Petrology, Sedimentation, and Paleontology of Middle Miocene Graded Sandstones and Mudstones, Kaiti Beach, Gisborne

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Abstract

RHYTHMICALLY bedded graded sandstone and mudstone of Middle Miocene (Lillburnian) age are exceptionally well exposed at Kaiti Beach, Gisborne. Microfossils and sedimentary structures indicate that deposition was largely by turbidity currents.

Data on grain size, sedimentary structures, and bedding thickness are given for 192.5 feet of strata, and these are discussed in terms of the turbidity current " model ".

Trace fossils formed by burrowing soft-bodied marine organisms and a calcareous polychaete tube are present in most rhythms and locally occupy up to 80 per cent by area of a given mudstone bed. A new genus, *Laminites,* is proposed for one of the trace fossils; this burrow is thought to have been formed by a holothurian.

Microfossils from one of the rhythms are graded in size and are inferred to have been derived from both shallow- and deep-water biofacies.

Flute casts, groove casts, and micro-crossbedding indicate turbidity current flow in an ENE direction.

Textural and mineralogical evidence suggest that much of the calcium carbonate in these rocks is detrital shell material, which locally has been partially dissolved and reprecipitated. Mineralogical composition of the sandstones suggests derivation from the following sources: (1) transported authigenic minerals, (2) hard parts of marine organisms, (3) a greywacke terrain, and (4) eruptive rocks. The appearance of fresh oscillatory-zoned plagioclase and volcanic glass in the lower part of the measured section suggests contemporaneous volcanism in the source area.

INTRODUCTION

RHYTHMICALLY bedded graded sandstone and mudstone of the Middle Southland Series are well exposed in sea-cliffs and the associated wave-cut platform at Kaiti Beach, Gisborne (Fig. 1). The section is of interest for the following reasons: (1) numerous primary sedimentary structures are well-developed; (2) the sediments contain numerous structures formed by burrowing organisms; (3) petrographic study indicates that the sediments were derived from several sources, including contemporaneous volcanism of Middle Miocene age. Part of this work has been reported elsewhere (Ghent and Henderson, 1965).

A detailed geological map of the Gisborne area has been presented by Stoneley (1962), who has assigned the rocks described in this paper to the Clifdenian and Altonian stages. Our work, however, indicates that most of the section studied is Lillburnian or younger in age (see section on micropaleontology). The section studied is continuously exposed and is bounded at both ends by areas covered with landslide debris. (Grid references of the limits of the section are on N.Z.M.S.1, Sheet N98, 416343–417340.) The beds strike about 035° and the average dip is 30°–35° to the north-west. The section is disrupted by several steeply dipping faults with apparent displacements up to 10ft, but the beds can be easily correlated across the faults.

Kuenen (1964) and Dott (1963) have emphasised that several criteria are necessary to establish a turbidity-current origin for a given group of strata. The following mutually associated features suggest that the graded sandstones at Kaiti Beach were deposited by turbidity currents: (1) mixture of shallow-water and deep-water microfauna in a given rhythm, (2) repetitious graded bedding, (3) alteration of relatively coarse-grained and fine-grained strata, (4) reworking of only the upper parts of beds by organisms, (5) presence of flute casts, convoluted laminae, and small-scale cross-lamination, (6) lack of large-scale crossbedding, wave-ripple marks, channel scour, etc.

An idealised succession of features associated with a turbidite rhythm has been given by Bouma (1962) and Dott (1963). Briefly, the five parts of a complete sequence are (Bouma, 1962: 49–50):

(e) Pelagic interval;
(d) Upper interval of parallel lamination in mudstone;
(c) Interval of current-ripple lamination and convoluted laminae;
(b) Lower interval of parallel lamination;
(a) Graded interval, usually massive.

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A similar sequence has been recognised in several rhythms at Kaiti Beach, but intervals (d) and (e) cannot be differentiated in the field. Micropaleontologic evidence suggests deposition of a substantial part of the mudstone from the turbidity current. In many rhythms the succession is incomplete or interrupted. The following types of interrupted or incomplete successions can be recognised: (1) rhythms with two distinct graded sandstone beds, separated by a sharp irregular contact, (2) rhythms beginning with interval (b) (most common type), (3) repetition of current ripple laminated layers (c) and mudstone layers (d, e) between more nearly complete sequences.

Possible causes of interrupted or incomplete sequences are: (1) erosion of the upper part of a rhythm by a subsequent turbidity current, (2) two turbidity currents following in rapid succession, the nose of the second overtaking and diving beneath the tail of the first, (3) decreasing capacity and competence of the currents away from the source so that incomplete sequence beginning with the (b) or (c) interval is deposited.

SEDIMENTARY STRUCTURES

Variation in Bedding Thickness

Measurements of bedding thickness were made on 190 rhythms, comprising 192.5ft of stratigraphic section. Variability of bedding thickness between rhythms was found to be far greater than variability of thickness of a bed within a given rhythm. Thickness was measured at three or four separated points along the outcrop of a bed and the results were averaged and recorded to the nearest quarter of an inch. Parts of the bed with loading structures or other small irregularities were avoided. It was found that thickness of ripple-laminated interval (c) and mudstone beds (d, e), particularly where they comprise the entire rhythm, are more variable than the thickness of the sandstone beds (intervals a, b, c), and in many cases the laminated fine sandstones and coarse siltstones pass into massive mudstone along the strike.

Units differentiated for measurement are sandstone beds (intervals a, b, c) and mudstone beds (intervals d, e). The contact between sandstone and mudstone was located on the difference in grain-size and colour and the presence of jointing in mudstone and not in sandstone. Sandstone beds were further subdivided into types with massive bases (a-type), laminated bases (b-type) and current-ripple laminated bases (c-type). Bedding-thickness statistics are given in Table I.

Numerous authors have discussed which intervals of a rhythm have been deposited directly by the turbidity current and which by highly diluted parts of turbidity currents, by later bottom currents, or by pelagic sedimentation (see, for example, Bouma, 1962).

These discussions have not led to many firm conclusions, and no attempt will be made to summarise all of the main arguments. Possible sedimentary models for the interpretation of turbidity-current deposition have been given by Sullwold (1961), Bouma (1962), and Potter and Pettijohn (1963), and as a first approach we shall attempt to analyse the Kaiti beach data with reference to these " models ".

There appears to be no strong positive correlation between the thickness of a sandstone bed and the thickness of the associated mudstone within the same rhythm. The low correlation coefficient (0.12) indicates that there is no strong linear relationship between the variables (Alder and Roessler, 1962: 161).

Sandstone beds with a-type bases are thicker than those with b- or c-type bases. According to the model presented by Bouma, complete turbidite rhythms (intervals a–e) are thought to be deposited nearest the source area and would be deposited over a smaller area of the basin than b-base or c-base rhythms. One would expect the rhythms nearer the source to be thicker, and one might also predict a greater variability in thickness of a-base sandstone beds than of b-base sandstone beds. This inference can be better appreciated with reference to Fig. 2, which is modified from Bouma (1962: 99). Very few data are available on the areal extent and scale of various types of turbidite sequences, but Carozzi (1957) has presented evidence for the tracing of individual beds over a distance of 30–40km. Supposing that the area over which b-base sandstone is deposited is at least twice as large as the area over which a-base sandstone is deposited by a given turbidity current, any change in the volume of sediment delivered would effect a larger change in thickness of a-base sandstones than of b-base sandstones. This is consistent with the bedding-thickness statistics from Kaiti Beach, there being a larger standard deviation for a-base sandstones than for b-base sandstones.

Another problem in this connection is that of the manner in which succeeding rhythms with a-base, b-base, and c-base sandstones have been deposited at a given point. The different types may have been deposited by turbidity currents from different source areas (Fig. 2), but a second possibility is that there are some unknown factors affecting the size and character of turbidity currents from one source area.

Convoluted Laminae

Convoluted laminae occur in most of the rhythms but are generally confined to a single horizon within each rhythm; 79 per cent of rhythms with a-base sandstones contain convolutions, as compared with 64 per cent of b-base sandstones. The laminae are commonly defined by wisps of carbonaceous matter. Grain size of quartz and feldspar in the convoluted laminae range up to 220μ, but the modal size is in the very-fine-sand class.

Convolutions have the typical sharp-crested anticlines and broad-bottomed box-like synclines that have been described by other workers (e.g., Potter and Pettijohn, 1963). In a few beds the convolutions pass into convolute balls about an inch in diameter. Within a given bed there is usually no common sense of overturning of the "folds". On exposed bedding surfaces the convolutions are seen to be highly irregular, with curving "fold axes".

The maximum amplitude of the convolutions ranges from about ½in to 5in, and the maximum wave length varies from about 4in to 32in. A-base sandstone beds are thickest and contain convolutions of largest amplitude, but the wave length of the convolutions does not appear to vary consistently with bedding thickness.

The convoluted laminae in the Kaiti Beach section are thought to have been formed by current drag (Ghent and Henderson, 1965). Briefly, the lines of evidence supporting this interpretation are: (1) cross-cutting of convolutions by straight worm burrows (type 1) which are undeformed, (2) constant relatively shallow depth of burrows of *Laminites kaitiensis*, which also post-date the convolutions, (3) occurrence of cross-bedded laminae in the synclinal troughs of some convolutions, and (4) local erosion and truncation of anticlinal crests on convolutions by the overlying turbidite. Since the turbidite sandstones do not usually show deep scour features in the underlying rhythm, it seems highly unlikely that much sediment was eroded from above the zone of convolutions.

Slump Structures and Small-scale Folds

No large-scale slump structures were observed in the Kaiti Beach section. Two rhythms contain small-scale folds, overturned towards the east, within the mudstone. The amplitude of the folds is about three inches. The shape and orientation of the folds suggest an origin by small-scale gravitational movement, rather than by loading.

Mudstone Clasts

Mudstone fragments of gravel size are found but are relatively rare in the Kaiti Beach sandstones, only six rhythms (3 per cent) containing mudstone clasts. In most rhythms the fragments occur near the centre or the top of the sandstone bed. One layer of mudstone-pebble conglomerate, 3½in thick, occurs at the base of one turbidite rhythm underlying a bed of sandstone 23.5in thick. The mudstone pebbles are close-packed, with sand filling the interstices, and they are usually elongated in the plane of the bedding. Maximum size of the clasts is 7in by 1½in, but most fragments are of pebble size. The lithologic character of the mudstone varies from pebble to pebble, suggesting mixing of pebbles derived from more than one source.

Inferred Current Directions

Sole markings inferred to have been formed by turbidity-current flow were rarely observed in place. Groove casts were measured in twelve rhythms and flute casts were measured in three rhythms. These sole markings are identical in appearance with those figured by Potter and Pettijohn (1963) and many other authors. The trends and vectors (corrected for the dip of the beds) are plotted in Fig. 1. They suggest an ENE direction for turbidity-current flow, which is consistent with current directions inferred from numerous measurements of micro-crossbedding components in the c-interval. Inferred current directions deviate from the tectonic strike of the beds.

MINERALOGY AND TEXTURE OF SEDIMENTARY ROCKS

Relationship Between Bedding Thickness and Grain Size

Several authors (Kingma, 1958; Dott, 1963; Kuenen, 1964) have observed a positive correlation between the thickness of turbidite rhythms and maximum size of clasts in the turbidite sandstone. This correlation is affected by at least three variables: (1) competence and capacity of the turbidity current, (2) size of material available in the source area, and (3) distance from the source area.

Sandstones from the Kaiti Beach section contain only a small percentage of grains larger than 250μ. Ten samples were studied in detail and the results are presented in Fig. 3a. Maximum size of quartz and feldspar only were considered, and there is a high positive correlation (correlation coefficient 0.93) between maximum size and sandstone-bed thickness. The correlation coefficient was found to be significant at the 5 per cent. level, using Student's t-test. This means that from a normal bivariate population with a correlation coefficient of zero (no linear relationship) samples of ten varieties with a correlation coefficient of 0.93 are obtained less than 1 time in 20 (Alder and Roessler, 1962: 163).

The weight percentage of mud (diameter $< 63\mu$) in sixteen different basal sandstones was determined by sieve analysis and is plotted against sandstone-bed thickness in Fig. 3b. It should be recognised that some of the material which passed the finest mesh sieve consists of shell fragments of lath shape with long dimensions up to 125μ, but this abnormal fraction is small and does not affect the main conclusion. The correlation coefficient is negative and high (— 0.84) and was also found to be significant at the 5 per cent level. Observations on mud content are expressed as a percentage, but comparing its interrelationship with an "outside" variable such as bedding thickness should reduce (or mask) the bias arising from the constant-item sum (Chayes, 1960: 4185).

According to the turbidity current model one would expect the thicker sandstone beds with the coarsest grain-size to be deposited nearest the source. The low percentage of mud in these thicker sandstone beds represents particles which were trapped between the interstices of the larger grains as the latter were deposited. If the principle of autosuspension can be applied to turbidity currents (Shepard, 1963: 138-140), the mud carried in suspension would have uniform concentration throughout the flow. As the coarser grains settled rapidly from suspension they would drag muddy water down with them. At greater distances from the source thinner beds would be deposited, and under a flow regime of decreasing velocity and turbulence a proportionally greater amount of mud would be deposited.

PETROGRAPHY OF SANDSTONES

General Petrography

Sandstones from the Kaiti Beach section are light-grey to medium-grey on fresh surfaces (N7–N5, rock-colour chart). Mud ($< 63\mu$) content of the sandstones varies from about 16 to 50 per cent. Some of the samples collected from the basal parts of rhythms contain 50–75 per cent of mud and are more properly classified as sandy mudstones. The modal grain size of the sandstones is in the very-fine-sand class. Sandstones with a relatively low content of calcium carbonate are friable and have relatively high porosity, whereas sandstones with the highest carbonate content are well cemented and have a lower porosity.

Quartz, calcite, and plagioclase are the most abundant minerals in the Kaiti sandstones; the quartz : feldspar ratio ranges from about 2:1 to 15:1. Quartz grains are typically elongate and range from very angular to sub-rounded according to the classification of Powers (1953). The elongate grains typically have a preferred orientation in the plane of the bedding. Some of the quartz from the stratigraphically highest part of the section is equant, clear, contains a few small inclusions of zircon, and has widely separated fractures and shadowy extinction. A few grains of this quartz exhibit bipyramidal faces. Throughout the stratigraphic section turbid quartz is abundant, and some of the grains contain marginal sprays of sericite and chlorite which suggest " chavaux-de-frise " structure (Pettijohn, 1957: 304–305). Quartz aggregates are rare. Where quartz is in contact with calcite the margins of the quartz grains are typically etched and corroded.

Plagioclase, microcline, and perthite are present throughout the section, but plagioclase is far more abundant than alkali feldspar. Two distinct types of plagioclase are present. One type is turbid, sericitised, and unzoned, has a composition in the range calcic oligoclase–sodic andesine, and is present throughout the section. The second type is fresh, clear, shows euhedral oscillatory zoning, and has an average composition close to An 55 (most commonly An 52–58, one grain gives An 70). Many grains of this latter type are broken and have skeletal shapes. The more calcic cores of some grains are preferentially replaced by calcite. A second, less important, mode of occurrence of this type of plagioclase is as small euhedral phenocrysts in porphyritic volcanic-rock fragments. The euhedrally oscillatory-zoned plagioclase contains small inclusions of apatite, zircon, opaque iron oxide, and glass (?). Samples that contain the oscillatory zoned plagioclase have a lower quartz : feldspar ratio than those that contain only unzoned plagioclase. The limits on the stratigraphic occurrence and age of the euhedrally zoned plagioclase are discussed in the section on micropaleontology.

Rock fragments consist of mudstone, porphyritic volcanic rocks, devitrified volcanic glass, chert, and brown to clear volcanic glass. Some of the devitrified glass is difficult to distinguish from chert. Light fractions (sp. gr. < 2.52) were separated from four samples and studied in immersion oils and by X-ray diffraction. No zeolites were detected, but clear isotropic glass was present in K-271.* The refractive index of this glass ranges from 1.49 to 1.50. Volcanic detritus is most abundant in those samples that contain zoned plagioclase.

Minerals with a density greater than bromoform comprise less than 1 per cent by weight of the sand fractions. Two distinct populations of heavy minerals are present. The first, present in all of the samples studied, consists of pink garnet, pale-coloured amphibole, biotite, chlorite, rounded zircon, epidote, anhedral magnetite, sphene, and pyrite. The second is present only in those samples with abundant volcanic rock fragments and euhedrally zoned plagioclase. Euhedral magnetite with inclusions of rhombohedral phase (detected by X-ray diffraction) is the characteristic mineral of this population, and euhedral zircon and brown hornblende accompany the magnetite in some samples.

Glauconite

Glauconite pellets have been observed in all the sandstones and mudstones that have been examined petrographically, but they never make up more than 1 per cent by volume of the rock. Maximum grain-size of the glauconite in the sandstone is 300μ and the maximum size of the associated quartz and feldspar is always slightly larger. In turbidite rhythms that were examined in detail the maximum size of the glauconite varied only slightly in the vertical direction within the sandstone bed, but became noticeably smaller in the mudstone. For example, in sample K-145, the maximum size of glauconite in the sandstone is 160μ, whereas the maximum size of glauconite in the mudstone is only 64μ.

Rounded elongate pellets are the most common form of the glauconite, but a few grains with irregular shape, traversed by small fractures, also occur. Aggregate structure was observed in all grains except one which was fan-shaped and displayed pleochroism, high birefringence, and curved cleavage traces. These properties suggest replacement of detrital biotite by glauconite (Carozzi, 1960: 50–51). Small patches of glauconite also occur within some clasts of devitrified volcanic glass(?) and mudstone. Locally calcite appears to replace (?)glauconite (e.g., K-322).

The glauconite was not studied in detail, but the evidence for size grading of glauconite within a turbidite rhythm suggests that much of it has been redeposited. Similar conclusions have been reached about glauconite from Tertiary Flysch sandstones in the Alps (Dzulynski, *et al.,* 1959).

PETROGRAPHY OF MUDSTONES

Mudstones from Kaiti section are medium greenish-grey (5 Gy 6/1–5/1, rock-colour chart), homogeneous, and typically display evenly spaced jointing normal to the bedding planes. Under the microscope they are seen to consist of a clay-silt matrix of calcite, quartz, feldspar, and phyllosilicate minerals with scattered grains of quartz, plagioclase, glauconite, and " illite " ranging in size from coarse silt to fine sand. These coarser grains usually lie with their long dimensions orientated parallel to the bedding of the rhythm. The silicate detritus in burrow fillings is often in the fine-sand class and is associated with unbroken foraminiferal shells. Foraminiferal shells within the mudstone range up to 368μ in maximum dimension, and they usually contain blebs of pyrite. Pyritic casts are not uncommon; the absence of the shell material indicates that the shells were either broken or dissolved away. Carbonaceous matter is also common in the mudstones, but it was not studied in detail.

Slides of orientated clay fractions were prepared from four mudstone samples. Diffractograms from all of the clay samples have a strong, sharp 10Å peak, indicating the presence of " illite " and/or glauconite. In addition, one pattern had peaks at about 14Å, 7Å, and 3.5Å. Heating the sample to 500° C caused all of these peaks to collapse, and treatment of a second slide with ethylene glycol caused the 14Å peak to shift to about 17Å. These data suggest the presence of kaolinite and montmorillonite (Warsaw and Roy, 1961). Mixtures of three clay minerals (a 10Å mineral, montmorillonite, and kaolinite) are not uncommon in Tertiary argillaceous rocks (see, for example, Weaver, 1958: 169–170).

DISTRIBUTION OF CALCIUM CARBONATE IN TURBIDITE RHYTHMS

Graded sandstones and mudstones in the Kaiti section locally contain abundant calcium carbonate. This calcium carbonate occurs: (1) in continuous to discontinuous zones in the basal portions of sandstone beds (zones up to 8in thick), (2) in isolated ellipsoidal concretions in the middle of sandstone beds, (3) in concretionary mudstones toward the tops of rhythms, and (4) in rare veins and layers $\frac{1}{8}$in to 1in thick in mudstone, parallel to bedding. Concretionary zones can be distinguished by their greater hardness and greater resistance to weathering. Rhythms with thick sandstone beds more commonly contain concretionary zones (Table II).

The calcium carbonate contents of sandstones and mudstones were compared by leaching the samples (15–30 grams) in dilute HCl and determining the weight per cent of insoluble residue. It was felt that this method was the only convenient one by which the carbonate content of a relatively large number of fine-grained samples could be obtained with convenience and moderate accuracy. The results are set out in Table III.

Several generalisations can be made from these analyses: (1) in rhythms with no concretionary zones carbonate content increases with decreasing grain-size, (2) mudstones beneath concretionary sandstones (e.g., K-286) have a higher $CaCO_3$ content than those from beneath non-concretionary sandstone, (3) in discontinuous basal concretionary zones the non-concretionary parts of the bed have a relatively high content of $CaCO_3$ compared to sandstones from rhythms with no concretionary zone (e.g., K-210 has 30 per cent $CaCO_3$ in concretionary parts and 12 per cent $CaCO_3$ in non-concretionary parts of the sandstone).

In thin section the calcite can be classified into the following types: (1) shell debris, (2) sparry calcite, which represents either recrystallised shell debris or chemically precipitated calcite, and (3) microcrystalline calcite of doubtful origin (see Ferray *et al.,* 1962: 26). There appears to be a gradual progression in sandstones from those containing a high percentage of readily identifiable shell debris to those containing nothing but sparry calcite. In mudstones shell debris and microcrystalline calcite are more abundant than sparry calcite but no systematic variation has been observed.

In sandstones that contain the highest amount of identifiable shell debris (e.g., K-253) detrital silicate constituents appear to " float " in calcite (Fig. 4). Maximum grain-size of the calcite crystals is 240μ, but much of the calcite is finer than 4μ. Shell debris consists of Foraminifera and comminuted remains of exoskeletons of other organisms. The maximum size of the shell debris is 540μ, and the largest shell fragments are usually slightly larger than the largest grains of associated quartz of feldspar. Contacts between the shell fragments and the microcrystalline calcite of the matrix are both fuzzy and sharp; in many cases the organic origin of the calcite is suggested not only by the shape of the grains but also by the turbid character of the calcite and the presence of blebs of pyrite within it. The continuous calcite fabric appears to be largely of detrital origin, and the marginal corrosion and veining of silicate clasts as well as the dense character of the carbonate fabric seem to be due to partial solution of carbonate grains and reprecipitation *in situ* as cement. There is no evidence that crystallisation of calcite has been accompanied by an appreciable volume-increase or that a large volume of the silicate grains have been replaced by calcite (Carozzi, 1960: 38–39).

As the relative amount of obvious shell material and microcrystalline calcite decreases the relative amount of sparry calcite increases. In transitional types grains of calcite, quartz, and plagioclase and rock fragments are rimmed with radially orientated crystals of chemically precipitated calcite (e.g., K-322). Sandstones with little or no recognisable shell debris contain sparry calcite with a diameter usually in the range 100–200μ. Even in these rocks the silicate grains appear to " float " in calcite and there is no evidence for volume increase accompanying calcite crystallisation or extensive replacement of silicate. Sparry calcite from veins (e.g., K-158) is different in character from that of the sparry cement in sandstones. Calcite from veins is less turbid and occasionally twinned and the grain shapes and contacts are more regular. The average grain-size of the sparry cement is greater, but the maximum grain-size of calcite in coarse-grained " patches " within the veins is slightly larger (300μ).

The minor-element content of organic calcium carbonate is sensitive to diagenesis (e.g., see Chave, 1954; Lowenstam, 1961; Curtis and Krinsley, 1965), and Chave (1952) has demonstrated that the magnesium content of organic calcite can be estimated from the d $10\bar{1}4$ spacing. This measurement was made on several samples from Kaiti Beach (Table IV). It has been demonstrated that the amount of magnesium in solid solution in calcite is reduced by diagenesis (Chave, 1954) and an attempt has been made to relate the Mg-content of Kaiti Beach calcite to the degree of recrystallisation of organic calcite and the amount of chemically precipitated calcite present. Curtis and Krinsley (1965) have pointed out that diagenetic reactions should lead to an equilibrium distribution of trace elements—e.g., magnesium, among the coexisting grains of calcite. This grain-to-grain distribution could be detected in the Kaiti samples only by the use of an electron probe, since it would be impossible to separate the different types of calcite physically. The bulk magnesium content, however, should give some indication as to the relative effects of recrystallisation and the amount of chemically precipitated calcite among different samples.

The estimated magnesium content of calcite from sandstones with little identifiable shell material (K-226) is comparable to that of vein calcite (K-158) and calcite from mudstones. The problem cannot be assessed quantitatively, but the positive correlation of estimated magnesium-content of calcite with the amount of identifiable shell material is consistent with the interpretation that different beds have undergone different degrees of diagenesis and addition of secondary calcite. On the basis of the present evidence the relative effects of diagenesis of detrital calcite cannot be quantitatively separated from the effects of addition of secondary calcite, but the evidence from the fabric of the calcite cement as well as the high percentage of shell debris suggests that in some samples the amount of secondary calcite was small. There appears to be no correlation between the amount of shell debris present and the stratigraphic position or the thickness of the bed.

The Origin of Calcium Carbonate Concretions

The time of formation of concretionary zones in the sandstones and mudstones is considered to be early diagenetic (Pantin, 1958). Because of the inferred nature of turbidity current deposition, the concretions in the sandstones cannot be syngenetic, because the basal sand would have been very rapidly covered by deposition from the turbidity current. It also appears unlikely that the concretions in the mudstones are syngenetic, because of the degree of reworking by burrowing organisms and the fact that some burrowing structures project down into the mudstone from the overlying sandstone. These data suggest that in the interval between the deposition of successive turbidity currents, as well as some time after the deposition of the overlying sandstone, the muds were weakly consolidated enough to be extensively burrowed. Since organic remains are undeformed, and there is a general lack of phenomena such as pressure solution and welding of quartz grains and deformation of mica flakes, one would infer that the concretionary zones were formed before consolidation and compaction were complete.

The presence of calcite veins, isolated concretions in the middle of beds, and discontinuous concretionary zones in basal sandstones indicate that calcium carbonate was redistributed during diagenesis. It is not possible to make an accurate estimate of the original carbonate content of a given rhythm, and so the details of the carbonate redistribution cannot be determined. Evidence outlined above suggests that there need have been only local redistribution of carbonate in the basal sandstones. The development of discontinuous basal concretionary zones as well as of isolated ellipsoidal concretions in the middle of sandstone beds was probably controlled by slight differences in permeability and local variations in pH due to decaying organic matter.

The relatively high calcite content of mudstone immediately beneath concretionary sandstone seems difficult to interpret on any primary deposition basis. Contacts between sandstone and mudstone were likely to have been relatively permeable channelways along which connate waters were squeezed during compaction. Connate water from the carbonate-rich basal sandstone would be enriched in calcium bicarbonate. Precipitation of calcium carbonate could have occurred within the mudstone owing to the increase of pH by partial anaerobic decomposition of organic matter which released ammonia (Weeks, 1957); another possibility is an increase in pH due to base exchange reactions between clay minerals and the cations in the interstitial water (Degens, 1965).

MACROPALEONTOLOGY

Four types of trace fossils together with examples of a small calcareous polychaete tube were observed in the section. All five fossils were observed within beds rather than on exposed bedding planes as is more usual for trace fossils. Consequently, the spatial distribution within a bed and the distribution in successive beds could be determined. Several other types of trace fossils were observed on bedding-plane surfaces but were not seen in place; as these structures contribute little paleoecologic information, they are not discussed in this account.

One trace fossil, *Laminites kaitiensis* gen. and sp. nov., has been recognised in two stratigraphic sections of approximately the same age (Miocene) and about 150 miles apart. This trace fossil is considered to be of greater paleoecologic significance than the others, which are less well known and cannot be recognised with certainty in other sections.

Giving names to these other forms would serve little useful purpose, and they are herein referred to by notation.

Descriptions

LAMINITES gen. nov.

Type species: *Laminites kaitiensis* sp. nov.

DIAGNOSIS: Large subcylindrical pascichnid burrows filled with fine, concave laminations which are successively light and dark in colour.

Laminites kaitiensis sp. nov. (Plate 1

1964. Trace fossil type A, Balance, p. 489, fig. 19

MATERIAL: Holotype, V.T.1 (V.U.W. Paleontological Collection). No para types are designated, but material is abundant at the type locality.

DESCRIPTION: Long, gently meandering, laminated burrows which are subcircular in cross-section and filled with material of the same grain-size, but slightly lighter in overall colour, than the enclosing sediment. Laminations are concave or in some cases biconcave, 1.5–3mm thick, successively light- and dark-coloured and parallel to one another. Most cross-sections observed are ovoidal and are probably oblique to the long axis of the burrow, but some are nearly circular. The maximum width of burrows measured is 7.5cm (in longitudinal section), and burrows up to 45cm long have been observed. All burrows have a preferred orientation parallel to the bedding and are almost invariably in the portions of rhythms just above the laminated interval (interval c), although in rare cases some truncate convoluted laminae. Cases of one burrow cutting across another are not uncommon.

REMARKS: The type A trace fossils described from Takapuna Beach, Auckland, by Ballance (1964) have been examined by one of the authors (R.A.H.), and are considered to be examples of *Laminites kaitiensis*. The trace fossil from the lower Barremian sandstone of St Kumpers, Westphalia, which was illustrated by Kuenen (1961, fig. 3) appears to be another species of *Laminites* distinguished from *L. kaitiensis* by its smaller size. *Laminites* is a member of the Pascichnia group (winding burrows and trails of vagile mud-eaters) of Sielacher (1953).

Some well-exposed bedding surfaces have over 80 per cent of their area occupied by *L. kaitiensis*, indicating a large amount of reworking of the soft sediment by this organism alone (Plate 2). Soft-bodied sediment-eating animals of this size and abundance are rare in the deep seas of the present day. Holothurians are one such group, but very little information is available on the ecology of deep-water forms. Shallow-water holothurians "graze" the surface of the seabed rather than make burrows, but the prominent caudal appendages of some deep-sea forms may have a respiratory function, allowing the animals to burrow (Bruun, 1957). The lamination of *Laminites kaitiensis* would be produced by separate packets of faeces extruded into the burrow and packed around the rounded posterior of the animal.

Type 1 Trace Fossils

This notation designates thin cylindrical burrows, 6–12mm thick, with a maximum observed length of 30cm, which tend to be straight but sometimes branch into two diverging arms. Their filling is not laminated and is of a different grain-size from the enclosing sediment. In mudstone beds the burrows are filled with sand which is lighter in colour than the surrounding mudstone, and they locally occupy as much as 5 per cent of the area of exposed mudstone surfaces. The burrows occur only rarely in sandstone beds, but where they do the filling is often mudstone. Where concretionary sandstone overlies mudstone with Type 1 burrows the sand filling of the burrows is also concretionary. They usually show a preferred orientation parallel to the bedding, but examples which are oblique to the bedding are not uncommon.

The burrows were probably made by a sediment-eating annelid and are possibly synonymous with the type D burrows of Ballance (1964). The difference in grain-size between the burrow filling and the enclosing rock is probably due to the animal's ingesting material of different grain-size from that which surrounded its anus. If, during feeding, the animal was orientated parallel to the bedding throughout its length, the grain-size of the burrow filling would not differ from that of the surrounding rock and the burrows in the mudstone would not be macroscopically visible. Consequently there may have been a much higher proportion of reworking of the mudstone than has been observed; the same is not true of the sandstones, for here the lamination would be disturbed. Because burrows are most common in the mudstone and are generally orientated parallel to the bedding over much of their length, the animal must have fed largely on mud horizons. Macroscopically visible burrows in the mudstone, where the animal ingested sand while its posterior was encased in mud, may record the escape towards the sea-floor of the animals after the overlying rhythm had been deposited.

Type 2 Trace Fossils

Type 2 trace fossils are irregular tube-like bodies up to 2mm wide with a maximum observed length of 20mm. They occur exclusively in mudstone beds, being lighter in colour but similar in grain-size to the surrounding rock. They are generally elongate parallel to the bedding and are typically concentrated in packets which are also elongated parallel to the bedding and measure up to 15cm by 4cm. Type 2 fossils comprise up to 50 per cent of a packet and up to about 5 per cent of an exposed surface of a mudstone bed.

These structures are probably the burrow-fillings of a small sediment-eating worm, and may be synonymous with the type C trace fossil of Ballance (1964). Alternatively, they may be fossil faecal pellets. They are almost identical in appearance to the trace fossil from a North Atlantic deep-sea core illustrated by Bramlette and Bradley (1940, Pl. 5, fig. 2). Their arrangement in packets may reflect an origin due to a colony of animals or to the sphere of influence of one animal.

Type 3 Trace Fossils

Type 3 trace fossils are regular, dark-coloured, elongate, ellipsoidal bodies up to 1mm wide and 6mm long which are of similar grain size to but darker in colour than the enclosing rock. They are restricted to mudstone beds, are usually elongate parallel to the bedding, and generally comprise less than 1 per cent by area of an exposed mudstone surface.

Because of their regular shape and size these structures are interpreted to be fossil faecal pellets.

Calcareous Polychaete Tubes

Small, straight or gently meandering, subcylindrical calcareous tubes with a maximum diameter of 4mm and a maximum observed length of 10cm occur both in sandstone and in mudstone beds. They are badly crushed and their poor preservation precludes accurate taxonomic classification, but they probably belong to the family Serpulidae. Orientation is both parallel and oblique to the bedding. The tubes are common in mudstones, where they are randomly distributed throughout the bed, and rarer in sandstones, where they are commonly concentrated in scour casts. The concentration of the polychaete tubes in scour casts with other coarse detritus indicates that they have been transported and mechanically sorted by turbidity currents. The calcareous polychaete tubes occasionally truncate trace fossils, indicating that some were indigenous to the environment of sedimentation.

Discussion

The distribution of trace fossils and the calcareous polychaete tubes in the Kaiti Beach section is given in Table V.

Three paleoecological conclusions may be drawn from the above data:

(1) The sea-floor, in this environment of deposition (deep water with the sudden periodic influx of turbidity currents), carried an abundant fauna of soft-bodied sediment-eating creatures, which were largely restricted to the mud layer covering the sea floor. Either the mud was higher in nutrients than the underlying sand layer or the respiratory or other physiological processes of the organisms ceased to function when they penetrated deeper into the substrate.

(2) These organisms have re-worked a large proportion of mudstone beds and have significantly altered the texture and fabric of the upper portions of the turbidite rhythms. Many Foraminifera, perhaps all, have remained intact during reworking.

(3) The general absence of several of these fossil types from the lower horizons of sandstones suggests that many of the animals were killed when a turbidity current deposited its load on the sea-floor. The most likely cause of death would be respiratory failure. The occurrence of the fossils in the mudstone beds of successive rhythms suggests that the sea-floor was recolonised by a new generation of organisms after the deposition of each rhythm.

MICROPALEONTOLOGY

Sample numbers used below refer to Fossil Record forms which are filed in the New Zealand Fossil Record masterfile for the Gisborne District at the New Zealand Geological Survey Head Office, Lower Hutt. Full details of the localities and faunal lists are recorded on these sheets.

Age of Rocks Examined

Stoneley (1962) has given a general age of Clifdenian–Altonian for rocks that include the section here described. Foraminifera from three mudstone samples have been examined in the present investigation and have shown the section to be mostly of Lillburnian age or younger. A sample (N98f535) taken 6ft stratigraphically above the base of the section gave an age of undifferentiated Lillburnian—Clifdenian, and a second (N98f536i) taken 30ft stratigraphically above the base of the section contained specimens of *Orbulina universa* d'Orb. and *O. suturalis* Bronnimann, giving a definite Lillburnian age. A third sample (N98f534) taken 82ft above the base of the section gave an undifferentiated Lillburnian–Clifdenian age, but since it overlies definite Lillburnian, it must be Lillburnian also. The volcanic detritus discussed above appears between 32 and 73 feet stratigraphically above the base of the section, where the rocks are of undoubted Lillburnian age.

Paleoecology

A column through a complete turbidite rhythm was collected and broken parallel to the bedding into five adjacent samples (N98f536i–v) which correspond respectively to the sedimentary intervals (d)–(a) discussed above with samples ii and iii both being taken from interval (c). Individual samples weighed about 500 grams. These samples were used to determine depth, significant faunal change, and size grading of Foraminifera within the rhythm.

Size Grading of Foraminifera

Both the total fauna and individual species are size-graded within the rhythm in the same manner as the terrigenous clasts. No species or groups of species are common to all the samples. *Gaudryina convexa* (Karrer) was selected as a useful indicator of size-grading in samples iii–v. Planktonic species are the most abundant group in samples i–iv, but many of these are so small in samples i and ii that they cannot be identified accurately at the generic level. Consequently, three related genera, *Globigerina, Turborotalia,* and *Globoquadrina,* which are all of similar size when adult, were selected as indicators of size-grading in samples i–iv. All the specimens of *G. convexa* in samples iii and iv were picked. A portion of the specimens *G. convexa* from sample v and a portion of the specimens of *Globigerina, Turborotalia,* and *Globoquadrina* from samples i and iv were picked, and these selections are considered to be representative of the size ranges of the groups and their proportions in the individual samples. The maximum shell diameters of the specimens (the long axis of the shell in the case of *G. convexa*) were measured, using an ocular scale. Some specimens of *G. convexa* used were broken, with the juvenile growth-stages missing. The length of the long axis of these shells was deduced by measuring the maximum shell breadth, determining the ratio of shell breadth to shell length of complete shells for various stages of ontogeny, and assuming these ratios to be constant within the species. The numbers measured, maximum sizes, minimum sizes, average sizes, and standard deviations in size of the groups in the individual samples are shown in Table VI.

Juveniles of the two groups tend to be concentrated towards the top of the rhythm and adults towards the base. Such a distribution is abnormal for unsorted samples of Foraminifera and is indicative of strong mechanical size-sorting (Vella, 1963a). Values of standard deviation and size range of the two groups in successive samples suggest that sorting was imperfect but of comparable efficiency in the various sedimentary intervals comprising the rhythm. The absence of large planktonics in the mudstone (sample i) suggests that all the mud fraction was derived from the turbidity current and that a pelagic layer (interval e above) is absent or very thin. The homogeneous lithologic nature of the mudstone beds of all the rhythms comprising the section suggests that most of the mudstone beds were deposited by turbidity currents.

Distribution of Depth Indicators

Vella (1962) has outlined depth biofacies for the Pliocene of the Wairarapa. Later (1963) he has discussed the distribution of Foraminifera from different depth biofacies in Upper Miocene (Kapitean) graded beds at Cleland Creek, Wairarapa, having first established depth biofacies and their order from other samples of approximately equivalent age. The distribution of Foraminifera in the Middle Miocene graded beds at Kaiti seems to be very similar to that described by Vella, but detailed depth biofacies information for the Middle Miocene is unavailable and the depth ranges of most of the microfossils in the samples here discussed are unknown. However, some taxa are of use as depth indicators, either because their depth ranges are approximately known from other parts of the Tertiary column or because they are still living and their present-day depth ranges are known. In addition, the percentage of planktonic specimens in the total foraminiferal fauna is known to increase with depth at present (Phleger, 1960) and this relationship appears to be true for the New Zealand Cenozoic (Vella, 1962). Probable neritic forms in the Kaiti samples include the Foraminifera *Gaudryina convexa, Quinqueloculina* cf. *triangularis, Oolina hexagona, Zeaflorilus* cf. *parri, Elphidium* sp., and *Notorotalia* sp. (Burdett *et al.*, 1963; Vella, 1957; 1962; 1963) and the Ostracoda *Leptocythere, Munseyella,* and *Hemicytherura* (van Morkhoven, 1963). The only species suggesting deep water is *Melonis* cf. *pumpilioides*. True *pumpilioides* of the present day ranges in depth from 330 to over 1,500ft in the Atlantic (Phleger and Potter, 1951) and is characteristic of very deep-water faunas off California (Crouch, 1952; Natland, 1953). The bulk planktonic content of the rhythm sampled in detail is greater than 60 per cent., suggesting at least bathyal depths (Vella, 1962) but percentages near the top of this rhythm and in the two additional mudstones sampled are much higher (90–95 per cent). The rhythms as a whole contain microfossils from mixed-depth biofacies. The distribution of depth indicators in the various samples is shown in Table VII.

Although several species other than those listed may be restricted to shallow water, the data listed in Table VII suggest that both shallow-water species and shallow-water specimens are concentrated towards the base of the rhythm sampled in detail. A similar pattern was described by Vella (1963) for the Kapitean graded beds at Cleland Creek. The percentages of planktonic specimens show a general increase towards the top of the rhythm, suggesting that deep-water Foraminifera are concentrated towards the top also.

DISCUSSION

Size sorting of Foraminifera and the mixture of microfossils from both deep and shallow-water biofacies make a strong case for turbidity current deposition. The apparent zonation of specimens derived from deep and shallow water within the intensively sampled rhythm suggests that the load of the turbidity current was not homogeneously mixed. The coarse detritus at the base of the rhythm was probably derived largely from shallow water, while the fine detritus towards the top of it was probably derived largely from deep water. A considerable amount of detritus must have been eroded from the sea-floor and incorporated into the turbidity current after its inception.

The high percentages of planktonic specimens in samples i–iv suggest that the turbidity current incorporated material from the eupelagic biofacies of Vella (1962) in which planktonic specimens comprise more than 60 per cent of the total shells. The minimum depth of deposition of this biofacies was thought by Vella to be about 4,000ft, and it is likely that deposition of the Kaiti turbidites occurred at depths at least as great as this.

PROVENANCE OF SEDIMENTS

Four different sources of sediment for the Kaiti Beach sandstones and mudstones have been inferred. These sources are: (1) a greywacke terrain, (2) eruptive rocks, (3) hard parts of marine organisms, and (4) transported authigenic minerals.

Glauconite is an authigenic mineral, but evidence for size-grading within a turbidite rhythm suggests that in the Kaiti sediments much of the glauconite has been transported.

Much of the calcium carbonate in the sediments is thought to be of organic origin. The presence of shallow-water benthonic Foraminifera as well as fragments of other thick-shelled marine organisms within the sandstones indicates the derivation of this clastic fraction from a shallow-water shelf environment. Pelagic Foraminifera are considered to have been part of the " normal " pelagic sediment in the basin.

Very little is known of the petrography of the Mesozoic greywackes of the North Island of New Zealand. Some of the minerals and rock fragments present in the Kaiti sandstones could have been derived from greywacke of similar composition to that of the Wellington district, described by Reed (1957). Assuming that greywackes to the north have a similar composition, the following minerals in the Kaiti sandstones could have been derived from such a source: (1) quartz showing " chavaux-de-frise " structure, (2) turbid, sericitized calcic oligoclase-sodic andesine, and (3) alkali feldspar. Some of the rock fragments—e.g., chert and mudstone, as well as heavy minerals such as garnet, sphene, rounded zircon, and epidote could also have been derived from a greywacke terrain.

The presence of abundant euhedrally, oscillatory-zoned plagioclase indicates either a volcanic or hypabyssal source rock (Pittman, 1963). The variation in the shape of the plagioclase, from crystals with perfect outlines to fragments with a broken or skeletal appearance (Carozzi, 1960: 120), and the presence of devitrified and fresh glass suggest a pyroclastic origin. The lack of rounding of plagioclase grains and the presence of delicate skeletal shapes suggest that the grains did not undergo prolonged abrasion. The lack of sericitisation of the zoned labradorite as compared to the more strongly altered oligoclase-andesine, which would presumably be more stable in a weathering environment, suggest that the zoned plagioclase was not subjected to rigorous weathering. The pyroclastic debris has been mixed with sediment from other sources, and the grain-size of zoned plagioclase is approximately the same as that of associated detrital quartz. In addition, large grains of zoned plagioclase are not detrital components of the mudstones. These facts suggest that the volcanic plagioclase, and probably most of the glass as well, was transported by turbidity currents rather than being supplied directly to the deeper part of the basin by eruption. Since volcanic plagioclase is present in most of the rhythms after it first appears in the section, direct airfall into the deeper part of the basin would require repeated eruptions. The interval of time represented by the deposition of the mudstones is much greater than that represented by the deposition of the sandstones, and it seems highly unlikely that some coarse-grained volcanic plagioclase would not be erupted during the time that mud was being deposited. In addition, the correlation between the grain-size of the volcanic plagioclase and the detrital quartz in the sandstones is difficult to explain except by deposition from turbidity currents. A possible origin, then, is that pyroclastic debris was supplied to a shelf area either by direct airfall or by erosion and short transport. This pyroclastic debris was thoroughly mixed with other sedimentary components before it finally came to rest in the deeper part of the basin.

Refractive indices of fresh glass (1.49–1.50) indicate rhyolitic composition, but little can be said about the original composition of devitrified glass. The composition of plagioclase phenocrysts cannot be used to determine the bulk composition of the magma precisely. The plagioclase from Kaiti (average, An 55), for example, is as calcic as the most calcic plagioclase described by Norris (1964: 17–19) from the sediments of the Chatham Rise. The latter ranged from An 20 to An 55 (most common composition An 35–45) and was associated with rhyolitic glass (r.i. = 1.498–1.504). Euhedral zircon, bipyramidal quartz, brownish-green hornblende, and euhedral magnetite (+ rhombohedral phase) in the Kaiti rocks are consistent with a pyroclastic origin, and the presence of quartz suggests derivation from an acid eruption.

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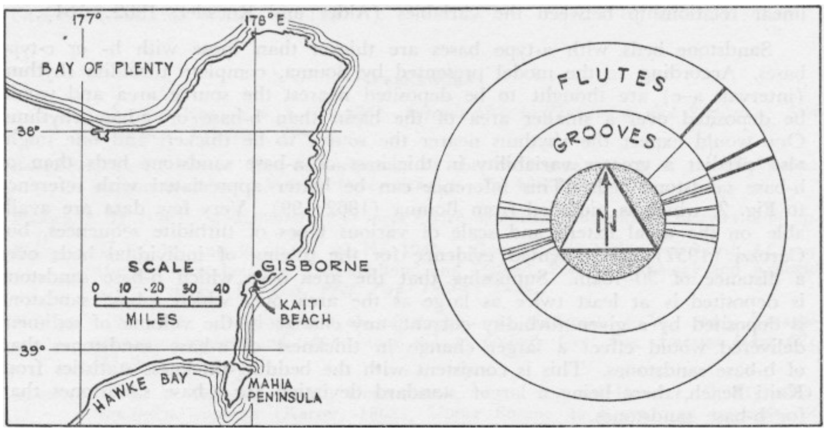

FIG. 1.—Location of the Kaiti Beach section. Inset is a plot of inferred current directions based on sole markings on the sandstone beds. The tectonic strike of the beds is about 035°.

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* Sample numbers refer to specimens curated by Department of Geology, Victoria University of Wellington.

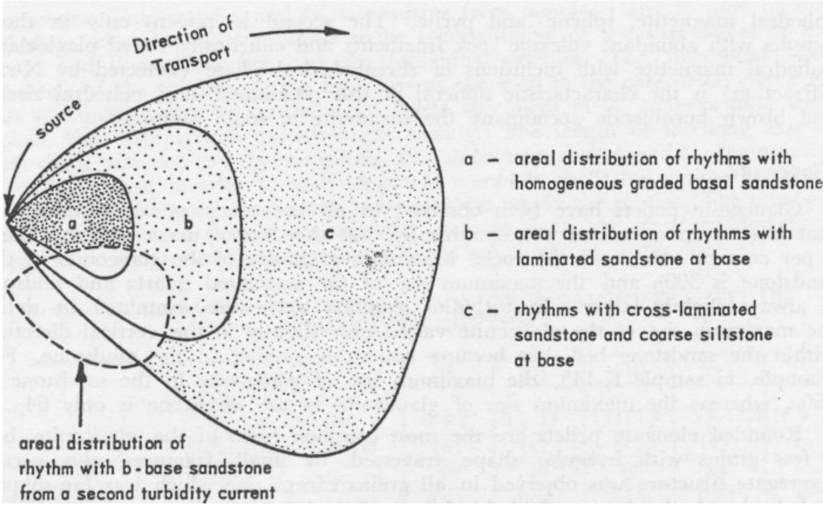

FIG. 2.—Hypothetical areal distribution patterns of turbidite rhythms with different intervals at the base. Modified from Bouma (1962: 99).

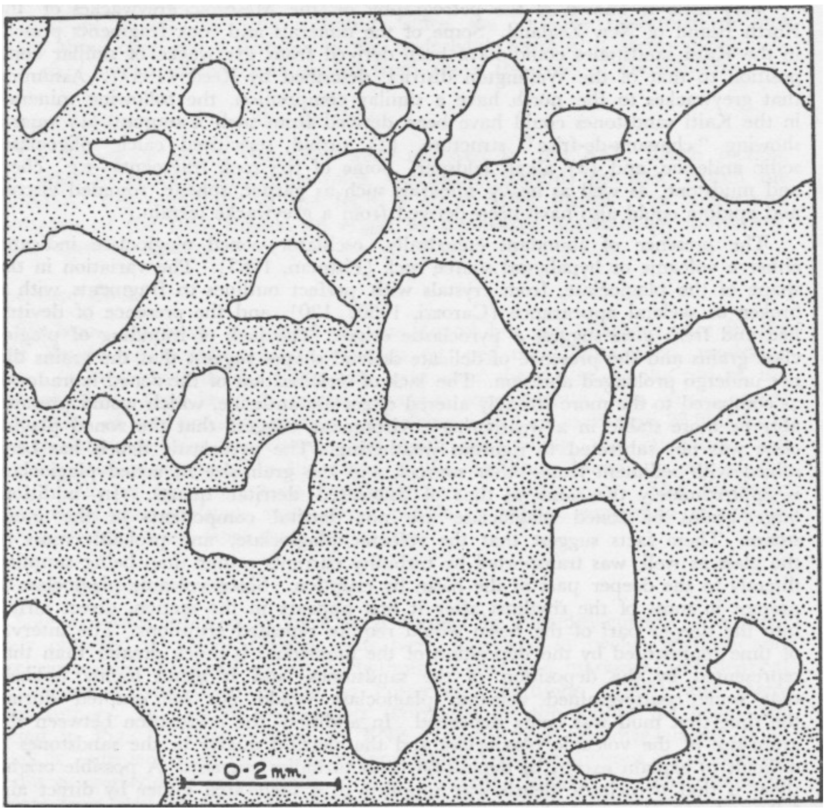

FIG. 4.—Camera-lucida drawing of textural relations between silicate clasts (clear) and calcite matrix (stippled). Note that the silicate clasts "float" in calcite. This texture was observed in all concretionary sandstones which were studied microscopically. See Table III for weight-percentage of calcium carbonate in sandstones.

Type of Bed Measured	Number Observed	Mean Thickness[1]	Standard Deviation
(a-base) sandstone[2]	64	14.5in	5.25in
(b-base) sandstone	69	5.25in	3.0in
(c-base) sandstone[3]	56	About 2in	—
(a-base + b-base) sandstone	133	9.5in	6.25in
Total thickness of rhythms	190	12.25in	9.5in

1—Recorded to the nearest 0.25 inch.
2—Does not include rhythms with two graded intervals.
3—Thickness is variable, mean thickness estimated for an individual bed.

TABLE I.—BEDDING THICKNESS OF KAITI TURBIDITES

Bedding Thickness (inches)	Number of Beds with Concretionary Zones	Percentage of Beds with Concretionary Zones.
$\frac{1}{4}$–5	11 of 99 beds	11
5$\frac{1}{4}$–10	8 of 38 beds	21
10$\frac{1}{4}$–15	12 of 22 beds	55
15$\frac{1}{4}$–20	9 of 17 beds	53
20$\frac{1}{4}$–25	5 of 9 beds	55
25$\frac{1}{4}$ or greater	2 of 4 beds	50

TABLE II.—DISTRIBUTION OF CALCAREOUS CONCRETIONARY ZONES IN SANDSTONE AND MUDSTONE ACCORDING TO BEDDING THICKNESS.

Type	Number of Samples	Range in $CaCo_3$ Content	Mean $CaCO_3$ Content
Mudstone	5	13–21 weight p.c.	17
Mudstones below concretionary sandstones	3	35–42 weight p.c.	37
Sandstones (concretionary)	5	30–40 weight p.c.	35
Sandstones (Non-concretionary)	8	6–12 weight p.c.	9

TABLE III.—$CaCO_3$ CONTENT OF SANDSTONES AND MUDSTONES.

Sample No. and Description	d $10\bar{1}4$ (Å)	Estimated Weight (per cent) Mg
K-158 (vein)	3.031	2.5
K-145 (mudstone)	3.031	2.5
K-225 (mudstone)	3.030	2.5
K-253 (sandstone)	3.020	5.5
K-286 (sandstone)	3.021	5.5
K-322 (sandstone)	3.025	4.0
K-226 (sandstone)	3.028	3.5

Magnesium content estimated from curves of Chave (1952). Internal standards used were quartz and synthetic fluorite. Measurements are considered precise to 0.002Å.

TABLE IV.—ESTIMATED MAGNESIUM CONTENT OF KAITI BEACH CALCITE.

Fossil	Percentage of Beds with Fossil
Laminites kaitiensis	69
Type 1	57
Type 2	49
Type 3	27
Polychaete tubes	55

Only 11 per cent of the rhythms did not have observable fossils of the above types.

TABLE V.—FREQUENCY OF OCCURRENCE OF TRACE FOSSILS AND CALCAREOUS POLYCHAETE WORM TUBES IN THE KAITI BEACH SECTION.

	Sample	(i)	(ii)	(iii)	(iv)	(v)
	Depth below top of rhythm (inches)	0–8.5	8.5–13	13–15.5	15.5-18.5	18.5–23
	Sedimentary interval	(d)	(c)	(c)	(b)	(a)
Globigerina *Turborotalia* *Globoquadrina*	Number of specimens	50	49	42	68	—
	Maximum size (mm)	0.27	0.23	0.30	0.37	—
	Minimum size (mm)	0.10	0.10	0.13	0.17	—
	Average size (mm)	0.16	0.16	0.22	0.26	—
	Standard deviation (mm)	0.05	0.05	0.04	0.05	—
Gaudryina convexa (Karrer)	Number of specimens	—	—	6	12	24
	Maximum size (mm)	—	—	0.50	0.67	0.63
	Minimum size (mm)	—	—	0.23	0.30	0.43
	Average size (mm)	—	—	0.32	0.43	0.53
	Standard deviation (mm)	—	—	0.09	0.09	0.06

TABLE VI.—DATA ON SIZE DISTRIBUTION OF FORAMINIFERA WITHIN A TURBIDITE RHYTHM

Taxon	734	735	736(i)	736(ii)	736(iii)	736(iv)	736(v)
Gaudryina convexa (Karrer)					x	A	B
Quinqueloculina cf. *triangularis* d'Orb.	x	x			x		x
Zeaflorilus cf. *parri* (Cushman)							x
Elphidium sp.							x
Notorotalia sp.	x	x	x		x		x
Leptocythere sp.					x	x	
Munseyella sp.				x	x	x	
Hemicytherura sp.					x		
Melonis cf. *pumpilioides* (F. & M.)			x				
Percentage of planktonics	90–95	90–95	90–95	80–85	50–55	70–75	< 10

x, fewer than 10 specimens; A, 10 to 20; B, more than 20.

TABLE VII.—DISTRIBUTION OF DEPTH INDICATORS IN THE DIFFERENT SAMPLES