOHN, 1957, p. 594, it can be calculated that material the size of the means mentioned above (~ 0,1 to ~ 0,01 mm) need have a maximum suspension velocity of only about 8 cm/sec (about $1\frac{1}{2}$ miles an hour.)

The diagram (Diagram 7) of the relationship between mean size and standard deviation (or sorting) is particularly important. It can be seen that as the grain size decreases the sorting follows sympathetically, but at a region of mean size about 7 Ø and standard deviation about 2 Ø the sorting begins to improve as the grains sizes become smaller. This can be adequately explained as being due to the mixing of two moderately well sorted populations, namely fine to very fine sand (mean size 2 to 4 Ø) and clay (mean size 9 Ø and smaller). When the two populations are mixed in sub-equal proportions - giving a mean size of about 6 Ø - the sorting is at its worst. That there are two populations can be seen from the photographs of PLATE I where light and dark laminations can be seen, being the coarser and finer material respectively. Some samples are essentially "pure end-member populations" and show the characteristically low sorting values of less than 1,0 Ø. (The fact that none of the very fine grained samples show low sorting values can be attributed to the inability to completely disaggregate the hard, indurated material. Also the relatively high sorting values of between 0,5 and 1,0 Ø for the coarser material can be ascribed to some clay matrix being formed from the breakdown of rock fragments and other unstable minerals of sand size. This will be discussed in greater detail in a later section.)

As has been shown by FOLK and WARD, 1957, the relationship between mean size and sorting ($\sigma_I$) is that of a portion of a sine wave for any particular suite of rocks. This trend is confirmed in the present study (Diagram 7) where the crest of the wave (i.e. the poorest sorted material) is due to the mixing of two relatively pure populations in an energy environment where no further sorting can take place. This is most likely to take place in the lagoonal type of setting where the energy conditions are low.

From Diagram 8 it can be seen that all but two of the samples analysed are positively skewed. As with the standard deviation the samples which show the least skewness or a nearly symmetrical distribution ($Sk_I$ = 0,00) are those belonging to the "end-member populations". As the two populations become mixed so the skewness values increase. The positive skewness of the majority of the samples indicated that there is more coarse than fine material. It is here suggested that the observed results do not reflect the absolute truth in that more samples should show negative skewness i.e. more fine material and that the erroneous situation is due to the incomplete disaggregation of the samples prior to size analysis. As most of the theoretical considerations pertaining to the grain size distributions and associated parameters of a particular milieu have been arrived at from the study of Recent sediments, the problem of disaggregation has not affected these studies. Thus the effect of mixing populations of various grain sizes - which is "the prime influence on skewness" (CRONAN, 1972, p. 105) - can be depressed and complicated in the older, consolidated sediments.

The proportions in which the two populations are mixed also has a very marked effect on the kurtosis parameter (cf. Figs. 1 and 2 in SPENCER, 1963). From Diagram 9 it can be seen that the coarser samples i.e. with $M_z$ between 2∅ and 4∅, are those which are most leptokurtic ($K_G$ more than 1,11 cf. FOLK, 1968, p. 48 for the verbal limits of kurtosis). This is due to the fact that only small amounts of the clay sized material are present. From TABLE I it can be seen that those samples which are very or extremely leptokurtic (i.e. $K_G > 1{,}50$) have, with few exceptions, less than 15% clay material. Also from this table, "those samples which have sub-equal amounts of the two populations are the ones which approach a platykurtic curve, i.e. having $K_G < 1{,}11$.

The relationship that exists between the sorting (standard deviation) and the skewness has been shown by FOLK and WARD, 1957, to be that of a circular or elliptical pattern. As the present author's samples are all (except two) positively skewed this trend is not apparent. It is probable that should disaggregation have been more complete there would have been larger amounts of fine material present and this would have had the effect of moving the mode to the right and thus resulted in more negatively skewed values.

The relationship between the sorting and the kurtosis is complex and obscure. It should be mentioned however that those samples which are platykurtic are those which are poorly sorted i.e. due to mixing of two or more populations.

Diagram 6 shows the relationship between skewness ($Sk_I$) and kurtosis ($K_G$). It is seen that "nearly all leptokurtic curves ... show extreme skewness" FOLK and WARD, 1957, p. 22) and as the curve flattens (i.e. $K_G$ gets smaller) so the curve approaches being symmetrical ($SK_I$ =

0,00). This can be explained as follows: A fairly pure fine sand ($\pm$ 85% sand) will have a very dominant mode and therefore be peaked ($K_G > 3,0$) but the remaining $\pm$ 15% of the clay fraction will impart a distinct "tail" to the frequency curve giving a strong positive skewness ($Sk_K > + 0,5$). As more and more of the clay fraction is added, so the frequency curve takes on a bimodal nature and the overall kurtosis is reduced to become more normally distributed and symmetrical.

A complex and yet useful method of representation of the four statistical parameters $M_z$, $\sigma_I$, $Sk_I$, and $K_G$ can be obtained by plotting them together. An helical curve results "which probably goes through several ... cycles" (Ibid., p. 24, Fig. 18).

It is therefore apparent that the samples analysed in the present study are basically a mixture of "fundamental populations of log-normal grain sizes" (SPENCER, 1963, p. 183). The one population is of fine to very fine sand and the other of clay sized material, which are mixed in varying proportions to give the observed bimodality of the frequency distributions and their associated statistical parameters.

In a recent work BULLER and McMANUS, 1972, have made use of "simple arithmetic measures based on metric scales for the description and analysis of those sediments which exhibit a considerable range of average grain-sizes" (p. 2). They plotted their results on double logarithmetic paper. They further state "that as sediments become finer so they become better sorted" (p. 6) which is to a certain degree at variance with the work of FOLK and WARD, 1957, who have found the sine wave relationship between sorting and mean size. The reason for the difference of opinion is that the latter workers used a formula for sorting which covers 90% of the distribution curve while the former workers only utilized the central 68% of the curve. As has been shown above, small percentage of material of a markedly different size added to a log-normally distributed population has a very marked effect on the sorting parameter.

If, instead of calculating the sorting (QDa) utilizing only the central 68% of the sediment population, 90% is taken into consideration, it is found that there is a marked reduction in the quality of the sorting. Finer material is about 20% more poorly sorted and coarser material about 5% more poorly sorted when the larger portion of the distribution curve is considered. The validity of the above-mentioned statement "that as sediments become finer so they become better sorted" is therefore questionable. Also, as has been mentioned above the significance of the mean (and even more so the median which is plotted against QDa) must be treated with the utmost caution. The median in particular, does not take any form of polymodality into account and FOLK, 1968, p. 45, states that "its use is not recommended".

BULLER and McMANUS, 1972, further claim "the phi transformation produces simple units whose substitution into formulae makes computation easy. The danger of the phi system lies in the computational simplicity of the statistical formulae leading workers to expect statistical values that are easy to interpret. The paradox of this simplification is that the results are more difficult to interpret in geological terms: the more complex the phi-based formula (as for skewness and kurtosis) the more difficult they are to interpret" (p. 4). This has clearly been shown not to be the case as the work of FOLK and WARD, 1957, SPENCER, 1963, VISHER, 1969, ROGERS, 1971, CRONAN, 1972, THOMAS, et al., 1972, and others who have been able to recognise the mixing of log-normal, or nearly so, populations (usually two such populations) in varying amounts.

Each log-normal population can be recognised by the straight line plot it makes on an arithmetic probability vs. phi diameter cumulative frequency curve of a size analysis. From the pioneer work of FOLK and WARD, 1957, and the numerous published works supporting their findings, it is indeed surprising that a reversion to a lengthy and cumbersome calculation procedure - one of the parameters of which (QDa) is not sufficiently accurate to allow valid conclusions to be drawn and another (Md) the use of which is not recommended - should be proposed. From such plots very little can be deduced; one can only really plot data and hope that it will fall on one or other of the regression lines and in so doing "define" an environment of deposition.

## 5.3 Textural Attributes

From Diag. I (and it's corresponding histogram, Diag. 2) it can be seen that there is a marked spread in the textural characteristics. It will be noted that sand sized material forms less than 20% of the total of the samples analysed while silt and silty-clay sized material accounts for nearly 68%. Also of interest is the fact that no 'true' clay sized material was found.

PETTIJOHN, 1957, p.51 states, "that neither disintegration nor decomposition yields silt in appreciable amounts", while SPENCER, 1963, p. 189, claims "that the construction of facies maps using a sand-silt-clay triangle has no genetic meaning for silt as a genetic class does not exist". This conclusion is further strengthened by the work of THOMAS, et al., who have a mixture of sand and clay in the Lake Ontario sediments as well as a silt mode but this latter population is a carbonate fraction and can thus be discounted in a consideration of the deposition of clastic material.

It is therefore apparent that the high silt content of the presently studied rocks is due to the inability of the analytical technique to sufficiently well or completely disaggregate the samples into the constituent populations of sand and clay. Thus an unnaturally high percentage of a population is found which does not in fact exist. It is felt that more complete disaggregation of these indurated sediments would reveal them to be composed of two populations, namely fine and very fine sand and clay.

These remarks are borne out by the declarations of SELLEY, 1970, and the photomicrographs (Plate II) of the coarser grained samples, where it can be seen that numerous grains would not have been able to survive transport had they been in the state that they are now. This breakdown of the more unstable material subsequent to deposition can and has caused serious deviations from the true situation pertaining at the time of deposition.

## 5.4 Specific Gravity

Diagram 12 shows the results of the specific gravity determinations - by pycnometer bottle - for the two sets of core samples (see also TABLE I). It is immediately apparent that the samples from the Colchester borehole (CO 1/67) have a higher overall specific gravity than do the Addo (AD 1/68) borehole samples. The CO 1/67 samples range in value from 2,51 to 2,66 gm $cc^{-3}$ and average 2,61 $\pm$ 0.03 gm $cc^{-3}$, while the corresponding values for the AD 1/68 samples are 2,46 to 2,64 and 2,55 $\pm$ 0,04 gm $cc^{-3}$.

However, if the results are subdivided into formational groups one finds that the marine deposits of the Sundays River Formation have consistently lower S.G. values than the terrestrial Kirkwood Formation as can be seen from the table below:-

| | CO 1/67 | AD 1/68 | Mean |
|---|---|---|---|
| Sundays River Fm. | 2,59 | 2,53 | 2,53 $\pm$ 0,04 |
| Kirkwood Fm. | 2,63 | 2,57 | 2,60 $\pm$ 0,04 |
| Mean | 2,61 | 2,55 | |

Although the lower (Kirkwood) formation has higher S.G. values in both cores, the spread of values i.e. the standard deviation, throughout the entire length of the two cores is constant.

The progressive increase in the S.G. with depth has been explained by WINTER, 1973, as being due to compaction and a lithological variation. From Diagram 12 it is clear that in AD 1/68 there is a reasonably clear change in the S.G. values when one moves into the Kirkwood Fm. from the Sundays River Fm., but this trend is not apparent in the CO 1/67 borehole. To rely entirely on compaction as the force necessary to increase the S.G. does not appear to be very satisfactory for two reasons, namely:- (a) the standard deviation of the S.G. results is consistent throughout the entire length of the core and (b) examination of thin sections from both cores does not reveal any particularly marked increase in the amount of compaction characteristics such as interpenetration of competent grains or increases in the amount of silica cement which could have resulted from the pressure solution of quartz grains.

It is more difficult to propose, however, an alternative explanation for the increase of the S.G. values with depth. That compaction has been a contributing factor cannot be excluded as samples from similar depths from the two cores have similar values. But that different lithological units should compact at similar rates is incongruous, and a combination of physical and chemical conditions i.e. pressure and the alteration of unstable grains and rock fragments, is thought to be primarily responsible for the increase in specific gravity with increasing depth below the surface.

## 5.5 Clay Mineralogy

### 5.5.1 Discussion

From a purely geological point of view many aspects of clay mineralogy are still not clearly understood. The whole subject is in a state of flux and little agreement has been reached concerning many aspects.

Within a fairly thick body of fine grained sedimentary rock — as is found in the Algoa Basin — lateral and vertical variations in the mineralogy as well as the structure, texture, etc. are to be expected and are found to be the rule rather than the exception.

There are three schools of thought regarding the origin of these dissimilarities of the clay mineralogy. The first group of workers explains the heterogeneity as being primarily due to the changes in the source area of supply of what they consider to be purely detrital clay-mineral sized material. The changes in the provenance area may be either petrological or climatical or both. Another group of workers sees the diversities in the clay content as being due to sorting of the inherently different sizes of the clay particles or floccules by the currents of the transportation medium. The last group explain the lateral and vertical variations of the clay mineralogy as being due to the alteration and modification of pre-existing i.e. detrital, (clay) minerals at the site of deposition and by subsequent lithification, i.e they believe that most of the clay minerals are of a diagenetic nature or have been changed by post-depostional processes.

It is possible in some instances to be reasonably certain which of the three possible modes of origin is most likely to have been operative. For example, if the clay mineral content of beds which have markedly different depositional environment characteristics is the same, then it is likely that the mineralogy was controlled by the source area conditions. When the mineralogy however, varies in rocks of the same depositional sequence, either the provenance area has undergone lithologic or climatic variation or diagenetic alteration has been operative. To unravel the correct solution from these possibilities is by no means an easy task.

### 5.5.2 Results

Diagrams 14 and 15 are an attempt to show the variations of the clay mineralogy with depth in the two sets of core samples. The percentage of clay in the total sample is obtained from the size analysis results. (See Table I) and the proportions of the different clay mineral species were obtained by using the method of JOHNS, et al., 1954, and PIERCE and SIEGEL, 1969, i.e. the areas of the 17A°, 10A° and 7A° peaks of the diffractogram obtained from the glycollated sample are measured with the 10A° peak area being multiplied by a factor of four to give the relative percentage of illite and the other two peaks (17A° and 7A°) being the relative percentages of montmorillonite and chlorite plus kaolinite respectively. No attempt was made to separate the relative amounts of chlorite and kaolinite but those samples in which kaolinite forms an appreciable amount of the clay fraction (recognised after heat and/or acid treatment or the splitting of the 3,5A° peaks) are so indicated on the diagrams (Diagrams 14 and 15).

It must be understood that there is serious doubt as to the accuracy of quantitative estimates of clay mineral content. PIERCE and SIEGEL, 1969, have shown that five different methods of calculation of the relative proportions of different clay minerals from the same diffractograms give five different results. Each method of calculation is internally consistent i.e. it is precise but the true answer (i.e. accuracy) need not be obtained. DANCHIN, 1970, and HOFMEYER, 1971, have argued that quantitative calculations of clay mineral content are of little value due to the numerous factors causing uncertainties e.g. crystallinity of the different phases etc. The results shown in Diagrams 14 and 15 are therefore, to be considered as a reasonable guide only, and not the true, accurate amounts of the different clay mineral types present in each sample.

The most noticeable feature concerning the proportions of the different clay minerals is that there is a marked increase in the relative proportion of montmorillonite at the expense of chlorite + kaolinite, with an increase in depth. There is also an increase in the actual 'amount' of montmorillonite as one moves downwards into the continental deposits. The proportions and the 'amount' of illite, which is in nearly all cases the dominant clay mineral, does not show much variation when considering the amount of clay in the total sample. Illite cannot be used as an indicator of environment of deposition even in the broadest terms. The montmorillonite is however, concentrated in the continentally deposited Kirkwood Formation.

It must be considered that the majority of the clay minerals are detrital (the exceptions are when the total clay fraction is small and could reasonably have formed from the breakdown of unstable sand sized grains) and the problem arises as to the different mineralogy of the different environments. WEAVER, 1958, has shown that as a rule clay minerals do not form in their depositional environments and that also they are not strongly modified by diagenesis during and after deposition. Yet GRIM, 1953, has stated "that it seems certain that chloritic mica and illite also tend to form during diagenesis from other minerals. Thus illite probably forms from montmorillonite; chloritic material appears to develop from kaolinite and possibly also from montmorillonite" (p. 352).

There is no evidence to support the claim that there were dramatic changes in either the climate pertaining in the source area of the presently studied rocks or that the provenance material altered radically with progressive erosion. It can thus be assumed that the changes in the mineralogical character of the clay fraction are due to either the environment of deposition or to modification subsequent to deposition or to a combination of these two factors. It seems reasonable to assume that the sediments of the Kirkwood Formation, which were deposited under lagoonal and flood-plain conditions, were altered subsequent to deposition. The shallow water milieu would probably have resulted in fairly rapid evaporation and this could have had the effect of raising the salinity of the environment under which conditions "montmorillonite and illite clay minerals would form at the expense of whatever material was supplied" (GRIM, 1953, p. 353). That evaporites are found in these sediments is well known; the author has collected gypsum from several localities and there are salt pans scattered over a considerable area of the Algoa Basin.

Sample AD 1959 is noteworthy. It has an appreciable decrease in the amount of montmorillonite and an increase in the chlorite content when compared with the samples immediately above. The proportions of the clay minerals in this sample are more akin to those of the marine samples (e.g. AD 290) and it is tentatively suggested that the sample AD 1959 could belong to the Bokkeveld Group and not to the Uitenhage Group, thus representing 'basement'. The borehole CO 1/67 is known not to intersect the contact between the Uitenhage Group and the 'basement' (WINTER, 1973).

## 5.6 Heavy Mineralogy

During the routine examination of thin sections as well as while checking the quality of the disaggregation of the sample during the size analysis, it was noted that some size fractions were particularly rich in heavy minerals. In some cases a marked coloration of a particular size fraction was produced due mainly to the presence of garnet.

Six samples, 3 from each core, were therefore selected for heavy mineral study and the crop was separated as mentioned earlier. The results of the point counting as well as data from HILL, 1972, and DE VILLIERS and WARDAUGH, 1962, are given in Table II. It should be noted that no attempt was made to separate the 'opaques' and some rutile could be included in this category. The 'others' group includes amphiboles and minerals not easily recognisable.

On comparing the results of this study with that of HILL, 1972, it is immediately apparent that there is a marked variation in the proportions of garnet and zircon;

the ratios are almost reversed. "Zircon is generally regarded to be associated with acid igneous rocks when euhedral, or with reworked sediments when well rounded. However, it is known that rounding of zircons can take place by magmatic resorption, especially in effusive igneous rocks" (HILL, 1972, p. 36). From this it is apparent that he (Hill) is relying on an igneous source for the majority of his zircons. In the present study this is not felt to be the case due to the fact that zircon plays a minor role in the heavy mineral suite and that the occurrence of euhedral grains of zircon is rare. They do however, occur and this, together with the fact that there are two (at least) populations of garnet indicates a more complex source. The possibility that a fairly substantial portion of the heavy mineral crop may be multicycle cannot be overlooked.

Concerning the garnets, the most obvious variation is that of colour. From Table II it can be seen that the major portion of this mineral is colorless; however, the remaining portion of the coloured variety shows marked differences, colours ranging from very pale pink through pale and moderate pink to light red. Equally noticeable is the variety in shape. Most of the grains are angular or very angular but have high sphericity values (after POWERS, 1953). There are also however, grains that show all intermediate stages of roundness to those which are both well rounded and highly spherical. Garnets with high rounding and low sphericity were not seen. Concoidal fracture, inclusions and pitting are common. The measured refractive index for the grains was 1.788 $\pm$ 0,003 which is indicative of almandine garnet.

The rutile grains are usually deep red-brown in colour and some may be opaque.

Zircons are, as mentioned earlier, far less frequent in the Kirkwood Formation than in the lower levels of the succession (Enon Formation) which are not intersected by the cores. Euhedral grains are present but rare, while some are well rounded and have either high or low sphericity values.

The other heavy minerals are present only in minor amounts and it is felt that they are derived from the same source which supplied the garnets and the rest of the sediment in general. This aspect of the study will be discussed in more detail later (see Basin Analysis).

## 5.7 Electron Microscopy

### 5.7.1 Discussion

In an attempt to ascertain whether it was possible to see any segregation of different clay mineral types due to their inherent size differences, and also to study their morphological characteristics, Transmission and Scanning Electron Microscope (T.E.M. and S.E.M. respectively) photographs of some selected samples were taken. (Mr. C. Fowle of the Physics Department of U.C.T. took the T.E.M. photographs while Dr. W. Siesser, using the S.E.M. at Rhodes University, kindly undertook to photograph two of the author's clay samples)

### 5.7.2 Results

The results of the electron microscopy were disappointing and little information could be obtained from any of the electron photomicrographs received by the author.

Transmission electron microscope (T.E.M.) photographs (Plate III) of sample CO 1938 shows what is probably illite in pseudo hexagonal flakes. The scanning electron microscope (S.E.M.) (Plate III) photograph (CO 3040) shows the platy nature of what is almost certainly chlorite and the irregular outline of the sheets is evident. CO 5543, a T.E.M. photograph, shows two distinct mineral types - one of irregular outline - which is thought to be montmorillonite and the other a lath-shaped phase which is similar in appearance to the illite reported by Dr. Weaver in GRIM, 1953, p. 122, Fig. 40.

# 6. WACKES

## 6.1 Discussion

The term 'graywacke' is one that was introduced more than a hundred years ago and has suffered a very chequered career ever since. Numerous authors have recommended that the term be removed from classifications or have advocated its complete deletion from geological literature. For length of definition in the 1973 A.G.I. Glossary of Geology graywacke is unsurpassed, and not without reason - these rocks are not easily understood and are even more difficult to define. The samples of the present study which are composed primarily of material of sand size can, it is felt, be classified as 'graywackes' or more appropriately, 'wackes' after the schemes of GILBERT, 1954 and DOTT, 1964. The latter author recommends the term 'graywacke' as a field term and "not a rock but an extremely large and widespread rock clan with many compositions" (DOTT, 1964, p.627 and Fig. 3, p.629).

The essential features of graywackes are an excess of matrix with an odd assortment of stable and unstable minerals as well as rock fragments making up the framework grains. These are neither well sorted nor well rounded. This could only have been achieved through rapid erosion, transport, deposition and burial with incomplete or very little chemical weathering. From a study of the sedimentary structures and their associated paleontological and lithological characteristics it has been found that graywackes are "deep water marine turbidites; others are shallow marine sediments; yet others are fluviatile" (CUMMINGS, 1962, p.60). However, Cummings points out that "modern sediments of comparable origin, whether found in nature or deposited experimentally, are not graywackes. Thus if the principle of uniformitarianism is applied, the peculiar texture of greywackes cannot be an original detrital feature, but must be the result of post-depositional alteration of 'normal sand'. If this is so then the greywacke problem is a problem, not of sedimentation, but of post-depositional cementation" (Ibid., p.60).

In similar vein DOTT, 1964, states that "curiously, when modern sands are analysed and interpreted texturally, the 'matrix question' never seems to arise, reflecting the inherent problems and view points generated by different methods of study of ancient and recent sands" (p. 631). The fact that agreement about the genesis of the matrix in graywackes is not universal should not be held as a reason for abandoning the term from classification schemes. Such schemes are descriptive - the matrix is present and must, therefore, be taken into account. Once having classified a rock as a (gray) wacke it's genesis can then be interpreted.

Numerous authors have found that they can explain the presence of the matrix in graywackes as being due to the post-depositional alteration of unstable grains after sedimentation. CUMMINGS, 1962, proposed and tested this hypothesis and has shown that complete disintegration of 15% of all sand grains of a 'normal sand' and the transference of all the alteration products to form matrix results in the sand plotting in a field occupied by graywackes (in a triangular diagram with matrix (<0,05mm), fine sand (0,05 - 0,25mm), and coarse sand (>0,25mm) as end members). A very similar situation is achieved if all the sand grains are altered to a depth of 7,5 μm with the transference of all the alteration products to the matrix (See Fig. 5 in CUMMINGS, 1962). CARRIGY & MELLON, 1964, have shown that rock fragments "are relatively plastic or flexible compared to more rigid grains such as grains of feldspar, quartz or chert, and may tend to be crushed or disaggregated during compaction, flowing into the adjacent pore spaces and forming an intergranular filling or matrix" (p. 462). The experiments of WHETTEN & HAWKINS, 1970, "demonstrate that the minerals commonly found in the matrices of graywackes may have been sand grains that have undergone diagenetic transformation. Graywacke matrix need not be recrystallized interstitial mud or argillaceous detritus" (p. 357). BRENCHLY, 1969, interprets the matrix found in graywackes rich in volcanic fragments (from Northern Wales) as being of diagenetic origin. WALKER, 1967, has reported in situ alteration of unstable minerals in the Sonoran desert, which supports arguments for a diagenetic origin of the matrix found in sediments containing appreciable quantities of unstable grains.

Graywackes are common throughout the geological column, (PETTIJOHN, 1957, p. 309), and the youngest ones (of Cretaceous and Tertiary age) have "an exceptionally immature sand fraction" (CUMMINGS, 1962, p. 62).

It has also been noted by various workers (CUMMINGS, 1962, BRENCHLEY, 1969) that the presence of a cementing material in the sand, e.g. calcite, has had an inhibiting effect in the formation of a diagenetic matrix. It is believed that the reduction of the porocity and permiability caused by the introduction of chemical cement is, in many cases, sufficient to eliminate diagenetic alteration of unstable grains except under severe physical stress. DICKENSON, 1970, has detailed the different types of interstitial constituents found between the framework grains and has warned that "many lithic grains have ill-defined boundaries and are difficult to distinguish from matrix. As a consequence the exact estimation of lithic grain and matrix is impossible" (p. 1298). Similarly DOTT, 1964, concurs; "there is a high degree of judgment and uncertainty in point counting immature sandstones, and because of these inherent problems and biases, the comparibility of many published modal analyses of graywackes is in doubt. Many may not even be reproducible" (p. 631).

A further problem exists; should there be both detrital and authigenic clays present in the rock these must be distinguished. This is often an extremely difficult task to perform with a petrographic microscope and special equipment i.e. X-ray diffraction microcamera is needed. It should be noted that this latter piece of equipment was not available in the present study.

## 6.2 The Present Study

Throughout the cores of the present study there are rocks which can be classified as wackes (GILBERT, 1954; DOTT, 1964) while the number that can be called arenites is indeed small. Mudstones on the other hand, are frequent.

It can be seen from the thin section descriptions of selected samples (Appendix B) and from the size analysis statistics (Table I) that the wackes contain a number of mineral types as well as rock fragments, which are usually angular. The sorting of these particles is generally moderately poor. These factors justify the classification of the rocks as wackes and therefore the rocks are now described more fully.

In most of these coarser grained samples the framework grains are sub-equally divided between the three classic components namely:- quartz (or "siliceous resistates" of DOTT, 1964), feldspars and 'rock fragments' (i.e. unstable material). The subdivision of quartz into mono- and polycrystalline varieties, metaquartzites etc. (FOLK, 1968) is not considered warranted under the present circumstances because (a) it is felt that further subdivision and fragmentation at this stage of classification is not justified and can, if deemed necessary, be remedied by a further triangular diagram depicting the "resistate" types and (b) it has been shown by BOGGS, 1968, that the 'recognizability' of rock types when crushed to various sand-size grades, is dependent to a very large extent on the initial grain size and texture of the parent rock and it is only the fine grained (<5 Ø ) parent rock types whose textures can be recognized in fine and very fine sand. These are the size grades of the sand stones of the present study. Thus what may be counted as a monocrystalline quartz grain during point-counting may well be a fragment of a coarse metasediment and should be tallied as a rock fragment.

Most of the thin sections can be seen to contain both fresh and altered plagioclase, and some samples have a small percentage of alkali feldspars, microcline included. Concerning the "siliceous resistates" it is noted that mono- and polycrystalline varieties of quartz are present and in the former type inclusions are frequent, indicative of a plutonic souce (FOLK, 1968), although some of these may well be second-cycle grains. The rock fragments present appear to be of two varieties - mainly sedimentary with minor amounts of volcanic fragments. It can be stated with reasonable confidence that "rock fragments .... are more likely to represent a first-cycle parent" (BOGGS, 1968, p. 1326).

Not only are the three major components in sub-equal proportions but they are of the same size range; there is no conspicuous size difference between the components as seen in thin section. (It is also interesting to note that during size analyses it was observed that the heavy minerals present - usually mainly garnet, sometimes imparting a pink hue to a particular size fraction - all concentrated towards the finest fraction of these already fine sandstones, as is to be expected). Also, most of the grains are subangular to angular (by visual comparison, POWERS, 1953) and the few grains that are rounded can be attributed to a previous cycle of erosion.

For the majority of the framework grains the rounding is generally poor. Using the POWERS, 1953, scale of rounding (by visual comparison) most of the grains of quartz and feldspars are sub-angular to angular and some of the feldspars show prismatic outline. Few grains are rounded and may be considered as exceptionally shaped sedimentary rock fragments. The shape of the rock (labile) fragments varies considerably but it is believed that this is due to post-deposition modification and not to the transportation and depositional influences. More will be said about these particles later.

The range of sizes of detrital grains present is, on average, fairly large and it can be seen from the size analysis statistics (Table I) that $\sigma_I$ (standard deviation) is infrequently less than 1,0 $\phi$. This is, according to the verbal limits set by FOLK, 1968, p. 46, the upper limit of "moderately sorted" sediments, and no samples have better sorting than this category. Numerous samples are "poorly sorted" while a few are "very poorly sorted". However, these results must be interpreted with caution.

The material which binds the framework grains into a consolidated rock is of two sorts (a) carbonate cement and (b) "matrix". The former type, namely calcite, is not frequently encountered. When it is, it is seen that there is a paucity of matrix although in some cases framework grains have a pelicle of matrix which appears to have formed prior to the introduction of the chemical cement. This latter material has then had the effect of preventing the formation of any further matrix, as has been shown by both CUMMINGS, 1962, and BRENCHLEY, 1969. Silica cement is very infrequent and can definitely not be considered as a cementing material for the rocks in general. This form of precipitate is restricted to sporadic occurences of enlarged (overgrown) detrital grains and may in fact have been formed during a previous cycle of sedimentation. There is so little rounding of the vast majority of the grains that it is likely that overgrowths could have survived transport.

In the thin sections it can be seen that detrital grains appear to 'float' in carbonate cement where this is in sufficient quantity. Commonly the boundaries between the grains and the cement is highly irregular and 'pitted', suggesting replacement and/or corrosion of the grain by the later-formed cement. This idea however, must be treated cautiously. GLOVER, 1964, has shown that many grains which appear to have been corroded when seen in thin section on a flat-stage microscope only, are in fact, not so at all (see GLOVER, 1964, Figures 3 to 7 inclusive), but when tilted to the appropriate angle on a universal stage the contact is seen to be smooth. The present author repeated this procedure and found that in many instances Glover's results were confirmed (See Plate II, 5 & 6). It is not here proposed that there is no corrosion of detrital grains by later-formed cement, but rather that this phenomenon must be verified by making use of a universal stage to be able to view along (or nearly so) the plane of contact between the grain and the cement.

The 'matrix' poses more of a problem. Since the work of CUMMINGS, 1962, it has become clear that the genesis of the matrix in wacke-type rocks is not a 'cut-and-dried' matter, but needs careful study. As has been pointed out above, the presence of chemical cement restricts the amount of argillaceous matrix that can be formed. This immediately suggests that the matrix is diagenetic in nature. In the thin sections it can be seen that it is the rock fragments (and to a much lesser extent the altered feldspars) which have been subjected to all stages of deformation and 'mobilization'. In some cases it can be clearly seen that what were at one stage detrital grains have now become sufficiently deformed to be termed 'matrix'. That this material was at no stage detrital clay can be proved by the number of fresh feldspar grains still present - chemical weathering could not have been sufficient to reduce all unstable material to 'clay' and attrition was not pronounced (viz. angular grains). It is believed that, in the presently studied rocks, the major portion of the matrix is of a diagenetic, i.e. post-sedimentation, nature and not due to detrital mud deposited together with the sand sized material.

DOTT, 1964, p. 631, has pointed out that ambiguous and non-reproducible results are frequently obtained when doing modal analyses of (gray) wackes by point counting. The uncertainty that exists of whether a point is 'matrix' or 'rock fragment' makes the results unreliable. It has been found here that the same slide does not give the same modal analysis when counted twice although the difference is usually fairly small. From Diagram 3 it can be seen that if more than 500 points are counted a reasonably consistent result is obtained. However this is subject to a certain degree of judgment.

The alteration of a certain portion of the framework grains (i.e. the relatively plastic or flexible rock fragments) which disaggregate, crush or flow into the pore spaces and the stability of the other grains (i.e. only very minor interpenetration or concavo-convex contacts between adjacent quartz and/or feldspars) must have a reasonably pronounced effect on any statistics derived from the granulometric analysis of such a sediment. In a sediment of this nature which is fairly well indurated there is the problem of disaggregation prior to sieving and/or pipetting. How much fragmentation of the unstable, altered material takes place is an unknown factor and it is very difficult to estimate what effect the alteration of the unstable grains will have on the relative proportions of the different size fractions. If it is accepted that most of the matrix in the present wackes is of post-depositional origin - as is believed to be the situation - the first statistic, namely the mean, need not be markedly affected but the spread or standard deviation ($\sigma_I$) will be increased to a noticeable degree. Under the present circumstances it is not possible to compare the size analyses results obtained by sieving with those from a thin section because of the distortion of a reasonably large number of grains by diagenetic effects.

## 7. RED BEDS

### 7.1 Introduction

The problem (and associated controversy) of the genesis of red beds has been taxing the minds of many eminent geologists for more than a century. More and more data are being published but agreement is by no means universal yet, and probably will not be for a long time to come.

Two schools of thought are prevalent, namely;
(a) those in favour of a hot, humid, tropical-type climate with deep weathering of upland material which is the source of supply of the red detritus. Thus the red beds so formed inherited their colour from the provenance area and
(b) those in favour of a hot, dry, desert-type climate in the provenance and depositional environment with later, in situ alteration of the iron oxides and the iron-bearing silicates. Numerous lines of evidence for both theories have been produced in the voluminous literature.

Notwithstanding these differing points of view, it is generally accepted that certain physico-chemical conditions are vital prerequisites for the formation of red-coloured i.e. hematitic, sediments. These sediments may be sandy or muddy. The conditions are: High temperature (therefore low latitude), the presence of water, oxidizing and suitable pH and Eh conditions for hematite stability, and a source of supply of the iron-bearing minerals.

Certain 'facts' have emerged concerning the nature of the red-coloured sediments. Some of these 'facts' are:
(i) The rock colour can be due to discontinuous, particulate coatings on detrital grains which may be between grain contacts (THOMPSON, 1970, p. 605) or may not be between the grains (MILLER AND FOLK, 1955, p. 344, WALKER, 1967, p. 365). Hematite may also be as a 'matrix' or 'cement' between the grains, suggesting that the hematite is either pre- or post-depositional,
(ii) Sand dunes reddened with age and their contained iron-bearing minerals, particularly the magnetic varieties, decline in quantity with age. Reddening may cease with the onset of cementation. Furthermore, two sands with the same intensity of red pigmentation may have suffered markedly differing histories and be of different ages (NORRIS, 1969, p. 9 - 10),
(iii) Red beds can be formed in both the marine and the continental environments (MILLER & FOLK, 1955, p. 343). Few red beds appear to have formed from reworked sediments (except reworked red beds). Also, most red sandstones are arkoses or graywackes, therefore erosion and deposition must have been rapid,
(iv) An igneous or metamorphic source of iron-bearing minerals is essential for the formation of red beds regardless of the climate in the source area or in the environment of deposition (Ibid. p. 339),
(v) Iron-bearing oxides, particularly magnetite-ilmenite "dissolve out of the rock if it is subjected to reduction at any time in its diagenetic or even post-diagenetic history (Ibid, p. 341),
(vi) Most of the red colouration forms at the site of deposition from the alteration of iron-bearing oxides

and silicates, and therefore, climatic conditions in the source area are not of paramount importance (WALKER, 1967),

(vii) Red, green and drab sediments may be intimately bedded together and it is unlikely that this can be adequately explained by recourse to differing source materials for the different coloured rocks; provenance, transport and depositional-environment climate are expected to be the same. The colour variations can be most readily explained as being due to local reducing conditions causing dissolution of the magnetite-ilmenite present.

From these abovementioned 'facts' it must be clearly understood that red beds in general are not to be used as indicators of any particular type of climate pertaining in either the source area or in the environment of deposition.

The amount of iron necessary to produce a red coloured sediment is very small. "The iron content of ancient red beds ranges from 0.2 to 4.2 and averages 1.7 percent" (WALKER & HONEA, 1969, p. 538). "Some bright red samples .... contain only 0.1 percent of extractable iron" (Ibid. p. 539). Although intense weathering in the source area produces deep soil, the fact that most red beds are of the arkosic and graywacke clans indicates that erosion must have been rapid, cutting through the soil quickly to expose the underlying bed-rock. This material was then the major source of supply for the sediments and the minerals bearing the iron. Iron oxides and iron bearing silicates do alter in deeply weathered soils "to pigment incorporated in the clay fraction" (VAN HOUTEN, 1968, p. 400) but this should not be seen as the major source of supply of colouration.

The red colouration in both the sandstones and fine grained rocks is due to the presence of hematite. (Other iron oxides and iron-bearing silicates do not colour the rocks red). From laboratory studies "the importance of:

(a) the ageing of brown amorphous ferric oxide to goethite and hematite;

(b) the conversion of goethite to hematite by dehydration at 'surface' temperatures; and

(c) the relative stability of crystalline hematite in reducing environments, compared with that of amorphous ferric oxide" (Ibid., p. 404) indicate the diagenetic nature of the pigment. However it is difficult to "determine whether the hematite pigment in the red beds was:

(a) inherited directly from red soil;

(b) derived from limited development in the source area or in transit, by post depositional conversion of brown ferric oxides to red hematite; or

(c) produced by intrastratal alteration of iron-bearing silicates" (Ibid., p. 404).

## 7.2 <u>Discussion</u>

From the hand specimen descriptions (Appendix A) it can be seen that the red coloured sediments of the present study are the finer grained varieties while the drab rocks are the sandstones. However, in the sequence of the Kirkwood Formation (only this formation and the Enon Formation contain red beds), the coloured and drab rocks are intimately interbedded. That iron-bearing minerals and rock fragments are available for the colouration of the wackes is seen from the heavy mineralogy (Table II) and the thin section descriptions (Appendix B). It is unlikely that the two different coloured rock types had different source areas — the inter-bedding precludes this and in some samples (AD 1390, CO 4540, CO 5543, CO 6234) there is a mixture of red and drab detritus making up the rock. Thus it can be safely stated that seasonal climatic fluctuations were not responsible for the colouration. It must also be remembered that the red shale units are frequently tens of feet thick; too much to be able to account for in a seasonal hypothesis. Likewise, climatic variations in the environment of deposition can be excluded as an explanation.

The drab, coarser sediments are seen to contain pellets, streaks and laminae of variegated (mainly red with subordinate patches of green) fine, shaly sediment. However, the sandstones have appreciable proportions of iron-bearing components.

The finer sediments are believed to have been deposited under very quiet, shallow water conditions associated with the flood plains and swamps(?) of meandering rivers. The climate is believed to have been dry (but not pure desert as vegetation must have been locally abundant to account for all the preserved trees) and evaporation would increase the probability of excellent oxidation conditions. The coarser, sandy material would tend to be covered over far more quickly and in this way inhibit oxidation. Pellets, streaks etc. of red mud could easily be caught in the sands as the river eroded its way through only partly-consolidated detritus it had deposited.

None of the marine sediments are oxidized and this tends to support the contention that the sediments which were not subaerially exposed (probably only infrequently or seasonally) were not oxidized enough to become red beds.

Numerous authors have specified that an igneous or metamorphic source is necessary for the formation of red beds (e.g. MILLER & FOLK, 1955) but in the present study this does not appear to have been the case. Except for minor volcanics, the whole of the provenance region for the sediments of the Algoa Basin is a thick, Paleozoic (and possibly some Lower Mesozoic ), sedimentary succession. Of these source rocks only very minor portions are themselves red beds (i.e. Lower Beaufort Group) and these are not thought to have contributed significantly to the Uitenhage Group. Thus the hypothesis that reworked red beds accounts for the Algoa Basin red beds can be discounted.

The arkosic-wacke composition of the sandstones precludes the idea of intense weathering in the source area and it therefore seems that the only reasonable explanation of the red coloured sediments is one based on factors operative in the environment of deposition or immediately subsequent to deposition.

# 8. BASIN ANALYSIS

## 8.1 Introduction

An attempt is made to bring all the data together. The analytical techniques have been stated and the results derived from them discussed. These now need to be consolidated into a composite picture of the events relating to the basin as a whole and the classic four-fold division of the study of sedimentary deposits, namely: Provenance, Dispersal, Depositional Environments and Lithification plus Diagenesis, can be applied. However, due to the fact that the two studied cores are axial to the length of the basin and as no data from surface exposures are presented, a fully comprehensive three-dimensional analysis of the basin is not justified - it is therefore clear that the remarks expressed in the analysis of the basin as a whole, are of a more general nature.

## 8.2 Provenance

The Algoa Basin lies between the longitudinal folds of the Cape Fold Belt and it is this upwarping of the thick pile of sedimentary (and very minor volcanic) rocks which has supplied the material for the Upper Mesozoic sediments. The Cape Supergroup comprises the arenaceous sediments of the Table Mountain and Witteberg Groups while the intermediate Bokkeveld Group is of alternating arenaceous and argillaceous rocks. Further to the North are the rocks of the Karoo Supergroup, beginning with the glacial and fluvio-glacial deposits of the Dwyka Group and followed by the arenaceous and argillaceous rocks of the Ecca and Beaufort Groups. The uppermost Karoo groups are sufficiently far removed from the Algoa Basin as to be of no interest with regard to its provenance.

The basal sedimentary formation of the Uitenhage Group - the Enon Formation (which was not studied, but has been observed in the field by the author) - can be considered to be fanglomerate deposits derived mainly from the arenaceous sediments of the Cape Supergroup. Boulders and cobbles of quartzite are almost the only rock type present and only rarely are Dwyka fragments seen. These very coarse clastic rocks do not extend over the whole of the basin floor as borehole AD 1/68 intersects the contact between the Kirkwood Formation and the Bokkeveld Group without passing through any Enon Formation. This formation can, therefore, be expected on the peripheries of the basin only.

But the waters draining into the basin were also charged with finer material derived mainly from the sediments to the north of the Cape Fold Belt. HILL, 1972, has shown that the heavy minerals of the lowest portions of the sequence are rich in zircons while deficient in garnets, the reverse being true for the higher formations of the Uitenhage Group (see TABLE II). It appears that the garnet proportion in fact increases in the higher portions (i.e. Sundays River Formation). Also from TABLE II it is seen that from the work of DE VILLIERS & WARDAUCH, 1962, the Cape Supergroup has a heavy mineral crop richer in zircons than garnets while the Lower Karoo Supergroup rocks (except possibly the Lower Ecca and this only probably regionally) is much more likely to be able to account for the heavy mineral suite of the Uitenhage Group.

From the thin sections descriptions (Appendix B) it is evident that weathering in the source area did not completely destroy the relatively unstable feldspars - some appear altered and some very fresh. Thus the provenance lithologies were not subjected to deep weathering to produce clay sized material, rather this fine grained detritus forming the thick argillaceous beds in the Algoa Basin was probably derived from the erosion of fine sediments of the Lower Karoo sequence. On the other hand the coarser portions of the Uitenhage Group were most likely supplied by the erosion of the arenaceous members of the Lower Karoo Supergroup as well as the more consolidated argillaceous fraction, the latter producing the frequently encountered rock fragments. It should be noted that although much of the sedimentary sequence of the Lower Karoo Supergroup is indeed well indurated at the present time, it is likely that at the time of erosion to supply material for the Uitenhage Group lithification had not proceeded to this advanced stage. Therefore, subsequent to deposition diagenetic alteration and compaction destruction of relatively soft, non-lithified rock fragments of an argillaceous nature would probably proceed rapidly and easily. The feldspathic material which usually forms less than 10% of the grains counted in the Kirkwood and Sundays River Formations, could well have been supplied by the graywackes and other arenaceous material of the Lower Karoo Supergroup.

It is therefore suggested that the provenance rocks for the Enon Formation were those of Cape Supergroup arenites while most of the Kirkwood and Sundays River Formations were derived from the Dwyka, Ecca - and possibly the lower portions of the Beaufort - Groups of the Karoo Supergroup with minor dilution from the Cape Supergroup rocks. This is supported by the fact that the clay mineralogy of the continentally deposited Kirkwood Formation is very similar to that of the Lower Karoo Supergroup sediments (see HOFMEYER, 1971, vol. 2, p. 26 - 29), being dominated by illite and chlorite, with montmorillonite being subordinate.

## 8.3 Discussion

Before discussion of the dispersal and depositional environments of the Algoa Basin sediments, it is felt wise to briefly consider the tectonic setting of the southern portion of Africa during the period late Permian to late Cretaceous. The ideas expressed here have been briefly summarized from the work of DINGLE, 1973.

The folding of the Cape Orogeny began towards the end of the Permian and climaxed in mid-Triassic times, giving rise to the folded and sometimes overturned Cape Supergroup rocks and also affecting the Karoo Supergroup up to and including the Lower Beaufort Group. Rifting between East and West Gondwana began towards the end of the Triassic period, accompanied by large scale faulting of the folded region. These faults have downthrows to the south and this had the effect of enhancing the valleys.

The first marine incursion began at the end of the Triassic to early Jurassic time, ($\sim$180 my) with continental sedimentation (Enon Formation) taking place further inland while "by early Upper Jurassic times at the latest, a marine connection existed up the south-east coast of Africa from the South Cape (Knysna) to Madagascar (Majunga Basin), which, according to Breen (1972) probably lay somewhere to the east of Natal at this time" (DINGLE, 1973, p. 39). "The paralic regime shifted northwards between the long basement ridges as a succession of shallow marine transgressions encroached onto the land ... in any one area the first transgressions were probably short lived, and were followed by periods of non-marine sedimentations" (IBID, p. 40).

Erosion during the Jurassic period was fairly intense although BIGARELLA, 1970, postulates desert conditions for this period. However, locally there must have been sufficient moisture to support fairly abundant growth as large tree trunks, now silicified, and other plant remains, abound in the continental deposits of the Uitenhage Group (note: the old name for the Kirkwood Formation was Varigated Marls and Wood Beds).

The age of the last movements of the faults in the Cape Fold Belt has been placed prior to the Enon Formation by HILL, 1972, and it is certain that "major faults within the Algoa Basin are overlain by the Sundays River Formation" (DINGLE, 1973).

By the end of the Cretaceous period the land began to rise and the sea, which now bounded Africa on three sides, retreated.

## 8.4 Dispersal

The sediments of the present study tend to be confined to two size ranges, namely fine and very fine sand-sized material and clay-sized material, which indicate two types of regimes for deposition.

Very little rounding of the grains of the sand-sized particles has taken place and it can be assumed that suspension rather than traction was the dominant mode of transport of the particles until just prior to their final deposition. Those particles which are rounded have more than likely suffered at least one prior cycle of sedimentation if not two (i.e. eriosion of Cape Supergroup rocks to form parts of the Karoo sequence which was eroded to supply the Algoa Basin).

It is seen from thethin section descriptions (Appendix B) that many unstable particles are still recognisable and it must therefore be assumed that dispersal was rapid yet not too intense, otherwise these unstable fragments would have been destroyed either by chemical and/or mechanical processes. Therefore, it is apparent that the dispersal system was not one which transported material for extreme distances prior to deposition.

During the size analysis procedure it was noted that the heavy minerals were concentrated in the finer fraction of the sands. This is to be expected - due to the differences in specific gravities between the light and heavy minerals, smaller heavy minerals are transported with hydraulically equivalent, bigger light minerals.

Mention has already been made of the fact that the Enon Formation is not continuous over the whole floor of the basin. Furthermore, it is obvious that the basin deepens towards the South-East as the thickness of the Kirkwood Formation in AD 1/68 is some 875 feet (266m) while in CO 1/67 this formation is 4145 ft. (1264 m) thick. (See WINTER, 1973, for isopach maps of the entire basin).

Finally it should be noted that it was not possible to determine dispersal directions from the core samples.

## 8.5 Depositional Environments

From what has been stated previously it is apparent that the Algoa Basin (and others of a similar nature along the Southern coast of Africa) are of a rather special nature, having formed by a combination of folding and faulting. These basins were subsequently flooded by a sea directly consequent to the break-up of Gondwanaland. It is thus to be expected that the sediments were derived from a region where weathering had been incomplete, transportation fairly brief and deposition rapid, without reworking and resulted in texturally and mineralogically immature rock.

The lowermost, unstudied sequence is the Enon Formation of thick, poorly stratified fanglomerates and minor, associated, lenticular sandstones.

Having moved away from the source region of folded sedimentary strata, the debris-laden streams would be expected to reduce their velocity very quickly and therefore the rocks of the Kirkwood Formation can be considered to be the fluvial deposits of the system. Rivers carrying fine sand and clay would meander across relatively flat plains and the sands would be deposited as point bars, which would coalesce as the rivers eroded their channels in lateral, downstream and vertical directions. In this way fairly thick sandstone bodies were built up from what were originally 'shoestring' sands. These rivers would, at times, flood their banks and the fine material would be deposited on flood plains. Swampy conditions could also be expected and these would also result in large tracts of country being covered by clay deposits. Flood plains would result in subaerial conditions of deposition and although a desert type of climate has been proposed for the area during the Jurassic period (BIGARELLA, 1970), vegetation was present to a considerable degree. It is therefore apparent that oxidizing conditions under probably fairly high temperatures were operative at the time and this would account for the red bed sequences. Fairly intense evaporation from the brakish zone would account for the isolated occurences of gypsum that have been found in the Uitenhage Group rocks.

The environment was not static. Subsidence appears to have kept pace with deposition up till a time when the marine environment began to transgress over the basin and overstep the terrestrial deposits. As has been noted above, the basin deepens to the South-East, a further indication of instability of the region.

Contemporaneous with the deposition of the terrestrial sediments was the formation of a delta type environment in the shallow marine region. It is likely that the sea was, at least initially, very quiet with only minor currents and was probably also not very saline in the juvenile stages. The formation of a delta in this quiet water would therefore be a very likely situation.

The quiet water, tidal flat type of environment is indicated by the frequently found flaser bedding, interbedded and interlaminated fine sands and muds, wavy bedding etc. The thicker sequence of mud would have been built up in the quieter regions of the flats and at the high water line while the sands would be associated with the channels, runnels and rivers which dissected the flats and at the low water line where sandy flats and bars would form. Small scale ripples would be common on such sand flats.

Carbonaceous remains are plentiful throughout the marine sequence and it is to be expected therefore, that the environment was at least slightly reducing until lithification had occurred. Although the same material is believed to have been supplied for both the marine and terrestrial deposits, it is only the latter which were oxidized and the shales of the marine rocks are generally dark (see Appendix A for the colours). Isolation of parts of the marine waters in swampy conditions would result in precipitation of the minor amounts of gypsum that have been found. Macrofossils, although evident are not abundant.

It is apparent that stability had not been achieved in the region as the marine-deltaic sequence transgressed - more than likely in uneven pulses - over the continental deposits. However, subsidence was not so rapid as to radically alter the environmental characteristics. The sandy bars, the flaser bedding and the other small scale primary structures associated with deltaic sequences are represented by a sequence 3370 ft. (1027 m) and 667 ft. (203 m) in the Colchester and Addo boreholes respectively.

How much thicker the succession was prior to the erosion which must have followed the marine regression, is not known.

## 8.6 Lithification plus Diagenesis

Subsequent to deposition the rocks of the Algoa Basin have been lithified and diagenetically altered. Unfortunately very little can be said of the fate of the fine grained fraction other than that compaction and consequent loss of interstitial water has resulted in hard shales. Much data are probably obtainable from these fine grained rocks but special equipment is needed to differentiate between detrital and diagenetic clay material. This equipment was not available to the author. As has been noted earlier, there is a marked difference in the clay mineralogy of the two formations studied. There is the increase in the relative amount of montmorillonite in the Kirkwood Formation. Conversely, illite and chlorite might have developed from the montmorillonite (GRIM, 1953, p. 352), but it is important to note that the clay mineralogical differences between the two formations is not dependant on gross lithological character. There is a decrease in the relative amounts of montmorillonite in both sandstones and shales when the marine deposits of the Sundays River Formation are encountered. This suggests that diagenetic alteration of the unstable material has taken place in the marine milieu.

Much more information can, however, be gained from a study of the coarser fraction which is interbedded with the fine material. The most noticeable aspect of the arenaceous rocks is that some samples are very well cemented with calcite cement while the majority of samples available to the author are bonded by a clayey matrix. Different samples which have the different bonding materials do, however, have essentially the same components of clastic particles; furthermore, when the secondary carbonate is present there is a distinct lack of matrix material. It seems reasonable to assume that the sands were deposited as 'clean' sands, devoid of clayey material in the interstitial spaces and that during compaction and the resultant diagenetic phases, those sands which became cemented with calcite were then 'sealed off' from any further possible alteration of their unstable components - principally rock fragments. When however, the sands were not cemented the diagenetic alteration attacked these unstable components and altered them to the clayey matrix.

Compactional pressure has had a marked effect on these sediments. Nevertheless, interpenetration and suturing between 'competent' grains i.e. quartz and fresh feldspars, is not as common or marked as would have been the case were there not such a high proportion of 'incompetent' rock fragments. These particles have not only altered to a clayey 'mush' (the extreme case) but have, in most instances, been deformed and flowed plastically into the voids between 'competent' grains during compaction.

The effect on the detrital particles by the calcite cement must be interpreted with caution. Etching of quartz and feldspars by the carbonate may well have taken place but this must be proved. Many of the heavy minerals, particularly the garnets, are pitted; this may well be at least partially due to the previous cycle of sedimentation.

It is the present author's belief that the sandstones of the present study are now (gray) wackes not due to deposition as 'dirty' sandstones but rather that 'clean' sandstones with unstable clastic particles have been diagenetically altered to their present state.

The basin can, therefore, be considered as a typical example of intermontane (graben?) deposition with lateral and vertical facies changes due to marine transgression with subsequent lithification by compaction, carbonate cementation and diagenetic alteration of the unstable clastic fragments.

## 9. ECONOMIC POTENTIAL

For many years the Uitenhage Group of the Algoa Basin has been considered to be a potential producer of natural gas and/or petroleum, and the first hole drilled with this in mind was in 1908. However, this venture proved unsuccessful.

Geological mapping of the area continued and in the late 1960's interest in the basin was again aroused. Detailed mapping - field and aerial - geophysical exploration and drilling has been carried out (see WINTER, 1973, p. 20 for a review of "previous investigations and current exploration") but to date, regrettably no economically exploitable reserves of petroleum have been discovered.

No mineral reserves are known to exist in the Algoa Basin and although some small salt pans are productive, there is no apparent economic potential other than the agricultural activity which is largely dependant on subsurface or canalized water.

## 10. FUTURE RESEARCH

The rocks of the Algoa Basin Uitenhage Group have been fairly extensively studied from a lithological point of view. Paleontological studies have also been conducted. It is felt that a sedimentological study of the Uitenhage Group, utilizing samples from both the surface and subsurface, would be most valuable.

A further field which has received practically no attention is the geochemistry of this Group. DANCHIN, 1970, and HOFMEYER, 1971, have done extensive studies of various aspects of selected South African shales and this could well be extended to the so far untouched Uitenhage Group.

Particular, specialized aspects of the mineralogy, for example the clay minerals and heavy minerals, could provide further insight into such interesting subjects as the provenance lithologies as well as effects of diagenesis.

It is confidently felt that much scope remains for further research on the rocks of the Uitenhage Group in the Algoa Basin.

# TABLE I.

## Sample Statistics.

# TABLE I

| Sample | Mass | S.G. | Sand | Silt | Clay | $M_z$ | Q50 | $\sigma_I$ | $Sk_I$ | $K_G$ | $K_G'$ | $M_D$ | $QD_a$ | $Sk_a$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AD 90 | 240 | 2,49 | 6,03 | 69,54 | 24,42 | 6,0 | 6,0 | 2,6 | 0,0 | 1,12 | 0,529 | 0,0160 | 0,0498 | 0,0362 |
| AD 137 | 169 | 2,46 | 0,40 | 54,95 | 44,65 | 7,5 | 7,4 | 2,2 | +0,1 | 0,78 | 0,442 | 0,0070 | 0,0129 | 0,0071 |
| AD 184 | 189 | 2,51 | 3,10 | 55,18 | 41,72 | 7,3 | 7,0 | 2,3 | +0,2 | 0,95 | 0,486 | 0,0078 | 0,0139 | 0,0068 |
| AD 240 | 581 | 2,53 | 59,18 | 23,44 | 17,39 | 4,5 | 3,3 | 1,3 | +0,8 | 1,08 | 0,520 | 0,1020 | 0,0742 | -0,0272 |
| AD 293 | 112 | 2,49 | 0,23 | 47,70 | 52,07 | 7,8 | 7,6 | 2,2 | +0,2 | 1,05 | 0,510 | 0,0052 | 0,0085 | 0,0043 |
| AD 343 | 605 | 2,55 | 88,86 | 9,80 | 1,34 | 2,8 | 2,6 | 0,7 | +0,6 | 2,18 | 0,686 | 0,1650 | 0,0525 | -0,0185 |
| AD 392 | 140 | 2,49 | 1,51 | 54,02 | 44,47 | 7,3 | 7,1 | 2,2 | +0,1 | 0,89 | 0,462 | 0,0074 | 0,0139 | 0,0077 |
| AD 440 | 496 | 2,56 | 36,70 | 44,32 | 18,97 | 5,0 | 4,5 | 2,2 | +0,6 | 0,90 | 0,474 | 0,0440 | 0,0391 | -0,0011 |
| AD 490 | 397 | 2,70 | 71,06 | 15,84 | 13,09 | 4,2 | 3,4 | 2,3 | +0,8 | 2,46 | 0,711 | 0,0950 | 0,0640 | -0,0240 |
| AD 539 | 503 | 2,50 | 90,27 | 9,73 | - -- | 2,6 | 2,5 | 0,9 | +0,5 | 2,54 | 0,720 | 0,1780 | 0,0655 | -0,0095 |
| AD 590 | 100 | 2,57 | 1,03 | 58,15 | 40,82 | 7,1 | 7,0 | 2,0 | +0,2 | 0,87 | 0,466 | 0,0078 | 0,0187 | 0,0084 |
| AD 649 | 63 | 2,61 | 0,37 | 61,52 | 38,11 | 7,1 | 6,8 | 2,2 | +0,2 | 0,96 | 0,488 | 0,0090 | 0,0138 | 0,0062 |
| AD 692 | 495 | 2,62 | 93,69 | 6,32 | - -- | 1,9 | 1,9 | 0,8 | +0,3 | 1,55 | 0,608 | 0,2720 | 0,1250 | 0,0180 |
| AD 741 | 114 | 2,61 | 1,08 | 58,90 | 39,30 | 7,0 | 7,0 | 1,8 | 0,0 | 1,00 | 0,500 | 0,0780 | 0,0124 | 0,0068 |
| AD 786 | 103 | 2,55 | 1,20 | 67,20 | 31,60 | 6,9 | 6,8 | 2,0 | +0,2 | 1,13 | 0,530 | 0,0100 | 0,0139 | 0,0061 |
| AD 844 | 222 | 2,64 | 3,18 | 64,73 | 32,09 | 6,7 | 6,3 | 1,8 | +0,3 | 1,27 | 0,559 | 0,0130 | 0,0122 | 0,0018 |
| AD 890 | 205 | 2,58 | 9,05 | 72,74 | 18,21 | 5,7 | 5,4 | 2,0 | +0,3 | 1,12 | 0,529 | 0,0240 | 0,0296 | 0,0104 |
| AD 943 | 176 | 2,57 | 4,67 | 70,08 | 25,24 | 6,3 | 6,0 | 2,0 | +0,1 | 1,04 | 0,510 | 0,0170 | 0,0205 | 0,0065 |
| AD 990 | 540 | 2,57 | 90,11 | 9,89 | - -- | 2,5 | 2,4 | 0,9 | +0,2 | 1,31 | 0,567 | 0,1900 | 0,1090 | 0,0135 |
| AD 1044 | 266 | 2,55 | 2,50 | 64,05 | 33,45 | 7,0 | 7,0 | 1,7 | 0,0 | 1,00 | 0,500 | 0,0078 | 0,0107 | 0,0055 |
| AD 1089 | 217 | 2,58 | 0,41 | 65,01 | 34,57 | 6,8 | 6,8 | 2,4 | 0,0 | 1,00 | 0,500 | 0,0090 | 0,0226 | 0,0154 |
| AD 1141 | 553 | 2,54 | 78,11 | 12,14 | 9,75 | 3,5 | 3,3 | 1,8 | +0,5 | 3,79 | 0,786 | 0,1120 | 0,0495 | 0,0065 |
| AD 1190 | 520 | 2,50 | 58,75 | 23,77 | 17,42 | 4,7 | 3,8 | 2,3 | +0,7 | 1,30 | 0,565 | 0,0720 | 0,0583 | -0,0073 |
| AD 1242 | 581 | 2,53 | 93,21 | 6,79 | - -- | 2,2 | 2,1 | 0,8 | +0,3 | 1,59 | 0,614 | 0,2200 | 0,0925 | 0,0225 |

T A B L E   I   (Continued)

| Sample | Mass | S.G. | Sand | Silt | Clay | $M_z$ | Q50 | $\sigma_I$ | $Sk_I$ | $K_G$ | $K_G'$ | $M_D$ | $QD_a$ | $Sk_a$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AD 1290 | 679 | 2,58 | 88,64 | 5,15 | 6,21 | 2,9 | 2,7 | 1,6 | +0,5 | 2,65 | 0,725 | 0,1550 | 0,0750 | -0,0030 |
| AD 1334 | 135 | 2,59 | 0,11 | 42,70 | 57,19 | 7,6 | 7,6 | 2,2 | 0,0 | 1,00 | 0,500 | 0,0052 | 0,0119 | 0,0074 |
| AD 1390 | 545 | 2,56 | 81,35 | 10,47 | 8,18 | 3,3 | 2,8 | 1,5 | +0,8 | 3,30 | 0,768 | 0,1440 | 0,0680 | -0,0320 |
| AD 1440 | 600 | 2,55 | 0,45 | 11,95 | 37,50 | 7,0 | 6,9 | 1,6 | +0,2 | 0,82 | 0,450 | 0,0080 | 0,0109 | 0,0051 |
| AD 1490 | 481 | 2,53 | 0,20 | 58,03 | 41,79 | 7,6 | 7,6 | 1,7 | 0,0 | 1,00 | 0,500 | 0,0052 | 0,0072 | 0,0042 |
| AD 1543 | 145 | 2,64 | 1,13 | 31,43 | 67,44 | 8,4 | 8,4 | 2,0 | 0,0 | 1,00 | 0,500 | 0,0030 | 0,0056 | 0,0036 |
| AD 1595 | 185 | 2,64 | 2,78 | 57,78 | 39,44 | 6,9 | 6,9 | 2,8 | 0,0 | 1,00 | 0,500 | 0,0080 | 0,0229 | 0,0161 |
| CO 1138 | 93 | 2,56 | 29,00 | 51,30 | 19,70 | 5,4 | 4,7 | 2,4 | +0,4 | 0,96 | 0,490 | 0,0380 | 0,0572 | 0,0223 |
| CO 1240 | 730 | 2,51 | 65,63 | 16,59 | 17,78 | 4,1 | 2,8 | 2,6 | +0,8 | 1,30 | 0,565 | 0,1440 | 0,0962 | -0,0455 |
| CO 1340 | 551 | 2,54 | 60,33 | 31,53 | 8,14 | 4,0 | 3,0 | 1,8 | +0,8 | 1,00 | 0,500 | 0,1250 | 0,0760 | -0,0360 |
| CO 1440 | 352 | 2,57 | 20,97 | 59,27 | 19,73 | 5,5 | 4,9 | 2,2 | +0,5 | 0,84 | 0,457 | 0,0340 | 0,0374 | 0,0080 |
| CO 1540 | 177 | 2,55 | 1,16 | 84,98 | 13,86 | 5,3 | 4,5 | 1,6 | +0,7 | 1,03 | 0,507 | 0,0440 | 0,0255 | -0,0165 |
| CO 1637 | 114 | 2,61 | 53,03 | 27,97 | 19,00 | 4,4 | 3,3 | 2,2 | +0,8 | 0,95 | 0,487 | 0,1020 | 0,0740 | -0,0210 |
| CO 1740 | 156 | 2,57 | 11,64 | 53,89 | 34,47 | 6,5 | 6,5 | 2,5 | +0,1 | 1,25 | 0,555 | 0,0110 | 0,0326 | 0,0234 |
| CO 1840 | 100 | 2,63 | 1,48 | 74,96 | 23,56 | 6,1 | 5,6 | 2,0 | +0,4 | 0,89 | 0,471 | 0,0210 | 0,0240 | 0,0065 |
| CO 1938 | 108 | 2,62 | 2,99 | 52,52 | 44,49 | 6,9 | 6,8 | 2,5 | +0,2 | 0,80 | 0,444 | 0,0090 | 0,0949 | 0,0171 |
| CO 2040 | 108 | 2,65 | 0,05 | 43,49 | 56,46 | 7,9 | 7,9 | 2,0 | 0,0 | 1,00 | 0,500 | 0,0042 | 0,0074 | 0,0044 |
| CO 2140 | 92 | 2,58 | 20,13 | 38,27 | 41,55 | 6,8 | 6,8 | 2,3 | 0,0 | 1,00 | 0,500 | 0,0090 | 0,0433 | 0,0352 |
| CO 2240 | 152 | 2,60 | 2,49 | 38,58 | 58,94 | 7,1 | 8,2 | 2,2 | -0,6 | 0,52 | 0,342 | 0,0032 | 0,0245 | 0,0234 |
| CO 2340 | 184 | 2,59 | 16,08 | 68,22 | 15,70 | 5,1 | 4,7 | 0,9 | +0,4 | 0,92 | 0,479 | 0,0380 | 0,0371 | 0,0069 |
| CO 2440 | 147 | 2,61 | 23,42 | 62,53 | 14,05 | 5,1 | 4,4 | 1,8 | +0,7 | 1,02 | 0,512 | 0,0470 | 0,0348 | -0,0048 |
| CO 2540 | 405 | 2,61 | 8,45 | 68,26 | 23,29 | 5,8 | 5,2 | 2,2 | +0,4 | 0,95 | 0,487 | 0,0270 | 0,0344 | 0,0106 |
| CO 2640 | 290 | 2,61 | 89,40 | 8,03 | 2,56 | 2,3 | 2,3 | 1,0 | +0,3 | 2,21 | 0,688 | 0,2050 | 0,0885 | 0,0185 |
| CO 2739 | 384 | 2,62 | 76,36 | 14,56 | 9,08 | 3,7 | 3,3 | 1,7 | +0,6 | 3,36 | 0,772 | 0,1020 | 0,0530 | -0,0100 |

TABLE I (Continued)

| Sample | Mass | S.G. | Sand | Silt | Clay | $M_z$ | Q50 | $\sigma_I$ | $Sk_I$ | $K_G$ | $K_G'$ | $M_D$ | $QD_a$ | $Sk_a$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CO 2840 | 379 | 2,62 | 39,75 | 45,77 | 14,48 | 4,9 | 4,3 | 2,3 | +0,5 | 0,93 | 0,482 | 0,0520 | 0,0620 | 0,0210 |
| CO 2933 | 174 | 2,61 | 28,68 | 62,01 | 9,31 | 4,9 | 4,9 | 1,8 | 0,0 | 1,00 | 0,500 | 0,0330 | 0,0575 | 0,0345 |
| CO 3040 | 410 | 2,59 | 82,56 | 12,36 | 5,09 | 3,2 | 2,9 | 1,1 | +0,7 | 3,00 | 0,750 | 0,1350 | 0,0510 | -0,0210 |
| CO 3139 | 200 | 2,60 | 0,69 | 68,22 | 31,09 | 6,8 | 6,5 | 1,7 | +0,2 | 0,85 | 0,460 | 0,0110 | 0,0133 | 0,0047 |
| CO 3237 | 207 | 2,60 | 2,11 | 67,68 | 30,21 | 6,5 | 6,5 | 2,0 | 0,0 | 1,00 | 0,500 | 0,0110 | 0,0205 | 0,0175 |
| CO 3340 | 381 | 2,58 | 45,05 | 33,75 | 21,20 | 5,4 | 3,9 | 3,9 | +0,7 | 1,52 | 0,603 | 0,0670 | 0,0884 | 0,0226 |
| CO 3440 | 368 | 2,61 | 63,16 | 31,96 | 4,88 | 3,7 | 3,4 | 1,3 | +0,5 | 2,14 | 0,682 | 0,0950 | 0,0605 | -0,0005 |
| CO 3540 | 244 | 2,63 | 88,67 | 6,00 | 5,33 | 2,0 | 2,0 | 1,1 | +0,5 | 4,03 | 0,800 | 0,0250 | 0,0875 | 0,0275 |
| CO 3643 | 152 | 2,63 | 0,37 | 75,02 | 24,62 | 6,5 | 6,5 | 1,7 | +0,1 | 0,89 | 0,471 | 0,0110 | 0,0173 | 0,0097 |
| CO 3735 | 162 | 2,60 | 0,06 | 55,71 | 44,23 | 7,3 | 7,3 | 1,7 | 0,0 | 1,00 | 0,500 | 0,0064 | 0,0095 | 0,0051 |
| CO 3843 | 201 | 2,63 | 0,76 | 46,72 | 52,52 | 7,2 | 7,6 | 2,1 | -0,2 | 0,85 | 0,460 | 0,0052 | 0,0182 | 0,0147 |
| CO 3940 | 268 | 2,60 | 57,82 | 36,32 | 5,85 | 4,0 | 3,6 | 1,2 | +0,6 | 2,80 | 0,737 | 0,0820 | 0,0450 | -0,0222 |
| CO 4040 | 287 | 2,54 | 88,39 | 6,76 | 4,84 | 2,6 | 2,4 | 0,8 | +0,6 | 2,87 | 0,741 | 0,1900 | 0,0630 | -0,0180 |
| CO 4140 | 393 | 2,62 | 89,87 | 7,68 | 2,44 | 2,5 | 2,5 | 0,9 | +0,3 | 1,33 | 0,570 | 0,1780 | 0,0665 | 0,0550 |
| CO 4239 | 155 | 2,65 | 1,12 | 36,95 | 61,93 | 7,8 | 7,8 | 1,7 | 0,0 | 1,00 | 0,500 | 0,0045 | 0,0067 | 0,0037 |
| CO 4340 | 158 | 2,64 | 0,90 | 35,20 | 63,90 | 8,0 | 8,0 | 1,9 | 0,0 | 1,00 | 0,500 | 0,0039 | 0,0075 | 0,0047 |
| CO 4443 | 202 | 2,62 | 0,07 | 49,65 | 50,28 | 7,6 | 7,6 | 1,8 | 0,0 | 1,00 | 0,500 | 0,0052 | 0,0082 | 0,0045 |
| CO 4540 | 461 | 2,62 | 58,26 | 33,33 | 8,41 | 3,9 | 3,3 | 1,9 | +0,7 | 1,83 | 0,646 | 0,1200 | 0,0680 | -0,0330 |
| CO 4638 | 235 | 2,62 | 89,63 | 6,39 | 3,98 | 2,2 | 2,2 | 0,8 | +0,8 | 2,10 | 0,678 | 0,2200 | 0,0535 | -0,0015 |
| CO 4740 | 450 | 2,62 | 2,91 | 46,70 | 50,39 | 7,6 | 7,6 | 1,8 | 0,0 | 1,00 | 0,500 | 0,0052 | 0,0082 | 0,0046 |
| CO 4840 | 465 | 2,63 | 29,30 | 59,58 | 11,12 | 4,7 | 4,3 | 1,8 | +0,5 | 1,54 | 0,606 | 0,0510 | 0,0460 | 0,0050 |
| CO 4940 | 521 | 2,63 | 7,74 | 70,66 | 21,60 | 5,8 | 5,7 | 2,1 | +0,5 | 0,87 | 0,466 | 0,0190 | 0,0340 | 0,0239 |
| CO 5040 | 288 | 2,65 | 0,44 | 81,98 | 17,58 | 6,0 | 5,7 | 1,8 | +0,3 | 1,06 | 0,513 | 0,0190 | 0,0213 | 0,0077 |
| CO 5143 | 170 | 2,66 | 0,39 | 50,46 | 49,17 | 7,6 | 7,6 | 1,2 | 0,0 | 1,00 | 0,500 | 0,0052 | 0,0049 | 0,0019 |
| CO 5247 | 105 | 2,65 | 0,24 | 28,33 | 71,43 | 8,4 | 8,4 | 1,5 | 0,0 | 1,00 | 0,500 | 0,0030 | 0,0033 | 0,0042 |

T A B L E  I  (Concluded)

| Sample | Mass | S.G. | Sand | Silt | Clay | $M_z$ | Q50 | $\sigma_I$ | $Sk_I$ | $K_G$ | $K_G'$ | $M_D$ | $QD_a$ | $Sk_a$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CO 5340 | 82 | 2,64 | 0,16 | 46,36 | 53,48 | 7,8 | 7,8 | 1,7 | 0,0 | 1,00 | 0,500 | 0,0045 | 0,0068 | 0,0037 |
| CO 5435 | 186 | 2,66 | 0,80 | 77,83 | 21,37 | 6,1 | 5,9 | 1,7 | +0,1 | 0,98 | 0,496 | 0,0170 | 0,0184 | 0,0056 |
| CO 5543 | 635 | 2,62 | 49,19 | 33,54 | 17,27 | 5,0 | 3,9 | 2,3 | +0,8 | 1,66 | 0,624 | 0,0670 | 0,0416 | -0,0206 |
| CO 5639 | 100 | 2,63 | 0,27 | 51,15 | 48,58 | 7,6 | 7,6 | 1,7 | 0,0 | 1,00 | 0,500 | 0,0052 | 0,0073 | 0,0036 |
| CO 5741 | 144 | 2,66 | - -- | 62,89 | 37,11 | 7,2 | 7,2 | 1,6 | 0,0 | 1,00 | 0,500 | 0,0070 | 0,0084 | 0,0036 |
| CO 5843 | 128 | 2,66 | 1,93 | 52,16 | 45,91 | 6,7 | 6,1 | 2,6 | +0,4 | 0,76 | 0,432 | 0,0150 | 0,0265 | 0,0126 |
| CO 5940 | 345 | 2,65 | 16,14 | 48,43 | 35,43 | 6,5 | 6,0 | 2,8 | +0,3 | 0,90 | 0,474 | 0,0160 | 0,0328 | 0,0182 |
| CO 6040 | 430 | 2,62 | 9,03 | 51,90 | 39,07 | 6,4 | 5,6 | 2,8 | +0,4 | 0,92 | 0,479 | 0,0210 | 0,0328 | 0,0132 |
| CO 6140 | 466 | 2,64 | 0,50 | 81,27 | 18,23 | 6,0 | 5,9 | 1,6 | +0,2 | 0,79 | 0,442 | 0,0170 | 0,0213 | 0,0087 |
| CO 6240 | 264 | 2,60 | 70,17 | 7,15 | 22,68 | 4,0 | 2,6 | 3,1 | +0,7 | 1,63 | 0,617 | 0,1650 | 0,1832 | 0,0238 |
| CO 6345 | 182 | 2,61 | 0,16 | 50,94 | 48,90 | 7,7 | 7,5 | 2,7 | +0,2 | 0,95 | 0,487 | 0,0056 | 0,0151 | 0,0103 |
| CO 6438 | 126 | 2,66 | 0,04 | 82,88 | 17,08 | 6,1 | 6,1 | 1,5 | +0,1 | 0,94 | 0,485 | 0,0150 | 0,0181 | 0,0079 |
| CO 6540 | 447 | 2,59 | 74,06 | 16,32 | 9,71 | 3,4 | 2,8 | 2,1 | +0,8 | 2,75 | 0,735 | 0,1440 | 0,0810 | -0,0345 |
| CO 6640 | 414 | 2,63 | 30,47 | 55,11 | 14,42 | 5,0 | 4,4 | 2,0 | +0,5 | 1,15 | 0,534 | 0,0470 | 0,0443 | 0,0037 |
| CO 6740 | 475 | 2,63 | 0,25 | 79,73 | 20,02 | 5,9 | 5,5 | 2,0 | +0,4 | 1,06 | 0,514 | 0,0220 | 0,0297 | 0,0113 |
| CO 6840 | 403 | 2,66 | - -- | 73,18 | 26,82 | 6,6 | 6,6 | 1,9 | 0,0 | 1,00 | 0,500 | 0,0100 | 0,0171 | 0,0109 |
| CO 6940 | 521 | 2,61 | 49,10 | 40,30 | 10,60 | 4,4 | 3,9 | 2,0 | +0,5 | 1,45 | 0,593 | 0,0670 | 0,0210 | 0,0105 |
| CO 7045 | 93 | 2,63 | 0,47 | 31,65 | 67,88 | 9,8 | 9,8 | 4,5 | +0,1 | 0,33 | 0,454 | 0,0011 | 0,0169 | 0,0159 |
| CO 7137 | 56 | 2,61 | 0,58 | 31,30 | 68,12 | 8,5 | 8,5 | 2,0 | 0,0 | 1,00 | 0,500 | 0,0023 | 0,0051 | 0,0031 |
| CO 7235 | 35 | 2,65 | 3,97 | 70,59 | 25,44 | 6,2 | 5,8 | 2,0 | +0,3 | 0,89 | 0,471 | 0,0180 | 0,0240 | 0,0090 |
| CO 7342 | 56 | 2,58 | 1,66 | 45,32 | 53,02 | 8,3 | 7,8 | 3,6 | +0,3 | 1,05 | 0,512 | 0,0045 | 0,0179 | 0,0136 |

# T A B L E   I I.

## Heavy Mineralogy.

# TABLE II.

## HEAVY MINERALS

| Sample No. | Garnet Coloured | Garnet Colourless | Rutile | Zircon | Sphene | Epidote | Tourmaline | Opaques | Apatite | "Others" |
|---|---|---|---|---|---|---|---|---|---|---|
| AD 341 | 16,9 | 41,6 | 3,0 | 3,1 | 2,4 | 6,5 | 2,3 | 21,4 | 1,3 | 1,6 |
| AD 990 | 24,0 | 47,3 | 3,3 | 4,6 | 1,9 | 2,9 | 1,5 | 13,7 | 0,2 | 0,6 |
| AD 1290 | 6,7 | 20,8 | 3,8 | 5,2 | 4,8 | 6,7 | 1,9 | 20,3 | 4,2 | 3,6 |
| CO 3340 | 4,1 | 53,4 | 5,5 | 3,4 | 4,1 | 0,7 | 4,1 | 18,5 | 4,1 | 2,1 |
| CO 4638 | 15,1 | 39,0 | 2,8 | 3,0 | 1,8 | 6,2 | 1,0 | 28,3 | 2,2 | 0,5 |
| CO 6240 | 6,8 | 24,2 | 7,7 | 3,8 | 5,5 | 1,5 | 0,6 | 39,8 | 5,7 | 4,4 |
| Mean* | 1,2 | 11,4 | 4,4 | 30,3 | 5,8 | 4,7 | 3,1 | 37,6 | 0,6 | 0,9 |
| 22* | - - | 0,6 | 13,2 | 59,4 | - - | 1,2 | 10,1 | 13,1 | 1,8 | 0,6 |
| L. Beau.+ | 27,3 | | 3,3 | 17,6 | - - | - - | 2,0 | 33,8 | 13,8 | 2,2 |
| U. Ecca+ | 38,9 | | 3,0 | 8,9 | - - | tr. | 1,0 | 36,8 | 8,0 | 3,4 |
| M. Ecca+ | 58,0 | | 2,0 | 3,0 | - - | - - | - - | 31,5 | 2,0 | 3,5 |
| L. Ecca+ | 1,0 | | 2,0 | 20,0 | - - | - - | - - | 61,0 | 8,0 | 8,0 |
| Dwyka+ | 42,6 | | 1,0 | 5,2 | - - | 1,8 | 2,1 | 37,1 | 4,0 | 6,2 |
| Witteberg+ | tr. | | 13,8 | 31,8 | - - | tr. | 2,1 | 45,5 | tr. | 6,8 |
| Bokkeveld+ | - - | | 4,8 | 52,3 | - - | - - | 3,8 | 35,8 | 2,0 | 1,3 |
| T.M.S.+ | - - | | 3,7 | 40,0 | - - | - - | 3,0 | 50,3 | - - | 3,0 |

# APPENDIX A.

## Hand Specimen Descriptions.

## Notes Pertaining to Hand Specimen Descriptions.

a) Colours described are from the Rock-Color Chart, 1963, and were matched on the dry specimens. Wet samples often partially disintergrated very rapidly and due to the small initial size of the sample this was undesirable.

b) Coarser fractions are, when possible, fully described in thin section (Appendix B) and these should be consulted in conjunction with the hand specimen descriptions which are, of necessity, brief.

## HAND SPECIMEN DESCRIPTIONS

Core AD 1/68

AD 90 Medium gray (N5) shale with carbonised fragments on lamination planes, with lenses of light gray (N7) very fine sandstone. Very thin laminations, micro-slumping and channeling are the primary sedimentary structures present.

AD 137 Medium dark gray (N4) shale with very minor light gray (N7) very fine sandstone lenses. Very thin laminations and carbonized fragments.

AD 184 Medium dark gray (N4) shale with minor laminations of light gray (N7) to medium light gray (N6) very fine sandstone. Fossils abundant on one of the bedding planes, together with carbonized fragments. (See Plate I, photo. 1).

AD 240 Medium light gray (N6) fine sandstone with lenses of medium gray (N5) shale and lenses and boring fillings of light gray (N7) medium sandstone. Lignite and plant remains present on bedding planes.

AD 293 Medium gray (N5) shale with very minor medium light gray (N6) (?) very fine sandstone.

AD 341 Greenish gray (5 GY 6/1) medium sandstone with lenses and discontinuous beds (1 -2mm.) of medium gray (N5) shale sometimes with carbonized material.

AD 392 Dark gray (N3), apparently unbedded, shale.

AD 440 Finely interbedded medium dark gray (N4) shaly siltstone and light gray (N7) fine to medium sandstone with carbonaceous fragments in the fine fraction. Pinching -and-swelling, slumping, and overturning on a very small scale (3mm thick lamelli). See Plate I, photo. 2.

AD 490 Light olive gray (5 Y 6/1) fine sandstone with irregular lenses of medium dark gray (N4) shale and streaks of carbonized remains indicating small scale (1 cm.) cross laminations.

AD 539 Greenish gray (5GY 6/1) medium sandstone with very minor thin (<0,5mm) medium dark gray (N4) shale streaks otherwise apparently "massive".

AD 590 Dark gray (N3) shale with carbonaceous fragments and thin lamelli and lenses of light olive gray (5 Y 6/1) (0,5 - 1,0 mm) very fine sandstone. Compaction deformation and micro-faulting present.
See Plate I, photo. 3.

AD 649 Dark grey (N3) silty (?) shale.

AD 692 Greenish gray (5 GY 6/1) medium sandstone with minor lenses of dark gray (N3) shale. Abundant rock fragments present.

All the above samples belong to the Sundays River Formation and are marine deposits. The remaining AD 1/68 samples are all terrestrial accumulates belonging to the Kirkwood Formation.

AD 741 Maroon or grayish red (5 R 4/2) shale with irregular patches and streaks of greenish gray (10 GY 5/2) due to the reduction of iron.

AD 786 Dark reddish brown (10 R 3/4) shale with irregular pale green (10 G 6/2) patches.

AD 844 Grayish red (5 R 4/2) silty (?) shale.

AD 890 Grayish red (10 R 4/2) silty (?) shale.

AD 943 Dark red (5 R 3/2) shale with light olive (10 Y 5/2) patches.

AD 990 Fine to medium sandstone, grayish yellow green (5 GY 7/2) with very minor carbonaceous matter. Visible rock fragments.

AD 1041 Grayish red (5 R 4/2) shale with irregular patches of pale yellowish green (10 GY 7/2) and a very light gray (N8) calcarious concretion.

AD 1089 Grayish red (5 R 4/2) shale with pale green (10 G 6/2) irregular patches and streaks.

AD 1141 "Massive", "unbedded" light grayish olive (10 Y 5/2) fine sandstone.

AD 1190 Grayish yellow green (5 GY 7/2) fine sandstone with irregular laminations, patches and lenses of medium greenish gray (5 G 5/1) shale with irregular carbonaceous fragments and streaks. Also minor slumping and differential compaction.

AD 1242 Moderate olive gray (5 Y 4/2) medium sandstone, "massive" and "unbedded" with abundant rock fragments.

AD 1290 Light olive gray (5 Y 5/2) medium to fine sandstone "massive" and "unbedded" with abundant rock fragments.

AD 1334 Dark grayish red (5 R 3/2) shale with irregular patches of grayish yellow green (5 GY 7/2). Sheared and "polished"by faulting (?).

AD 1390 Grayish yellow green (5 GY 7/2) medium to fine sandstone with rock fragments and irregular patches of grayish red (10 R 4/2) shale revealing small scale cross bedding and channeling.

AD 1440 Dark reddish brown (10 R 3/2) shale.

AD 1490 Grayish red (10 R 4/2) shale with irregular patches of pale yellowish olive (10 Y 7/2) and an irregular pale olive (10 Y 6/2) carbonate concretion.

AD 1543 Grayish red (5 R 4/2) shale with very minor grayish green (10 GY 5/2)patches. "Polishing" due to faulting.

AD 1595 Grayish red (10 R 4/2) shale with irregular patches and streaks of grayish yellow green (5 GY 7/2). Highly sheared in several directions to a grayish black (N2) in parts.

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Core CO 1/67

CO 1138 Light gray (N7) laminations (1mm.) of fine to very fine sandstone interlaminated with medium dark gray (N4) shale. Channeling, slumping, differential compaction and lensing are primary sedimentary structures present. Carbonized remains are abundant.

CO 1240 Light bluish gray (5 B 7/1) fine sandstone interlaminated with lenses and patches of medium dark gray (N4) shale. Carbonized plant remains are present and one small shell (brachiopod ) cast.

CO 1340 Medium greenish gray (5 GY 5/1) fine sandstone showing small scale cross bedding with lignite on the bedding planes and medium dark gray (N4) shale lamelli 2 - 3 mm. thick.

CO 1440 Light olive gray (5 Y 6/1) fine to very fine sandstone with medium dark gray (N4) shale. Primary sedimentary structures are channeling, differential compaction, load casting (?) and micro-faulting. Tiny fragments of lignite are also present.

CO 1540 Light olive gray (5 Y 6/1) fine to very fine sandstone grading into medium dark gray (N4) to dark gray (N3) shale showing cross bedding (trough), slumping, "ball-and-pillow" and faulting (?). Very minor lignite also present. See Plate I, photo. 4.

CO 1637 Light gray (N7) fine sandstone interlaminated with medium gray (N5) to medium dark gray (N4) shale, showing cross bedding, slumping and disturbed laminae.

CO 1740 Dark gray (N3) silty (?) shale with thin streaks and irregular patches of light gray (N7) fine sandstone showing disturbed bedding. Minor amounts of lignite also present.

CO 1840 Medium dark gray (N4) silty (?) shale with light olive gray (5 Y 6/1) very fine sandstone laminations. Slumping, folding and generally disturbed bedding on a very small scale. See Plate I, photo. 5.

CO 1938 Dark gray (N3) silty (?) shale with very minor light gray (N7) to light olive gray (5 Y 6/1) very fine sandstone patches and streaks.

CO 2040 Medium dark gray (N4) shale with a lamination 2 - 3 mm. thick of greenish gray (5 GY 6/1) very fine sandstone.

| | | |
|---|---|---|
| CO | 2140 | Medium dark gray (N4) to dark gray (N3) shale with light olive gray (5 Y 6/1) fine to very fine sandstone lenses, laminations and patches. Differential compaction, small scale faulting, slumping and minor amounts of lignite present. |
| CO | 2240 | Medium greenish gray (5 G 5/1) very fine silty shale. A partial fossil cast present. |
| CO | 2340 | Light gray to medium light gray (N7 to N6) very fine sandstone grading into medium dark to dark gray (N4 to N3) silty (?) shale. Fossils and lignite present. |
| CO | 2440 | Medium gray (N5) silty (?) shale with minor, irregular (flaser ?) lenses of greenish gray (5 GY 6/1) very fine sandstone. Some lignite present. |
| CO | 2540 | Medium dark gray (N4) silty (?) shale. |
| CO | 2640 | Greenish gray (5 GY 6/1) medium to fine sandstone with visible rock fragments and very thin minor lenses of medium gray (N5) shale. |
| CO | 2739 | Medium greenish gray (5 GY 5/1) fine sandstone with thin layers (~ 0,5mm.) of (?) medium light gray (N6) shale revealing the cross bedding structure in the sandstone, with a very light gray (N8) carbonate-rich "concretion"(?). Lignite is fairly abundant. |
| CO | 2840 | Intimately interlaminated (flaser ?) medium dark gray (N4) shale and greenish gray (5 GY 6/1) fine to very fine sandstone showing slumping, pinching-and-swelling, differential compaction, channeling and micro-faulting. See Plate I, photo, 6, |
| CO | 2933 | Medium dark gray (N4) silty shale with thin lamelli (~ 0,5 mm.) of dark greenish gray (5 G 4/1) very fine sandstone. |
| CO | 3040 | Medium greenish gray (5 GY 5/1) fine sandstone with thin streaks of medium gray (N5) shale. |
| CO | 3139 | Dark gray (N3) hard, concoidally fracturing, structureless shale. |
| CO | 3237 | Medium dark to dark gray (N4 to N3) hard shale with minor lignite. |

CO 3340 Greenish gray (5 GY 6/1) hard, fine sandstone with lamelli (2 - 3 mm.) of medium dark gray (N4) shale. of irregular orientation, with lignite present.

CO 3440 Greenish gray (5 G 6/1) fine to very fine sandstone with minor medium gray (N5) shale patches.

The following samples all belong to the Kirkwood Formation.

CO 3540 Medium greenish gray (5 GY 5/1) medium to fine sandstone.

CO 3643 Grayish red (10 R 4/2) shale.

CO 3735 Brown gray (5 YR 3/1) shale.

CO 3843 Grayish red (5 R 4/2) shale with grayish green (5 G 5/2) irregular patches.

CO 3940 Light olive gray (5 Y 6/1) fine to very fine sandstone with irregular lenses and streaks of brownish gray (5 YR 4/1) shale.

CO 4040 Medium greenish gray (5 GY 4/1) medium to fine sandstone.

CO 4140 Light olive gray (5 Y 6/1) hard, carbonate cemented, rock-fragment rich, medium to fine sandstone.

CO 4239 Grayish red (10 R 4/2) shale with minor irregular streaks of grayish green (10 GY 5/2) reduced iron.

CO 4340 Olive black (5 Y 2/1) shale.

CO 4443 Grayish red (5 R 4/2) shale with minor grayish green (5 G 5/2) irregular patches.

CO 4540 Grayish yellow green (5 GY 7/2) fine sandstone with highly irregular patches and streaks of grayish red (5 R 4/2) shale. Carbonate cemented. (Cf. AD 1390).

CO 4638 Grayish olive (10 Y 4/2) fine to very fine, rock-fragment rich sandstone.

CO 4734 Dark grayish red (10 R 3/2) shale.

CO 4840 Dusky brown (5 YR 2/2) silt and dark yellowish brown (10 YR 4/2) very fine sandstone.

CO 4940 Dark grayish red (10 R 3/2) shale with irregular, pale green (10 G 6/2) patches.

| | | |
|---|---|---|
| CO | 5040 | Grayish brown (5 YR 3/2) shale. |
| CO | 5143 | Moderate brown (5 YR 3/4) shale. |
| CO | 5247 | Dusky brown (5 YR 2/2) shale. |
| CO | 5340 | Dusky brown (5 YR 2/2) shale. |
| CO | 5345 | Grayish olive (10 Y 4/2) very fine sandstone (?silty) and dark greenish gray (5 GY 4/1) silty shale. |
| CO | 5543 | Grayish yellow green (5 GY 7/2) fine to very fine sandstone with irregular, convolute bedded, micro-cross laminations of grayish red (5 R 4/2) shale, (Cf. CO 4540). |
| CO | 5639 | Grayish brown (5 YR 3/2) shale. |
| CO | 5741 | Dusky brown (5 YR 2/2) shale. |
| CO | 5843 | Grayish brown (5 YR 3/2) shale. |
| CO | 5940 | Medium greenish gray (5 G 5/1) fine to very fine sandstone with irregular bedded, thin (1 mm.) medium gray (N5) to black (N1) carbonaceous shale revealing small scale cross bedding. Some carbonate cement. |
| CO | 6040 | Blackish red (5 R 2/2) shale with irregular patches of grayish olive (10 Y 4/2) shale. |
| CO | 6140 | Dark grayish red (5 R 3/2) shale with irregular olive gray (5 Y 3/2) patches and streaks. |
| CO | 6234 | Medium greenish gray (5 GY 5/1) medium to fine sandstone with grayish red (5 R 4/2) shale pellets and streaks. |
| CO | 6345 | Dusky brown (5 YR 2/2) shale. |
| CO | 6438 | Grayish brown (5 YR 3/2) (silty ?) shale. |
| CO | 6540 | Grayish green (5 GY 6/1) medium to fine sandstone with very minor medium dark gray (N4) shale lamelli. |
| CO | 6640 | Dark grayish red (10 R 3/2) shale with irregular grayish green (10 GY 5/2) patches and streaks. |
| CO | 6740 | Grayish red (5 R 4/2) shale with minor grayish green (5 G 5/2) patches and streaks. |

| | | |
|---|---|---|
| CO | 6840 | Dusky brown (5 YR 2/2) (silty ?) shale. |
| CO | 6940 | Grayish brown (5 YR 3/2) very fine (silty ?) sandstone with irregular pale olive (10 Y 6/2) pale greenish yellow (10 Y 8/2) and grayish yellow green (5 GY 7/2) patches. |
| CO | 7045 | Greenish black (5 GY 2/1) shale. |
| CO | 7137 | Dusky brown (5 YR 2/2) shale. |
| CO | 7235 | Blackish red (5 R 2/2) shale. |
| CO | 7342 | Grayish black to black (N2 to N1) shale. |

# APPENDIX B.

## Thin Section Descriptions.

Notes pertaining to the thin section descriptions.

a) Roundness descriptions are by visual comparison using the POWERS, 1953, scale as a standard.

b) Terms applied to quartz types, e.g. "stretched metaquartzite" etc. are from FOLK, 1968.

c) Point counting was done using a mechanical stage with a grid spacing larger than the largest grain present. The microscope used was a Leitz S.M. Pol. with a binocular head with a 1,25X magnification of the 6,3X eyepieces and a 10X objective lens, i.e. approximately 80X magnification. Unless otherwise stated 500 points were counted.

d) Classification of the rock is after the scheme of GILBERT, 1954, which is essentially that advocated by DOTT, 1964.

e) Size variations of the clastic grains were not measured in thin section; granulometric analyses by wet sieving and pipetting has resulted in the tabulation of various statistics (as shown on TABLE I).

f) Textural classification of the sediments is based on the sand: silt: clay percentages obtained from the size analyses and are shown in DIAG. 1.

## THIN SECTION AD 341

The rock consists of clastic grains of quartz, feldspar (both plagioclase and alkali varieties), rock fragments and sporadic heavy minerals set in a matrix which is believed to be the decomposition product of rock fragments. Carbonate cement is very minor.

The quartz grains exhibit a marked variation of size, shape and roundness characteristics. Subangular to sub-rounded grains are present. Sutured or curved contacts between quartz grains and between the other competent fragments are common, even though the sample comes from a comparatively shallow depth. Extinction variation in the quartz is variable too; from straight to markedly undulatory.

The feldspars are of the same size and shape characteristics as the quartz but show a marked degree of variation in the amount of alteration, from very fresh with clearly visible multiple twinning to completely altered and no visible twinning. Untwinned alkali feldspars are also variably altered.

Rock fragments abound and although they are of the same order of size as the quartz and feldspars they are usually more rounded when not deformed due to compaction. Fine grained (volcanic ?) fragments predominate and there are some fine grained sedimentary fragments. Most of this material is still "fresh" but there is some which is sufficiently altered to cause most of the other clastic grains to have a coating of clayey (chloritic ?) matrix.

There are two types of heavy minerals seen, namely isotropic garnet and high birefringent zircon, with the former predominating. These minerals are markedly smaller than the other clastics and though some are angular others are sub-rounded to rounded, indicative of more than one cycle of erosion, transport and deposition. The heavy mineral suite is described in detail in the text.

Occasional patches of calcite cement are present.

Point counting 1000 points reveals the following composition:-

| | |
|---|---|
| Quartz | 37,3% |
| Rock Fragments | 29,0% |
| Feldspars | 6,7% |
| Matrix | 24,7% |
| Ore | 2,3% |

This rock can therefore be called a subfeldspathic lithic wacke but was probably a subfeldspathic lithic arenite sand at the time of deposition.

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## THIN SECTION AD 490

Clastic grains of quartz, feldspar (plagioclase, microcline and untwinned alkali feldspar) and rock fragments are set in a matrix of altered feldspar and rock fragments and some detrital clay-sized material. Authigenic silica, iron-ore and carbonate cement make up the remaining few percent and there are a few scattered grains of heavy minerals.

The shape of the quartz grains varies from angular (in a few cases grains are very angular) to sub-rounded. Overgrowths on the quartz though present, are scarce and interpenetration is not frequent either. Many of the quartz grains show undulatory extinction and composite grains ("stretched metaquartzite") are also present, as well as grains containing inclusions and vacuoles.

Twinned and untwinned, alkali and plagioclase feldspars in all degrees of alteration-state are present. These grains are usually better rounded than quartz, being sub-rounded with the occasional grain being sub-angular. The "prismatic" shape of cleavage fragments of feldspar is to be seen although the corners are usually rounded. Rock fragments are of the fine-grained variety (presumably both sedimentary and volcanic types being present) but the degree to which most have been altered makes identification uncertain. Many of these fragments are rounded, others have been distorted in shape due to compaction pressure. Most fragments are altered to an advanced degree and are now only recognisable as matrix between the remaining clastic grains.

Numerous cavities are filled with iron-oxide, some of which is possibly due to the breakdown of rock fragments or else due to redistribution of detrital grains of iron-oxide. Also filling cavities, and in some places apparently enlarging them, is calcite cement. This material has corroded the quartz and feldspar grains.

Point-counting 1000 grains reveals the following composition:-

| | |
|---|---|
| Quartz | 27,9% |
| Feldspar | 11,3% |
| Rock Fragments | 20,2% |
| Matrix | 29,3% |
| Calcite | 1,9% |
| Iron-ore | 9,9% |

This is thus a lithic wacke, but was probably a lithic arenite at the time of deposition.

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## THIN SECTION AD 539

Quartz and rock fragments are the major clastic components of this rock. They are set in a matrix (which is presumably derived from the breakdown of rock fragments) and carbonate cement with the former predominating. Feldspars are infrequent and it is believed that this mineral has not contributed much to the formation of matrix. Iron ore is present in minor amounts both in detrital form and due to breakdown of the rock-fragments.

Quartz forms about 35% of the whole rock. The shape of this mineral ranges from well-rounded (only a few grains) to angular but many grains have had their outline modified by compaction pressure - tending to higher degrees of roundness - or by the action of the carbonate cement, usually causing more angularity. This crystallization in interstitial pores has, most probably, produced a certain amount of local expansion of the packing. Some quartz grains are seen to be "floating" in the calcite. Most of the quartz has undulatory extinction to a greater or lesser extent and only a small percentage has straight extinction. Composite grains are present too.

The rock fragments are of the fine-grained variety and are often iron-rich. They are of the same order of size as the quartz grains but are better rounded though more deformed by compaction, particularly when altered to some degree. Fine-grained sedimentary and igneous (basic? volcanic) fragments appear to be the most likely types.

Feldspars are present but amount to less than 5% of the whole rock. Twinned and untwinned, altered and unaltered grains are evident.

Matrix exceeds cement (20 - 25% and c. 15% respectively), the former being derived from the breakdown of the rock-fragments while the latter is only calcite. Although there is some 'suturing' of grain contacts, any silica derived from this has not precipitated in situ as overgrowths are rare. The calcite is not dispersed uniformly throughout, but tends to be patchy and is probably due to recrystallization of fossil fragments.

Heavy minerals (other than the already mentioned iron ore) are garnet; which is usually sub-angular and smaller than the grains of quartz and one only(?) grain of zircon(?) which is well-rounded. Minute needles of rutile(?) occur as inclusions in grains of quartz.

Point-counting 900 grains has revealed the following:-

| | |
|---|---|
| Quartz | 34,8% |
| Rock Fragments | 23,5% |
| Matrix | 21,4% |
| Calcite | 12,5% |
| Feldspar | 3,9% |
| Iron Ore | 3,7% |
| Heavy Minerals | 0,9% |

This rock is a sub-felspathic lithic wacke.

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## THIN SECTION AD 692

The rock is seen to be clastic, consisting primarily of grains of quartz rock-fragments and minor amounts of plagioclase and alkali feldspar as well as a few scattered heavy minerals. Iron ore forms a minor portion and the whole is cemented by calcite. Matrix, derived from the breakdown of rock-fragments, forms a small proportion of this rock.

The quartz grains vary little in size and the sorting is moderately good. Most of the quartz grains are very angular to angular with only a few being sub-angular or sub-rounded (by visual comparison). Quartz grains are seen to be "floating" in cement while in other cases there are sutured contacts between grains. Numerous composite grains are present. Chert is present in minor amounts and overgrowths are infrequent. Corrosion by calcite cement of the quartz is common however, while inclusions are scarce.

Rock-fragments are of fine-grained varieties of igneous (presumably extrusive) and sedimentary types. The degree of rounding of these is considerably better than that of the quartz with numerous particles being rounded to well-rounded. Many of these fragments, however, have had their shape altered due to pressure (compaction) and some chemical alteration resulting in minor amounts of matrix. The larger grains in this rock are usually the rock-fragments.

Feldspars present are both plagioclase and alkali (see Plate II, photo. 2 ) and are weathered to varying degrees. Although the feldspars form a small proportion of this rock, their size and shape characteristics are similar to the quartz grains and not to the rock-fragments.

Heavy minerals are of two types, namely garnet and zircon, with the former being more common, having the typical corroded appearance and fractures. These grains are smaller than the other clastics.

Iron ore appears to be of two types; namely primary i.e. deposited as clastic fragments and as an alteration product between clastic grains (probably due to the break-down of rock-fragments).

Calcite cement is fairly abundant. Detrital grains are seen to be completely surrounded by the carbonate and there is a gradation to where it has merely filled voids between touching grains. Corrosion of the clastic grains, particularly quartz, is to be seen. There appears to have been some volume expansion during the crystallization process, disrupting the framework of clastic grains.

A point count analysis of 300 grains revealed the following composition:-

| | |
|---|---|
| Quartz | 34,1% |
| Feldspar | 2,2% |
| Rock fragments | 25,8% |
| Calcite | 20,0% |
| Matrix (+ ore) | 17,9% |

This is a subfelspathic lithic wacke.

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## THIN SECTION AD 990

This rock consists of a mixture of clastic particles of quartz (which predominates), feldspar (both plagioclase and alkali), rock fragments and heavy mineral grains. There is a small proportion ($\sim$ 5%) of carbonate cement (calcite) and matrix material ($\sim$ 10%) of a clayey nature presumably derived from the breakdown of the rock fragments and feldspars. A further cement — silica — is believed to be due to solution of existing grains (subsequent to deposition) and then precipitated in voids as well as due to pressure solution from compaction.

The grains show a marked variation in the degree of roundness. Numerous grains are angular (some are very angular - by visual comparison) while others are sub-rounded to rounded.

This grain-supported framework has been subjected to a certain degree of pressure as is seen by the interpenetration of grains and this process has altered the shape of most of the grains largely invalidating a visual comparison of roundness. Many of the heavy mineral grains present have rounded corners while some quartz, feldspar and rock fragments are angularly shaped. This indicates that the former minerals have probably suffered more than one cycle of sedimentation. The predominant heavy mineral, garnet, is pitted and fractured in some cases. A few grains of zircon(?) are present too.

Present in minor amounts is isotropic, black iron ore.

There is a marked degree of variation in the extinction pattern of the quartz present. Many grains show undulatory extinction while others are typically monocrystalline. Numerous quartz grains can be termed "stretched metamorphic" with either smooth, cremulated or granulated borders between extinction areas.

In some places the carbonate cement has replaced the edges of the quartz grains. Numerous quartz grains present have inclusion, often in large quantities. Microlites and vacuoles are common.

The feldspars (plagioclase and alkali) show a marked degree of variation in alteration, grading from some grains being very fresh (with clearly visible twinning) to those which are completely altered feldspars.

Rock fragments are common ($\sim 25\%$) and appear to be of different types. Many are sub-rounded to rounded, others are sub-angular to angular while most have been reshaped due to pressure suturing.

The rock fragments present appear to be of three types, namely fine-grained sedimentary, fine grained volcanic and chert. Some carbonate cement fills what must have been primary voids in the sediment and has reduced the porosity.

Point counting 450 grains reveals the following composition:-

| | |
|---|---|
| Quartz | 48,7% |
| Feldspar | 4,7% |
| Rock fragments | 22,6% |
| Heavies | 3,6% |
| Calcite | 3,1% |
| Matrix | 12,2% |
| Ore | 5,1% |

Compositionally this rock is a subfelspathic lithic wacke.

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## THIN SECTION CO 1340

Framework grains consist of quartz, feldspar and rock fragments, set in a matrix of clayey material derived primarily from the breakdown of unstable grains. Detrital opaque grains are scattered between the framework grains.

In general the quartz grains are angular to very angular although some are sub-rounded and interpenetration is slight. Composite grains of quartz are present but in limited amounts, some quartz exhibits undulatory extinction while others have inclusions typical of granitic parentage, while others are of more than one sedimentary cycle. Secondary enlargement of quartz is infrequent. The feldspar grains are of both plagioclase and alkali (microcline and orthoclase) varieties, sometimes remarkably fresh, otherwise altered to varying degrees,

The size and shape characteristics of the feldspars are the same as those of quartz, some grains are rounded but others show the prismatic habit. The shape does not appear to be determined by the degree of alteration, angular and rounded grains are fresh and altered.

Rock fragments appear to be predominantly of a sedimentary nature although some might be volcanic. However, most of these particles are partly or completely altered and deformed by compaction and it is frequently impossible to discern the original outline of the fragment. Under these conditions this material is considered to be matrix.

Only very small amounts of carbonate cement are to be seen in this section -- probably recrystallized detrital fragments.

Besides the opaque grains, the other heavy minerals are mainly garnet and a few scattered zircon grains. Garnets are typically angular to very angular and tend to be smaller than the other clastic grains as well as being markedly pitted. Some of these grains are coloured a brownish pink.

The opaque grains appear to be of two sizes; a few large, scattered "grains", usually deformed, but larger than the clastics and also tiny opaque grains which are found between clastic grains. The latter could be detrital but the larger portions have the typical cement characteristics.

Point counting reveals the following composition:-

| | |
|---|---|
| Quartz | 31,0% |
| Feldspar | 7,6% |
| Rock fragments | 15,0% |
| Matrix | 34,4% |
| Ore | 12,0% |

This rock is a subfeldspathic lithic wacke but better named as a subfeldspathic lithic arenite considering that the majority of the matrix is derived from an altered detrital component.

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## THIN SECTION CO 2640

This rock consists of framework grains of quartz, rock fragments and feldspar, along with minor amounts of opaque ore and heavy minerals. Calcite cement is patchy but very minor, while the binding material is attributed to the decomposition products of the unstable rock fragments and to a lesser extent feldspars. It is believed that most of what is classified as matrix was detrital fragments at the time of deposition. About half of the rock would then be composed of lithic fragments of both sedimentary and volcanic origin although the latter source contributed only small amounts of material.

Many fragments have survived compactional pressure, but numerous are deformed or destroyed to form interstitial "mush", some are well rounded and few are angular.

Quartz grains are varied, some having inclusions, with perfect, singular extinction, others show straining with undulatory extinction while yet others are composite grains. Grains are angular or sub-angular, few are rounded and interpenetration between adjacent quartz grains is present but to a limited extent. Likewise overgrowths are infrequent. Sorting appears to be moderate to good.

The feldspars are predominantly plagioclase and are angular to sub-angular and of the same size range as the quartz. Alteration of these feldspars is not uniform, some grains are fresh, others are not. Some show prismatic habit. Deformation is apparent in that twins are bent in a few cases.

Heavy minerals are mainly garnet (which all appear to be colourless) — which might be "placered" into layers only one grain thick — and opaques, other than inclusions in quartz grains. At the time of deposition this rock was probably a subfeldspathic lithic arenite but is now classified as a subfeldspathic lithic wacke.

Point counting reveals the following composition:-

| | |
|---|---|
| Quartz | 36,2% |
| Feldspar | 5,6% |
| Rock fragments | 21,2% |
| Matrix | 30,6% |
| Ore | 5,8% |
| Heavies | 0,4% |
| Calcite | 0,2% |

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## THIN SECTION CO 2739

Quartz is the most prominent detrital fraction. Grains are angular to sub-angular and only a few are sub-rounded, while sphericity is both high and low. Although infrequent some of the grains show silica overgrowth and this, therefore, predates the calcite cement which forms nearly one third of the rock. Grains are seen to have irregular edges against the cement and this might be due to either etching or to differential grinding thickness. Some of the quartz grains show undulatory extinction but most are monocrystalline. A few are polycrystalline and might be "metamorphic rock-fragments" derived from a sedimentary parent.

Rock fragments appear to be mainly sedimentary but some might be volcanic. These particles are generally better rounded than the quartz grains although some are deformed by pressure. Relatively few of the fragments are sufficiently altered as to be unrecognisable, and thus be classified as matrix. This is apparently due to the carbonate cement which probably reduced permiability sufficiently to inhibit alteration.

Many of the feldspars - both plagioclase and microcline - are fresh and only a few of this mineral type are altered, again due to cementing carbonate. Prismatic shaped feldspars are present.

The carbonate cement which, even within the field of view at medium power, has varied crystallographic orientation is due in part to recrystallized fossil fragments. Single 'crystals' of calcite may surround several detrital grains, some of which appear to 'float' in the cement but this may be due to random sectioning.

Heavy minerals are scarce and are mainly garnet and opaques. The former are angular, corroded and pitted and usually colourless. Some of the ore is in the form of cement. Heavy mineral inclusions within quartz grains are fairly frequent.

Point counting reveals the following composition:-

| | |
|---|---|
| Quartz | 39,0% |
| Feldspars | 7,4% |
| Rock Fragments | 13,0% |
| Matrix | 10,4% |
| Ore | 1,8% |
| Calcite | 28,4% |

If it is considered that the major portion of the matrix is due to alteration of detrital rock fragments then this rock is a calcite-cemented, lithic arenite.

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## THIN SECTION CO 3040

The framework grains are composed of quartz, rock fragments and feldspars with minor iron ore and heavy minerals (mainly garnet). Matrix, derived from the alteration of unstable grains, and minor carbonate cement, bind the whole together.

The quartz grains are typically angular to sub-angular and are usually of low sphericity. This mineral type and the other elongate grains tend to be preferentially oriented parallel to the bedding. Grains showing strained, undulatory extinction are fairly frequent as are polycrystalline grains. Numerous grains have inclusions. Contacts between touching quartz grains show little interpenetration - the 'incompetent' rock-fragments have yielded to compaction pressure. Silica enlargements of grains is present but uncommon and silica cement is not a lithifying component - some of the overgrowths may have originated during a previous sedimentary cycle.

The rock fragments tend to be more rounded than the quartz grains and are also more highly deformed, due to pressure. Most of these fragments are of fine grained sedimentary origin while some might possibly be devitrified volcanic material. Those particles which are elongated tend to be parallel to the bedding. A considerable portion of these fragments are no longer recognisable as discrete particles and are classified as matrix. Very little of what is matrix can be positively identified as being detrital.

Feldspar grains are altered or very altered, only a few are fresh, most are angular to sub-angular and some of the altered grains are deformed. Plagioclase is dominant. A small portion of the matrix can be ascribed to the breakdown of feldspars.

Heavy mineral grains are infrequent and are mostly garnets, which are colourless and highly pitted, as well as being angular or very angular. Iron ore occurs as tiny grains and as void fillings, possibly from the breakdown of rock fragments.

Calcite cement is present as scattered patches and may be due to recrystallization of carbonate fragments which were originally detrital grains.

Only 302 grains were counted and the following composition was obtained:-

| | |
|---|---|
| Quartz | 36,1% |
| Feldspar | 7.6% |
| Rock fragments | 25,5% |
| Matrix | 21,8% |
| Ore | 6,6% |
| Heavies | 0,3% |
| Calcite | 2,1% |

This rock is a subfeldspathic lithic wacke.

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## THIN SECTION CO 3440

This clastic rock consists of grains of quartz, feldspar and rock fragments (with minor iron ore and a few scattered heavy mineral grains) set in a carbonate cement and also having some matrix probably derived from the breakdown of the more unstable material.

The quartz grains have a large variation in both size and shape. Numerous grains are angular or very angular while others are sub-rounded to rounded, probably indicative of a previous cycle of transportation and deposition. Shape varies from very elongate to very equant (FOLK, 1968, p. 9). When in contact with the carbonate cement, some grains appear to have been severely corroded, others not, while numerous grains appear to "float" in the cement. Vacuoles are frequent but inclusions, rutile (?) needles etc. are not and although some grains do show undulatory extinction this is not a common feature, but composite (polycrystalline) grains are common. Deformation of quartz grains due to compaction pressure is minimal.

Feldspar grains are of the same order of size as the quartz, many being elongate and numerous being prismatic in shape. Twinned and untwinned feldspar are present and although many grains are altered there are abundant very fresh plagioclase grains. As with the quartz grains, many feldspars are corroded at the edges by the cement while one grain was found which had one set of twins completely replaced and the other set partially replaced by the cement.

Rock fragments appear to be of two types, fine-grained sedimentary and fine-grained igneous (volcanic). These particles are often rounded to sub-rounded and are frequently very altered. It is believed that this fraction has been the main contributor to the matrix material.

Iron ore, some of which is detrital, is mostly due to breakdown of unstable material.

Heavy minerals (other than iron-oxides) are scarce with only a few scattered grains of isotropic, pitted, angular garnet.

A modal analysis of this thin section, counting 600 points, revealed the following composition:-

| | |
|---|---|
| Quartz | 34,3% |
| Rock fragments | 14,3% |
| Feldspar | 10,0% |
| Matrix | 18,8% |
| Cement | 20,0% |
| Ore | 2,7% |

According to GILBERT's (1954) classification, this rock is a subfeldspathic lithic wacke.

---

THIN SECTION CO 3540

The classic quartz grains have a wide range of shape characteristics, some grains being well rounded while others are sub-angular, indicating that this is a multi-cycle sediment. The extinction under crossed-nicols shows the same wide variance with some grains being "stretched metamorphic" (FOLK, 1968, p.70) while others exhibit only straight extinction. Many quartz grains have vacuoles and/or microlites while others could be termed "recrystallized metamorphic". Rutile(?) needles are present in some grains. From this vast variety of quartz grain types, some confusion results in assigning silica to either "quartz" or "rock fragments" classes in the modal calculation as a grain showing "moderate" undulatory extinction may be as much a rock fragment as an obviously polycrystalline grain. Many of the quartz grains show "pressure solution" and concavo-convex contacts between grains, or have deformed, less competent grains.

Rock fragments, besides being of polycrystalline quartz, are either fine grained sedimentary or volcanic particles. Many rock-fragments exhibit a remarkable degree of rounding, being rounded (by visual comparison), while many others have been deformed by compaction. Some fragments are still fresh while others are partially or wholly decomposed to provide the matrix material which coats most grains. Some of the matrix material probably is due to decomposed feldspars.

Feldspars are of both the plagioclase and the alkali groups with the latter being both twinned (microcline) and untwinned (orthoclase). Many of the grains of feldspar are remarkably fresh while there are others which are altered. Some grains are rounded while others are prismatic and show very little abrasion although they are of the same order of size as their rounded counterparts. Tentative plagioclase compositions from measurements of the extinction angles (Michel-Levy's Method in ROGERS & KERR, 1942, p. 242) reveal the feldspar to be c. $An_{50}$. As with the other grains the contacts have been modified by compaction.

Carbonate cement is minor and scattered and is probably due to recrystallized detrital calcite.

Heavy minerals are not frequent and appear to be concentrated into layers (bedding planes?) and the most abundant type is isotropic, pitted, sometimes pink, garnet.

Iron ore is present along grain boundaries and is apparently due to the breakdown of rock fragments (?) while very minor amounts of what appear to be detrital ore are present.

This rock has a modal composition (from 1000 counted points) of:-

| | |
|---|---|
| Quartz | 42,6% |
| Rock fragments | 23,1% |
| Feldspars | 3,3% |
| Ore | 2,8% |
| Heavy Minerals | 1,2% |
| Carbonate Cement | 0,2% |
| Matrix | 26,6% |

This rock is a subfeldspathic lithic wacke.

-------------------

## THIN SECTION CO 4040

This rock is composed of detrital grains of quartz, rock fragments, feldspar, minor heavy minerals and detrital iron oxides in a matrix of alteration products of predominantly rock fragments as well as iron ore. Very minor patches of calcite are present but these are not as cement in that they appear to be recrystallized or fragmental carbonate remains.

Quartz grains are very varied in shape, ranging from very angular to sub-rounded or rounded and many are tabular or low in sphericity, these particles being reasonably well oriented parallel to the bedding. Different types of quartz grains are present; monocrystalline, strained, polycrystalline, and multicycle particles, some now having overgrowths in optical continuity. Interpenetration between grains is noticeable but not marked. Numerous grains show inclusions and bubble trains.

Feldspars, a great deal less frequent than the quartz, are not well rounded (some are classically prismatic) and tend to be in a rather advanced state of alteration although some grains are very fresh. Both plagioclase and alkali varieties are present but the former are more abundant.

Rock fragments are nearly as abundant as quartz, some are sedimentary while others are volcanic. Many are extremely altered and are now classified as matrix. Iron-rich varieties are common. Particles are frequently well rounded but often deformed between the more competent grains.

Most of the rock is bound by matrix which can be ascribed to the alteration of rock fragments, while in portions of the slide is an iron-rich cement which has apparently formed only in those void spaces not occupied by deformed grains (mainly rock fragments). Detrital iron ore is present in minor amounts as are heavy minerals, mainly colourless garnets which are angular, pitted and corroded.

Carbonate, when present, is as small patches, possibly due to the recrystallization of detrital fragments; it is not the prominent cementing agent.

A modal analysis reveals the following composition:-

| | |
|---|---|
| Quartz | 40,6% |
| Feldspar | 8,4% |
| Rock fragments | 16,6% |
| Matrix | 21,8% |
| Ore | 12,2% |
| Heavies | 0,2% |
| Calcite | 0,2% |

This rock is a subfeldspathic lithic wacke. If the matrix is accepted to have been derived from the destruction of unstable grains, then this rock is a lithic arenite.

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## THIN SECTION CO 4140

The most noticeable feature of this thin section is the large amount of calcite cement and the lack of matrix. Rock fragments are present but they are not sufficiently altered to be unrecognisable. Clastic quartz makes up more than half the framework grains while feldspars form less than 10%.

Quartz grains are angular to sub-rounded and numerous grains have silica overgrowths. One grain was seen which has chert enlargement but this is probably due to an earlier cycle of sedimentation. Inclusions, bubble trains and undulatory extinguishing of the quartz are common. Interpenetration between grains is very limited and many are almost completely surrounded by carbonate cement. Polycrystalline quartz is present in fairly small amounts. Although many of the grains appear to be elongated there is no existence of preferential orientation of these particles.

Rock fragments are more rounded than the quartz and feldspars and are not highly deformed and altered. Sedimentary varieties are most abundant but fine grained volcanic fragments are also recognisable. Rock fragments constitute about one quarter of the rock as a whole and about one third of the framework grains.

The feldspars - plagioclase predominating - are typically angular with prismatic habit and are in a reasonably advanced state of alteration but fresh grains are also present, indicating that some grains were altered prior to deposition but others not, i.e. multicycle sediments.

Of the heavy minerals, iron ore is the most common and although some is detrital a large portion has been redistributed subsequent to deposition, and is more akin to cement, although forming only small amounts of the whole rock. Garnet which is colourless and pitted, zircon, sphene and a few isolated mica grains complete the heavy mineral suite.

This rock is noted for its lack of matrix due to the cement preventing alteration of the unstable grains.

Point counting revealed the following composition:-

| | |
|---|---|
| Quartz | 38,0% |
| Feldspars | 5,8% |
| Rock fragments | 23,8% |
| Matrix | 3,0% |
| Heavies | 0,8% |
| Calcite | 24,2% |
| Ore | 4,4% |

Classified as a calcite-cemented, lithic arenite.

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## THIN SECTION CO 4540

The framework grains consist of quartz, rock fragments, feldspars, minor amounts of heavy minerals and iron ore set in a calcite cement with small quantities of matrix derived from the breakdown of unstable grains.

The quartz grains, which form slightly more than half of the total detrital fraction are very varied in shape, ranging from angular or very angular particles, with both high and low sphericity, to sub-rounded or rounded particles also with high and low sphericity. However, rounded particles are not common. Monocrystalline and polycrystalline varieties of quartz, and strained grains, are present. Numerous inclusions and bubble trains are to be seen.

Rock fragments, which form about one fifth of the total rock and about 35% of the detrital grains are of both sedimentary and volcanic types, and although generally altered and deformed, this process has not resulted in the formation of much matrix due to the fact that the calcite cement inhibited permiability. Undeformed fragments tend to be sub-rounded to rounded.

Feldspars constitute a little over 10% of the detrital fraction and are predominantly of the plagioclase type. Many of the grains are altered but not excessively so, while numerous are fresh and often angular or very angular. These grains are of the same order of size as the quartz and lithic fragments but only the quartz grains have been etched by the cement. The cement appears in distinct patches where the grain size is larger and the void spaces bigger. In portions of the slide the detrital material is noticeably finer grained and here there is little or no carbonate cement, only fine grained detritus and some matrix derived from nearby lithic fragments.

Heavy minerals, together with iron ore, constitute a noticeable proportion of this rock (c. 5%) and are mainly colourless garnets as well as zircons, rutile and sphene. The iron ore is both detrital and authigenic (?) i.e. recrystallized (precipitated) from unstable grains.

Point counting revealed the following composition:-

| | |
|---|---|
| Quartz | 37,8% |
| Feldspar | 8,8% |
| Rock fragments | 18,4% |
| Matrix | 8,4% |
| Ore | 3,6% |
| Heavies | 1,0% |
| Calcite | 22,0% |

This is a lithic arenite.

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## THIN SECTION CO 4638

This clastic rock has framework grains of quartz, feldspar and rock fragments with minor amounts of iron ore and heavy minerals. Calcite, present in very small amounts, appears as detrital grains rather than as cement. The rock is bound by a matrix which can be related to the deformation and alteration of the unstable grains - rock fragments and to a much lesser extent feldspars. Recrystallization of iron oxide to a minor extent also acts as a lithifying material.

The quartz grains are fairly uniform in size and are sub-angular to sub-rounded with a few being angular. When grains are elongated they appear to be roughly parallel to the bedding, but many grains have been deformed to a noticeable extent by compaction interpenetration. Monocrystalline (i.e. granitic (?) ) grains with inclusions are common and numerous grains now show strain extinction while polycrystalline (i.e. meta-quartzite) grains are abundant. Overgrowths are present too.

Feldspars are predominantly plagioclase and tend to be more angular than the quartz grains but are also more altered and deformed, although some grains of this mineral species are fresh but deformed. No microcline grains were observed.

Rock fragments account for just over 20% of the rock as a whole and about 40% of the detrital fraction. Fine grain varieties of the sedimentary and volcanic types are present and are usually in well rounded but elongated grains and often deformed. The matrix of this rock is ascribed to the alteration of these unstable fragments, as many are very highly deformed by compaction and diagenesis.

Iron ore, both detrital and secondary, is present in minor amounts and the heavy mineral suite is described elsewhere (p. 28 - 30, Table II).

Point counting revealed the following composition:-

| | |
|---|---|
| Quartz | 50,0% |
| Feldspar | 8,0% |
| Rock fragments | 22,8% |
| Matrix | 13,4% |
| Ore | 5,2% |
| Heavies | 0,2% |
| Calcite | 0,4% |

This rock is a subfeldspathic lithic wacke but was probably a lithic-arenite sand at the time of deposition.

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## THIN SECTION CO 5940

This clastic rock consists predominantly of quartz grains together with lesser amounts of rock fragments and feldspars, set in calcite cement with minor matrix derived from the alteration of the lithic fragments. Iron ore is present as both detrital and secondary cement while heavy minerals form a very minor constituent.

Quartz constitutes nearly half of the whole rock and little more than 60% of the detrital grains. These grains are angular to sub-rounded and many appear to be markedly corroded by the carbonate cement. Grain boundaries are also altered by interpenetration due to compaction, while numerous particles show secondary enlargement, some of which might be due to a previous cycle of deposition, but not all can be ascribed to this cause. Quartz varieties range from perfectly monocrystalline with numerous bubble trains and inclusions, through strained varieties to polycrystalline and metaquartzite. When the grains are not equidimentional they appear to be preferentially oriented parallel to the bedding.

The rock fragments account for about one fifth of the rock and about one third of the detritus and are fine grained varieties of sedimentary and volcanic origin, rich in iron and having a speckled appearance. Alteration is moderate and many of the grains are deformed by compaction but these factors have not produced much matrix, being retarded by the carbonate cement.

The feldspars are predominantly plagioclase with minor amounts of alkali varieties (orthoclase and microcline) and are usually sub-angular, edges being affected by the calcite. Most of the feldspars are altered to a marked degree but fresh grains are present too, some grains show distortion of the twins due to compaction and sutured contacts between competent grains are evident.

Although detrital grains of iron ore are present most appear to be derived from the rock fragments and are seen to be in close association with these labile fragments.

Heavy minerals are minor in amount (about 1%) and are mainly corroded, pitted, fractured, colourless garnet with lesser apatite, zircon and sphene; are better rounded (indicative of a previous cycle of deposition) and generally smaller than the other detrital components.

Calcite cement forms about one fifth of the rock and fills all pore spaces. Some parts of the calcite appear to be detrital grains and the cement may well be due to the recrystallization of such detrital material within the sediment. It is also apparent that the calcite is slightly later in age than some silica cement - not all the overgrowths are thought to be from a previous cycle of sedimentation. The amount of matrix in this rock is restricted due to the formation of the calcite cement and this rock is a (subfeldspathic) lithic arenite.

Point counting revealed the following composition:-

| | |
|---|---|
| Quartz | 45,4% |
| Feldspar | 7,8% |
| Rock fragments | 13,8% |
| Matrix | 7,2% |
| Ore | 7,8% |
| Heavies | 1,0% |
| Calcite | 17,0% |

---

THIN SECTION CO 6240

This rock consists of clastic grains of quartz, iron-rich fragments, feldspar, minor detrital iron ore and calcite, with very small amounts of heavy minerals. The rock is bound by a matrix and iron cement derived from the breakdown of the lithic fragments and recrystallization of the detrital ore as well as by interpenetration of adjacent grains due to compaction. Sorting of the components is generally poor and many of the grain boundaries have been modified so significantly as to make visual comparison of their roundness and shape characteristics unprofitable.

The quartz grains, which form nearly half of the rock, are widely varied in size and shape and many are strained; numerous are enlarged with secondary overgrowth and polycrystalline grains are frequently seen. Although most of the quartz grains are angular there are a few scattered ones which are very well rounded indicating a previous cycle (probably more than one) of transportation and sedimentation. Dusty inclusions are common, as are crystallites.

Feldspars - predominantly plagioclase - are angular and tend to be prismatic and are usually altered, but fresh grains are also present. Many of their grain boundaries are sutured by compaction.

Rock fragments, as mentioned, are very iron rich and commonly are rounded and deformed; some are completely altered to matrix. Mostly fine grained varieties are present, but some silty sedimentary particles are visible. Alteration has provided appreciable amounts of iron for recrystallization.

Heavy minerals are scarce and those present are mainly garnet and zircon. Carbonate, as recrystallized detritus (?) is present in minor amounts.

This rock is a subfeldspathic lithic wacke but was probably a subfeldspathic lithic arenite at the time of deposition.

Point counting revealed the following composition:-

| | |
|---|---|
| Quartz | 44,4% |
| Feldspar | 9,2% |
| Rock fragments | 19,6% |
| Matrix | 15,6% |
| Ore | 10,8% |
| Heavies | - - |
| Calcite | 0,4% |

-------------------

# APPENDIX C.

## Size Analysis Calculation Method and Pipetting Table.

SIEVE ANALYSIS OF SAND FRACTION    SAMPLE NO. CO 1440

| Size Limits (phi) | Size limits (µm) | Bkr + Spl Weight (gm) | Bkr Weight (gm) | Spl Weight (gm) | Weight Percent % | Cum. Percent % |
|---|---|---|---|---|---|---|
| 2,25-2,75 | 210-152 | 50,521 | 50,402 | 0,120 | 0,22 | 0,22 |
| 2,75-3,25 | 152-104 | 49,236 | 48,672 | 0,564 | 1,05 | 1,27 |
| 3,25-3,75 | 104-74 | 47,241 | 41,580 | 5,660 | 10,53 | 11,80 |
| 3,75-4,00 | 74-63 | 52,286 | 47,360 | 4,926 | 9,16 | 20,97 |
| | | Wt. Coarse Fraction | | 11,270 | | |
| | | TOTAL WEIGHT | | 53,750 | | |

# PIPETTE ANALYSIS OF SILT AND CLAY FRACTION

SAMPLE NO. CO 1440

| Size Limits (phi) | Size Limits (mic.) | Time (H. M. S.) | Depth (cm) | Beaker Number | Bkr. & Spl. / Beaker | Sample Wt. (g.) | Spl. Wt. x47,62 (g.) | Fraction Weight (g) | Weight Percentage (%) | Cumulative Percentage (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| > 4 | > 63 | | | | | | | | | |
| 4 – 5 | 63/31 | 0 – 0 – 0 | 25,0 | A | 41,688 / 40,682 | 1,006 | 47,48 | 11,80 | 21,95 | 42,92 |
| 5 – 6 | 31/ 15.6 | 0 – 3 – 20 | 23,2 | B | 45,100 / 44,344 | 0,756 | 35,68 | 9,20 | 17,12 | 60,04 |
| 6 – 7 | 15.6/ 7.8 | 0 – 15 – 0 | 26,1 | C | 45,150 / 44,589 | 0,561 | 26,48 | 5,85 | 10,88 | 70,92 |
| 7 – 8 | 7.8/ 3.9 | 0 – 20 – 0 | 9,0 | D | 44,200 / 43,763 | 0,437 | 20,63 | 5,01 | 9,32 | 80,24 |
| 8 – 9 | 3.9/ 2.0 | 1 – 0 – 0 | 6,5 | E | 43,268 / 42,937 | 0,337 | 15,62 | 3,58 | 6,66 | 86,90 |
| 9 – 10 | 2.0/ 0.98 | 2X – 0 – 0 | 3,3 | F | 45,500 / 45,245 | 0,255 | 12,04 | 2,69 | 5,00 | 91,90 |
| < 10 | < 0.98 | 19 – 30 – 0 | 7,6 | G | 49,638 / 49,440 | 0,198 | 9,35 | 4,35 | 8,09 | 99,99 |
| | | | | | | Wt. of dispersant/ 1000 ml. | 5,00 | | | |

Pre-Treatment:- Disaggregation

Temperature 30,0 °C

Analyst:- A. G. S.

Cum. % finest sand 20,97 %

Date:- 9- II- 73.

| | | |
|---|---|---|
| Wt. fine fraction | 42,48 | |
| Wt. coarse fraction | 11,27 | |
| TOTAL WEIGHT | 53,75 | 59,27 % SILT |
| Wt. silt fraction | 31,86 | 19,76 % CLAY |
| Wt. clay fraction | 10,62 | 79,03 % MUD |

# P I P E T T I N G  T A B L E.

(Depth of Pipetting = Settling Velocity X time of Pipetting)

| TEMP. °C. | TIME OF PIPETTING AND CORRESPONDING PARTICLE SIZE | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0s 4phi | 3m20s 5phi | 15m 6phi | 20m 7phi | 1h 8phi | 4h 9phi | 12h 10phi | 22h18m 10phi | 22h52m 10phi |
| | DEPTH OF PITETTING (cm) | | | | | | | | |
| 14 | 25 | 15,7 | 18,0 | 6,0 | 4,5 | 4,5 | 3,4 | 6,3 | 6,4 |
| 14,5 | 25 | 15,9 | 18,2 | 6,1 | 4,6 | 4,6 | 3,4 | 6,4 | 6,6 |
| 15 | 25 | 16,1 | 18,4 | 6,1 | 4,6 | 4,6 | 3,5 | 6,4 | 6,6 |
| 15,5 | 25 | 16,3 | 18,7 | 6,2 | 4,7 | 4,7 | 3,5 | 6,5 | 6,7 |
| 16 | 25 | 16,5 | 18,9 | 6,3 | 4,7 | 4,7 | 3,5 | 6,5 | 6,7 |
| 16,5 | 25 | 16,7 | 19,2 | 6,4 | 4,8 | 4,8 | 3,6 | 6,7 | 6,9 |
| 17 | 25 | 16,9 | 19,4 | 6,5 | 4,9 | 4,9 | 3,7 | 6,8 | 7,0 |
| 17,5 | 25 | 17,1 | 19,7 | 6,5 | 4,9 | 4,9 | 3,7 | 6,8 | 7,0 |
| 18 | 25 | 17,3 | 19,9 | 6,7 | 5,0 | 5,0 | 3,8 | 7,0 | 7,1 |
| 18,5 | 25 | 17,6 | 20,2 | 6,7 | 5,1 | 5,1 | 3,8 | 7,1 | 7,3 |
| 19 | 25 | 17,8 | 20,4 | 6,8 | 5,1 | 5,1 | 3,8 | 7,1 | 7,3 |
| 19,5 | 25 | 18,0 | 20,7 | 6,9 | 5,2 | 5,2 | 3,9 | 7,3 | 7,4 |
| 20 | 25 | 18,2 | 20,9 | 7,0 | 5,2 | 5,2 | 3,9 | 7,3 | 7,4 |
| 20,5 | 25 | 18,5 | 21,2 | 7,1 | 5,3 | 5,3 | 4,0 | 7,4 | 7,6 |
| 21 | 25 | 18,7 | 21,4 | 7,1 | 5,4 | 5,3 | 4,0 | 7,5 | 7,7 |
| 21,5 | 25 | 18,9 | 21,7 | 7,3 | 5,4 | 5,4 | 4,1 | 7,5 | 7,7 |
| 22 | 25 | 19,1 | 22,0 | 7,3 | 5,5 | 5,5 | 4,1 | 7,6 | 7,9 |
| 22,5 | 25 | 19,4 | 22,2 | 7,4 | 5,6 | 5,6 | 4,2 | 7,8 | 8,0 |
| 23 | 25 | 19,6 | 22,5 | 7,5 | 5,6 | 5,6 | 4,2 | 7,8 | 8,0 |
| 23,5 | 25 | 19,9 | 22,7 | 7,6 | 5,7 | 5,7 | 4,3 | 7,9 | 8,1 |
| 24 | 25 | 20,1 | 23,0 | 7,7 | 5,8 | 5,8 | 4,3 | 8,1 | 8,3 |
| 24,5 | 25 | 20,4 | 23,2 | 7,7 | 5,8 | 5,8 | 4,4 | 8,1 | 8,3 |
| 25 | 25 | 20,6 | 23,5 | 7,9 | 5,9 | 5,9 | 4,4 | 8,2 | 8,4 |
| 26,5 | 25 | 20,9 | 23,7 | 8,0 | 5,9 | 5,9 | 4,5 | 8,3 | 8,5 |
| 26 | 25 | 21,1 | 24,0 | 8,1 | 6,0 | 6,0 | 4,5 | 8,4 | 8,6 |
| 26,5 | 25 | 21,4 | 24,2 | 8,2 | 6,1 | 6,1 | 4,6 | 8,4 | 8,6 |
| 27 | 25 | 21,7 | 24,5 | 8,5 | 6,1 | 6,1 | 4,6 | 8,6 | 8,8 |
| 27,5 | 25 | 22,0 | 24,8 | 8,5 | 6,2 | 6,2 | 4,7 | 8,6 | 8,9 |
| 28 | 25 | 22,2 | 25,1 | 8,7 | 6,3 | 6,3 | 4,7 | 8,8 | 9,1 |
| 28,5 | 25 | 22,4 | 25,3 | 8,8 | 6,4 | 6,4 | 4,7 | 8,8 | 9,1 |
| 29 | 25 | 22,7 | 25,6 | 8,9 | 6,4 | 6,4 | 4,8 | 8,9 | 9,2 |
| 29,5 | 25 | 22,9 | 25,8 | 8,9 | 6,5 | 6,5 | 4,8 | 9,1 | 9,2 |
| 30 | 25 | 23,2 | 26,1 | 9,0 | 6,5 | 6,5 | 4,9 | 9,1 | 9,3 |

# COMPUTER PROGRAMME.

COMPUTER PROGRAMME.

```
LIST
SEND TO (COBOLPROGRAM)
DUMP ON (PROGRAM TEST)
WORK (GEN WORKFILE)
PROGRAM(GXSA)
INPUT 2 = CRO
OUTPUT 5 = LPO
COMPRESS INTEGER AND LOGICAL
TRACE 2
END


        MASTER TEST
        REAL KG,KGDSH
        IHDG=0
10      READ(2,100)SAMP,AMTA,AMTB,AMTC,AMTD,AMTE,AMTF,AMTG
100     FORMAT(A6,7F5.2)
        IF(SAMP.EQ.999999)GO TO 99
        RMZ=(AMTB+AMTD+AMTF)/3.0
        OI=(AMTF-AMTB)/4.0 + (AMTG-AMTA)/6.6
        SKI=((AMTA+AMTG-2*AMTD)/(2*(AMTG-AMTA)))
        SKI=SKI+((AMTB+AMTF-2*AMTD)/(2*(AMTF-AMTB)))
        KG= (AMTG-AMTA)/(2.44*(AMTE-AMTC))
        KGDSH = KG/(1+KG)
        IF (IHDG.NE.0)GO TO 30
        WRITE(5,200)
200     FORMAT(1H1,32X,26HSIZE ANALYSIS STATISTICS//,8X,
             8HSAMPLE NO,14X,
        12HMZ,14X,2HOI,13X,3HSKI,14X,2HKG,13X,3HKG'///)
30      IHDG=IHDG+1
        IF(IHDG.EQ.25)IHDG=0
        WRITE(5,210)SAMP,RMZ,OI,SKI,KG,KGDSH
210     FORMAT(1HO,8X,A6,13X,5(F6.2,10X))
        GO TO 10
99      STOP
        END
        FINISH
```

Note: The author is indebted to Miss M. A. Grey for writing and running this programme.

# DIAGRAMS.

DIAGRAM 1. Plot of the Sand:Silt:Clay percentages derived from size analyses of the AD 1/68 and CO 1/67 samples, i.e. texture.

| | |
|---|---|
| S | Sand |
| zS | silty Sand |
| cS | clayey Sand |
| sZ | sandy Silt |
| szc | sand silt clay |
| sC | sandy Clay |
| Z | Silt |
| cZ | clayey Silt |
| zC | silty Clay |
| C | clay |

DIAGRAM 2. Histogram of Sand:Silt:Clay percentages derived from size analyses. Nomenclature as for Diag. I.

DIAGRAM 3. Relationship between percentages of different components and number of points counted in modal analysis carried out on thin section of sample AD 341.

DIAGRAMS 4, 5 & 6. Relationships between various pairs of size analysis statistical parameters for all samples from AD 1/68 and CO 1/67.

DIAGRAMS 7, 8 & 9. Relationships between various pairs of size analysis statistical parameters for all samples from AD 1/68 and CO 1/67.

DIAGRAM 10. Relationship between Ska and QDa with reference to various "fields" as defined by BULLER & McMANUS, 1972.

DIAGRAM 11. Relationship between Md and QDa with reference to various "fields" as defined by BULLER & McMANUS, 1972.

DIAGRAM 12. Variation of Specific Gravity (S.G.) with depth for all samples from AD 1/68 and CO 1/67.

DIAGRAM 13. Arithmetic probability vs. Phi diameters of selected samples from size analyses. Straight line segments indicate normally distributed populations.

DIAGRAM 14. Variation in the clay mineralogy as a percent of the total sample, with depth in AD 1/68 samples. ( * indicates appreciable amounts of kaolinite.)

DIAGRAMS 15a & 15b. Variation in the clay mineralogy as a percent of the total sample, with depth in CO 1/67. ( * indicates appreciable amounts of kaolinite.)

DIAGRAM 16. X-ray diffractogram of the top and bottom of the 2 μm fraction, to illustrate the variation in mineralogy caused by settling. CH = Chlorite; I = Illite; K = Kaolinite.

DIAGRAM 16b. X-ray "diffractograms" obtained from an aluminium sample holder and glass slide. Note that the peak will affect the chlorite 001 peak.

DIAGRAM 17. Portions of the diffractograms of untreated and glycollated 2 μm fraction of sample CO 1440. CH = Chlorite; I = Illite; M = Montmorillonite; K = Kaolinite.

DIAGRAM 18. X-ray diffractograms of the heavy mineral suite (plus quartz) for selected samples; CO 6240, CO 4638, AD 990 and AD 341. Q = Quartz; Z = Zircon; S = Sphene; R = Rutile; G = Garnet; H = Hematite; I = Ilmenite.

DIAGRAM 19. Simplified geological map of the Algoa Basin and the surrounding country, showing the location of the two boreholes.

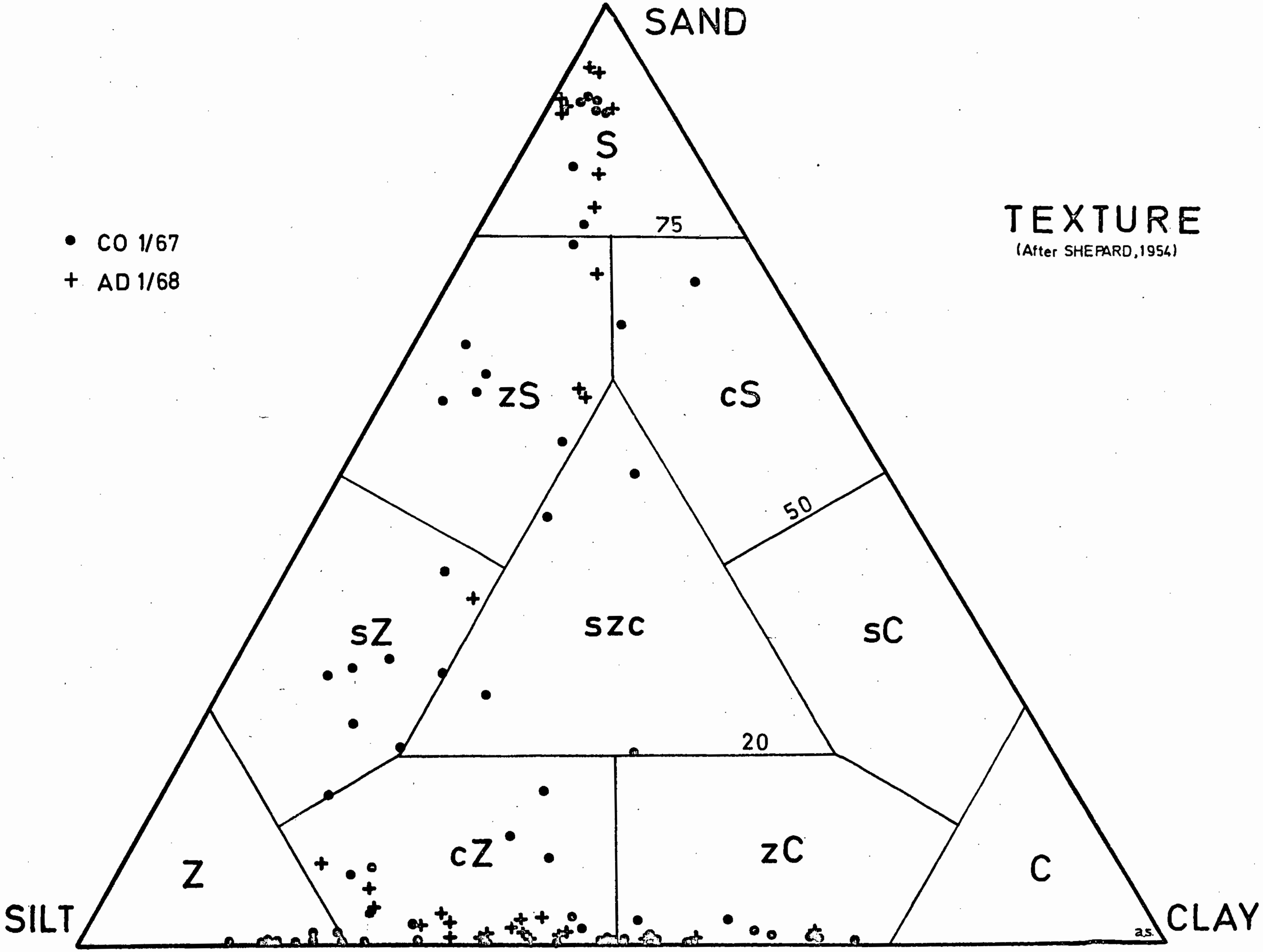
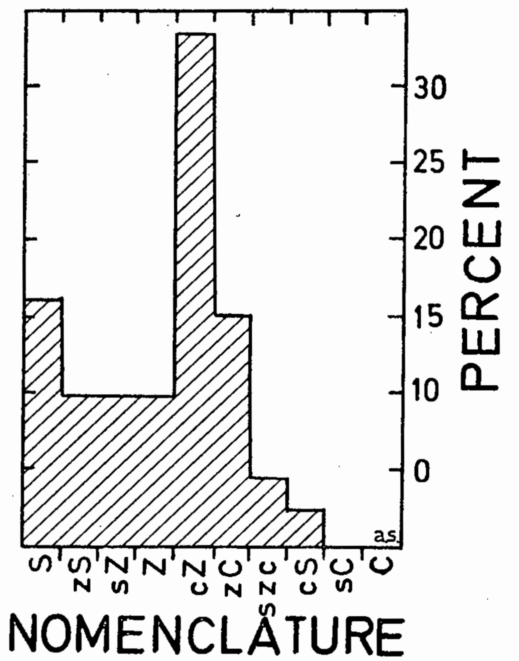

SAND
SILT
CLAY
S
zS
cS
sZ
szc
sC
Z
cZ
zC
C
75
50
20
• CO 1/67
+ AD 1/68
TEXTURE
(After SHEPARD, 1954)
a.s.

DIAGRAM 1

# DIAGRAM 2

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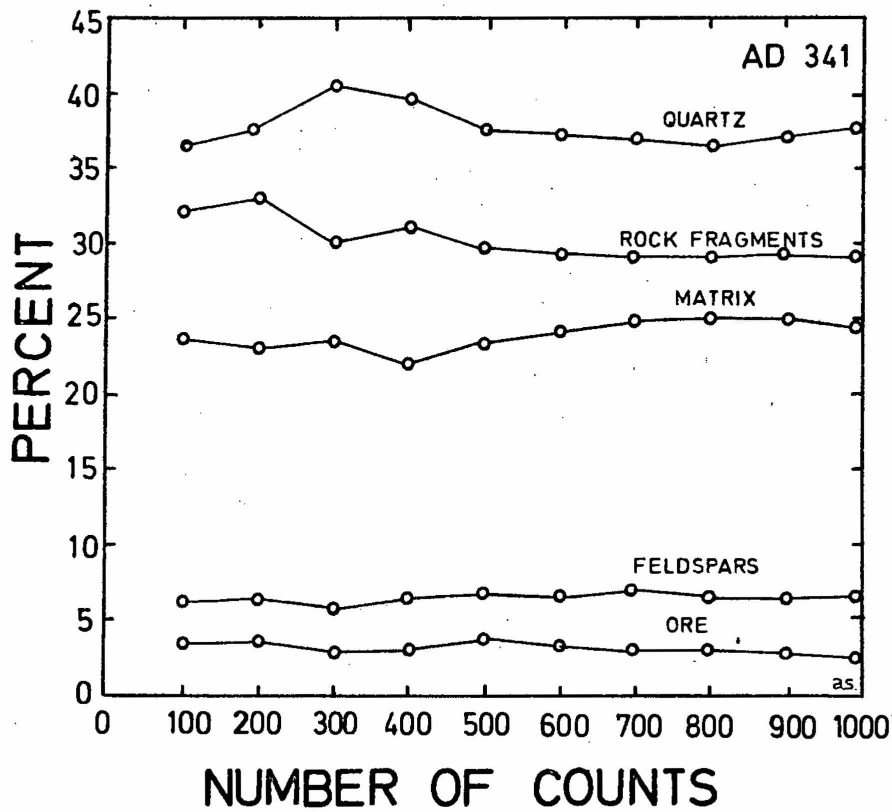
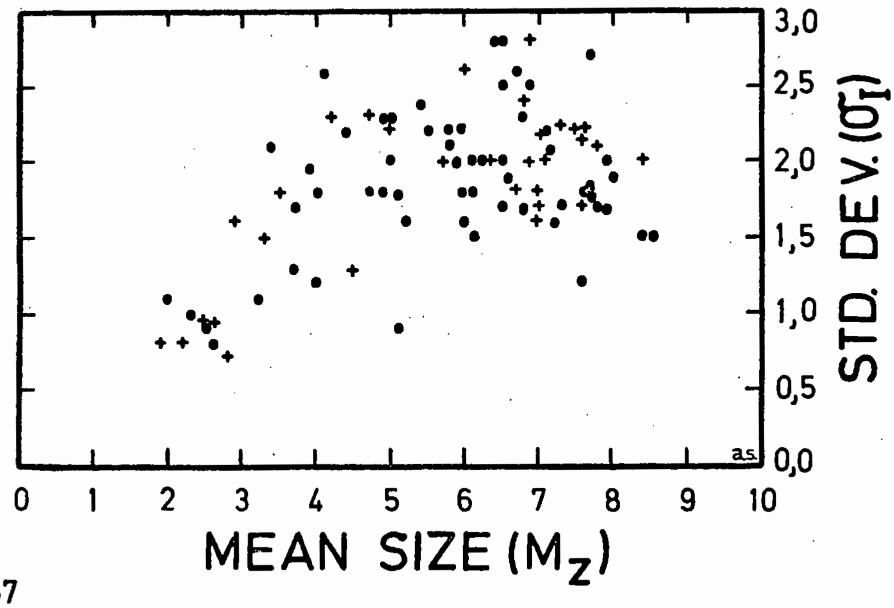


*DIAGRAM 4*




• CO 1/67

+ AD 1/68

*DIAGRAM 5*

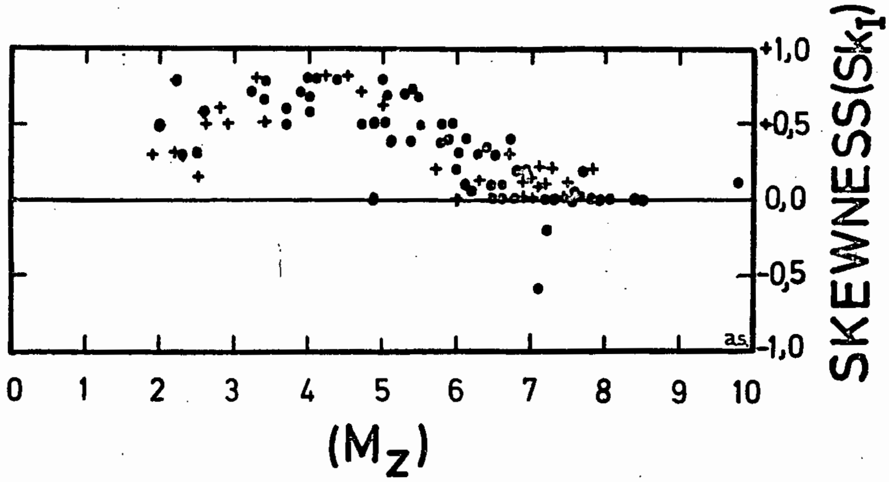
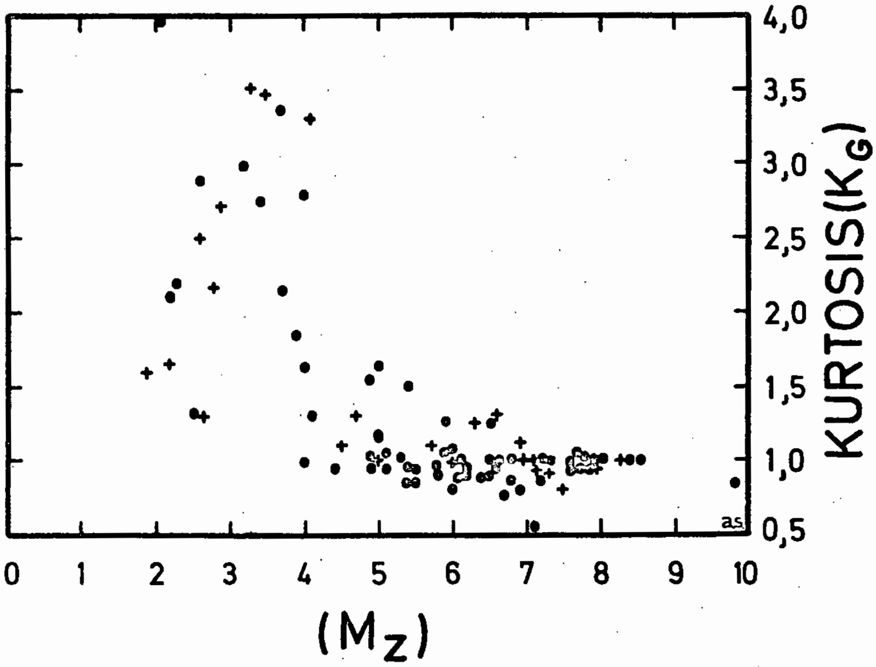
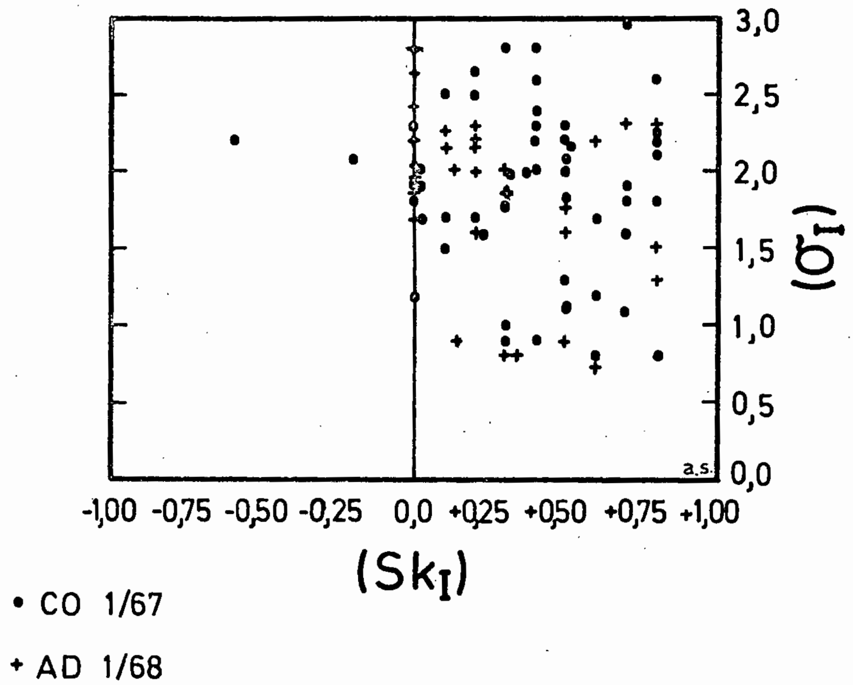


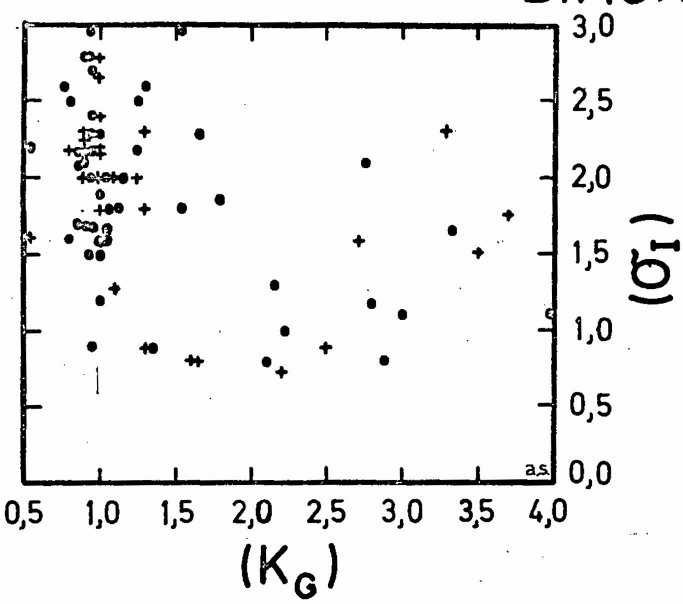

*DIAGRAM 6*



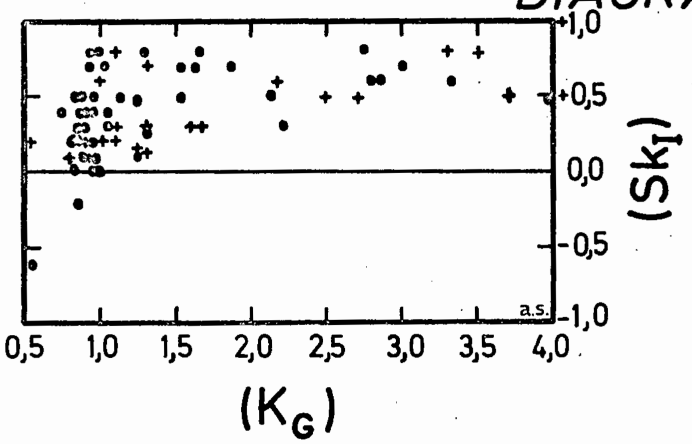
# DIAGRAM 7



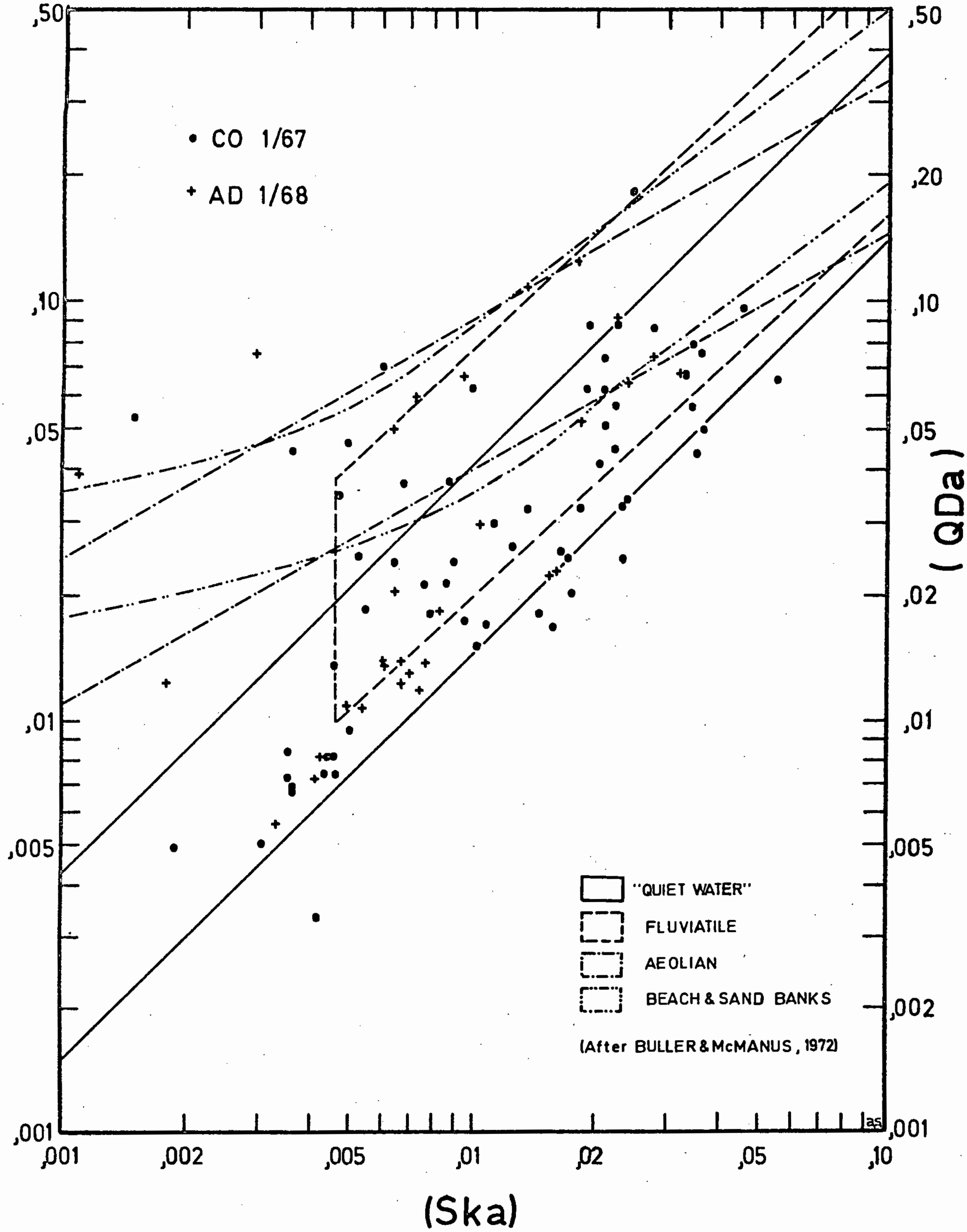

# DIAGRAM 8



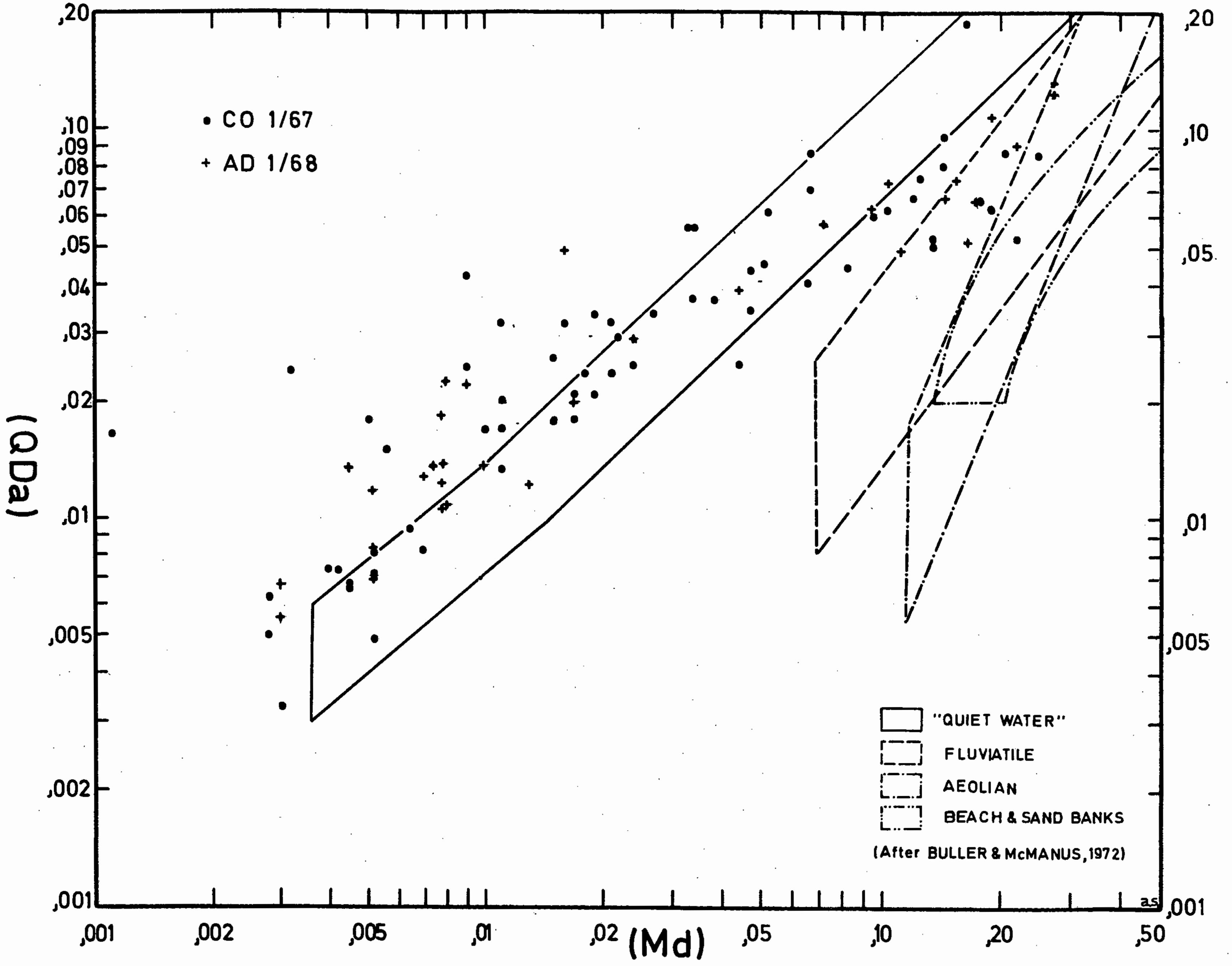

# DIAGRAM 9



# DIAGRAM 10



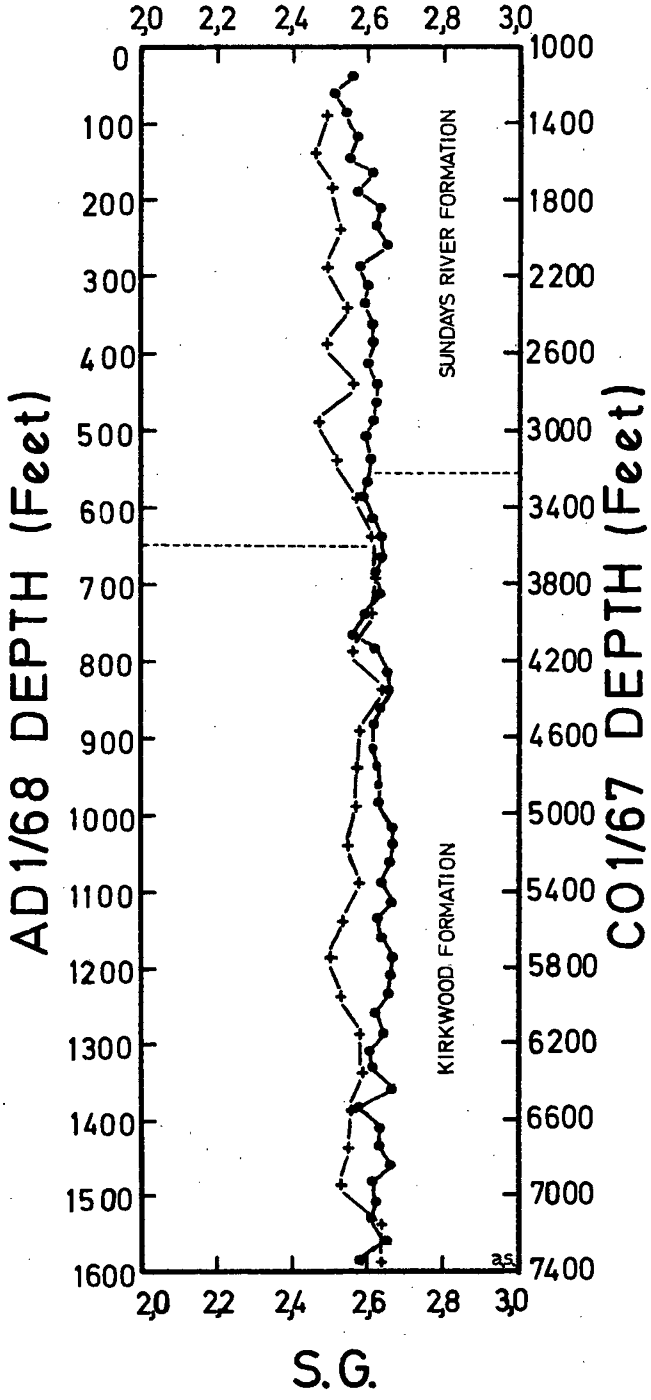
,50
,10
,05
,01
,005
,001
,001
,002
,005
,01
,02
,05
,10
,50
,20
,10
,05
,02
,01
,005
,002
,001
• CO 1/67
+ AD 1/68
"QUIET WATER"
FLUVIATILE
AEOLIAN
BEACH & SAND BANKS
(After BULLER & McMANUS, 1972)
(QDa)
(Ska)



• CO 1/67
+ AD 1/68
"QUIET WATER"
FLUVIATILE
AEOLIAN
BEACH & SAND BANKS
(After BULLER & McMANUS, 1972)
(QDa)
(Md)
,001
,002
,005
,01
,02
,05
,10
,20
,50
,03
,04
,06
,07
,08
,09

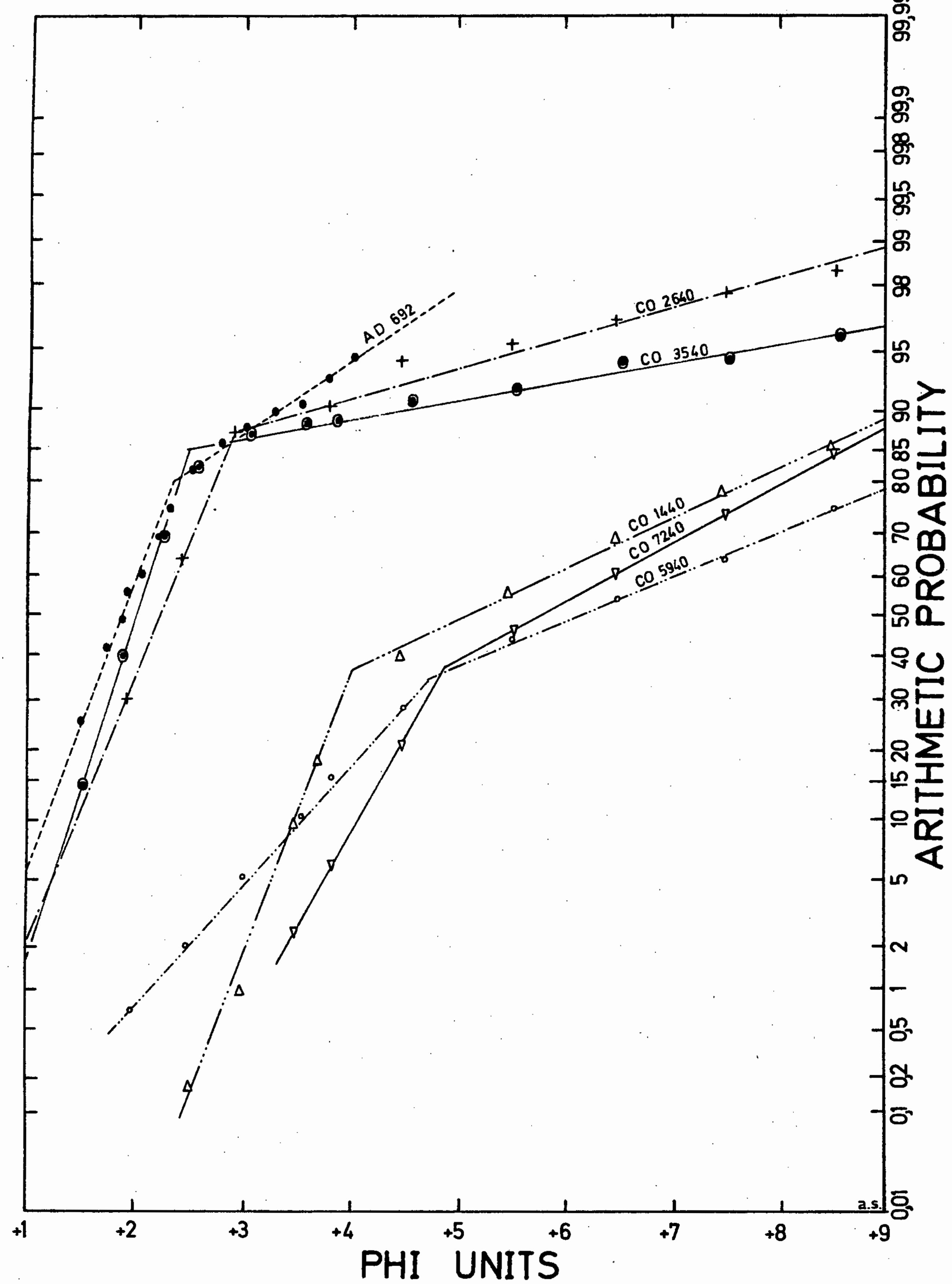

DIAGRAM 11

# DIAGRAM 12



2,0
2,2
2,4
2,6
2,8
3,0
AD1/68 DEPTH (Feet)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
CO1/67 DEPTH (Feet)
1000
1400
1800
2200
2600
3000
3400
3800
4200
4600
5000
5400
5800
6200
6600
7000
7400
SUNDAYS RIVER FORMATION
KIRKWOOD FORMATION
a.s.
S.G.

# DIAGRAM 13


AD 692
CO 2640
CO 3540
CO 1440
CO 7240
CO 5940
a.s.
+1
+2
+3
+4
+5
+6
+7
+8
+9
PHI UNITS
0,01
0,1
0,2
0,5
1
2
5
10
15
20
30
40
50
60
70
80
85
90
95
98
99
99,5
99,8
99,9
99,99
ARITHMETIC PROBABILITY

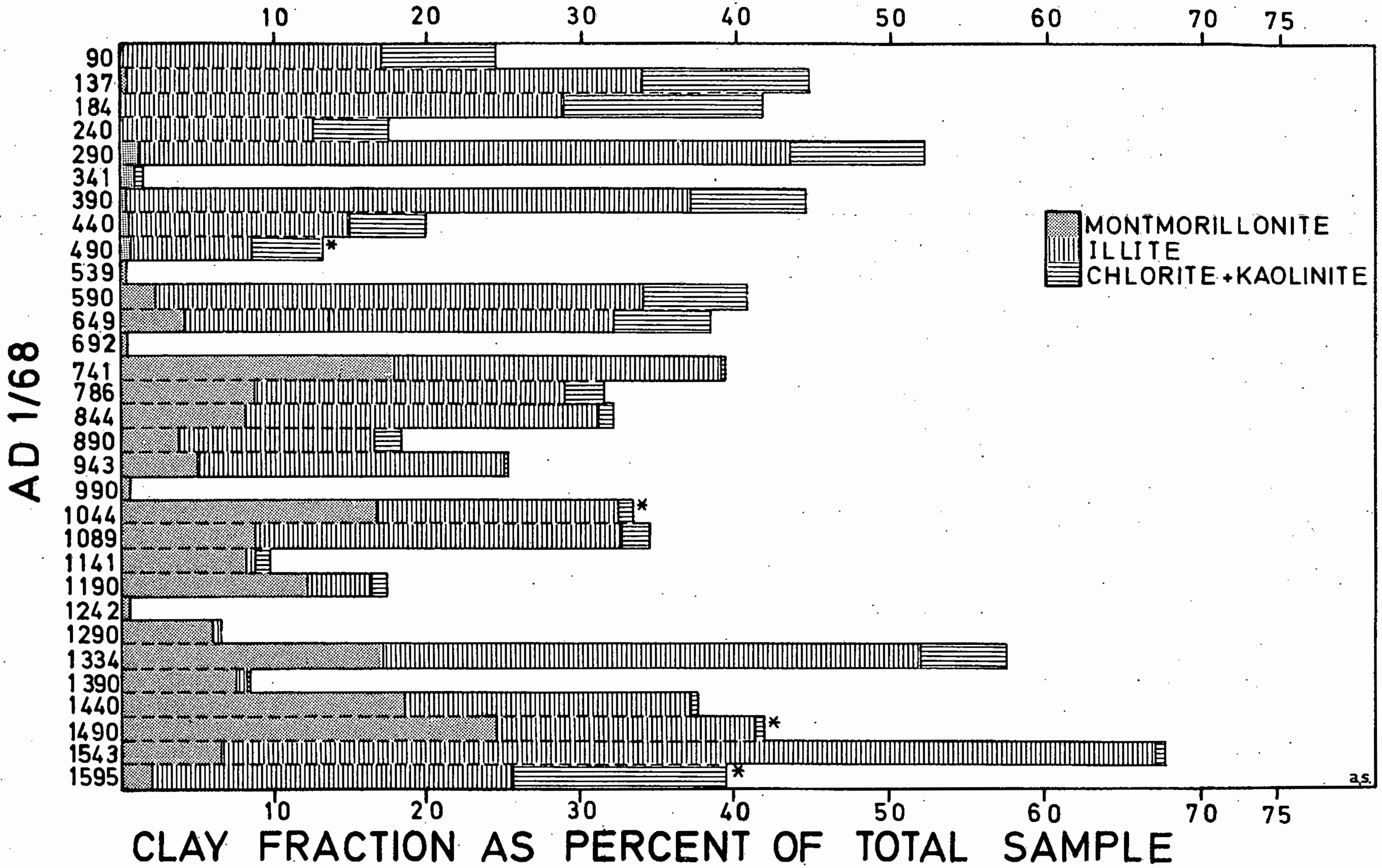

AD 1/68
90
137
184
240
290
341
390
440
490
539
590
649
692
741
786
844
890
943
990
1044
1089
1141
1190
1242
1290
1334
1390
1440
1490
1543
1595
10 20 30 40 50 60 70 75
MONTMORILLONITE
ILLITE
CHLORITE + KAOLINITE
*
CLAY FRACTION AS PERCENT OF TOTAL SAMPLE
a.s.

DIAGRAM 14

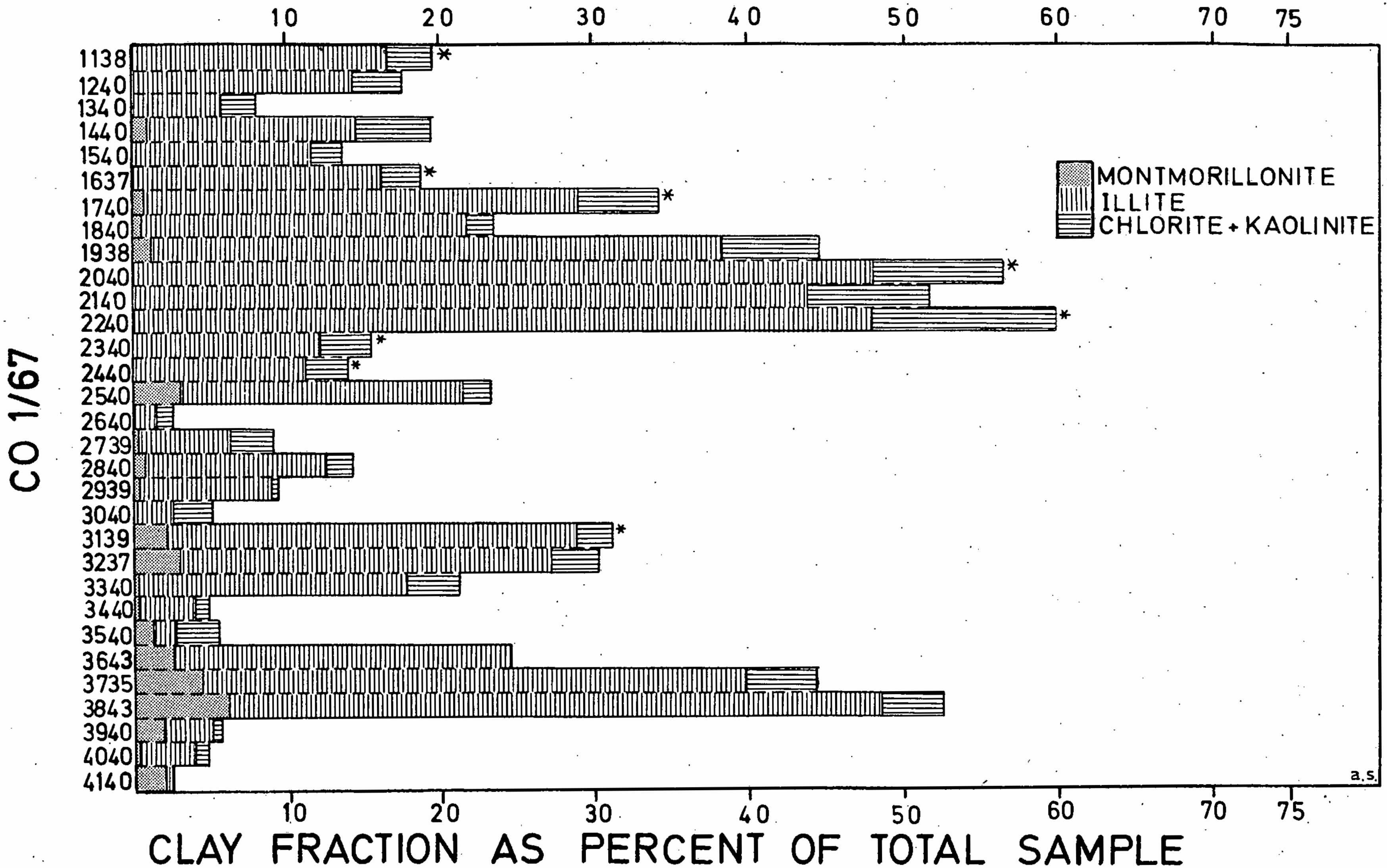

CO 1/67
1138
1240
1340
1440
1540
1637
1740
1840
1938
2040
2140
2240
2340
2440
2540
2640
2739
2840
2939
3040
3139
3237
3340
3440
3540
3643
3735
3843
3940
4040
4140
10 20 30 40 50 60 70 75
MONTMORILLONITE
ILLITE
CHLORITE + KAOLINITE
a.s.
CLAY FRACTION AS PERCENT OF TOTAL SAMPLE

DIAGRAM 15a

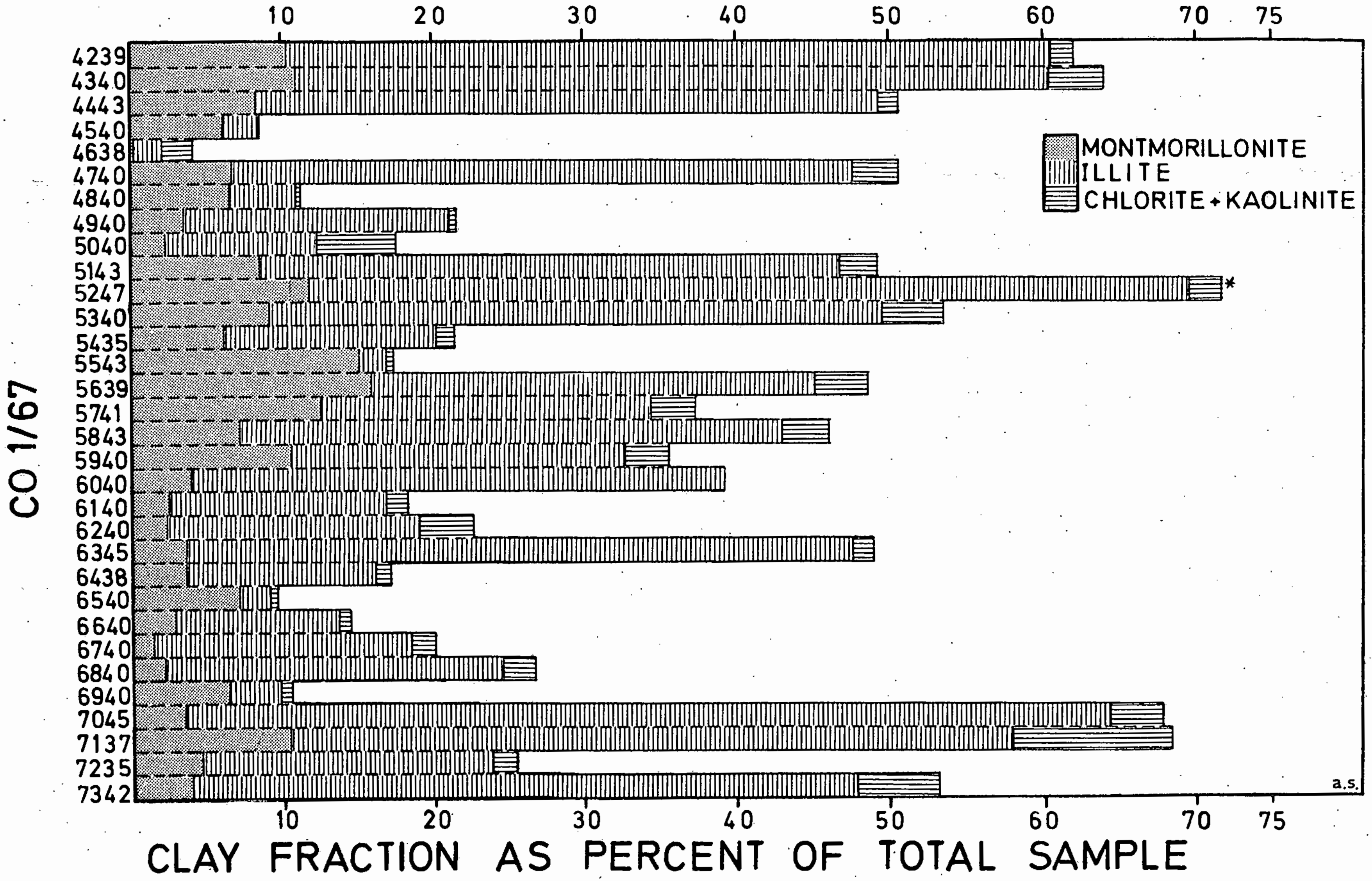
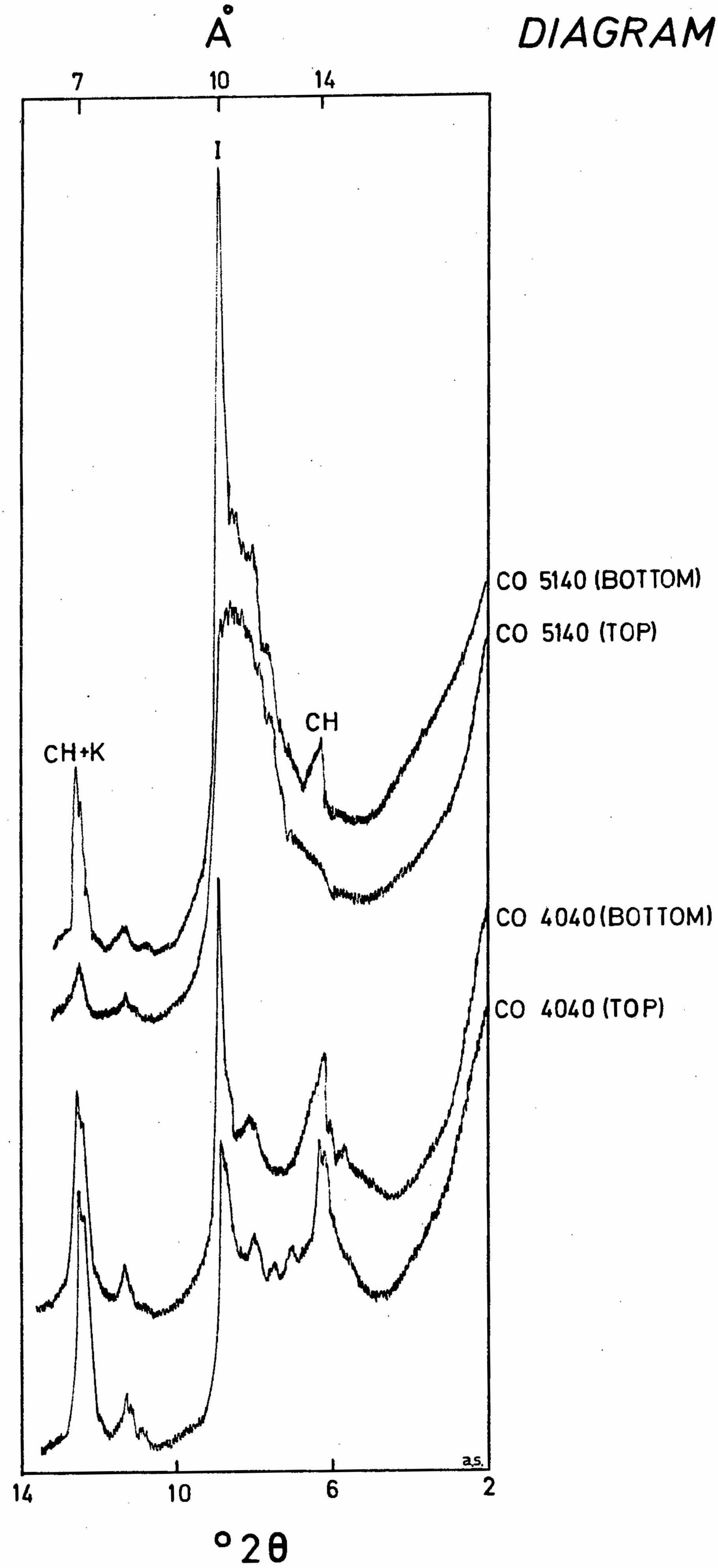

CO 1/67
10 20 30 40 50 60 70 75
4239
4340
4443
4540
4638
4740
4840
4940
5040
5143
5247
5340
5435
5543
5639
5741
5843
5940
6040
6140
6240
6345
6438
6540
6640
6740
6840
6940
7045
7137
7235
7342
MONTMORILLONITE
ILLITE
CHLORITE + KAOLINITE
*
a.s.
10 20 30 40 50 60 70 75
CLAY FRACTION AS PERCENT OF TOTAL SAMPLE

DIAGRAM 15b

# DIAGRAM 16



Å
7
10
14
I
CH
CH+K
CO 5140 (BOTTOM)
CO 5140 (TOP)
CO 4040 (BOTTOM)
CO 4040 (TOP)
a.s.
14
10
6
2
°2θ

DIAGRAM 16b

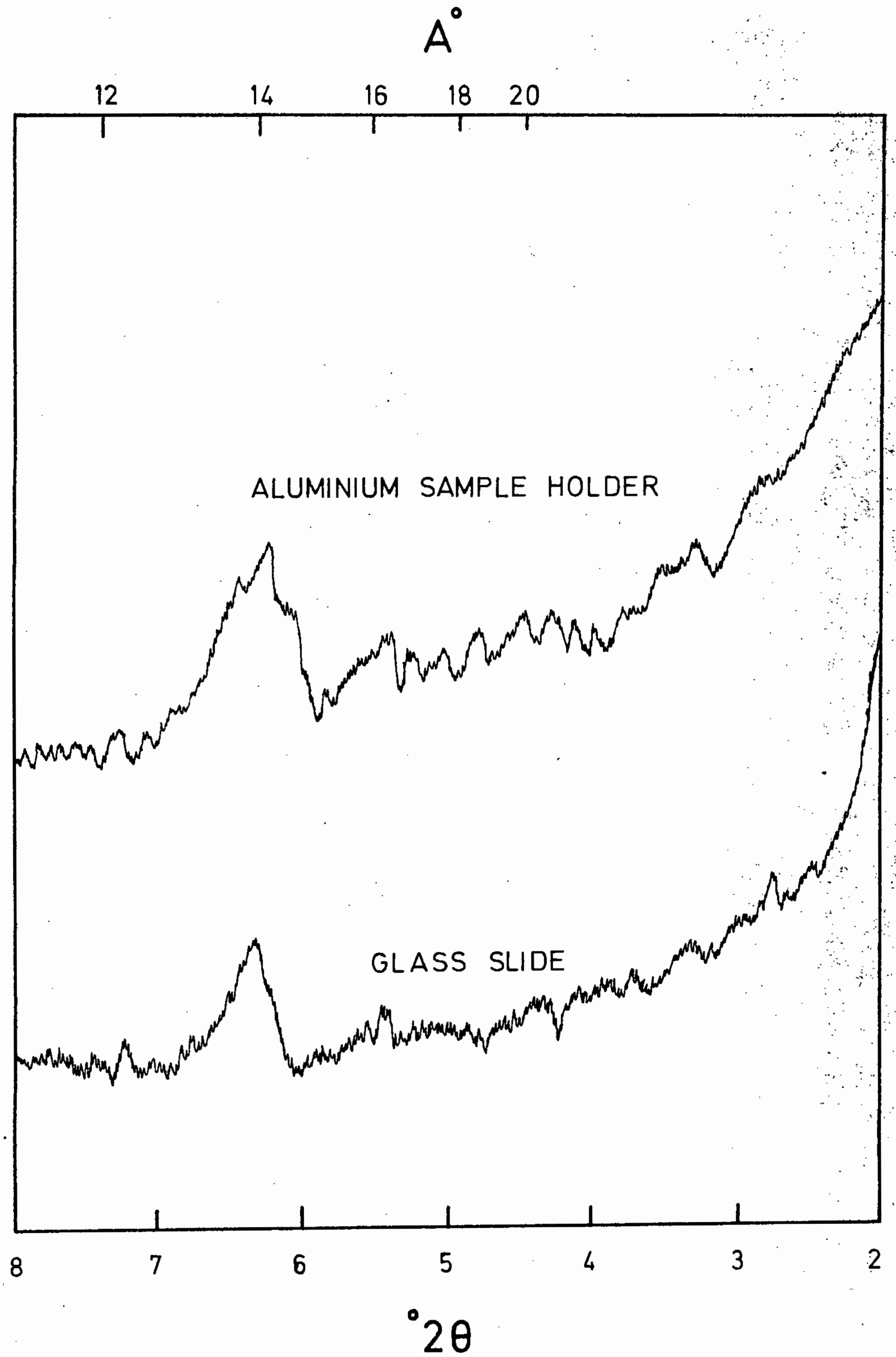
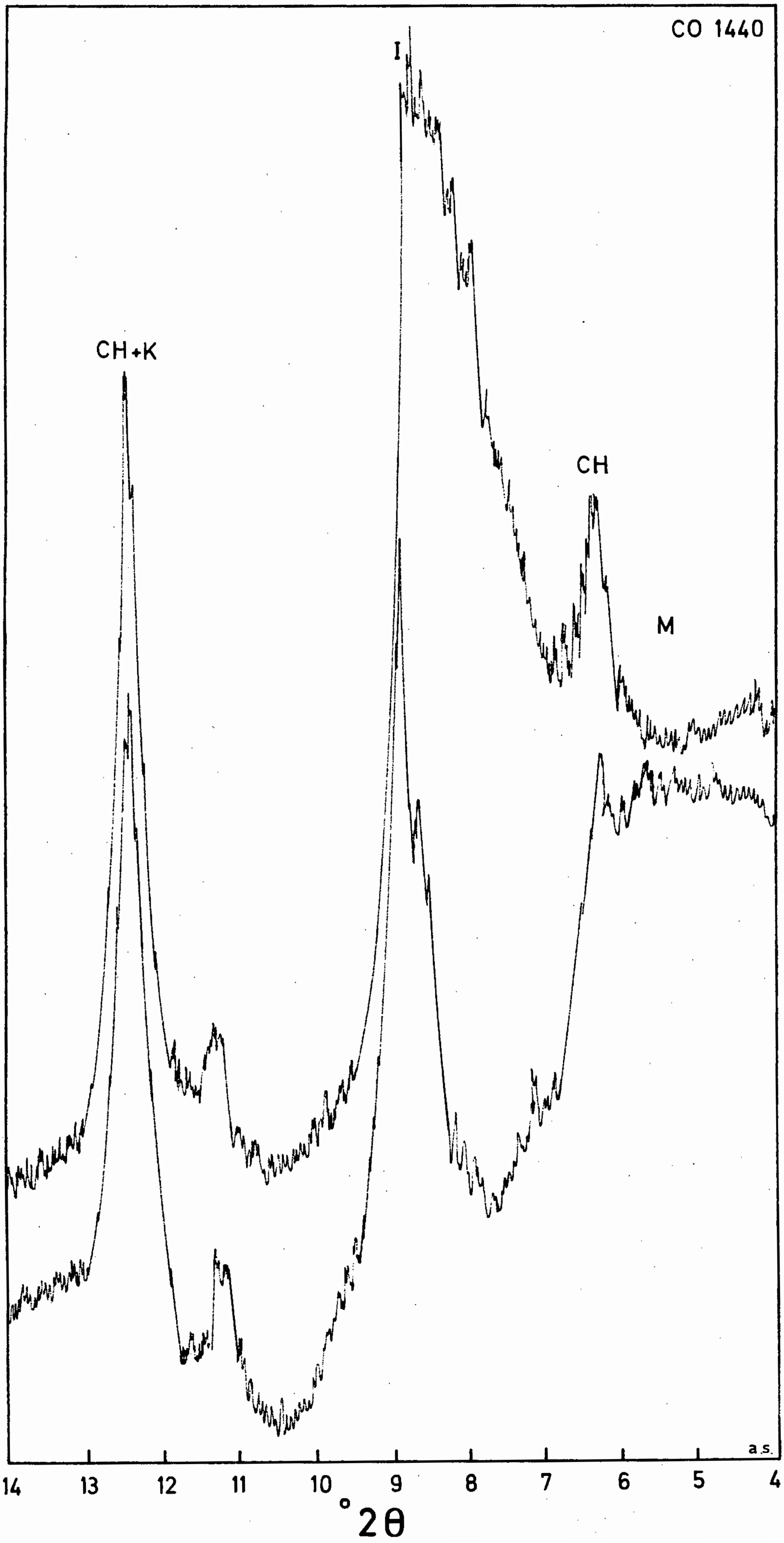

A°
12
14
16
18
20
ALUMINIUM SAMPLE HOLDER
GLASS SLIDE
8
7
6
5
4
3
2
°2θ

DIAGRAM 17



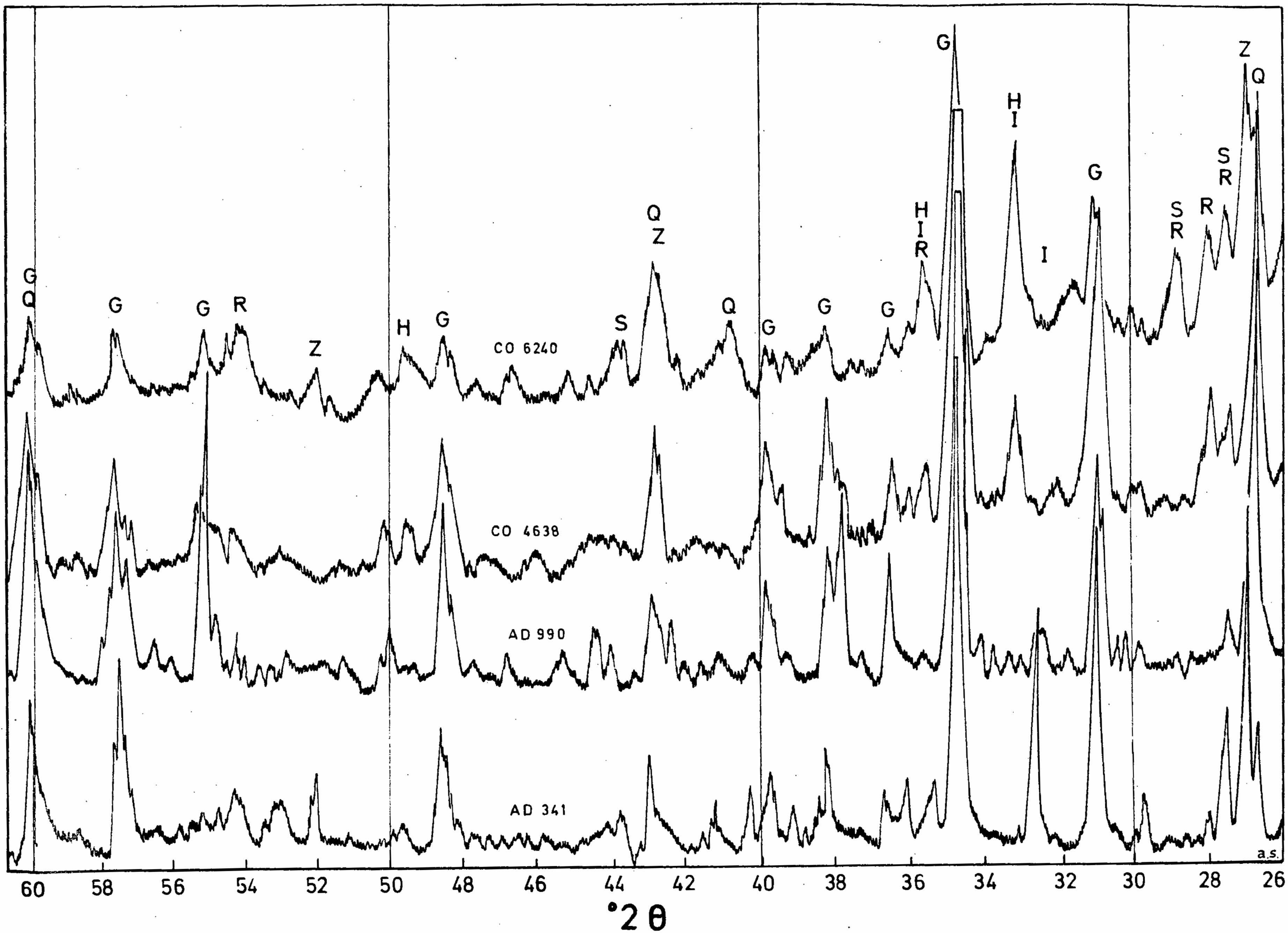

G Q
G
G
R
Z
H
G
CO 6240
S
Q Z
Q
G
G
G
H I R
G
H I
I
G
S R
R
S R
Z
Q
CO 4638
AD 990
AD 341
a.s.
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
28
26
°2θ

DIAGRAM 18

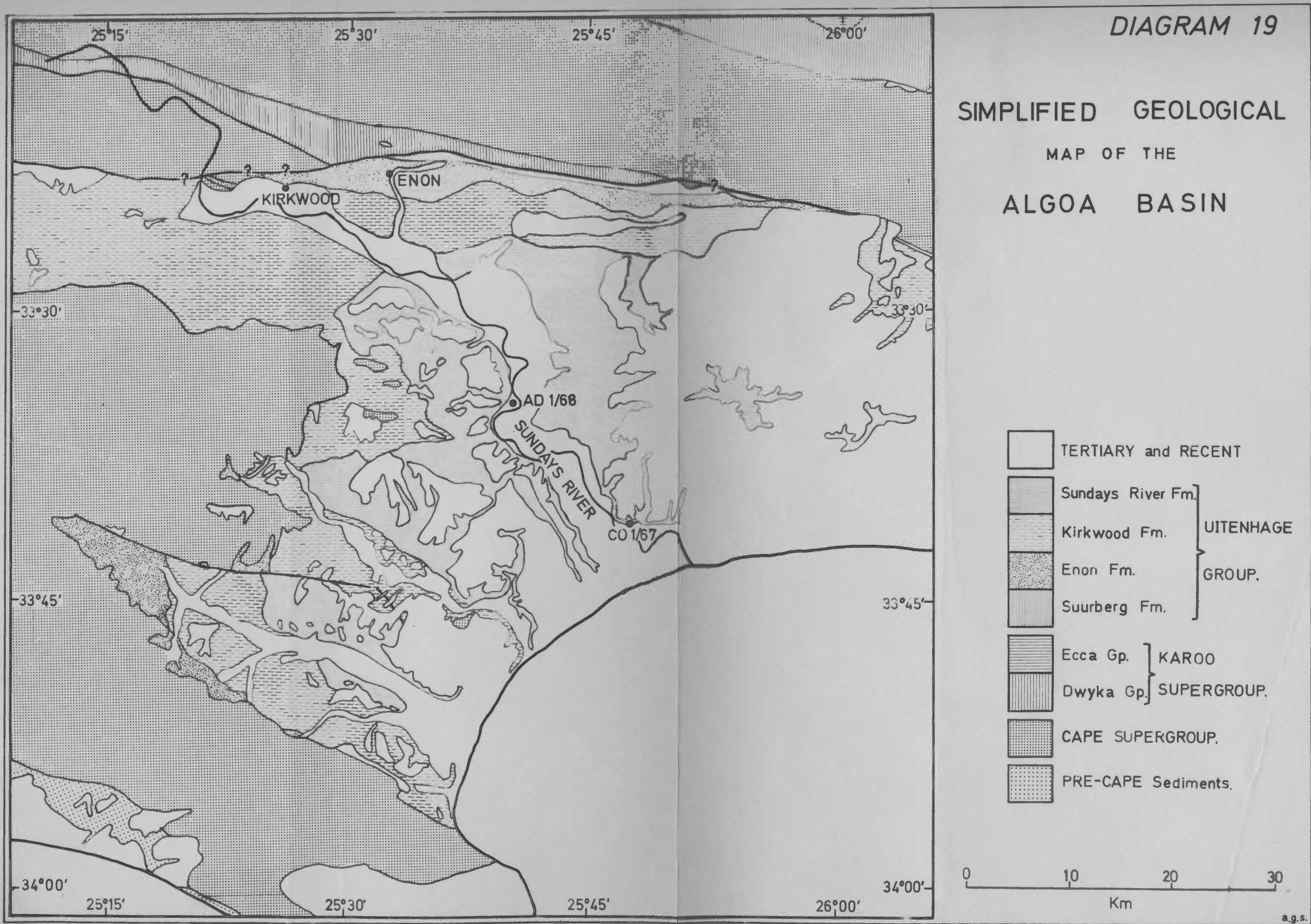


DIAGRAM 19
SIMPLIFIED GEOLOGICAL
MAP OF THE
ALGOA BASIN
25°15′
25°30′
25°45′
26°00′
33°30′
33°45′
34°00′
KIRKWOOD
ENON
AD 1/68
SUNDAYS RIVER
CO 1/67
TERTIARY and RECENT
Sundays River Fm.
Kirkwood Fm.
Enon Fm.
Suurberg Fm.
UITENHAGE GROUP.
Ecca Gp.
Dwyka Gp.
KAROO SUPERGROUP.
CAPE SUPERGROUP.
PRE-CAPE Sediments.
0
10
20
30
Km
a.g.s.

# PLATES.

## PLATE I

1. Fossils and carbonaceous fragment (lower centre) on a bedding plane of sample AD 184.

2. Sample AD 440. Flaser bedding (sandstone light, silty shale dark) with possible bioturbation disturbing the delicate structures.

3. Thinly interbedded sandstone (light) and dark carbonaceous shale showing penecontemporaneous micro-faulting. The faulted lens of sandstone reveals tiny cross laminations. Sample AD 590.

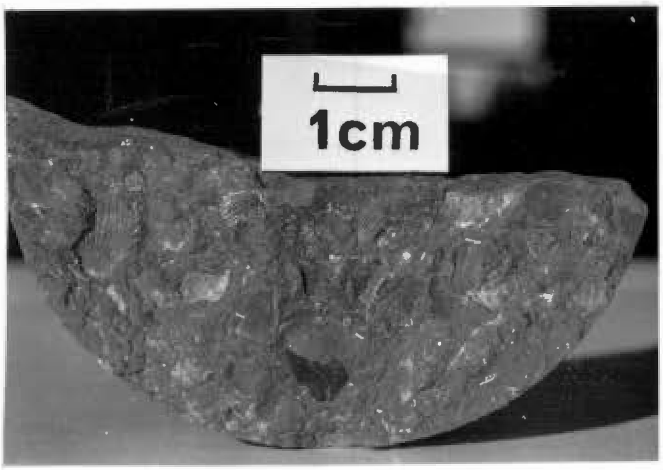
4. Sample CO 1540 showing the sharp contact between the dark, carbonaceous shale (with sandstone pellets) and the light coloured, crossbedded sandstone. Note the numerous channels revealed by the crossbedding and the disturbed bedding in the top left.

5. Sample CO 1840. Intimately interbedded sandstone (light) and silty shale (dark) showing deformation of bedding by penecontemporaneous folding and bioturbation(?).

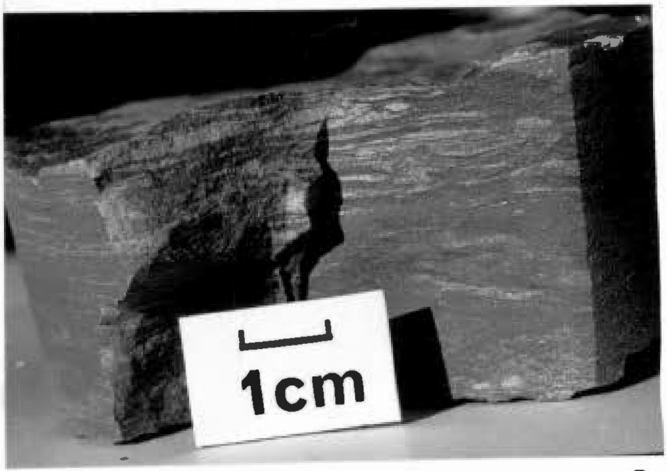
6. Sample CO 2840 showing the flaser type bedding which has been disturbed by bioturbation(?).

7. Portion of the core CO 1/67 as seen on the drill site.

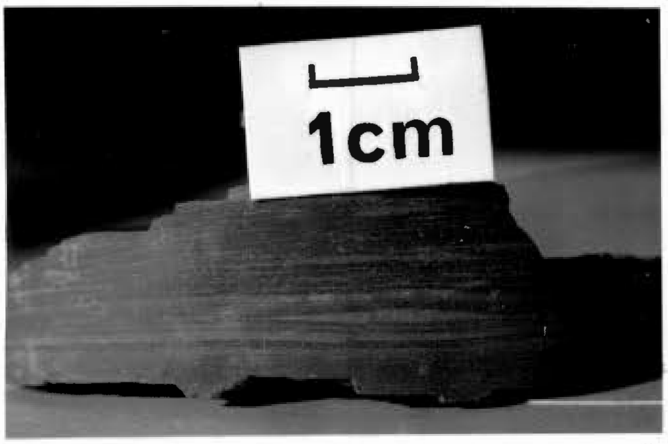
8. Exposure of the Sundays River Formation about 3 km south of AD 1/68.




1

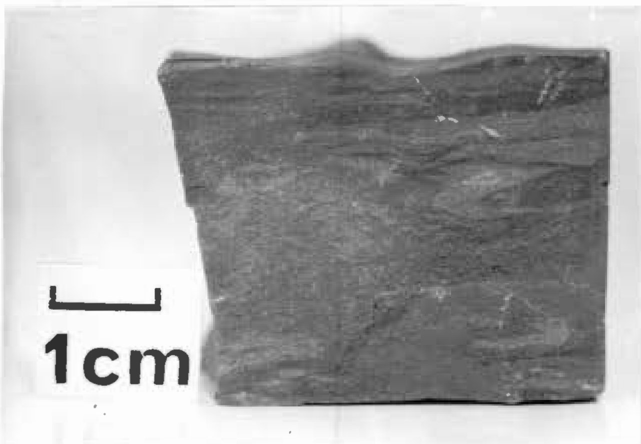



2



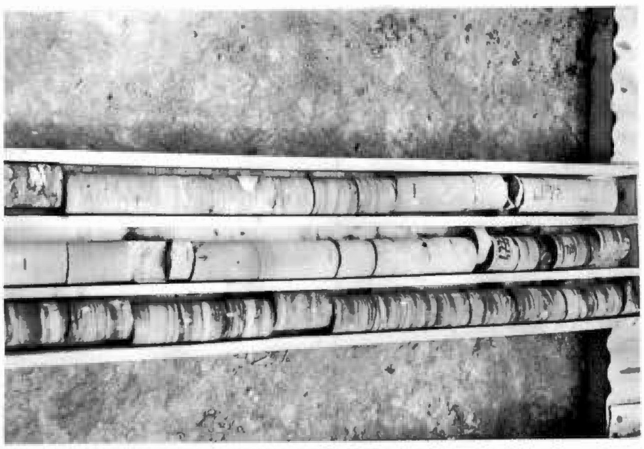

3


4




5


6



7

8

## PLATE II

1. Photomicrograph of sample AD 692. Note the prismatic feldspar in centre, the angular quartz grains, the numerous rock fragments and the carbonate cement. (Plane polarized light.)

2. Same as above but with crossed nicols. Note the microcline feldspar (upper centre) and the numerous very fine grained rock fragments.

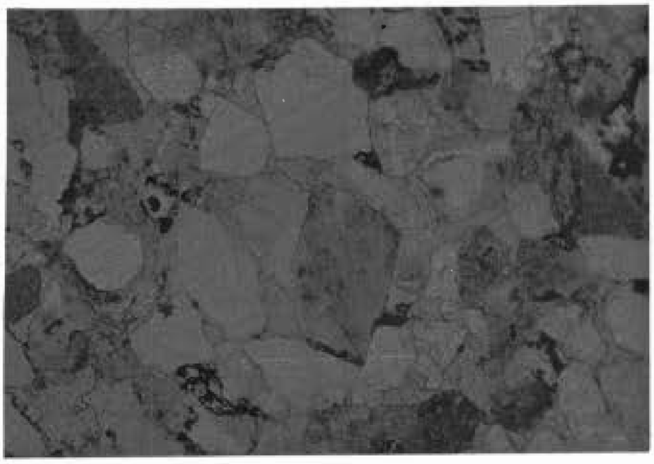
3. Photomicrograph of sample AD 990 showing the overgrowth on a well rounded quartz grain. Note the small amount of interpenetration between the two grains.

4. Apparent (?) corrosion of quartz and plagioclase feldspar by calcite cement. Photomicrograph of Sample AD 490.

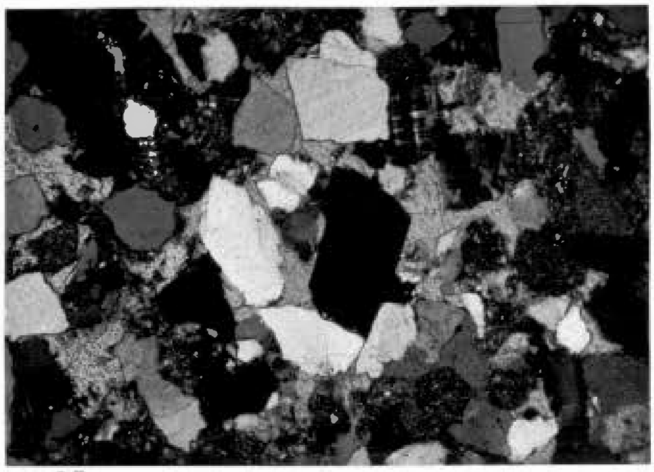
5. Photomicrograph of sample CO 4140 showing the apparent corrosion of a quartz grain by calcite cement. Slide mounted on a flat microscope stage.

6. Same as above but photographed with thin section tilted at an angle of about $50^{o}$ on U-stage. Note the straight contact between the quartz and the cement.

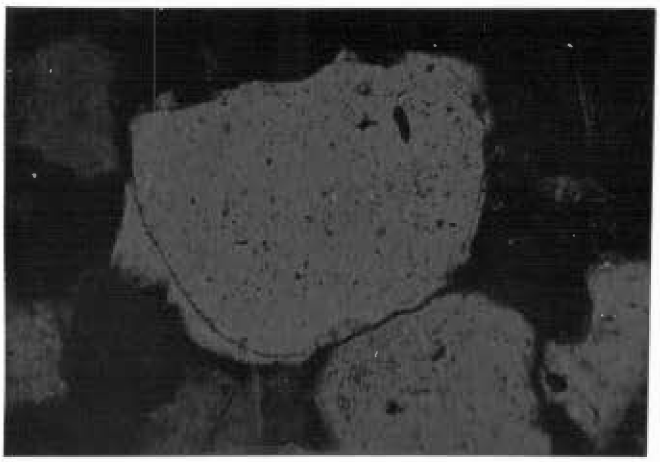
PLATE II



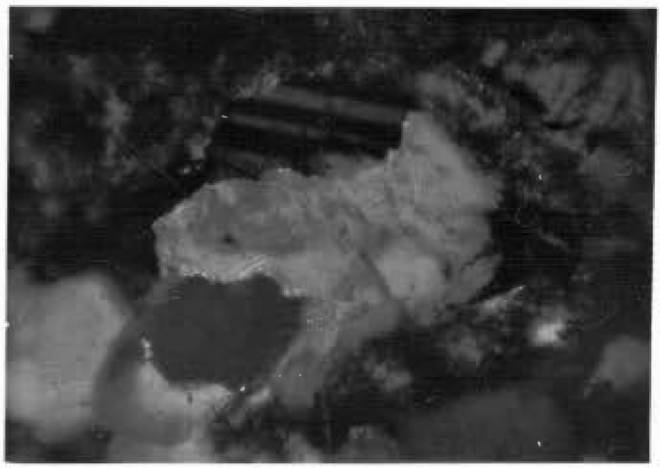
0,5 mm 1



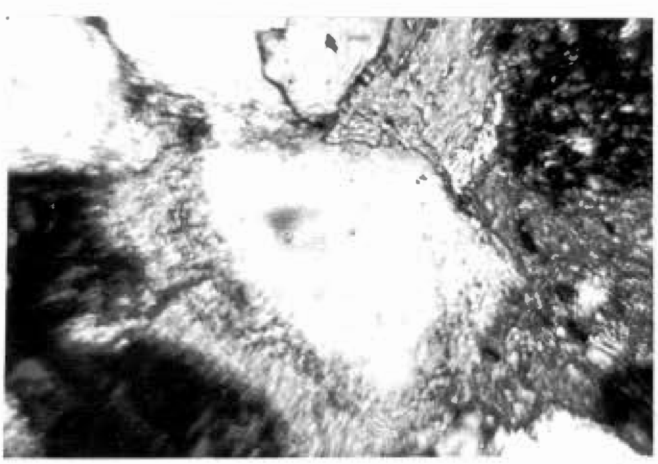
0,5 mm 2



0,1 mm 3



0,1mm 4



0,1 mm 5

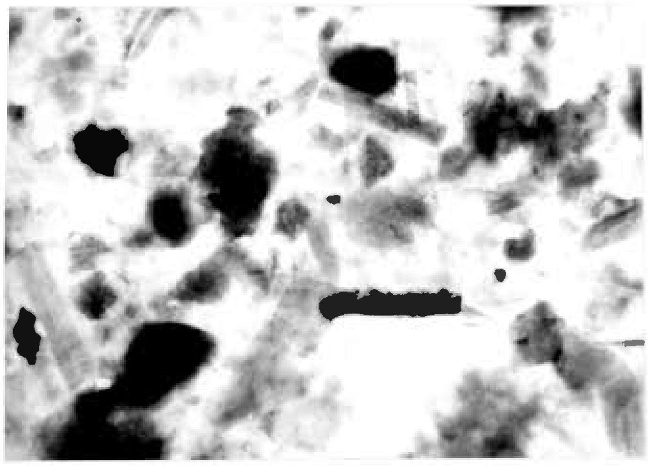
0,1mm 6

# PLATE III

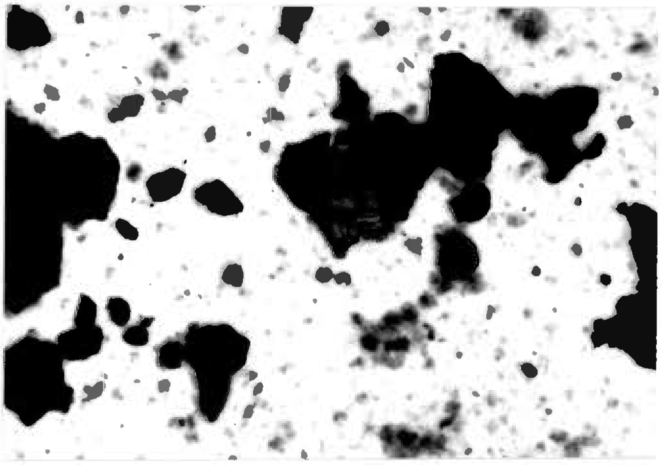
1. Transmission Electron Microscope photograph of sample CO 5543. The irregular patches are possibly montmorillonite while the laths are possibly illite.

2. Transmission Electron Microscope photograph of sample CO 1938. Pseudo-hexagonal flakes of illite(?).

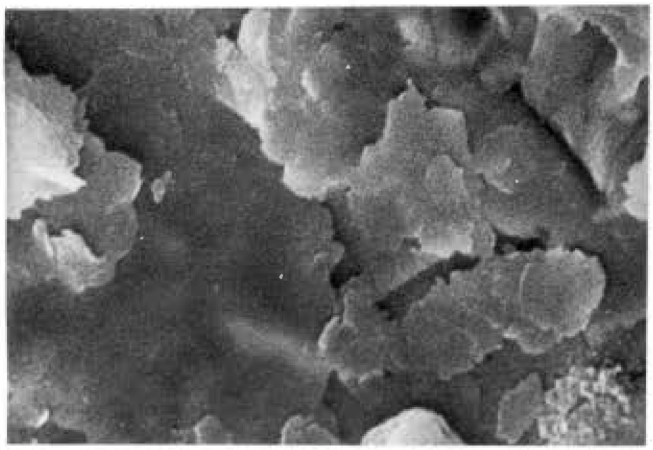
3 & 4. Scanning Electron Microscope photographs of sample CO 3040, showing what is believed to be flakes of chlorite.




1

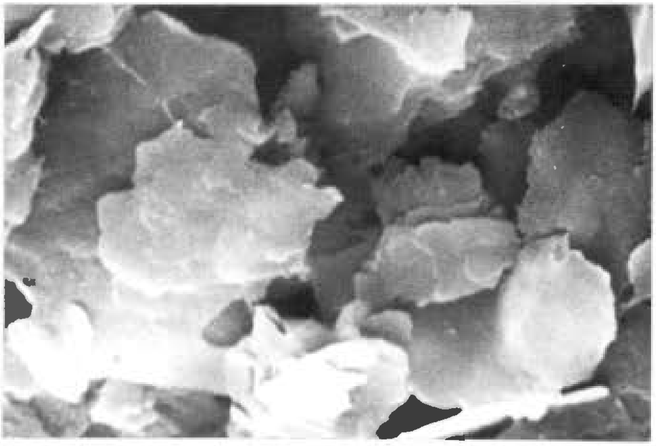



2



x 10 000

3



x 10 000

4

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