

# THE DISTRIBUTION OF CLAY MINERALS ON THE CONTINENTAL MARGIN OFF THE WEST COAST OF SOUTH AFRICA

by

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## ABSTRACT

The clay mineral assemblage on the continental margin off the west coast of South Africa is characterised by abundant illite (50-90 per cent); subordinate smectite (10-30 per cent) and kaolinite (5-20 per cent); and minor chlorite (<5 per cent). Although more marked regional variations occur in onland sediments, approximately the same proportion of clay minerals is found in the adjacent shales and in the sediments of the rivers draining the hinterland. A well-developed seaward distribution of clay minerals is observed. Illite is richest close to the coast, followed by kaolinite which is most abundant on the outer shelf, whereas the highest concentration of smectite occurs in the slope sediments. This distribution is in keeping with the known settling and flocculation characteristics of these minerals.

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## I. INTRODUCTION

The nature and distribution of unconsolidated sediments mantling the continental margin bordering South Africa and South West Africa is being investigated by the Marine Geoscience Group at the University of Cape Town. The mineralogy and geochemistry (Birch, 1975) of the clay fraction (< 2 µm) is being studied as part of the continental margin survey. The present work deals with the clay mineralogy off the Cape west coast (30°S to 35°S and 14°E to 20°E) between approximately Port Nolloth and Cape Agulhas (Fig. 1), whereas the margin to the north is being investigated by Rogers (in prep.) and Bremner (in prep.).

Clays have been studied for many reasons, but perhaps the most fundamental problem that has confronted the clay petrologist is whether clay minerals in the basin of deposition are basically "detrital" in nature or whether diagenesis has been sufficiently intense to mask the characteristics inherited from the source area. Seaward changes in mineralogy led some workers (Grim *et al.*, 1949; Grim and Johns, 1954; Powers, 1957 and Millot *et al.*, 1963) to conclude severe structural and chemical changes in the depositional environment. In more recent studies (Weaver, 1958a and b; Taggart and Kaiser, 1960; Griffen, 1962; Hofmeyer, 1971; Gillot, 1971; Morton, 1972) areal changes are attributed to variations in source and current dispersal and it is now realised that seaward transitions are intensified by differential flocculation of clay minerals in the marine environment (Van Andel and Postma, 1954; Whitehouse *et al.*, 1960; Porrenga, 1967). Numerous clay mineral investigations have also been made to aid provenance and dispersal studies, particularly adjacent to large rivers (Porrenga, 1966; Siegal *et al.*, 1968; Kunze *et al.*, 1968; Scafe and Kunze, 1971; Fleischer, 1972; Shaw, 1973).

The regional geology of the drainage area adjacent to the continental margin under study varies markedly. Metasediments of the Namaqualand complex lie north of the Olifants River, and sandstones, quartzites and shales of the Cape, Nama and Karoo Groups and Supergroups, as well as minor granites, are found to the south. The climate likewise changes from a mediterranean type, with moderately low precipitation (400-1 000 mm/yr) in the south to a semi-arid regime (100-700 mm/yr) north of the Olifants (Schulze, 1965). As the character of clay minerals is largely dependent on the geology and climate of the source area (Milne and Earley, 1958; Barshad, 1966; Johnson, 1970), it is also important to determine the influence onland variations exerted on the adjacent marine sediment. A comprehensive investigation (Danchin, 1970; Hofmeyer, 1971) of the shales in the drainage area has provided valuable geochemical and mineralogical information regarding the source material for the adjacent continental margin sediments.

Authigenic minerals, especially glauconite and phosphorite, are abundant on the South West African shelf (Birch, 1977). As diagenesis predominantly involves the clay component, a study of the mineralogy of this fraction could help to explain the variations that have been observed in the nature and abundance of these authigenic minerals. Some of the techniques used in clay mineralogical research are reviewed and the methods being employed routinely by the Marine Geoscience Unit are described in detail in an effort to standardise local clay mineralogical investigations.

## II. METHODS

Clay mineral research is complex and studies in this field have not yet reached the stage where pre-treatment, analytical methods, computation of results etc. have been

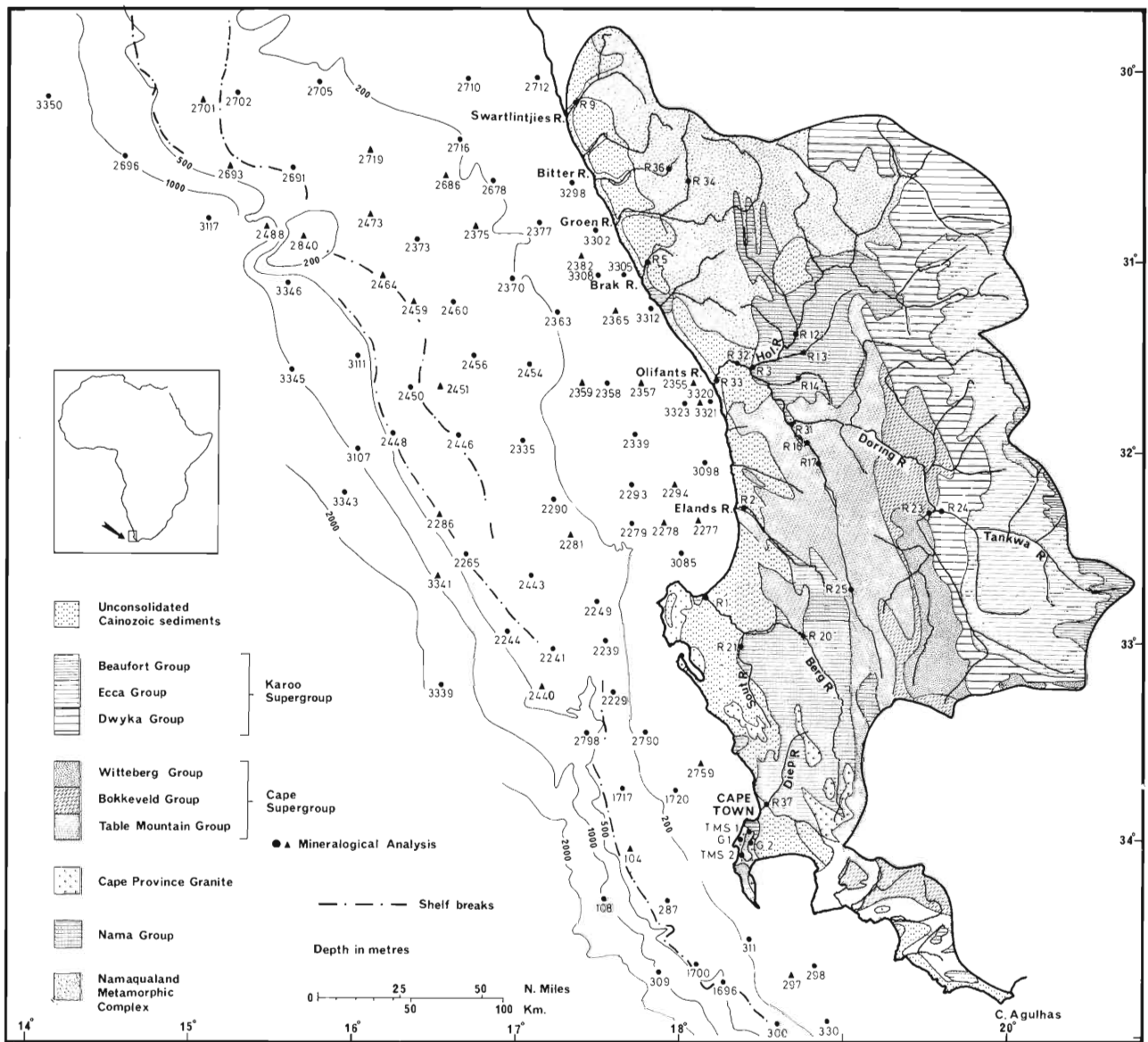


Figure 1  
Sample distribution and onland geology.

standardised (Pierce and Siegal, 1969). It is therefore important that the methods employed and the precautionary measures that are taken during the study, as well as the precision and accuracy of the determinations, are recorded in detail. Because this is the first mineralogical study of modern marine sediments to have been made off the South African coast, these aspects are recorded in detail in the present work.

Ninety-two marine samples (Fig. 1) were initially dialysed to remove interstitial salt and subsequently separated into  $< 2 \mu\text{m}$ ,  $2\text{--}15 \mu\text{m}$ ,  $15\text{--}60 \mu\text{m}$  fractions by repeated sedimentation using distilled water and no deflocculant. Sixteen river samples were similarly separated into  $< 2 \mu\text{m}$  and  $> 60 \mu\text{m}$  fractions, but were not pre-treated.

#### A. Sample Recovery

In this study grabs were used in the shoaler regions ( $< 250 \text{m}$ ) to recover sediment from the continental margin, and a gravity corer was employed in the deeper parts. Recent investigations (Siegal and Pierce, 1973) have shown that the clay mineral contents of samples show significant (at the 95 per cent confidence level) differences

according to the type of sampler used. As yet the reason for this discrepancy is not known. Although no test was made during this study, no variations in the clay mineral content due to differences in the sampling method could be detected.

#### B. Sedimentation

Sedimentation (Jackson, 1956) or centrifuging (Hathaway, 1956) is usually used to collect clay-size material for clay mineral research. It appears from recent studies (Spoljaric, 1971, 1972; Gibbs, 1972), that equivalent spherical diameter theory is not always applicable in calculating the settling rates of small ( $< 2 \mu\text{m}$ ) plate-shaped particles. Whether a dispersing agent is used or not, flocculation varies according to the mineral assemblage, the thickness of suspension, the amount of organic material, the type of oxide coating, and the exchange cation content of the samples (Gibbs, 1965; Hathaway, pers. comm., 1974; Pierce, pers. comm., 1974), as well as with temperature (Birch, 1971). It is possible, therefore, that because of an imperfect knowledge of the settling behaviour of clay-size material and due to a lack of control on flocculation from sample to sample, some mineralogical variation may be due to inaccuracies in the size segregation procedure.

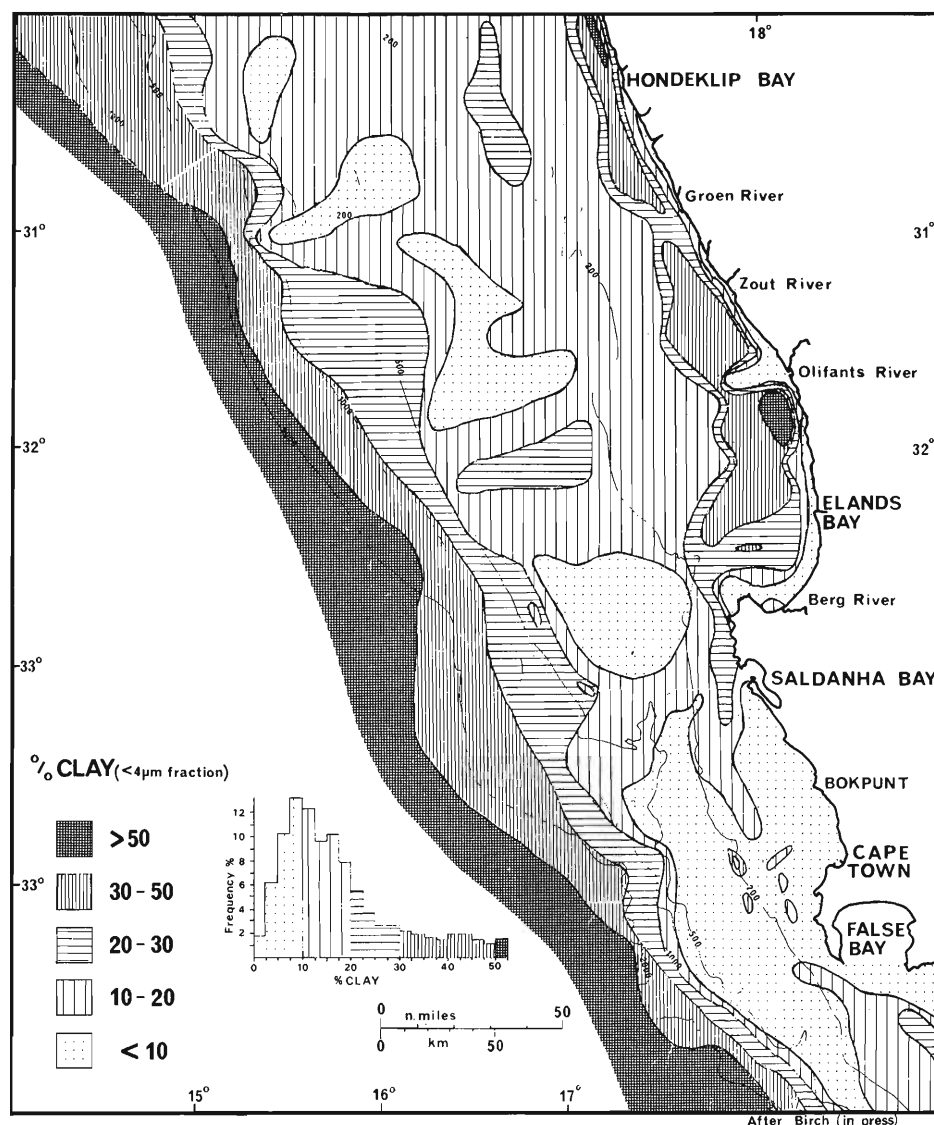


Figure 2  
Distribution of clay-size material ( $< 4 \mu\text{m}$ ) on the continental margin (after Birch, 1977).

### C. Pre-treatment

Calcium carbonate was removed with dilute (4:1) glacial acetic acid and the sample washed three times with distilled water. Buffering the acid with sodium acetate is unnecessary (Hathaway, pers. comm., 1974). In contrast to the findings of Schoen *et al.* (1972) and Anderson (1963), higher peak to background values were obtained in a pilot study using hydrogen peroxide than when employing sodium hypochlorite to remove organic matter. Consequently all samples were pre-treated with 30 per cent hydrogen peroxide to remove organic carbon. In the pilot study secondary Fe was removed from the clay samples by ammonium oxalate treatment (Le Riche and Weir, 1963; Gad and Le Riche, 1966), but as this procedure had no appreciable effect on the X-ray diffractograms, the process was not carried out during subsequent analyses.

As interlayer cations retain different amounts of water of hydration, the clay was also homo-ionically saturated with Mg to ensure that expansion as a result of hydration would be uniform. A 3 N magnesium chloride solution was added to an acidified (pH 3.5 to 4.0) clay suspension in a 3:1 ratio so as to render the suspension approximately 1 N with respect to Mg. The sample was then shaken gently for 4 hours and washed 3 times to remove excess Mg solution.

### D. Mounting

It has been found (Sudo *et al.*, 1961) that sample thickness is of fundamental importance. If the mount is too thin peaks are weak and diffuse and if the slide is too thick a high background is produced (Carroll, 1970), therefore the sample should ideally be between 0.07 and 0.12 mm thick (Klug and Alexander, 1962; Sudo *et al.*, 1961). In this study approximately 0.5 to 0.8 mg of prepared clay material was eye-dropped on to glass slides and quickly dried (less than 10 minutes) under an infra-red lamp at a maximum temperature of 50 °C.

### E. X-ray Diffraction Procedure and Mineral Identification

Two magnesium-saturated clay slides were prepared for each sample. One slide was used for diffracting the untreated clay sample and this was again X-rayed after heating to 550 °C for one hour. The second slide was treated with ethylene glycol. Expansion of smectite clays was achieved by carefully painting glycol on to the clay surface on the slide with a very fine brush. Untreated slides were scanned from 3 to 30°2 $\theta$  at 1°2 $\theta$  per minute and heated and glycolated samples from 3–13°2 $\theta$  at the same speed.

A Philips X-ray diffractometer unit fitted with a Geiger detector employing Ni-filtered CuK $\alpha$  radiation was used

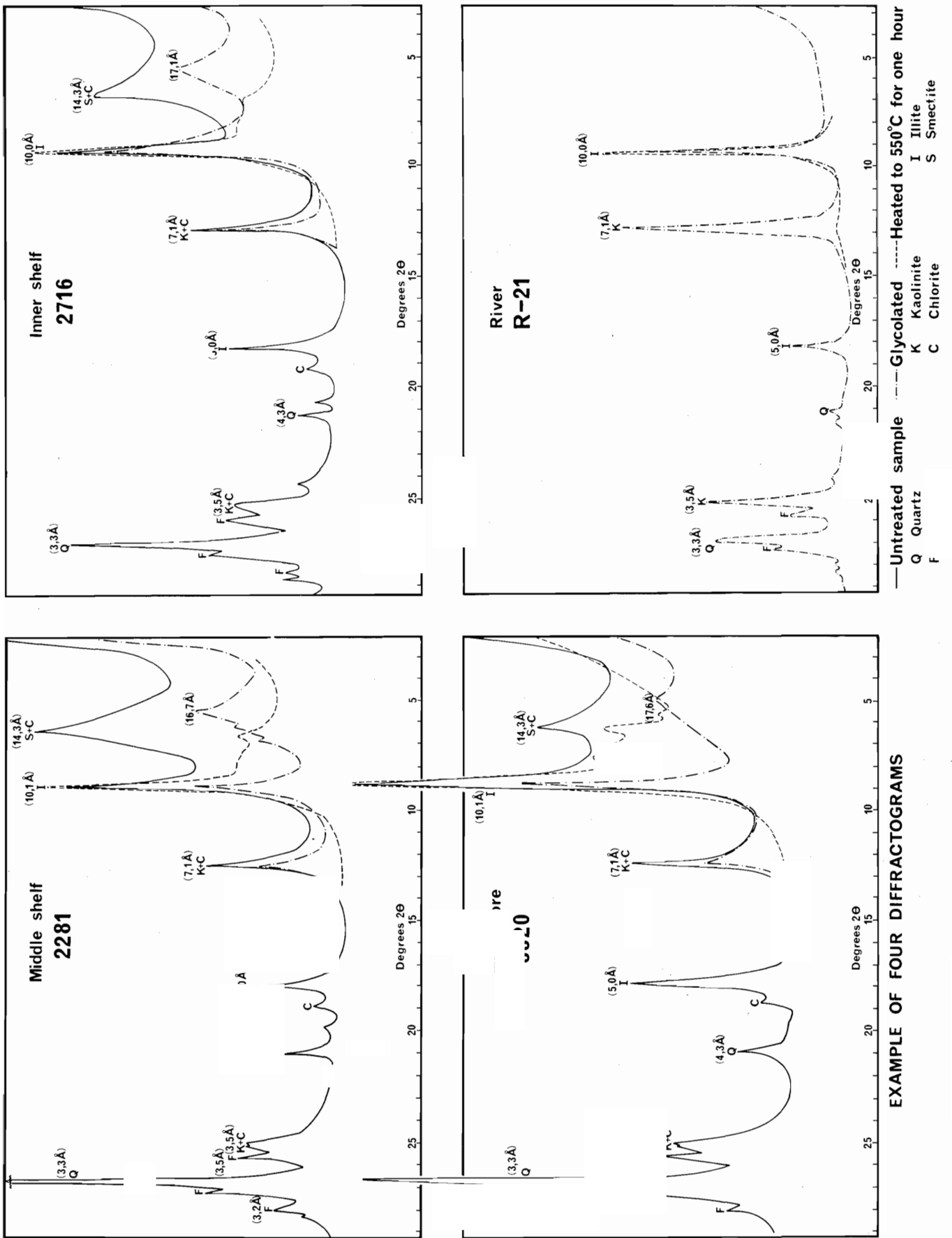


Figure 3  
Examples of four X-ray diffractograms of clay-size material.

with the following settings: Kv=48; mA=20; proportional counter=45; rate meter= $4 \times 10^2$ ; time constant=1; windows= $1^\circ, 1\text{mm}/1^\circ$ ; and attenuation=2.

The clay minerals mentioned in this work, e.g. illite, kaolinite, etc. are not specific mineral names, but are terms used in a colloquial sense to designate a group of minerals and no attempt has been made to identify specific mineral species. Mineral identification was made by observing the characteristic basal reflection maxima (Fig. 3). Illite was recognised by its 10 and 2.3 Å peaks which are not affected by heat or glycol treatment. Smectite was detected by its 14 Å reflection which expands to 17 Å on glycolation and which collapses on heating to 550 °C. Special attention was given to the identification of chlorite and kaolinite because of their similar d-spacings of the (002) and (001) reflections at 7 Å respectively. Various techniques have been used to distinguish kaolinite from chlorite most of which involve thermal and/or chemical treatment prior to X-raying. Biscaye (1964) has described a method for routinely differentiating kaolinite and chlorite by resolving their 2nd and 4th order basal diffraction peaks at 3.5 Å. Chlorite was found to be absent or present in only minor quantities when the samples were run at a slow speed ( $\frac{1}{2}^\circ/\text{min.}$ ) across this dual reflection. Preferential destruction of kaolinite by heating to approximately 550 °C has also been used (Dixon and Jackson, 1960) as a criterion to distinguish these two minerals. However, the behaviour of poorly crystalline materials, such as that found in recent sediments, is variable and temperatures as low as 450 °C may decompose some chlorites completely, leaving kaolinite little affected (Brown, 1961). Three samples containing illite, smectite, kaolinite and chlorite were heated to 550 °C in 50 °C intervals to examine the response of these marine clays to thermal treatment. Smectite collapsed at 300 °C causing enhancement of the illite reflection and at 500 °C the reflection at 7 Å was destroyed. At 550 °C the low angle background became depressed enough to reveal the presence of a broad chlorite peak at 14 Å. The same samples were boiled in 6 N hydrochloric acid at 80 °C for 18 hours. Kaolinite is not ordinarily decomposed by this treatment (Brown, 1961) and the persistence of a 7 Å reflection and the non-appearance of the 14 Å peak on heating facilitated the recognition of both kaolinite and chlorite in these samples. Subsequently the recognition of chlorite in the presence of kaolinite was made on a routine basis by the occurrence of a reflection at 14 Å on a diffractogram of a heated slide.

#### F. Semi-quantitative Analyses

Most semi-quantitative analyses (those not employing internal standards) are based on an early report by Johns *et al.* (1954). Some of the more important contributions have come from Schultz (1960, 1964), Griffen and Goldberg (1963) and Meade (1967). A recent study on the relationship between five of the most commonly used semi-quantitative methods has been made by Pierce and Siegal (1969). The large discrepancies in the results of the five methods for the same sample have been used by the latter authors to emphasise the urgent need for standardisation in sample preparation, analytical methods and semi-quantitative computations. The present lack of standardisation means that inter-area comparisons cannot be accurately assessed.

In this investigation semi-quantitative determinations were made by weighting the integrated peak areas on the glycolated diffractograms (Johns *et al.*, 1954). As poor resolution of the 3.5 Å peak occasionally prevented a quantitative estimate of the chlorite/kaolinite content to be made and because only minor chlorite was present in these samples, the area under the 7 Å reflection was totally assigned to kaolinite. The chlorite abundance was later estimated by a method described by Schultz (1964). Schultz found that for the Pierre Shale the amount of decrease in the

height of the 7 Å peak due to the removal of chlorite by acid treatment averages two-thirds of the height of the chlorite peak at 14 Å after heating at 550 °C and before treating with hydrochloric acid. Therefore, the part of the 7 Å peak that is attributed to reflections from chlorite is calculated by multiplying the height of the 14 Å peak obtained after heating by a factor of two-thirds. The remainder of the 7 Å peak height is assigned to kaolinite. Although the thermal characteristics of the Pierre Shale and the clays from the recent sediment off the South African west coast are undoubtedly different, this method provided a means of estimating the relative abundance of chlorite between samples. However, it was found most convenient to portray the regional distribution of chlorite as a ratio in terms of illite simply on an integrated peak-area basis.

Splits of four clay samples were sent to various geological institutions to assess the variation in a semi-quantitative mineralogical study. Diffractograms and semi-quantitative analyses were returned by Woods Hole Oceanographic Institution (U.S.A.) and Stellenbosch University (South Africa). The results of this investigation are presented in Fig. 4 and Table 1. Bearing in mind the lack of standardisation, the results of these determinations are remarkably consistent.

The empirical measure described by Biscaye (1965) was used to measure the crystallinity of the montmorillonite mineral, and an estimation of the K- and plagioclase feldspars distribution was made on a ratio of their peak areas at 3.20 and 3.18 Å respectively.

TABLE 1  
Semi-quantitative analyses of clay mineral abundance made by three geological institutions.

Sample	Smectite			Illite			Kaolinite		
	UCT	WHOI	US	UCT	WHOI	US	UCT	WHOI	US
2281	24	18	17	60	69	70	16	13	14
2716	19	11	21	60	68	61	21	21	18
3320	4	7	4	87	84	86	9	9	10
R-21	0	0	0	61	57	60	39	43	40

UCT: University of Cape Town.

US: University of Stellenbosch.

WHOI: Woods Hole Oceanographic Institution.

### III. AREAL DISTRIBUTION

Sediment from the western Cape shelf contains between 0 and 80 per cent clay-size material ( $< 4 \mu\text{m}$ ) and the average clay content for all samples analysed is over 17 per cent. The fine fraction therefore constitutes an important portion of the sediment on the continental margin. Clay-size material is most abundant on the inner shelf north of Saldanha Bay (Fig. 2) and on the outer shelf and slope, whereas the middle shelf is notably depleted in fine sediment (Birch, 1977). Clay values vary from greater than 50 per cent near the coast off the Olifants River to less than 10 per cent on the middle shelf.

#### A. Clay Minerals in the $< 2 \mu\text{m}$ Fraction

Illite is the dominant clay mineral on the continental shelf (Fig. 5). South of the Olifants River, illite shows a clear seaward depletion across the shelf, and although this trend is also evident to the north as well, it is complicated by a slight mid-shelf enrichment and moderately reduced values in the nearshore region off the Bitter River. The illite concentration decreases from 90 per cent near the coast to 50–60 per cent on the slope. Illite is also the most dominant clay mineral in the river sediments, but the Olifants River and its tributaries which drain the argillaceous sediments of the Karoo, Nama and Cape Groups and Supergroups are distinctly enriched in illitic clays compared to other rivers.

The distribution of smectite (Fig. 6) shows the reverse trend to that of illite. The concentration of this mineral

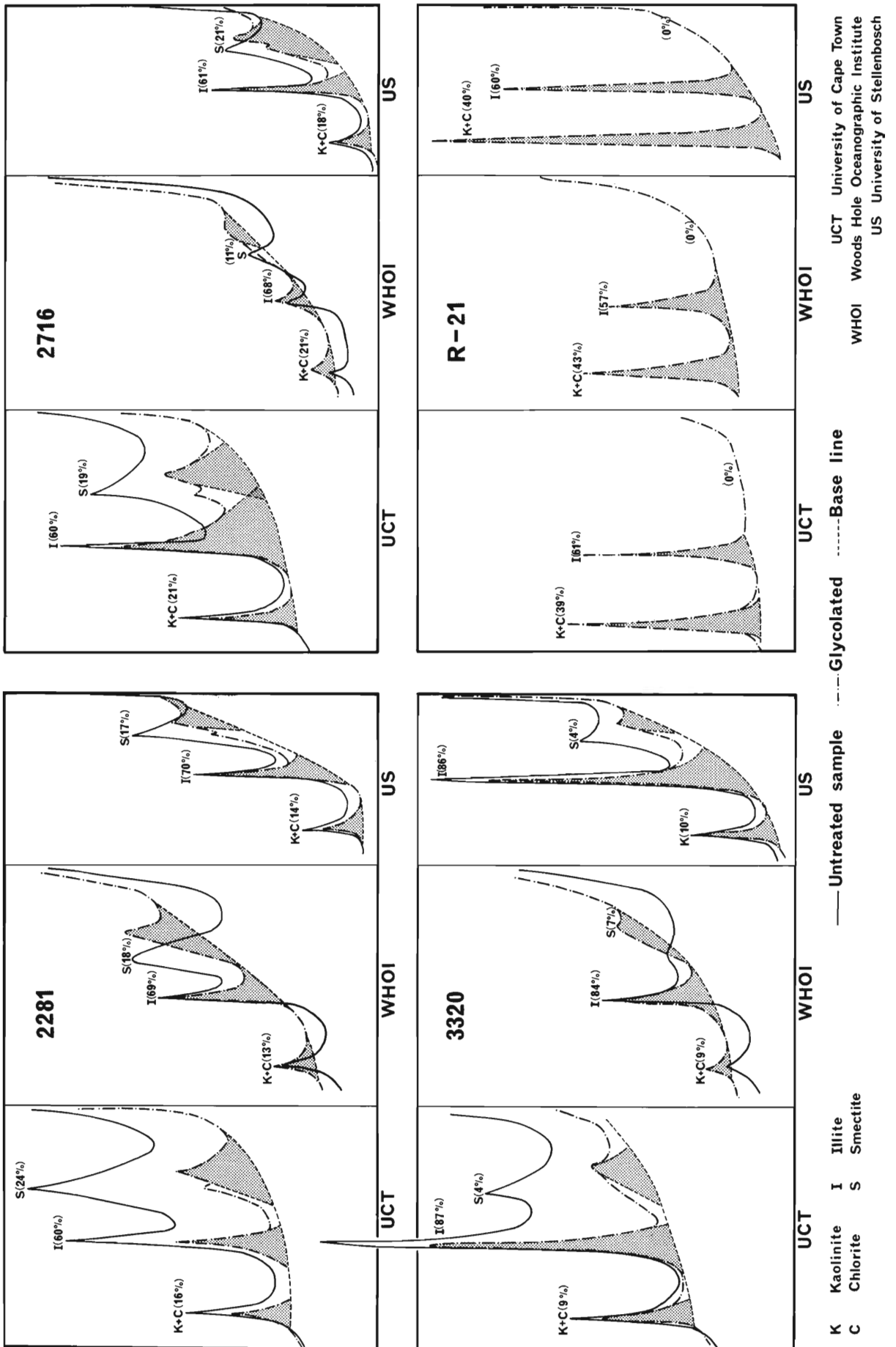


Figure 4  
 Comparative X-ray diffractograms made by three institutions.

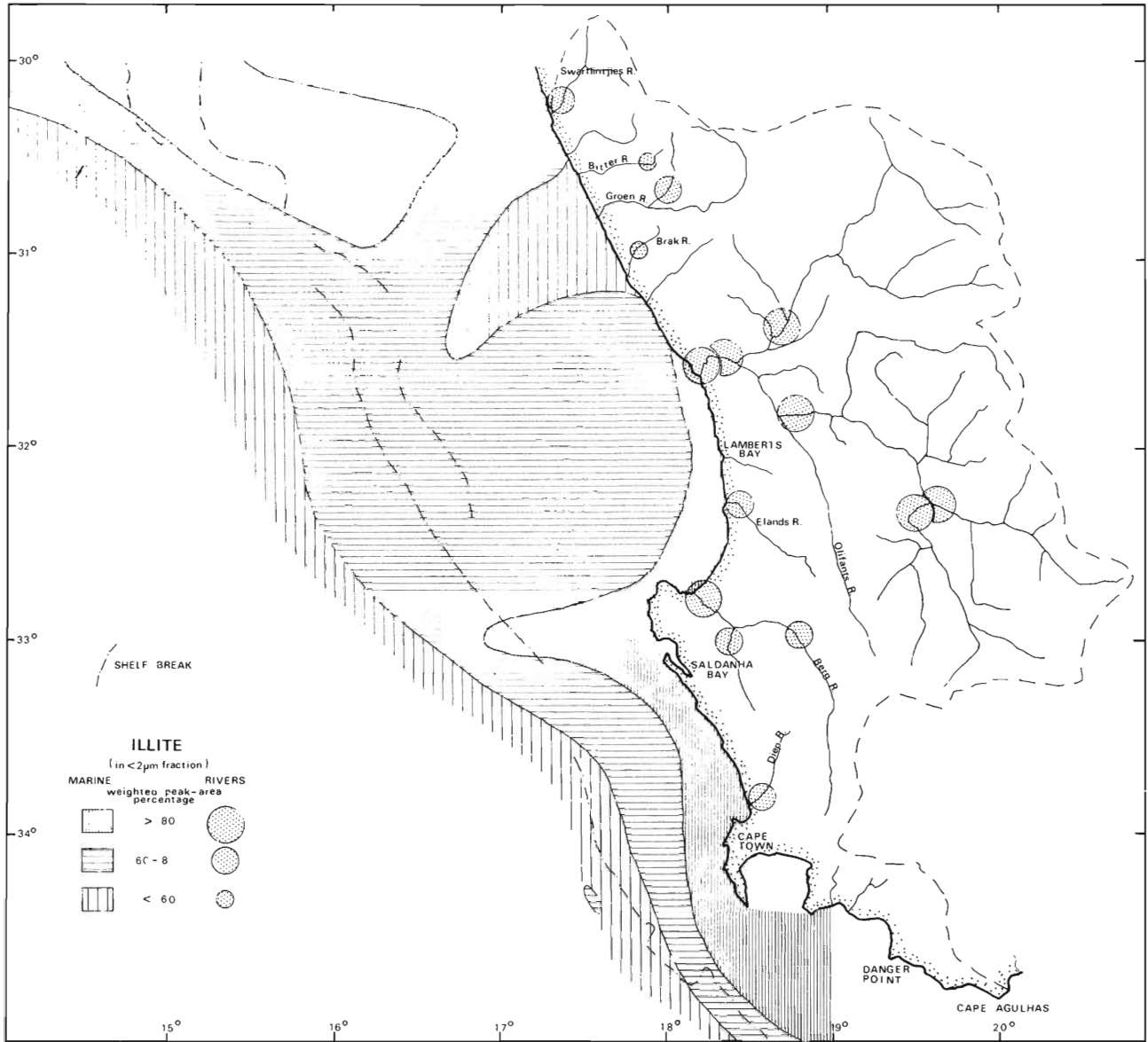


Figure 5  
Distribution of illite in the  $< 2 \mu\text{m}$  fraction.

clearly increases seawards, generally from less than ten per cent in the nearshore sediments to 20–30 per cent on the slope. Anomalous high smectite values occur on the inner shelf of the Groen River. This deposit of smectite-rich clay is responsible for the apparent paucity of illite off the Namaqualand coast (the shore bordering the Namaqualand metasediments) mentioned previously, and the slight depletion of smectite on the outer shelf in the north is related to a marginal enrichment in illite. River clays are notably depleted in smectite. No detectable quantities of this mineral were found in rivers draining the region to the south, but minor (six per cent) quantities occur in the tributaries of the Olifants River which erode sediments of the Nama Group and the Karoo Supergroup. This is not surprising since these argillaceous rocks are known to contain subordinate amounts of smectite (Danchin, 1970; Hofmeyer, 1971). The contribution of smectite from the Namaqualand metasediments is difficult to assess. Values are generally low, but one sample from the Bitter River contains more than 20 per cent of this mineral.

Because chlorite was only present in minor quantities, kaolinite and chlorite have been presented on an undifferentiated basis in Fig. 7. In contrast to smectite which in-

creases seawards and illite which increases landwards, kaolinite tends to be most concentrated on the outer shelf. Values of approximately 5–10 per cent are found on the slope and nearshore regions, and mid-shelf concentrations are between 15 and 20 per cent. A moderately developed zone of enrichment in the vicinity of shelf break includes values of between 20 and 30 per cent. The variation in the abundance of kaolinite in the rivers is significant. Clay in the upper reaches of the Berg River and in the Diep River, both of which drain extensive outcrops of Cape Granite, contains more than 25 per cent kaolinite. Rivers draining the Namaqualand metasediments contain clay which is likewise rich in kaolinite, some values exceeding 60 per cent (Brak River), whereas clay in the Olifants River, and especially its upper tributaries (Tankwa River) which drain the Karoo sediments, is markedly kaolinite-poor.

It has been found convenient to assess the chlorite contribution (Fig. 8) by expressing it relative to illite. The very variable chlorite/illite distribution is difficult to evaluate. High values off the Namaqualand coast occur adjacent to rivers which contain sediment depleted in chlorite, and it appears that only the Olifants River supplies the marine environment with detectable quantities of this mineral.

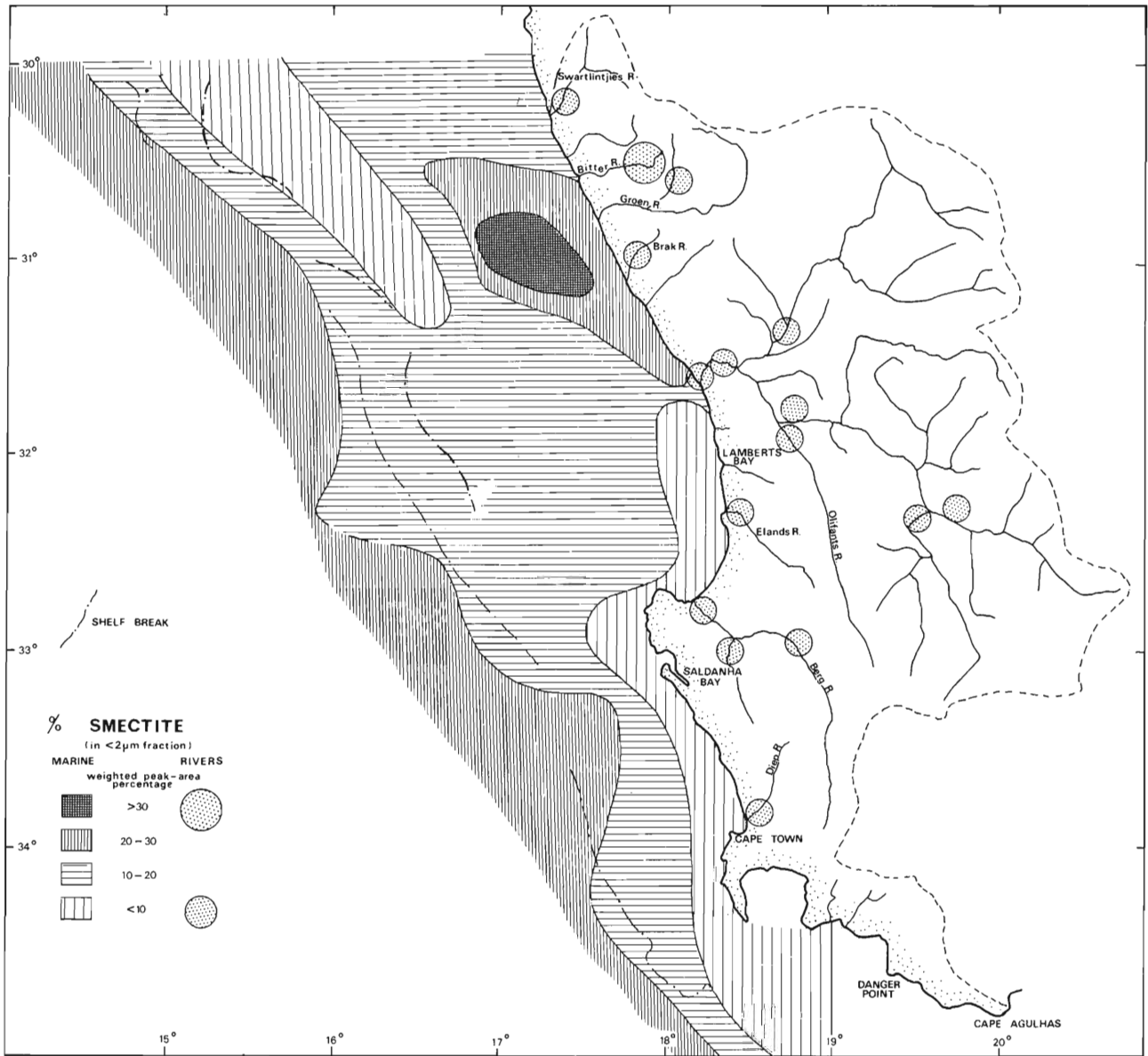


Figure 6  
Distribution of smectite in the  $< 2 \mu\text{m}$  fraction.

The presence of chlorite in the Olifants River sediments correlates with moderately high chlorite values reported by Hofmeyer (1971) for Nama sediments. Moderate chlorite enrichment occurs off Saldanha Bay as well as south of Cape Point. However, only minor chlorite could be detected in the clays from rivers draining the adjacent on-land sediments.

#### B. Non-clay Minerals in the $< 2 \mu\text{m}$ Fraction

On the continental shelf alkali feldspar is more common south of the Olifants River than in the north, but plagioclase is almost always more abundant than alkali feldspar. No clear areal distribution trends of feldspar are apparent in the marine clays. The feldspar content of the fine alluvial sediment is, like that of the clay minerals, more variable in the marine environment. Plagioclase was present in all river clays, whereas alkali feldspar occurred in sediment derived from the Bokkeveld and Witteberg Groups and was more abundant than plagioclase in rivers draining the Namaqualand metasediments. The large supply of alkali feldspar to the marine environment north of the Olifants River is not reflected in the feldspar concentration in the adjacent marine sediments. This feature is similar to the distribution of kaolinite in this respect.

#### C. Clay Minerals in the 2–15 $\mu\text{m}$ Fraction

As the  $< 2 \mu\text{m}$  fraction was utilised for both mineralogical and geochemical studies (Birch, 1975), no deflocculent could be added during the sedimentation process used to concentrate the material. Because of the unknown flocculation characteristics of these clays and since no measurement was made of the particle size being studied, a check was carried out on the coarse clay and fine silt (2–15  $\mu\text{m}$ ) fraction to assess whether the clay mineral assemblage of the coarser material differed radically from the  $< 2 \mu\text{m}$  clay.

A study of 35 samples indicated distribution trends in the 2–15  $\mu\text{m}$  material similar to those observed in the less than  $2 \mu\text{m}$  fraction study. The illite and kaolinite concentrations in the 2–15  $\mu\text{m}$  material increased at the expense of the smectite component relative to the  $< 2 \mu\text{m}$  fraction. However, the illite abundance increased shorewards and the smectite component increased seaward in a similar fashion to that observed in the  $< 2 \mu\text{m}$  study except that the trends were not as well developed. In addition, the anomalously high smectite concentration off the Namaqualand coast apparent in the  $< 2 \mu\text{m}$  fraction was also discernible in the investigation of the 2–15  $\mu\text{m}$  fraction.



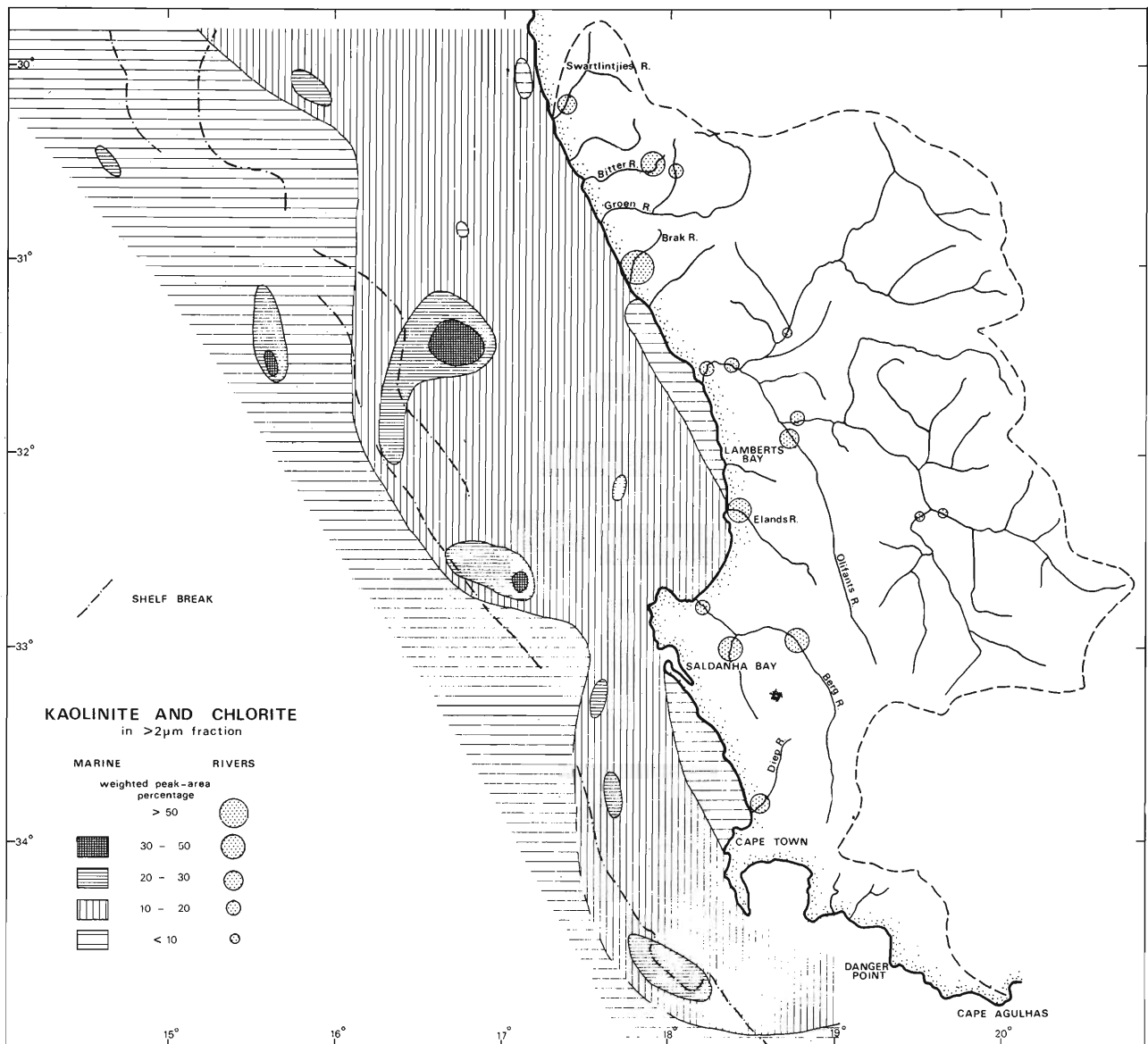


Figure 7  
Distribution of kaolinite and chlorite in the  $< 2 \mu\text{m}$  fraction.

#### IV. DISCUSSION AND CONCLUSIONS

Illite is frequently the most dominant clay mineral present in the marine sediments, mainly because of the high concentration of micas in many rock-types and owing to its relative resistance to chemical weathering (Biscaye, 1965). The preponderance of illite in these shelf sediments is clearly related to its abundance in the adjacent onland argillaceous rocks (Hofmeyer, 1971). Estimations made by Biscaye (1965) and Griffin *et al.* (1968) of illite for the south-east Atlantic coincide well with values reported in this work ( $> 50$  per cent and  $> 70$  per cent respectively).

The low smectite abundance noted by Griffin *et al.* (1968) and Biscaye (1965) ( $< 20$  per cent and  $< 9$  per cent respectively) for the south-east Atlantic is similar to values obtained in this study. However, the occurrence of high smectite values off the Namaqualand coast in the north requires explanation, especially as sediment in the streams draining the adjacent onland metasediments is seemingly smectite-poor. There are three possible sources for this material. It may be associated with a similar smectite enrichment on the inner shelf to the north which is considered to be derived from the Orange River (Rogers, pers. comm., 1975), but the absence of a clear northward continuation of the deposit tends to mitigate against such a

source. Smectite originates by the denudation of metamorphic rocks or by alteration of kaolinitic minerals (Meade, 1967). Smectite can also form from serpentinites (Barshad, 1966) or from micas (Kunze *et al.*, 1968) and chlorites (Griffin and Goldberg, 1963) which have been stripped of their potassium. It is therefore possible that the smectite is being derived either directly by denudation of the metasediments or by secondary alteration. Although most of the rivers draining the metasediments are poor in smectite a sample from the Bitter River contained more than 20 per cent of this mineral but, unfortunately, the Groen River, which is an obvious source for the deposit, has not been sampled (a small tributary of the Groen River contains less than ten per cent smectite). The smectite may also have originated by reworking of the local near-shore Cretaceous outcrops. Some of these clays are associated with light-green glauconite which shows a close association with the Cretaceous (Birch, 1971, 1975). The smectite is not as perfectly related to the underlying strata as the glauconite, but this may be expected as the clay would be more mobile. However, the problem cannot be resolved with the data at hand and will remain until further information becomes available.

The most crystalline smectite occurs on the slope and

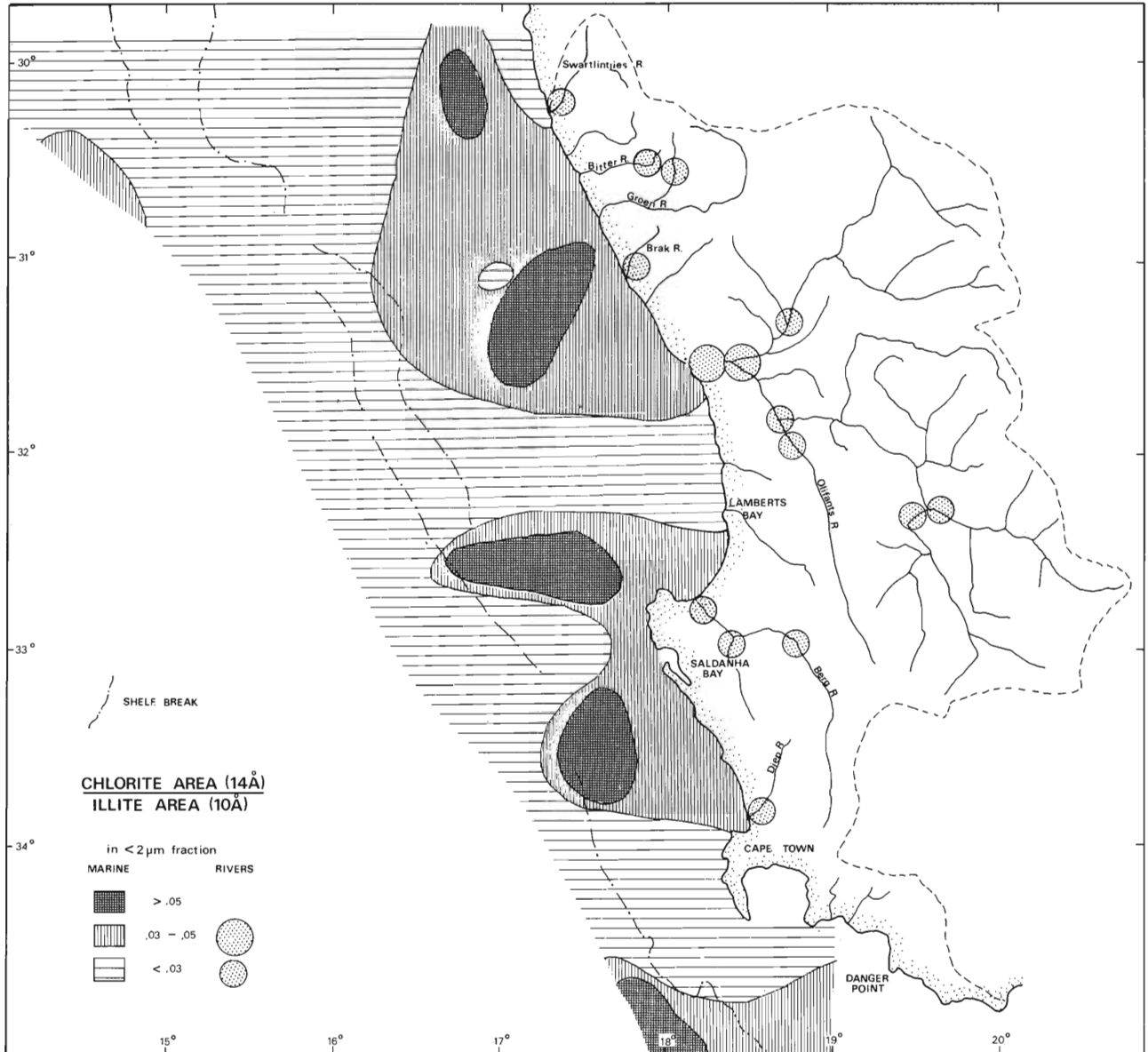


Figure 8  
Distribution of chlorite area/illite area.

nearshore regions in areas where the mineral is most abundant. A similar feature has been noticed by Bremner (1975) for the clays off South West Africa. The reason for this trend is not clear, but it could be due to relatively increased sedimentation on the inner shelf and slope which results in rapid burial of surface sediment and this blanketing effect may prevent alteration of the clay minerals (Milne and Earley, 1958). In addition X-ray traces produced by Hofmeyer (1971) and Danchin (1970) of the clays from the onland argillaceous rocks have sharp and well-defined reflections in relation to the broad, more diffuse peaks exhibited by the marine material. This implies a decrease in clay crystallinity on entering the marine environment.

Kaolinite is considered to be a low-latitude clay mineral (Biscaye, 1965) and is more abundant in regions undergoing intense weathering under tropical conditions (Milne and Earley, 1958; Griffin *et al.*, 1968). The semi-arid regime of the Namaqualand area is therefore not favourable to abundant kaolinite formation. Values of 10 to 15 per cent kaolinite off the Cape west coast are slightly higher than those reported by Biscaye (1965) and Griffin *et al.* (1968) for this region (i.e. 5–6 per cent and 5–10 per cent respectively).

The low-grade greenschist facies of the Namaqualand metasediments occurs close to the coast and contains chlorite, serpentine, epidote and actinolite (Joubert, 1971). Metamorphic rocks are frequently the source of abundant quantities of kaolin (Johnson, 1970) and serpentine minerals which have a kaolinite-type structure have been shown to be a parent material for some kaolinite (Meade, 1967). Another precursor of kaolinite is feldspar (Griffin *et al.*, 1968) which is a major component of the Nama sediments and the Cape Granite. It is therefore not surprising that the rivers draining these sediments contain abundant kaolinite. However, it is significant that no kaolinite enrichment occurs in the nearshore marine sediments off the Namaqualand coast. This is possibly because kaolinite is being transported across the shelf and is accumulating near the shelf break (see Fig. 7), but this would raise the question of why the smectite which is enriched in the nearshore sediments off the Namaqualand coast is not also being dispersed in a similar fashion. This may support an earlier suggestion that the smectite is being derived by reworking of Cretaceous outcrops, or that kaolinite has undergone alteration (Meade, 1967).

The distribution of chlorite is often reciprocal to that of kaolinite (Griffin *et al.*, 1968) and is most abundant in the

high latitudes. Chlorite is a primary rock mineral (mainly metamorphic) and undergoes minor chemical alteration in the sedimentary cycle, whereas kaolinite is a secondary mineral derived mainly from soil-forming processes (Biscaye, 1965). The maximum chlorite abundance, estimated on assumptions made by Schultz (1964), in the marine sediments is less than three per cent, which appears to be slightly low in relation to values reported by Griffin *et al.* (1968) and Biscaye (1965) for this region (< 10 per cent and 5–9 per cent respectively). The chlorite occurrence off the Namaqualand coast is probably derived from the on-land low grade metamorphic rocks or the Karoo sediments which also contain chlorite (Hofmeyer, 1971), the moderate chlorite enrichment off Saldanha Bay and Cape Point is possibly related to the chloritic Nama sediments (Hofmeyer, 1971) or to the metamorphics associated with the intrusive Cape Granite.

The variation in the abundance of the three major clay mineral species across the shelf is perhaps the most striking feature of this study. Seaward changes in clay mineralogy initially led some workers to conclude that structural and chemical changes occurred in the depositional environment (Grim, 1951). It has since been realised that these trends are related to differential settling and that this separation is enhanced by formation of floccules (Whitehouse and Jeffrey, 1955; Siegel *et al.*, 1968). Whitehouse *et al.* (1960) have calculated the settling rate of illite, kaolinite and smectite as 15.8, 11.8 and 1.3 m/day respectively. These workers point out that a horizontal flow of greater than 600 cm/sec is required to eliminate the effect of differential transport. This implies that the northward-flowing Benguela Current (30–50 cm/sec, Bang, 1973) could not override the effect of this process. Off the Cape coast illite is most abundant in the nearshore region, followed by kaolinite on the outer shelf and finally smectite is most concentrated in the slope sediments. This emphasises the importance of differential settling in the distribution of clay minerals off these shores. Although there are considerable changes in the onland geology and climate from north to south in the hinterland, there are no apparent latitudinal changes in the clay mineral assemblage on the adjacent continental margin off the Cape west coast.

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