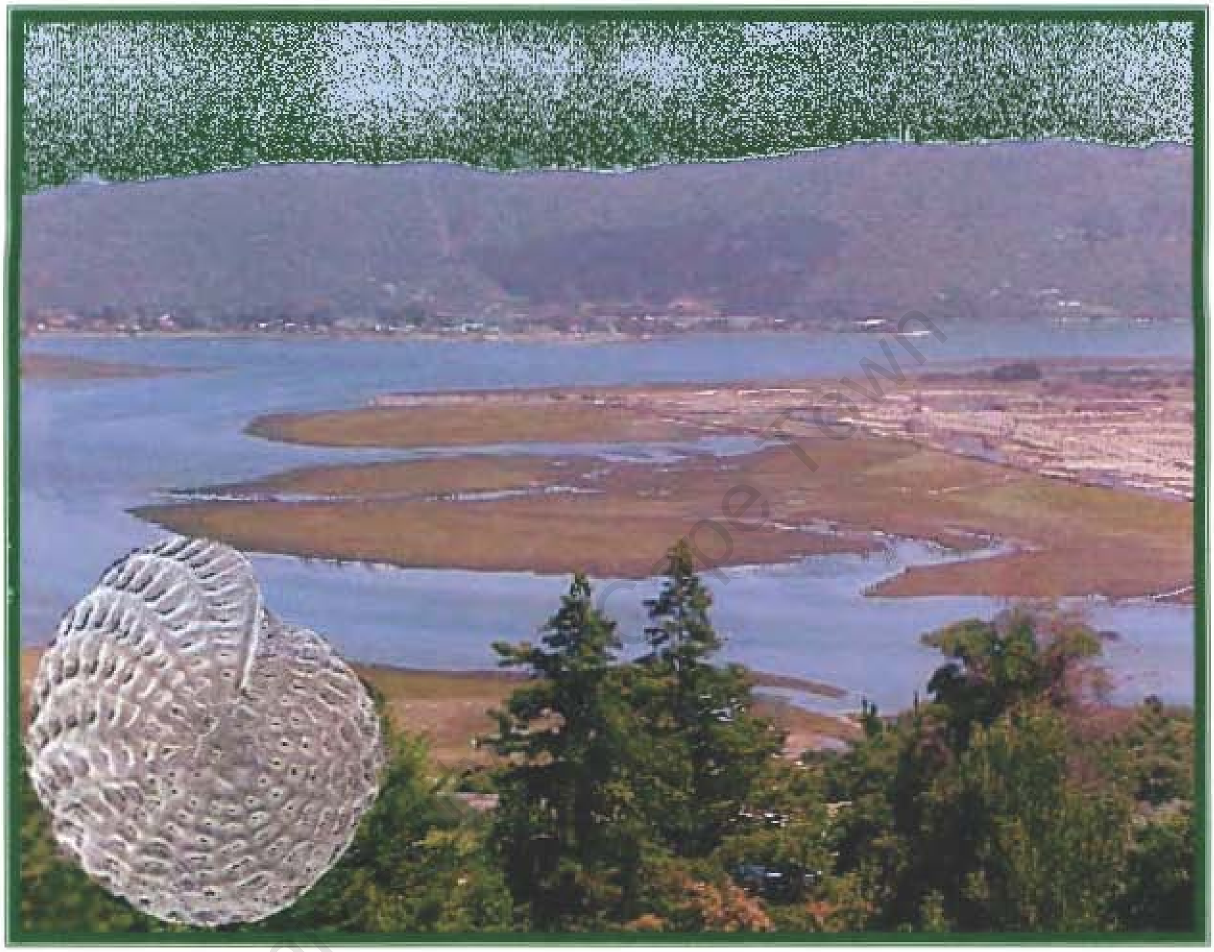
FORAMINIFERAL SPECIES DISTRIBUTIONS AND SEDIMENTOLOGICAL DYNAMICS OF THE KNYSNA ESTUARY, SOUTH AFRICA



Prepared by Keryn Simpson

SMPKER001

For the Department of Geological Sciences, UCT

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Dissertation submitted in fulfilment of the requirements for the degree of Master of Science

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Aerial photograph of the Knysna area: Taken in 1990; Surveys and Mapping, Mowbray, South Africa.

ABSTRACT

The Knysna Estuary is situated on a marine-cut platform in the Garden Route, 501km east of Cape Town. The total area of the estuary is 1827 ha, of which 1000 ha is intertidal marsh. The Knysna River inflow at Charlesford, about 18 km upstream of the Knysna Heads, affects the waters of the upper estuary, but has negligible influence on the rest of the estuary because of the large tidal influx. Although the status of the Knysna Estuary is considered to be in an acceptable environmental condition, pressures of development and tourism in the area are likely to cause substantial deterioration. Investigating the microfossil assemblages in the Knysna Estuary is imperative, since foraminifera serve as essential ecological indicators, and can be used to monitor the health of the ecosystem during development, as they are extremely sensitive to any environmental changes. The Knysna Estuary is well suited for investigating microfossil assemblages, since it has the richest fauna of larger benthic invertebrates of any of the South African estuaries and it is open to the sea throughout the year. The estuarine environment is therefore fairly stable and samples collected at a single time of the year are generally representative of the average conditions within the Knysna Estuary.

An analysis of the surface sedimentology and foraminifera was carried out on 42 surficial sediment samples, located in the main channel, from the weir on the Knysna River (head of the estuary), to the Knysna Heads (mouth of the estuary). Additional samples were collected from the Sout River, under the Railway Bridge, the sewage-treatment-plant outlet, on either side of the causeway connecting Thesen Island to the mainland, in the Ashmead Channel, around Leisure Isle, as well as from intertidal marsh areas in the lower, middle and upper estuary. Beach and rock pool samples on either side of, and between, the Knysna Heads were also analysed. The estuarine conditions, artificial structures in the estuary and the geology of the Knysna area are considered in relation to the sedimentology and foraminiferal species distribution across the Knysna Estuary.

Foraminiferal assemblages in the subtidal channel include foraminifera that have been transported into the sample sites from other parts of the channel, such as from the saltmarsh areas, the open ocean, and/or the coastal environment. A total of 105 species of foraminifera from 56 genera were recorded in the Knysna Estuary; including approximately 10 species that were reworked from Latest Pleistocene deposits. Most of the recorded foraminifera are compiled into a Scanning Electron Microscope photo-atlas. Six foraminiferal assemblages were identified in the Knysna Estuary. 1) A littoral assemblage, from beach and rock pool environments, consists mainly of genera which have adapted to high-energy, surf-zone conditions. Also associated with this assemblage are a moderate amount of reworked and broken foraminifera. 2) A shallow-marine assemblage, including both planktic and benthic foraminifera from the continental shelf that have less robust tests than littoral foraminifera. These species are found in the more sheltered seawater areas of the estuary, landward of the mouth. 3) An estuarine assemblage, containing species that live in sheltered waters with salinities slightly lower than seawater and relatively long residence times, is established best between the Railway Bridge and the White Bridge. This assemblage includes some typically estuarine species of

foraminifera such as *Ammonia parkinsoniana, Rotalia gaimardii* and *Haynesina germanica.* 4) A low-diversity upper-estuarine/hyposaline assemblage, which consists predominantly of *Ammonia parkinsoniana* with a number of agglutinated *Miliammina fusca.* 5) A mudflat/saltmarsh assemblage consisting essentially of agglutinated foraminifera such as *Trochammina inflata,* which thrives on saltmarsh areas in the middle and lower estuary, and *Miliammina fusca*, which is associated with *Juncus* or rush wetlands in the upper reaches of the estuary; and 6) a localized assemblage distinguished by an *Elphidiella* species in the Ashmead Channel.

An analysis of the sediment grain size and composition, as well as the water pH, salinity, temperature, current velocity and colour, provides ecological parameters for each sample, enabling relationships to be described between foraminiferal assemblages and environmental conditions. Species in the Knysna Estuary are influenced mainly by variations in salinity, food supply and current strength or turbulence. According to their abundance and diversity, foraminiferal assemblages were used to define various ecological regimes within the main subtidal channel, including: 1) A Bay Regime near the Knysna Heads, which contains turbulent sea water with relatively strong tidal currents. Due to the high energy in this region of the estuary the sediment comprises a scarce, moderate diversity, littoral assemblage of robust foraminifera. 2) A Lagoon Regime that dominates most of the middle and lower estuary is characterised by waters with limited fresh water inflow, relatively shallow depths, high foraminiferal species diversity, strong tidal flow and residence times of 1-2 weeks. Salinities are of the order 30 - 34 ‰; 3) A Barren Regime is established from approximately 1.5 km downstream to ~ 400 m upstream of the White Bridge, resulting from an absence of microfauna in the main channel samples; 4) An Estuarine Regime upstream of the White Bridge is affected by inflow from the Knysna River, contains water with salinities lower than 30 ‰, often exhibits stratification and accommodates only two species of foraminifera (upper estuarine/ hyposaline assemblage) in relatively high numbers; and 5) A River Regime above the Charlesford weir includes catchment-derived sediment and fresh river water, with no evidence of microfauna. If one were to consider the estuary as a whole, and not just the main subtidal channel, we would include an intertidal Saltmarsh Regime, accommodating high numbers of agglutinated foraminifera, comprising predominantly three species.

The use of foraminifera in estuarine studies and monitoring these environments is imperative. Foraminifera are reliable indicators of pollution and have been used to specify areas within the Knysna Estuary that are most vulnerable to the increasing economic demand in the Knysna area, such as under the White Bridge and in the Ashmead Channel. Furthermore, this study provides a valuable reference to evaluate the impact that rapid development on the shores of the estuary, increased road and boat traffic and amplified storm water and sewage works discharge will have on the Knysna Estuary, and particularly, to the microfauna, in the future. Since different species of foraminifera have preferred environmental habitats and non-living tests are transported in suspension and as bed load by tidal currents and wave action, they can be used as reliable indicators of sediment providences. Furthermore, foraminiferal tests of the littoral and shallow-marine assemblages can be used to define tidal strength and limits of marine influence in estuaries.

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Upper-most reaches of the Knysna Estuary.
Facing downstream (south). Photograph by K. Simpson, 2002.

1. INTRODUCTION

Since 1817, when the first ship attempted the treacherous passage through the Knysna Heads, Knysna has optimised adventure. Originally a country fair, the first festival was held in 1982 to promote the town's oyster farming and sporting activities were launched the following year. Today, thousands of tourists and athletes come to the estuary during July for the Oyster Festival and events such as the Forest Marathon, mountain bike and road races, off-road 4x4 trails, angling competitions, adventure races, bungee jumping, rock-climbing and abseiling off the Western Head, snorkelling, kayaking, yacht races, surf-ski and canoe challenges, bird-watching trails and an array of other activities. Knysna is blessed with its own micro-climate so, even in July, it's a good place to escape the winter. The Knysna Estuary is a typical estuary possessing a salinity gradient of varying intensity and structure and a diversity of habitats, colonised by an array of animal and plant taxa. These features, as well as the climate and the clarity of its water make the Knysna Estuary, biologically, the richest estuary along the South African coast (Day *et al.*, 1952 and Day, 1967). Attractions such as these, that have drawn people to the shores of the Knysna Estuary, are now threatened by rapid urbanisation in the Knysna area, which is disturbing the natural functioning of the estuary.

Of the South African ecosystems, estuaries are most threatened by human activities. This threat not only comes from human encroachment on the estuaries and their surrounding littorals, but also from interference with the saltmarsh environments and the catchment areas (Allanson, 2000). The Knysna Estuary ranks very highly in terms of conservation importance. The preservation of its fauna and flora alone would ensure that 42.7 % of South Africa's estuarine biodiversity would be conserved (Turpie, 2000). However, this substantial value does not take into account the microfauna.

Although the status of the Knysna Estuary is considered to be in an acceptable environmental state (Allanson, 2000), pressures of development and tourism in the area are likely to cause substantial deterioration. Economic demand has led to increasing encroachment onto the saltmarsh areas all around the Knysna Estuary, leading to the destruction and relocating of the pristine intertidal vegetation, as well as their associated macro- and micro-faunal communities. Sixty percent of the supratidal area of the Knysna Estuary has already been lost to development in the last 54 years (Maree, 2000). The immediate danger to the wetland areas lies in the accretion of suspended material (largely silts and clays delivered by the Salt River and storm water drains), as well as anthropogenic disturbance of these areas.

Studying the microfossil assemblages in the Knysna Estuary is of great importance with regard to understanding the ecology and dynamics of the Knysna Estuary and other estuarine environments. Foraminifera serve as essential ecological indicators and can be used to monitor the health of the ecosystem during development, since their distribution is controlled by environmental parameters, such as temperature, salinity, substrate, calcium carbonate availability, depth, turbidity, illumination, hydrostatic pressure, currents and tides, trace elements and dissolved oxygen in the water, as well as biotic factors such as food availability, predation, and competition (Lipps, 1993). Rapidly changing environmental conditions results in low species diversity and population density, associated with an increase in tolerant and opportunistic species and can create deformed, aberrant specimens (Boltovskoy *et al.*, 1991 and Samir and El-Din, 2001). Hence, benthic foraminifera reflect human-induced environmental perturbation and are therefore very important bio-indicators of contamination, eutrophication and siltation. Foraminifera can also be used to recognise different sedimentary facies, enabling a better understanding of the sediment dynamics in the estuary and therefore provide data for improved management plans. Nothing has yet been published on the foraminifera of the Knysna Estuary and very little research of this kind has been done on the coastal regions of South Africa. The Knysna Estuary is well suited for investigating microfossil assemblages, since it has the richest fauna of larger benthic invertebrates (numbers of species and individuals) of any of the South African estuaries. It is also open to the sea throughout the year, unlike many other estuaries that are closed for part, or most, of the year. Thus, the fauna is fairly stable and samples collected at a single time of the year are reasonably representative of the average conditions (Benson and Maddocks, 1964).

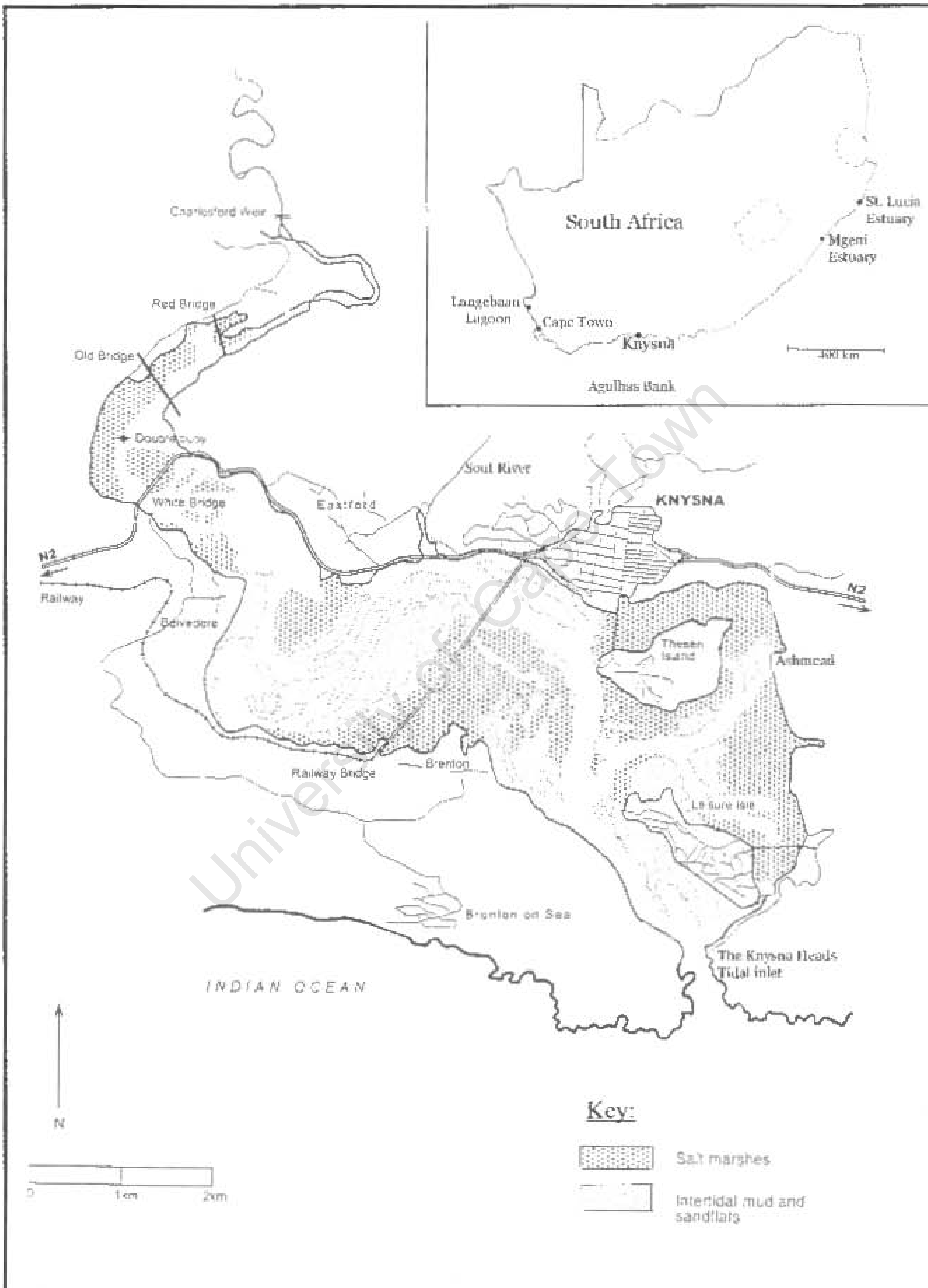
1.1 PROJECT OBJECTIVES

This thesis examines the sedimentology and micropalaeontology of the surface sediments, as well as the hydrographic parameters in the main channel of the Knysna Estuary from the head of the estuary, near Charlesford, to the mouth of the estuary at the Knysna Heads (Fig. 1.1). Research of this kind provides ecological parameters for each of the samples, enabling relationships to be depicted between foraminiferal assemblages, sediment types and various ecological parameters. This study will therefore, try to clarify the correlation between foraminiferal faunas and varying estuarine environmental conditions. It will also improve the currently limited database of micropalaeontological research in southern Africa.

The Knysna Estuary is one of the most biologically productive estuaries in South Africa and is listed as an area of primary importance in the National Marine Pollution Monitoring Programme. The fact that the Knysna Estuary is relatively unpolluted (Allanson *et al.*, 2000), makes it an excellent marine-pollution monitoring station for the southern coast of South Africa (Grindley, 1985). Foraminifera are very sensitive *in situ* monitors of environmental change and degradation and can therefore be used as indicators of pollution. This study, therefore, also specifies areas within the estuary that are vulnerable to contamination and will be polluted if development in the Knysna Area continues at its currently high rate.

Foraminiferal assemblages can assist in establishing various ecological regimes within the estuary, according to variations in foraminiferal abundance and species diversity. Variations in foraminiferal assemblages are related to changes in environmental parameters, such as pH, salinity, depth, dissolved oxygen concentrations, current strength, turbidity, nutrient content and/or sediment type across the estuary.

Fig 1.1 The Knysna Estuary and its location in South Africa
Modified from Largier *et al.* (2000).



1.2 PRACTICAL APPLICATIONS OF THE INVESTIGATION

An essential component of assessing anthropogenic and environmental change is to understand the magnitude of natural variation. This study will serve as a reference to evaluate the impact that urban sprawl and tourism has had, and will have, on the microfauna of the Knysna Estuary, given that they are sensitive to any hydrographic or ecological changes in their environment. Results from this thesis will allow for comparisons with other coastal regions of southern Africa and will add to the presently-limited database regarding the microfauna, in particular, the foraminifera of estuarine and shallow-marine environments around southern Africa.

The commercial and industrial applications for such research can be beneficial to activities such as monitoring pollution in estuarine and shallow-marine environments, as well as for oil and placer diamond exploration, where environmental reconstruction is an aid in the identification and recovery of these resources.

Results from this thesis may also be used to predict palaeo-environmental conditions, as well as the palaeo-hydrology in older sediments, since certain foraminiferal species flourish in distinct ecological settings that are related to fluctuations in the mean sea-level. Foraminifera are therefore reliable sea-level indicators, and when studied in vertical sections such as cores and exposures, they accurately reveal changes in sea-level through time.

1.3 STUDY AREA

The Knysna Estuary
Illustration modified from Report No. 30: Knysna (CMS 13) by J.R. Grindley, 1985.
Altitude: 500m, ECRU 79-01-10. Facing North.
(CMS 13 – CSIR Estuary Index Number) (ECRU – Estuarine and Coastal Research Unit)

1.3.1 GEOLOGY AND GEOMORPHOLOGY OF THE KNYSNA AREA AND THE CATCHMENT OF THE KNYSNA RIVER

The geology of the Knysna Estuary is well known. Toerien (1979) described the geology of the Knysna catchment area. Tyson (1971), Miller (1963 and 1975), Du Toit (1966), and Butzer and Helgren (1972) mapped the Cretaceous and Early Tertiary deposits of the Enon pebble Conglomerates. Butzer and Helgren (1977) provided accounts of the geomorphology of the soils of the area. Dingle, Siesser and Newton (1983) examined the Mesozoic and Tertiary geology of the area. Grindley and Eagle (1978) presented an analysis of sediments on the east and west of the causeway adjoining Thesen Island, recommending that part of the causeway be replaced by a bridge. Grindley (1985) has reviewed the geology of the Knysna area and the catchment of the Knysna River, combining the past geological and geomorphological studies.

Knysna has an interesting geological history and the coastal plain has undergone many changes in sea level. In the Pleistocene the coastal plain was submerged and the ocean reached the Outeniqua Mountains (Day, 1967). During the subsequent period of elevation rivers eroded the coastal plain and cut deep gorges into the mountainous catchment area as well as the emergent coastal plain. A period of subsidence followed and the drowned valley, which now forms the Knysna Estuary, started to fill with sediments (Day, 1967). The geology of the area is shown in Figure 1.3.1, derived from the 1:250 000

Geological Series (Map No. 3322 Oudtshoorn Sheet) of the Geological Survey, with the series of geological formations depicted in the key to Figure 1.3.1 (adapted from Toerien, 1979).

The oldest rocks in the area are found south of the Outeniqua Mountains to the west of Knysna. These are Late Precambrian in age and consist mainly of contorted bands of schists, phyllites and feldspathic quartzites of the Kaaimans Formation (Toerien, 1979). They adjoin outcrops of intrusive gneissic granite further to the west, but these rocks are not found in the Knysna River catchment. The catchment of the Knysna River lies within the mountain ranges of the Cape Fold Belt, with its long faults and fold axes striking east-west (Grindley, 1985). The Cape Fold Belt was deposited from the north and north-east in an approximately east-west-striking cratonic basin with it's major axis in the vicinity of 33° 30' S (Toerien, 1979). Most of the catchment comprises rocks of the Table Mountain Group (TMG), including the Peninsula, Cedarberg, Tchando and Kouga Formations (Toerien, 1979). Apart from the subordinate Cedarberg (shale) and Baviaanskloof (feldspathic sandstone) Formations, the TMG consist of supermature quartz sandstones, which are coarse-grained and cross-bedded, indicating deposition in a marine environment by major fluvial systems (Toerien, 1979 and Viljoen and Reimold, 1999). West of this area, advancing glaciers from the north-west and the north terminated the deposition of the thick Peninsula sandstone. This is evidenced by sporadic soft-sediment deformation in the top of the Peninsula Formation, as well as by thin conglomeritic sandstone and siltstone beds at the base of the Cedarberg Formation (Toerien, 1979). The Baviaanskloof Formation, the youngest of the Table Mountain Group (TMG) and the overlying Gydo Formation of the Bokkeveld Group, lie beyond the catchment of the Knysna River.

Formations surrounding the Knysna Estuary range in age from the Early Cretaceous Brenton Formation, to Quaternary deposits overlain by present day aeolian dune sands. The south-western shore of the Knysna Estuary exposes the Brenton Formation, which is composed of marine clays and sandstones (McLachlan *et al.*, 1976). Microfossils from the Brenton Formation correspond to fossils from the Sundays River Formation, Colchester Member on the continental shelf and in the Algoa Basin north of Port Elizabeth (Du Toit, 1966; Toerien, 1979; Dingle *et al.*, 1983), making the Brenton Formation younger than the Enon Conglomerate Formation. A detailed account of the Brenton Formation is provided by McLachlan *et al.* (1976). The Lower Cretaceous well-consolidated pebble conglomerates of the Enon Formation represents torrential deposits in an arid climate under strongly oxidizing conditions, giving these deposits their characteristic reddish colour (Toerien, 1979). Figure 1.3.2, from McLachlan *et al.* (1976), illustrates the geology surrounding the Knysna Estuary and shows the stratigraphic relationship between the Brenton Formation and the Enon Conglomerate Formation. These deposits are part of the Uitenhage Group. The terrestrial Enon conglomerates are succeeded upwards by estuarine deposits of rounded TMG sandstone clasts set in a sandy matrix (Grindley, 1985).

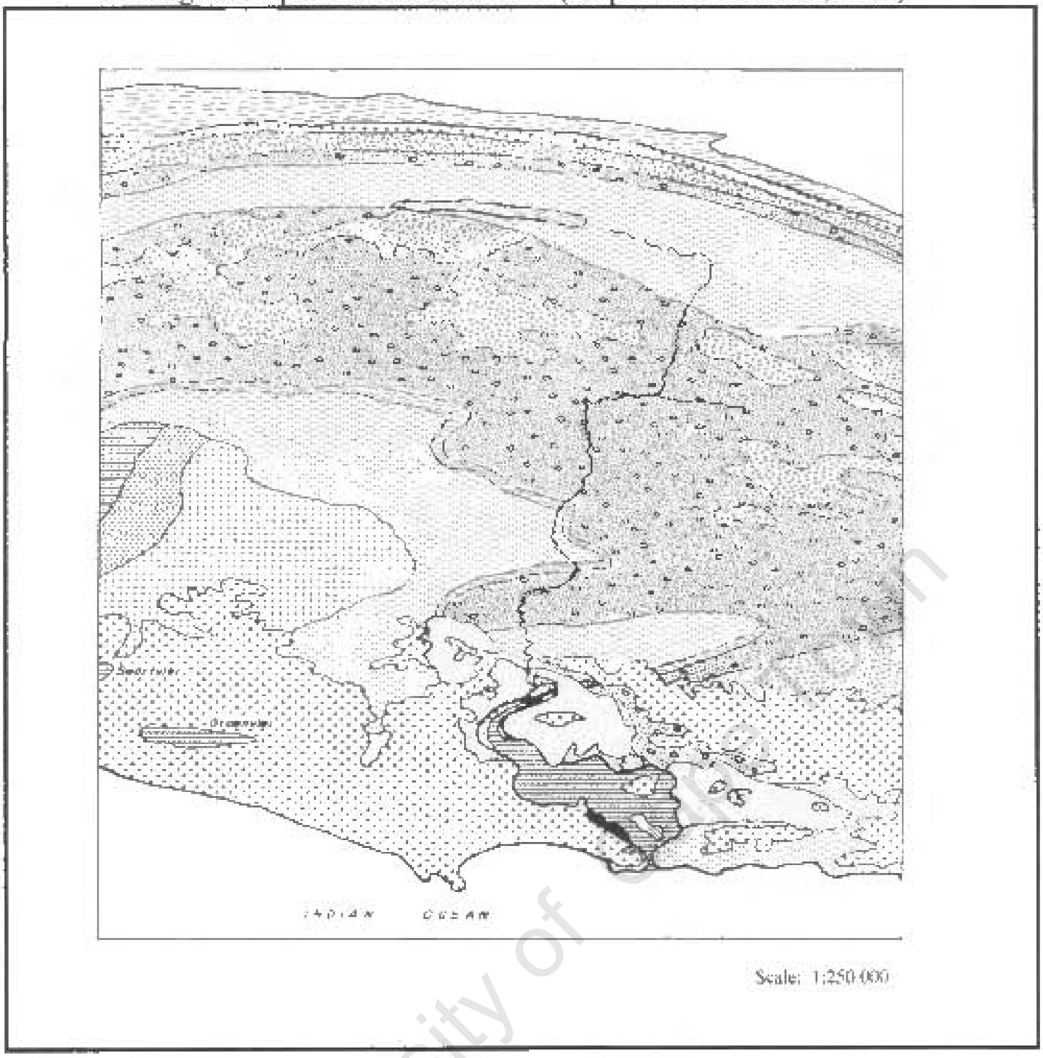
Prominent high level terraces on the mountain slopes form a striking topographical feature. They are remnants of extensive contemporaneous peneplains and are generally capped by silcrete, and to a lesser extent, ferricrete. These terraces are related to the equally striking wave-cut terrace, 180 – 240 m above sea level, forming the present coastal plain between the Tsitsikamma and Outeniqua Mountains and the sea (Toerien, 1979).

Tertiary and Quaternary fixed dunes, dune rock and colluvial slope deposits are present on gently sloping surfaces away from the Knysna Estuary channels. Aeolian sand was deposited on the coastal plain at various stages indicating drier conditions, and aeolianites were formed at various sea levels below the present sea level. The Quaternary deposits on land are largely overlain by younger vegetation-bound dunes which reach far inland, north and west of Knysna on the Tertiary marine platform (Toerien, 1979). The Knysna Heads, and the cliffs and hills extending to the east, are medium to coarse grained, quartzitic and massive, based on Table Mountain Group rocks of the Ordovician Peninsula Formation (Toerien, 1979). The hills west of the Knysna Heads, and some of the hills to the north and east, are fixed dunes of Tertiary to Quaternary age (Toerien, 1979). These areas are partly covered by recent vegetation-covered dunes.

The town of Knysna and parts of Thesen Island are composed of colluvial slope deposits of Tertiary to Quaternary age. Thesen Island consists of Recent (Holocene), poorly consolidated estuarine sediments dominated by fine sands. These sediments are known to be at least 24 m thick and the underlying geology is speculated to be either Enon Conglomerate or Table Mountain Group Quartzite (GIBB Africa, 1999).

Tyson (1971) pointed out that there are three distinguishable categories of soil in the Knysna area, including juvenile, shallow (rarely exceeding 30 m depth), sandy azonal soils with poorly developed horizons, brown or grey soils forming under present day conditions, and palaeosols. Azonal soils are found on all steep slopes, on recent dunes and in the wetlands. Deep, dark, organic-rich soils develop in areas prone to flooding, and the brown and grey soils are most extensive on the forested interfluves of the foothills. Soils surrounding the Knysna Estuary generally consist of acidic (pH 4.5 – 5.5), fine-medium sand, having originated from TMG quartzites and sandstones, or are windblown deposits from the littoral zone and coastal embayments (Grindley, 1985).

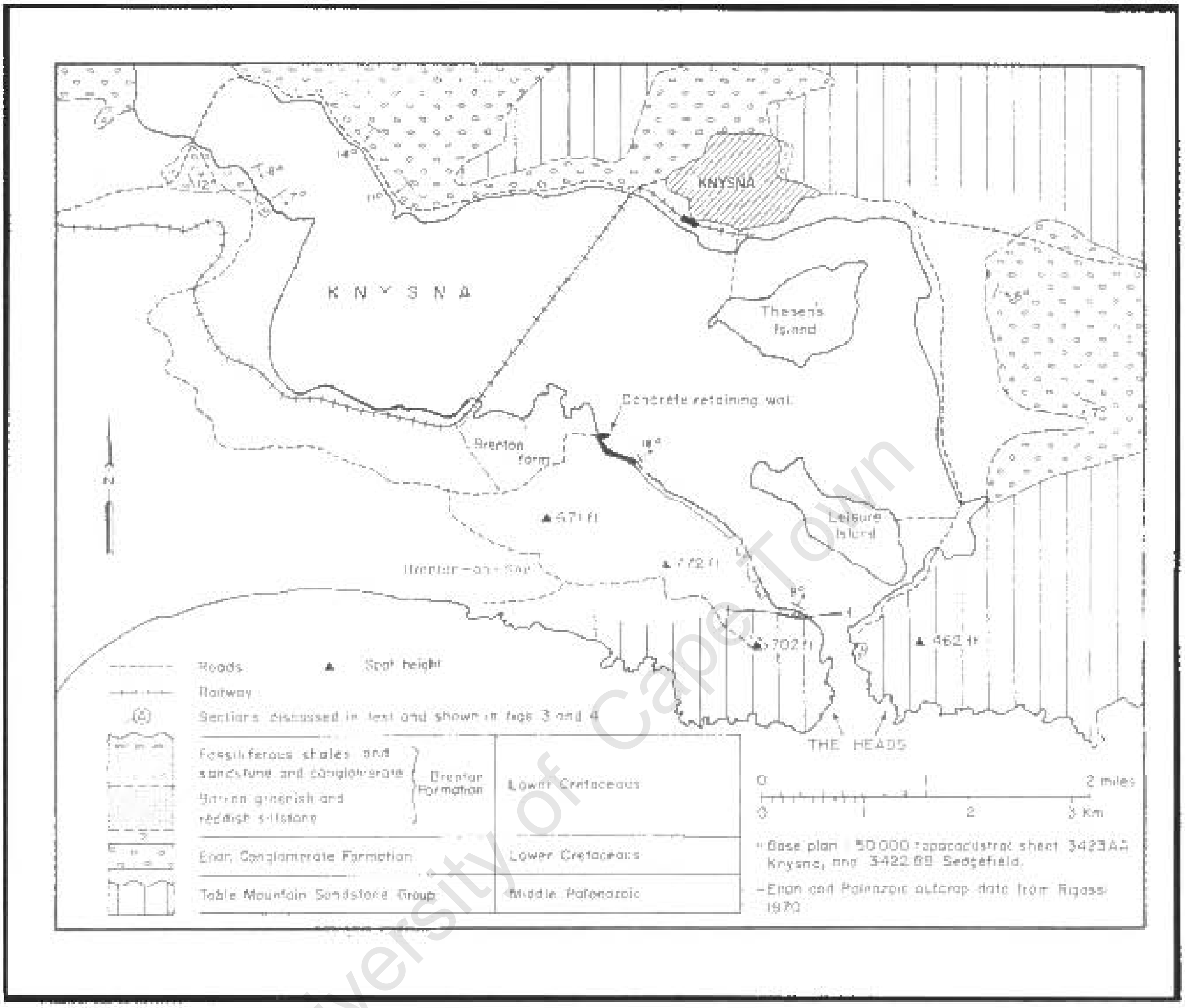
Figure 1.3.1 Geology of the Knysna area and the catchment of the Knysna River. Geological map no. 3322 Oudtshoorn (adapted from Toerien, 1979).



Key to Figure 1.3.1 Geology of the Knysna area

Tertiary and Quaternary Formations (Aeolian sand, Alluvial deposits and Aeolionite)	
Brenton Formation (Marine clays and sandstone)	
Enon Formation (Conglomerate)	
Gydo Formation (Shale, Siltstone)	Bokkeveld Group
Baviaanskloof Formation (Feldspathic sandstone)	Table Mountain Group
Kouga Formation (Quartz sandstone)	Table Mountain Group
Tchando Formation (Sandstone)	Table Mountain Group
Cedarberg Formation (Shale, arenaceous shale)	Table Mountain Group
Peninsula Formation (Quartz Sandstone)	Table Mountain Group
Homtini Member (Phyllite, feldspathic grit, Quartzite)	Kaaimans Formation (600-650 Ma)
Victoria Bay Member (Feldspathic Quartzite)	Kaaimans Formation (600-650 Ma)
Soetkraal Member (Phyllite, schist, quartzite)	Kaaimans Formation (600-650 Ma)

Figure 1.3.2 The stratigraphic relationship between the Brenton Formation and the Enon Conglomerate Formation (from McLachlan *et al.*, 1976).

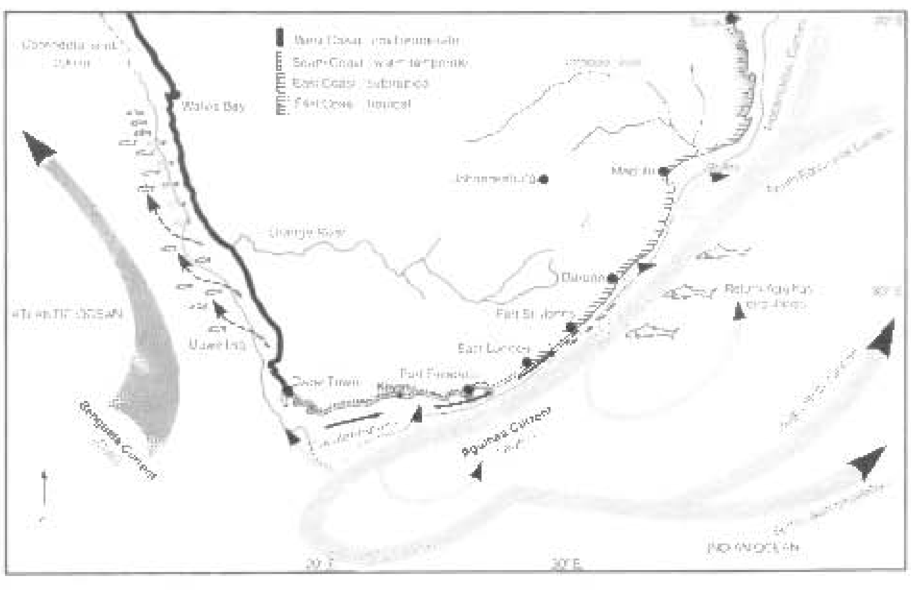


1.3.2 DYNAMICS OF THE KNYSNA ESTUARY

Knysna is situated on a marine-cut platform in the Garden Route, 500 km east of Cape Town, at 23°03'40''E; 34°04'35''S (position of the mouth). The Knysna Estuary is located between the Indian Ocean in the south and the Outeniqua Mountains in the north. The total area of the estuary is 1827 ha (Grindley, 1985), of which 1000 ha is intertidal marsh (Maree, 2000). It is perhaps more accurate to refer to the Knysna Estuary as an embayment, which is mostly marine dominated (Largier *et al.*, 2000). Estuaries can be classified according to the degree of mixing of fresh water and seawater, into three categories: stratified, partially mixed and well mixed (Dyer, 1979 and Largier *et al.*, 2000). Most of the Knysna Estuary is well mixed, since marine water is transferred readily through the Knysna Heads. The upper-estuary, north of the White Bridge, is stratified with respect to salinity due to the Knysna River discharge into this area.

The climate is temperate throughout the year, making this area a prime tourist destination. The warm, equatorial Agulhas Current is the major ocean current in the region. It is a swift and massive current, up to 160 km wide and flowing at a speed of up to 5 knots (2.6 m per second), transporting 80 million tonnes of water per second (Branch and Branch, 1981). It follows the edge of the continental shelf (~200 m depth) in a general south-westerly direction around the coast of South Africa. From the Transkei, southwards, the continental shelf break moves away from the shore, deflecting the Agulhas Current away from the coast (Fig. 1.3.3). Close inshore, cooler pockets of water flow parallel to the coast, but in a direction opposite to the Agulhas Current. As a result, the south coast, from about Port St. Johns to Cape Point, has cooler coastal waters and different flora and fauna from the east coast of southern Africa (Branch and Branch, 1981).

Figure 1.3.3. Map of southern Africa showing the major coastal ocean currents. From Branch and Branch (1981). Also shows the four coastal regions, each of which sustains distinctive marine fauna and flora.



The Knysna Estuary is fed by variable flow (0.09 m^3/s - >9m^3/s) from the Knysna River at Charlesford, 18 km upstream of the Knysna Heads, which has a mean annual discharge of 110 x 10^6 m^3 (Largier *et al.*, 2000). The Knysna River originates in the Outeniqua Mountains, with a catchment area of 526 km^2, and rainfall of ~922 mm is spread fairly evenly through the year. The Knysna River runs through one of the many gorges which dissect the Tsitsikama Forest and although the gradient is steep, erosion on the wooded slopes is minimal. The river water is clear, though peat-stained and the flow is fairly uniform. The influx of catchment-derived sediment into the estuary is low (Day, 1981).

The Knysna Estuary is S-shaped; with a subtidal channel ~19 km in length (refer to figure 1.1). It gradually broadens and deepens towards the mouth of the estuary, which opens between two impressive headlands (Day, 1981), known as the Knysna Heads. The Knysna Heads are rockbound and thus there is no lateral migration of the tidal inlet. The estuary is over 3 km wide, and covers an area of ~18 km^2. The maximum depth of the estuary is ~12 m at the mouth (Day, 1981). Relative to the river input, marine waters dominate the estuary and the tidal reach is about 10 km. The Knysna Heads limit the import of sand into the estuary and strong tidal currents through the rock-constricted channel prevent sand from being deposited in the mouth. There are two islands in the Knysna Estuary, Leisure Isle and Thesen Island, which are connected via causeways to the mainland.

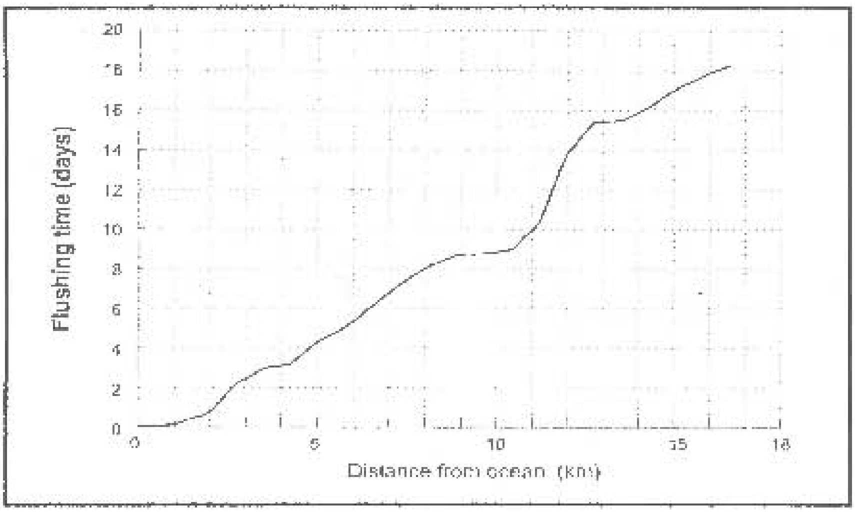
Landward of Leisure Isle, the estuary becomes much wider and extensive subtidal and intertidal banks are found. However the bulk of the water transported by the tides moves along the main channel, which is ~5 m deep and 300 m wide up to the Railway Bridge (Largier *et al.*, 2000). In the channel surrounding Thesen Island, peak tidal currents are 0.7 m/s during spring tides and 0.3 m/s during neap tides (Largier *et al.*, 2000). Landward of the Railway Bridge, tidal flow is contained in a narrowing and branching channel and tidal current velocities remain fairly strong. The main channel of the estuary splits around a series of low-lying islands, some containing oyster beds, while others are covered by saltmarsh vegetation. The bed of the channel is dominated by sand, but there is an increasing fraction of fine sediment (Reddering and Esterhuysen, 1984) associated with erosion from the surrounding muddy marshes. The open estuary is easily affected by winds, causing waves that may stir up the soft mud in the shallows (Day *et al.*, 1952). Where both the White Bridge and the Railway Bridge cross the estuary, embankments have been built on the intertidal marshes and longitudinal exchange is constricted to the subtidal channel. Upstream of the White Bridge, the estuary narrows, the channel is confined by steep natural banks and the intertidal area decreases (Largier *et al.*, 2000). Tidal currents weaken and channel sediment becomes muddy, organic-rich and terrigenous (Reddering and Esterhuysen, 1984).

As a result of constant wave action, the formation of sandbars is not possible in the rocky channel between the Knysna Heads. Wave action is strong on the rocky shores at the mouth, but landward of the Heads, the swells rapidly diminish (Day *et al.*, 1952). The total tidal range for the estuary is 1.6 m (microtidal), which is typical for southern Africa. Tidal influences dominate the hydrography of the mouth of the estuary and have a significant influence across the entire estuary. The strength of tidal currents is determined by the tidal prism (or intertidal volume) and the cross-sectional area of the channel.

The narrow mouth is characterised by very strong tidal currents throughout the water column. The average tidal flow through the Knysna Heads is ~1 000 m^3/s with mean flow velocities of 0.9 – 1.6 m/s (Grindley, 1976). Strong tidal currents persist for about 2.5 km landward from the mouth owing to the constriction imposed by Leisure Isle, a consolidated flood-tide sandbank. It is here that scour holes, as deep as 17 m, occur (Day *et al.*, 1952). Marker (2000) noted that sand ridges on the Leisure Isle sandflat have altered over time. Instead of an alignment approximately parallel to the shore (1988 – 1990), the ridges are now aligned at right angles to the shore. Marker (2000) attributed the alignment of these sand ridges to the fact that the intertidal sandflat has become more deeply submerged at each high tide, compared to the 1980s, resulting in stronger drainage over the sandflat with the outgoing tide. Away from the constricted mouth, tidal flows weaken.

Largier *et al.* (2000) suggest that on spring tides 80-85 % of the water that leaves the Knysna Estuary on the ebb-tide is replaced by new ocean water on the subsequent flood-tide (i.e. only 15-20 % of flood-tide volume is water that exited the estuary on the ebb-tide). In the presence of an alongshore flow in the ocean, we expect that this exchange ratio would be greater than 80 %, and even on the weakest tides the bulk of the flood-tide water is "new" ocean water, although it does not penetrate as far into the estuary as on spring tides. At distances greater than one tidal excursion from the mouth (beyond the Railway Bridge), the effect of tidal pumping is small and water is not readily replaced by "new" ocean water. This region of the estuary has relatively long (1-2 weeks) water-residence times, which increase with distance from the ocean (Largier *et al.*, 2000) (Fig. 1.3.4).

Figure 1.3.4 Longitudinal variations in residence times across the estuary. Diagram from Largier *et al.* (2000). Data collected over 3 days during high and low tides in April 1996.



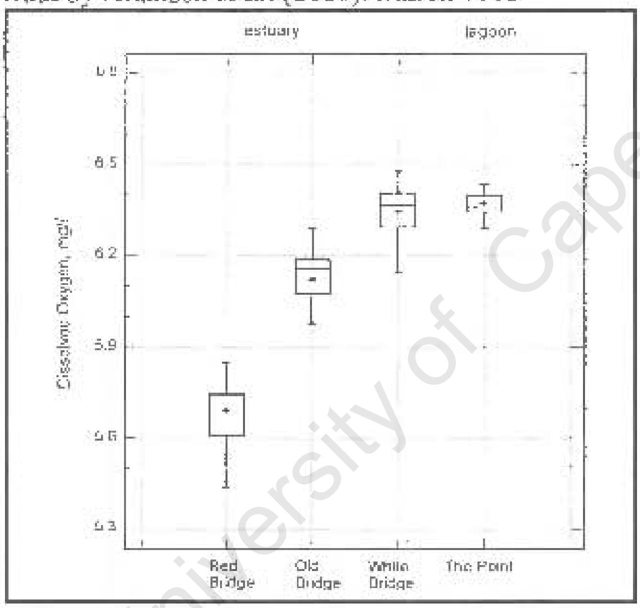
PHYSIO-CHEMICAL CHARACTERISTICS

The Knysna Estuary remains the one of the most light-transparent estuaries along the entire coastline of South Africa. The overall transparency of the water column varies seasonally from 1.67 m to 2.28 m as measured by a Secchi disk (Allanson *et al.*, 2000). These levels of transparency imply that there is always sufficient photosynthetic radiation passing through the water column to allow for the growth of extensive eelgrass meadows, upon which much of the nutrient mobilisation depends (Maree, 2000 and Allanson *et al.*, 2000). The maintenance of transparency is an essential requirement in the management of the estuary. Allanson *et al.* (2000), suggest that if nutrient loads increase substantially in the Ashmead Channel, due to the relatively high residence times, they will encourage phytoplankton blooms and/or dense accumulations of macro-algae. This will result in decreased transparency, which will lead to the loss of estuarine macrophytes such as eelgrass, and ultimately, a loss of biodiversity in the whole system.

The salinity increases rapidly within the first 8 km of the estuary downstream from the weir. Thereafter the salinity remains close to that of seawater (Allanson *et al.*, 2000). Comparisons of horizontal salinity variation in the estuary since the initial measurements of Day *et al.* (1952) and later by Grindley (1985), suggest that there has been no substantial change in the pattern of salinity since 1952. The ocean salinity is relatively constant (34.7 - 35.2 ‰), whereas temperatures vary between 15 °C and 23 °C, but can be as low as 9 °C below the thermocline in summer, or as high as 25 °C when directly influenced by the Agulhas Current (Schumann, 1999 and Largier *et al.*, 2000). The warm surface waters in summer are nutrient depleted (Carter *et al.*, 1987), whereas the winter waters are well mixed and uniformly cool (Largier *et al.* 2000). During summer, the easterly winds along the coast result in upwelling of cold, nutrient-rich bottom water, which is observed at the mouth of the estuary from time to time (Schumann, 2000).

The upper estuary contains relatively warm (>25 °C), hyposaline water. At high tide the lower estuary is filled with cool (~15 °C), salty, ocean water and the area between the White Bridge and the Railway Bridge contains warmer, salty water (Largier *et al.*, 2000). At low tide, low-salinity water (<30 ‰) spreads downstream from the river, warm, salty water moves seaward, and the cool, high-salinity water retreats out of the mouth. On the next incoming tide, this thermohaline structure is again pushed landwards (Largier *et al.*, 2000). The water pH generally remains below 7 in the uppermost estuary, thereafter increasing steadily to values of ~ 8.1 – 8.2 when seawater salinities are reached (Allanson *et al.*, 2000). Oxygen saturation of the water column in the main channel varies between 82 % and 97 % across the entire estuary (Allanson *et al.*, 2000). Oxygen levels in the upper estuary are significantly less than those in the middle of the estuary, between the White Bridge and the Railway Bridge (Fig. 1.3.5).

Figure 1.3.5 Box and whisker plots of dissolved oxygen concentrations (mg/l). Data by Allanson *et al.* (2000). March 1995



Allanson *et al.* (2000) attribute the lowered oxygen levels in the upper estuary to the natural biochemical oxygen demand (BOD) of the water column enriched with humic substances. Lowered water temperatures as a consequence of upwelling (Schumann, 2000), result in an increase in dissolved oxygen throughout the lower and middle reaches of the estuary up to Belvedere, with recorded values ranging from 6.7 – 7.38 mg/l (Allanson *et al.*, 2000). This influence did not, however, extend upstream of this point and levels of dissolved oxygen north of White Bridge remained fairly unchanged (5.10 – 5.99 mg/l). Another significant source of oxygen-rich water is the tidal drainage from the shallow Ashmead Channel. Here, nutrient-rich effluent from the Knysna sewage-treatment works, and sporadic storm-water inflows, leads to periodic phytoplankton growth and, more importantly, the maintenance of the extensive eelgrass meadows in the intertidal areas (Allanson *et al.*, 2000), which produce oxygen through the process of photosynthesis.

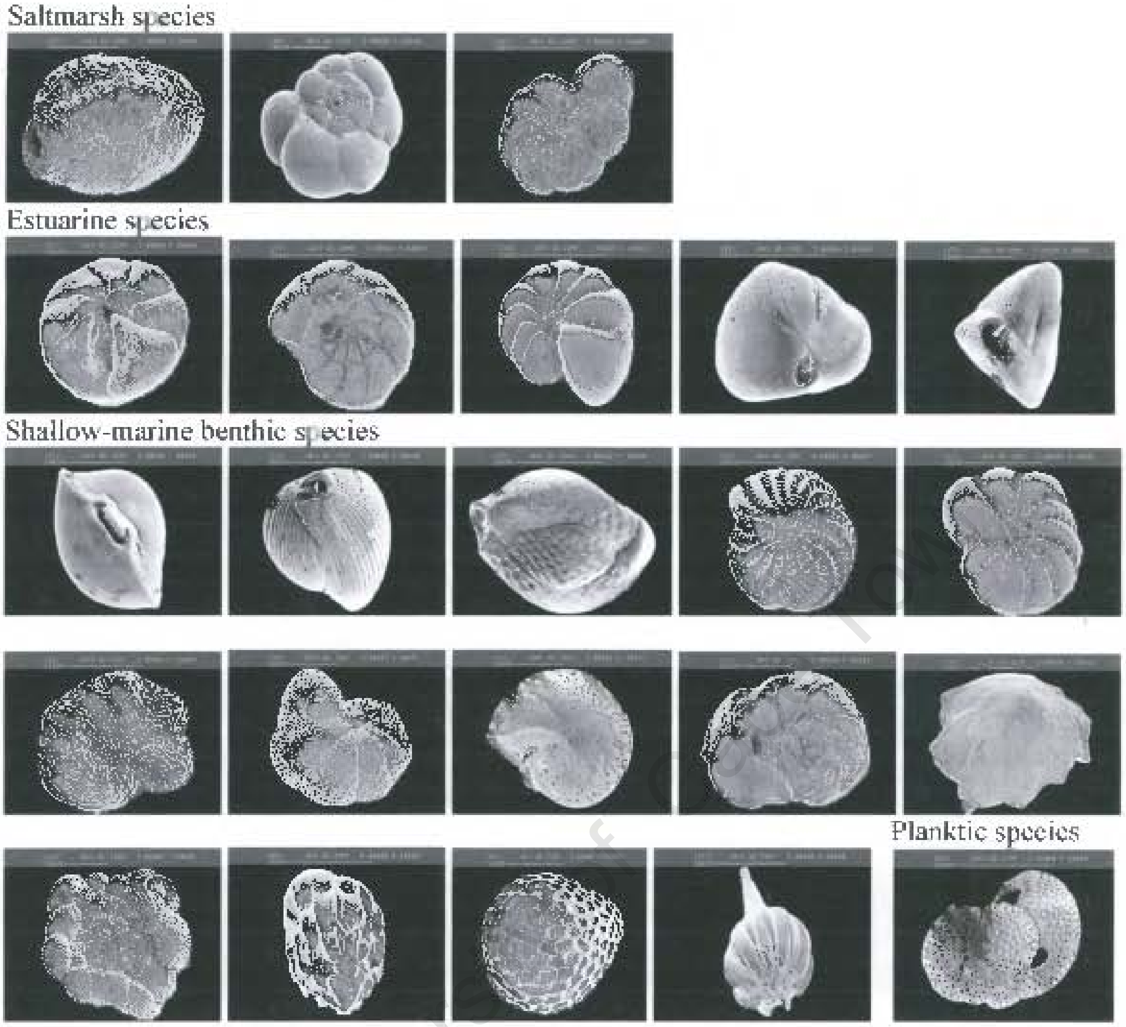
Rapid development, combined with large-scale mechanical landscaping, has made the Knysna Estuary extremely vulnerable to erosional processes. In addition to internal redistribution of sediment, large volumes of sediment have entered the estuary via storm water drains and the Sout River, covering eelgrass beds in the vicinity of their inflow (Grindley, 1976). Siltation, and accumulation of other (coarser) sediments, occurs because the Knysna Estuary is incapable of clearing land-derived sediment even when floods occur, as river flow is rapidly attenuated and rarely reaches the lower estuary.

Material tends to accumulate in the immediate vicinity of artificial structures. The estuary is crossed by two road bridges and a railway bridge, and all three have solid embankments which restrict tidal flow and encourage the deposition of sediments. Marker (2000) confirms that the Sout River is a major sediment source and that cover sands in the catchment area are being washed into the estuary as development occurs on the hills. Reddering (1994) also pointed out the extreme susceptibility of cover sands to erosion, particularly in the catchment area of the Sout River. Sedimentation has occurred immediately upstream of the Railway Bridge near the Salt River mouth, and although the texture of the estuarine sediment and the flood sediment, derived from the cover sands, were similar, the colours of these sediments are distinct. The flood sediment is yellow-brown in colour, in contrast to the dark grey estuarine sediment (Marker, 2000). Cover sands have always been prone to erosion during flood conditions, contributing to siltation in the estuary, however, the present period of rapid and extensive urbanisation repeatedly exposes these sands, posing more of a threat with every rain event on the estuarine plants and the macro- and microfauna (Marker, 2000).

An important factor controlling erosion is the recreational usage of the main channel. Boatwash generates considerable wave action which affects the erodible geology of the incoherent cliffs. Marker (2000) also noted that the Brenton shore is adversely affected by strong easterly winds, especially when accompanied by rain. The Brenton shore consists of semi-consolidated early Cretaceous, fossiliferous, marine clays (McLachlan *et al.*, 1976), which are vulnerable to wind and rain and easily undercut by wave action at high tide. Seepage at the base of the Brenton cliffs causes slumping and sand removal.

According to Allanson *et al.* (2000), agricultural activities in the catchment of the Knysna River have resulted in nitrogen and phosphorus loadings in the upper estuary, contributing to the supply of these essential nutrients to the estuary. Urbanisation has encroached upon intertidal wetlands and both stormwater and sewage-treatment-plant flows introduce nutrients into the water column. While these provide localised inputs, their contribution to the nutrient budget of the system compared with that introduced by the tidal prism is small (Allanson *et al.*, 2000). At present the tidal prism overrides the impact of nutrients (and/or toxic materials of anthropogenic origin) to the water quality of the estuary. Day (1981), recorded high nutrient concentrations and lush vegetation, attributed to the nutrient-rich sewage treatment effluent, in the channel north of Thesen Island. Dissolved phosphate levels remain relatively constant at about 1.2 μg PO_4 per litre throughout the estuary, which may be due to the buffering action of the bottom sediments (Day, 1981). Polynuclear aromatic hydrocarbons and polychlorinated biphenyls were undetectable in the water column (Allanson *et al.*, 2000). Among the heavy metals, lead and cadmium show elevated concentrations in the soft tissues of oysters, but not to dangerous levels (Allanson *et al.*, 2000). Nonetheless, heavy metal levels are of concern in light of both increased power boat and ferry activity in the estuary and the marked increase in traffic along the N2, which crosses the White Bridge.

1.4 INTRODUCTON TO FORAMINIFERA



Refer to Appendix 5 for species names.

Foraminifera are single-celled, testate protozoans that demonstrate a wide variety of test compositions and morphology. They inhabit all marine environments from the intertidal zone to the deep ocean floor, ranging from the poles to the tropics, and a variety of interrelated biotic and abiotic factors, such as temperature, salinity, calcium carbonate availability, pH, dissolved oxygen, turbidity, trace elements, illumination, substrate, hydrostatic pressure, currents, tides, food availability, predation and competition control their distributions (Lipps, 1993 and Boltovskoy *et al.*, 1991). They usually live for up to 6 months and their abundance in sediment samples may reach tens of thousands per square meter. Their diversity in tropical environments may exceed 60 or 70 species in a sample of 300 individuals (Lipps, 1993).

Foraminifera appeared at the Precambrian-Cambrian boundary and have evolved very rapidly through time. Major taxonomic diversification occurred during the Devonian and the Triassic to Early Jurassic, resulting in varying patterns of evolution and extinction that are of considerable biologic and geologic significance (Tappan and Loeblich, 1988 and Lipps, 1993). Their value as stratigraphic age markers is therefore very important, and they are the most important fossil group in both biostratigraphic and palaeo-environmental reconstructions (Lipps, 1993). The major impetus for foraminiferal research remains in their unsurpassed value for solving geological problems. Palaeotemperatures can be estimated through isotope analysis of foraminiferal tests; palaeodepths can be inferred from foraminiferal assemblages; the movement of water masses can be reconstructed through distributional studies; and the movement of tectonic plates can be recognised using foraminiferal data (Lipps, 1993). Studies by various authors (Alve and Olsgard, 1999; Debenay *et al.*, 2000; Jayaraju and Reddi, 1996; Samir and El-Din, 2001; and many others) have proven that benthic foraminifera reflect human-induced environmental perturbation, through test deformation, decreased numbers and species diversity, and can be used as reliable bio-indicators for monitoring coastal pollution.

Foraminifera can be either planktic or benthic in nature. Taxonomically, benthic foraminifera are much more diverse than planktic foraminifera, but the number of individuals is less among the benthic forms. Planktic foraminifera are composed of calcium carbonate and are designed to float. In structure, they are composed of bubble packs and spines, which serve as protection and also create buoyancy by increasing the test surface area (Boltvoskoy and Wright, 1976). Their shells are porous, thin and light, and some produce fat globules in their protoplasm. Interestingly, foraminifera have a symbiotic relationship with algae living inside them. During the day the algae moves out onto their spines to absorb sunlight and at night it returns inside the test (shell).

Benthic foraminifera live in or on the surface sediments and their tests are either calcareous or agglutinated. Calcareous benthic foraminifera secrete their tests chemically and thrive in subtidal channels, where water conditions are more alkaline and they are protected from desiccation. Agglutinated benthic foraminifera live in the upper marsh areas and are occasionally washed into the channels by tidal and rainfall runoff (Simpson, 2001). Agglutinated foraminifera tests reflect the composition of the local bottom sediment, since they are composed of grains selected on the basis of either composition, specific gravity, or size (Lipps, 1993 and Boltvoskoy and Wright, 1976). Agglutinated foraminifera build their tests through secreting a tectin lining, which cements sediment grains and sponge-spicules, placing the angular edges of the grains facing the inside of the test in order to channel light in (McMillan, 2001, pers. comm.). Due to the rich biomass of organics, the upper marsh is poorly oxygenated and more acidic, dissolving the carbonate tests of calcareous foraminifera. Agglutinated foraminifera, on the other hand, thrive in these organic-rich environments as their tests can withstand these acidic conditions (Scott and Medioli, 1980a and Boltvoskoy and Wright, 1976). Benthic foraminifera can attach themselves to a substrate by three mechanisms; clinging by pseudopodia, attaching with an organic membrane and cementing their tests by means of a calcite layer (Lipps, 1993 and Boltvoskoy and Wright, 1976). Test strength, morphology, and habitat of shallow-water free-living benthic foraminifera are correlated. Test strength increases with size and with the physical turbulence of the environment. Individuals from high-energy environments have stronger tests than smaller-sized individuals from low-energy environments

(Lipps, 1993). Southern African benthic foraminifera are mostly endemic, since they are localized in their latitudinal distribution, whereas planktic species are considered as having international bio-stratigraphic significance (Dale and McMillan, 1999).

Foraminiferal shells (tests) are beautiful, intricate and vary in size, shapes and patterns. Foraminiferal tests are built of chambers, which are cavities containing cytoplasm with a surrounding firm wall (Lipps, 1993). The test wall is composed of an organic lining, with calcium carbonate secreted onto the lining to build the chambers, which curl around each other. Adjacent chambers are separated by septa, but a connection is maintained by a hole or foramen for which the order Foraminiferida is named (Lipps, 1993). The opening on the last chamber through which pseudopodia extrude, is termed the aperture. The last chamber built is often broken off in the sample, as it is much thinner and more delicate than its predecessors. Tests may be single or multi-chambered. Multi-chambered species exhibit sutures, the external line of junction between adjacent chambers that may by arranged in a variety of ways (Lipps, 1993). When later chambers envelop earlier ones, the test is called involute. When earlier chambers are visible, the test is termed evolute. The test may coil in a single plane (planispiral) or in a spire (trochospiral). Each coil of the test is called a whorl (Lipps, 1993).

Foraminiferal functional morphology is still in its infancy and consists of suggestions and speculations on the function of the whole test, parts of the test, and the cytoplasm (Lipps, 1993). Foraminiferal tests are important as they reduce physical and chemical stress, enhance feeding in particular habitats, enable reproduction, aid in locomotion and maintain negative buoyancy (Lipps, 1993). The pseudopodia (or reticulopodia) of foraminifera are used in several life processes: locomotion, collection or capture of prey, digestion, elimination of waste materials, as well as shell construction and maintenance (Lipps, 1993). External modifications to the surface of the test are often referred to as ornamentation, although many of these surficial features are functional. Species that live in littoral environments usually display some kind of ornamentation. These functions probably include anchoring or stabilising the test in the sediment, deploying pseudopodia, contributing to the mechanical breakdown of food particles and prevention of predation (Lipps, 1993). Agglutinated foraminifera, on the other hand, show little surface sculpture (Lipps, 1993).

The life cycles of only 20 or so of the 4000 living species of foraminifera are known and these cycle exhibit considerable differences (Lipps, 1993). The tests of many species of foraminifera are dimorphic. This dimorphism may involve differences in size or in more obvious morphologic differentiation and it is the result of alternation of sexual and asexual generations. Foraminifera are different to most animals in having an asexually produced uninucleate haploid generation (gamont) alternating with a sexually produced multinucleate diploid generation (agamont or schizont) (Lipps, 1993). Asexual or sexual generations may be repeated, or in some taxa, simple fission or budding may occur. Asexually formed specimens generally have more protoplasm initially and form a larger proloculus, while specimens developing from gametes have less initial protoplasm and produce a smaller proloculus (Lipps, 1993).

Foraminifera constitute a major portion of the benthic biomass in shallow to deep marine ecosystems and their many trophic interactions indicate their importance in benthic food webs. Planktic foraminifera, similarly, occupy an important place in ecosystems within the water column (Lipps, 1993). Many species are opportunistic feeders, consuming whatever food particles they encounter. They are in turn the selective or accidental prey of fish, various invertebrates and perhaps other protozoans (Lipps, 1993). Foraminifera feed upon bacteria, pennate diatoms, algal gametes, algae, seaweed, copepods, spores, small echinoderms, micro-crustaceans, nanno-plankton and occasionally even other foraminifera in a wide variety of marine environments; hence their food items are usually less than 25 - 50 µm in size (Boltvoskoy and Wright, 1976 and Lipps and Valentine, 1970). Foraminifera are therefore key links in marine food chains, assimilating energy available from minute autotrophy and also retrieving energy available during the final stages of degradation of organic debris. When bacteria are eaten by foraminifera and other groups, energy not otherwise available is retrieved to support a variety of organisms (Lipps and Valentine, 1970).

Foraminiferal feeding mechanisms are related to test morphology. Foraminifera that take up dissolved organic matter from their environment generally have a large cytoplasmic surface area (Lipps, 1993). Passive herbivores should be common in food-rich environments. Marshes contain a great abundance of organic debris, bacteria and epiphytes of various kinds, which make up the diet of herbivorous foraminifera. Many attached foraminifera, whose test morphology corresponds to the substrate, may be passive herbivores (Lipps and Valentine, 1970). Some species (e.g. *Rosalina globularis*) may move in search of diatoms when this food source becomes scarce (Lipps, 1993). Most active herbivores have trochoid, lenticular, or flattened tests (Lipps, 1993). Carnivorous foraminifera, both active and passive, have test morphologies similar to herbivores, however they may have sticky pseudopods and the rhizopodal network may be analogous to a spider's web. Small crustaceans and various protozoans are known prey of carnivorous foraminifera (Lipps, 1993). The test shape of benthic omnivores should be similar to herbivores and carnivores as they use similar strategies to capture food (Lipps, 1993). Foraminifera that move through fine-grained substrates may be detrital and bacterial scavengers. They commonly have elongate tests, thus their movement through sediment is facilitated and may result in the production of minute burrows (Lipps, 1993). Foraminifera that extend their pseudopodia into the water column may be suspension feeders. They generally have erect tests with the aperture oriented away from the substrate (Lipps, 1993). Other variations are possible; *Elphidium crispum*, lenticular in shape, which lives in sandy sediments that are generally low in food supply, can use its pseudopodial nets to suspend itself between the strips of coralline algae, much like a spider (Lipps, 1993). Planktic foraminifera (and probably many benthic species as well) are omnivorous opportunistic feeders and have been observed to consume autotrophic and heterotrophic protests, metazoans and organic detritus. Many species of foraminifera, such as *Elphidium, Nonion*, and planktic species are known to house algal symbionts, usually diatoms, dinoflagellates, or chlorophytes. These foraminifera often have large, flattened discoidal or fusiform tests, with various kinds of internal partitions to accommodate algal cells (Lipps, 1993). The availability of nutritive material also affects test morphology. Studies by Arnold (1954c), Arnold (1967a), Bradshaw (1955, 1968), Boltovskoy (1956b), Phleger (1960b), Tolderlund and Bé (1971) and Walton (1955), prove that the test morphology, as well as the number of specimens in a given volume of sediment, is affected by the abundance and distribution of organic matter within the sediment.

Predators upon foraminifera range from highly specialised micro-carnivores that feed largely on foraminifera, to less selective ones that include foraminifera into their mixed diet, and to generalized feeders that ingest foraminifera along with much other material (Lipps and Valentine, 1970). Benthic foraminiferal densities may be substantially reduced by macrofaunal predation, either incidentally or selectively. Most incidental consumers of foraminifera are grazers on algae or detritus feeders (Lipps, 1993). Some gastropods, crustaceans and worms are believed to be selective predators of particular species of foraminifera (Lipps, 1993; and Lipps and Valentine, 1970). Foraminifera therefore support a variety of larger organisms, and thus contribute to the diversity and secondary productivity of ecosystems (Lipps and Valentine, 1970).

1.5 PREVIOUS WORK ON THE KNYSNA ESTUARY AND ITS ENVIRONS

Much work has been carried out in the Knysna area due to its attractive location. The late Professor J.H. Day undertook extensive work from 1964 to the 1980s on the ecology of southern African estuaries, including the Knysna Estuary. Current knowledge of South African saltmarsh vegetation is based on earlier ecological and physiological studies by Day (1981), who showed that the saltmarsh structure is determined by environmental gradients such as salinity and tidal inundation. The Knysna Basin Project (KBP), (Transactions of the Royal Society of South Africa, 2000, Vol. 55: 2), carried out from 1995 to 1998, provides a full scientific report on the Knysna Estuary and is aimed to synthesise research findings in the estuary from present studies which have implications for the management of the Knysna area as a whole. These findings laid down the present environmental conditions of the estuary, which were used in this study to explain variations observed in the microfaunal assemblages. Included in the Knysna Basin Project is a review of past marine and estuarine studies in South Africa (J.A. Day, 2000), as well as a bibliography of scientific and environmental literature relating to the Knysna Basin. Allanson (2000) assessed the reasons for establishing the KBP, reviewed the research findings, and discussed implications for the management of the Knysna Basin. Papers by Largier *et al.* (2000), Schumann (2000), and Marker (2000) give, respectively, a clear description of the hydrographic structure of the estuary during low river inflow and river flooding; the influence of offshore events, such as upwelling during the summer months, and patterns of sediment movements within some regions of the estuary. The distribution and diversity of the intertidal wetlands have been recorded and described by Maree (2000). Le Quesne (2000) demonstrated that the wetlands play an essential role in providing areas for feeding and refuge, offering excellent breeding grounds and nursery areas for a number of fish species. The chemistry of the water column, with particular reference to suspended solids and nutrients, was studied by Allanson *et al.* (2000).

Foraminiferal studies

There have been numerous studies of estuarine foraminifera from around the world, however most foraminiferal studies are based in developed countries throughout the northern Hemisphere, and especially in the United States and European countries. Foraminiferal studies with an ecological or palaeo-ecological emphasis began in earnest in the 1930s with the works of R. Norton and M.J. Natland in North America and W.A. Macfadyen in Europe (Lipps, 1993).

Fossil Prokaryotes and Protists (Lipps, 1993) provides a comprehensive account of fossil single-celled organisms and includes a description of foraminifera, their morphology and life cycles, biology and ecology, nutrition and predation, their evolutionary history and global palaeobiology and biostratigraphy. The role of foraminifera in the trophic structure of communities from various marine environments has been documented by Lipps and Valentine (1970). Murray (1968 and 1973) describes the composition, numerical abundance, size relationships, biomass and diversity of living foraminifera in lagoons and estuaries from various parts of the world. Boltovskoy and Wright (1976) illustrated global biogeographical provinces, based on foraminifera, around the world. Wang and Murray (1983) examined the use of foraminifera as indicators of tidal effects in estuarine deposits.

Few studies of foraminifera in modern South African estuaries have been published, and none of the systems that have been studied can be considered comparable to the Knysna Estuarine System. Studies of modern foraminifera around the South African coast include the work of: Albani (1965) in Durban Bay; Cooper and McMillan (1987) in the Mgeni Estuary, Durban; Phleger (1976 a/b) and Wright *et al.* (1990) in the St. Lucia Estuary, Zululand; G. Franceschini (2003, unpublished) and Compton (2001) in Langebaan Lagoon, on the south-west coast of South Africa. Both present day and fossil foraminiferal assemblages on the continental shelf of southern Africa have been studied by McMillan. McMillan (1974) recorded foraminifera collected from the continental shelf off the Knysna to Plettenberg Bay coast. This study may be used to compare onshore to offshore foraminiferal assemblages and species diversity. A study by McMillan (1986) describes how fossil foraminiferal distributions around southern Africa provide a guide to past changes in oceanic water temperatures. Albani (1965) recorded species from samples dredged in the vicinity of Salisbury Island, Durban Bay; and documented the species *Rotalia beccarii*, which has since been correctly identified as *Rotalia gaimardii*. Cooper and McMillan (1987) recognized distinct foraminiferal assemblages in the Mgeni Estuary consisting of marine, estuarine and reworked foraminifera, and their distribution was assessed. Wright *et al.* (1990) used foraminiferal assemblages in the St Lucia Estuary to identify sediment providences, thus providing an alternate method to statistical sediment grain-size and distributional analyses in estuarine systems. Phleger (1976a,b) researched the Holocene ecology, based on foraminifera, of the St. Lucia Estuary, Zululand, and calculated sedimentation rates by comparing living and dead foraminifera in benthic populations. McMillan did some research during 1973-1974 on foraminifera of the Knysna Estuary, however, his work was never published.

Identification of *Ammonia* species in South Africa, since the earliest in 1907, have been referred to as just one species: *Ammonia beccarii* (Linné), (see Phleger, 1976a,b and Salmon, 1978), however studies of some of these *Ammonia* tests have shown them to be a morphologically diverse group in which a number of distinct morphotypes can be recognised. McMillan (1987) published a paper on the variation in assemblages of *Ammonia* species living around the South African coast at the present day. In this paper he clears up any uncertainties concerning the genus *Ammonia* and gives a full account for the three species of *Ammonia* found around South Africa: *Ammonia parkinsoniana (d'Orbigny)*, *Ammonia japonica (Hada)*, and *Ammonia cf. koeboeensis (LeRoy)*. McMillan (1987) confirms that typical *Ammonia beccarii senso stricto* does not occur; either living or fossil, in this part of the world, and all South African species and morphotypes of this genus must be one of the three *Ammonia* species mentioned above.

Compton (2001) and Franceschini (2003, unpublished) researched the Holocene sediments and the foraminifera of the Saldanha Region on the west coast of South Africa. The foraminiferal zones from the subtidal channel to the upper marsh in Langebaan Lagoon are similar to the foraminiferal assemblages observed in the intertidal areas of the Knysna Estuary (Simpson, 2001). These studies confirm that saltmarsh foraminiferal assemblages are related to altitudinal variations in vegetation and are therefore reliable sea-level indicators. Studies of intertidal saltmarsh areas on the east, south and west coasts of the United Kingdom conclude that the distribution of foraminifera in the intertidal zone is a direct function of elevation with the duration and frequency of intertidal exposure as the most important factors (Horton *et al.* 1999). Recent studies from North America (Scott and Medioli, 1980; Scott and Leckie, 1990; Jennings and Nelson, 1992), South America (Scott *et al.*, 1996; Jennings *et al.*, 1995), Italy (Petrucci *et al.*, 1983), United Kingdom (Horton *et al.*, 1999) and Australia (Cann *et al.*, 2000) suggest that comparable low- and high-marsh foraminiferal assemblages can be recognised worldwide. A study by Zong and Horton (1998), from coastal sites on both the east and west of Britain, illustrates that the distributional patterns of diatom assemblages across the upper intertidal zone can also be divided into three groups correlating to the upper supratidal marsh, the lower supratidal marsh and the tidal flat areas.

Literature regarding the effect of pollution of coastal waters on foraminifera is relatively abundant and benthic foraminifera have proven to be reliable indicators for contamination in coastal marine and estuarine waters. Papers published until 1975 were listed and discussed by Boltovskoy and Wright (1976). Since then many new studies have transpired (Alve and Olsgard, 1999; Debenay *et al.*, 2000; Jayaraju and Reddi, 1996; and many others). While these studies conclude that pollution does affect foraminiferal density, species diversity, distribution patterns and test morphology, there is still no clear understanding of the relationship between pollutants and foraminifera. Not only do the pollutants vary in nature and concentration, but they have different effects on different species of foraminifera. Some pollutants are favourable for several species but, at the same time, harmful to others (Schafer, 1973; Setty and Nigam, 1984). Some authors noted an increase in the proportion of aberrant specimens in polluted areas (Alve, 1991, 1995; Geslin *et al.*, 1998; Samir and El-Din, 2001; Stott *et al.*, 1996 and Yanko *et al.*, 1994). Research by Samir (2000) and Samir and El-Din (2001) on the response of foraminifera and ostracods to various pollution sources, including industrial wastes containing heavy metals, agricultural waste and domestic sewage effluent, conclude that: 1) morphological abnormalities depend on the degree of pollution and the type of pollutants; 2) foraminifera are more sensitive to industrial wastes containing heavy metals than sewage effluent and agricultural waste; 3) agricultural wastes do not significantly harm benthic foraminifera and 4) benthic foraminifera are less tolerant to pollution than ostracods and molluscs.

2. METHODS

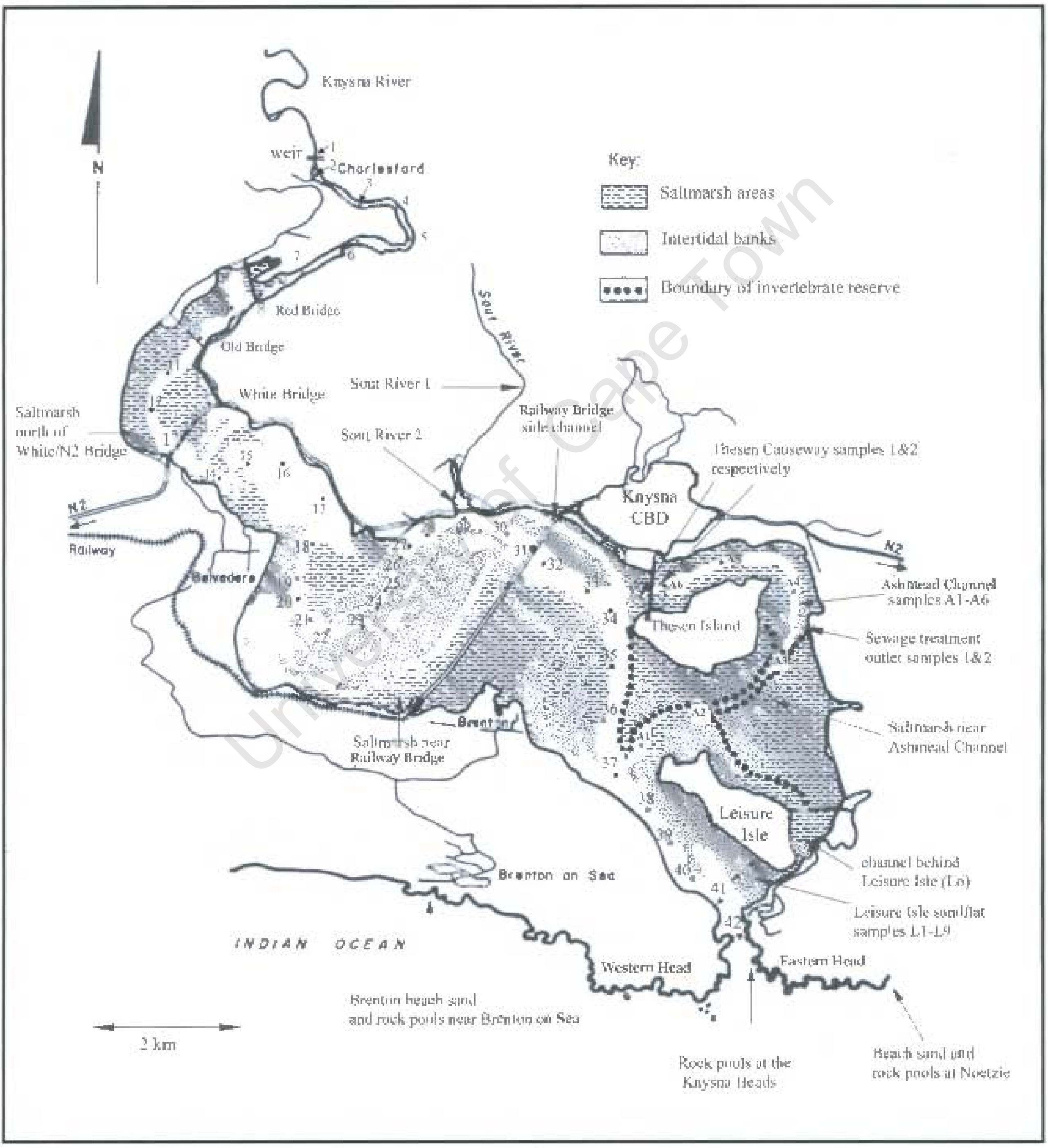
2.1 FIELD SAMPLING PROCEDURE

Sampling sites were chosen using a series of aerial photographs, maps, and a Global Positioning System (GPS). Forty-two main-channel sample sites were chosen for this study, from the weir on the Knysna River to the mouth of the estuary at the Knysna Heads. Sample sites 11 to 40 coincide with the National Parks Service navigation buoys which have been placed along the main channel. The rest of the sample sites were identified by geomorphological features, and sample 1 was collected at the Charlesford farm weir. The water depth of the sample sites ranges from 0.5 m to >10 m. Samples were collected in the middle of the main channel of the estuary, since the adjacent intertidal areas are depleted in foraminifera relative to the main channel. Desiccation of the intertidal mudflat sediments during low tide creates unfavourable conditions for foraminifera (Simpson, 2001). Foraminifera prefer to live in environments with a constant, shielding, water supply, such as in the main channel, and transportation of foraminifera by tidal currents is also most active in the main channel of the Knysna Estuary. Therefore, the best representation of foraminiferal assemblages in the Knysna Estuary occurs in the middle of the main channel

The main channel samples were collected at low tide, during the period 14 - 17 January 2002, by diving to the channel bed and scooping surface sediment of 5-10 cm depth into a container that holds approximately 500g. GPS coordinates were taken at each sample site (Appendix 3). The wet sediment samples were then placed into air-tight sample bags and labelled. The surface water temperature, pH, current velocity and the surface- and bottom-water salinities were measured at each sample point. Water colour, turbidity, depth, vegetation and shell abundance at each sample site were also noted. Surface samples were also collected between January and March 2002 at selected localities including: the mouth of the Sout River where it enters the estuary, in a side channel beneath the Railway Bridge, around the Ashmead Channel; where the sewage effluent enters the estuary in the Ashmead Channel, on either side of the causeway, which joins Thesen Island to the mainland, in the channel behind Leisure Isle, across the sandflat stretching between Leisure Isle and the main channel near the Knysna Heads, as well as rock pool and beach sand samples between the Knysna Heads, at Brenton-on-Sea on the Western Head and at Noetzie beach on the Eastern Head.

Seventy sediment samples were collected in total (Fig. 2.1), representing a good coverage of the study area, as well as the range of substrate types and the depositional environments. Appendix 2 contains illustrations of the various substrate types within the estuary, including samples from selected fresh-water, mudflat and littoral environments surrounding the estuary. Unfortunately, at the time of collection, the samples were not stained to reveal the living to dead ratios, although reworked and abraded foraminifera were noted. However, samples collected in the Ashmead Channel and across the Leisure Isle sandflat were stained with Rose Bengal solution, allowing for the recognition of living and non-living foraminifera.

Figure 2.1 Sample locations in the Knysna Estuary. Adapted from Grindley (1985).



2.2 SEDIMENTOLOGICAL AND MICRO-PALEONTOLOGICAL ANALYSIS

A portion of each sample was dried at a temperature of ~55 °C and weighed as the bulk dry sample. The dried material was then wet-sieved, through a 2mm, a 500 µm (micron) and a 63 µm sieve, separating the samples into, gravel (>2mm), very coarse to coarse sand (>500µm), medium to very fine sand (>63µm), and mud (<63µm) grain-size fractions. Once wet-sieved, the sediment fractions were dried and weighed in order to calculate the percentage of each grain-size fraction. Foraminifera were picked from the 63-500 µm sand fraction using a No.1 brush. Foraminifera were analysed on picking trays under a binocular-microscope and stored in glass slides. Four picking trays (~5 grams sand fraction each) were inspected per sample, so as to get a better understanding of species occurrence and abundance. They were subsequently sorted, identified and counted. Foraminifera were counted per four standard picking-trays of the sand fraction (63-500 µm), of which the average weight of sediment was ~ 20 grams. Thus graphs show foraminifera and species numbers per 20g of the 63-500 µm sediment (sand) fraction. Selected specimens were mounted onto stubs, coated with carbon and photographed with a Scanning Electron Microscope to aid identification and to illustrate the species. Lists of the recorded foraminifera and species numbers are given in Appendix 4.

Foraminifera were identified with the help of Dr I.K. McMillan, and journals and articles including studies by: Graham and Militante (1959), *Recent foraminifera from the Puerto Galera area, Northern Mindoro, Philippines.* Albani (1965), The *Foraminifera in a sample dredged from the vicinity of Salisbury Island, Durban Bay, South Africa.* Barker (1960), *Taxonomic Notes, HMS Challenger Expedition 1873-1876.* Dale and McMillan (1998), *Mud belt and middle shelf benthonic and planktonic foraminiferal assemblages and sedimentation processes compared through the Holocene successions at two tropical African (Sierra Leone) and two temperate African (western offshore, South Africa) sites.* Haynes (1981). Dale and McMillan (1999), *Field guide to the Late Cenozoic Micropalaeontological History, Saldanha Region, South Africa*, and McMillan (1974), *Recent and relict foraminifera from the Agulhas Bank, South African continental margin.* Bivalves and gastropods were generally identified with reference to Branch and Branch (1981), *The Living Shores of Southern Africa.* Light microscope photographs of the shells collected in the gravel fraction of some samples are illustrated in Appendix 2.

2.3 LIMITATIONS OF THE STUDY

The samples collected around the estuary and within the main subtidal channel represent the entire Knysna Estuary and the marine areas surrounding it, thus the data can be considered to be of good quality. However, there are gaps between the samples due to the vast area of the estuary, thus the sedimentology and microfauna between sample sites has to be extrapolated from adjacent sample data. Speculation in these areas should be near to the truth, since gaps between samples are no more than 500m. Although foraminiferal tests can provide an integrated record of environmental conditions over periods represented by the sediment sample, flood scouring and tidal currents in deeper water, and boat and wind action in shallower water, mixes and transports tests, making interpretation more difficult.

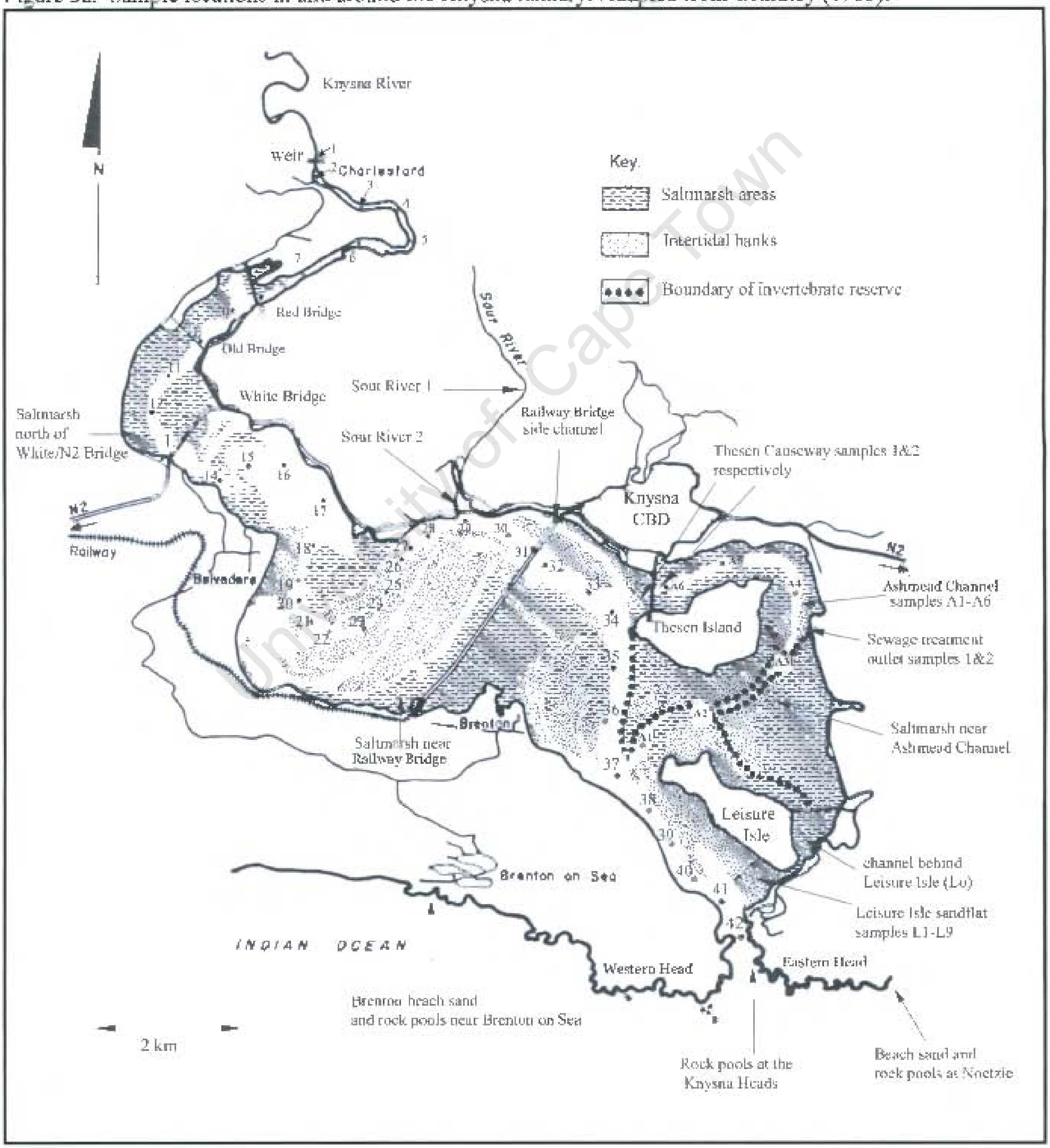
Salinity, pH and other ecological factors that were measured in the field were only measured during one week in January of 2002. However, the results obtained correspond closely to values collected by other researchers (Allanson, 2000, Largier *et al.*, 2000, and Schumann 2000), and therefore can be considered representative of general environmental conditions in the Knysna Estuary. Benson and Maddocks (1964), suggest that estuarine conditions are constant throughout the year due to the fact that the estuary is continuously open to the sea.

Very little work has been published concerning foraminifera around the South African coastline, resulting in a deprived database and placing limitations on describing the taxonomy of the species. Because very few authors have given details of foraminiferal assemblages, especially in estuaries around southern Africa, it is difficult to compare Recent, fossil and tidally influenced faunas. Ostracods were found in this study, but due to time constraints, species classification was not completed.

3. RESULTS

Sediment was collected from 42 samples along the main channel of the Knysna Estuary (Fig. 3a). Sample 1 is at the weir on the Knysna River and sample 42, eighteen kilometres downstream from sample 1, is located at the mouth of the Knysna Estuary, between the Knysna Heads. Sample 13 was collected under the White Bridge (over which the N2 national road runs), 6 km downstream from the weir, and sample 31 is under the Railway Bridge, 12.4 km downstream from the weir.

Figure 3a. Sample locations in and around the Knysna Estuary. Adapted from Grindley (1985).



In addition to the main channel samples, extra samples were collected around the Knysna Estuary and analysed (Fig. 3a). Sout River 1 is 100m upstream from the mouth of the Sout River, and Sout River 2 is located where the Sout River enters the Knysna Estuary near main channel sample 29. The Railway Bridge sample was collected in a side-channel under the Railway Bridge. A number of samples were taken in the vicinity of Thesen Island. Samples were also collected across the sandflat south of (adjoining) Leisure Isle and from other marine/wave dominated areas between, and on either side of, the Knysna Heads.

Thesen Island can be found in the north-east corner of the Knysna Estuary, to the south of the central business area of Knysna (Fig. 3b). It is surrounded to the west by the main channel of the estuary and to the north, east and south by the generally shallow Ashmead Channel. It is joined to the mainland by a causeway. Thesen Island is the largest island in the estuary with an area above high tide of approximately $1km^2$ and a surrounding intertidal zone of approximately equal area. Thesen Island causeway samples 1 and 2 are situated east and west of the causeway connecting Thesen Island to the mainland, respectively. A total of six samples were analysed from the entrance to the Ashmead Channel (sample A1), near main channel sample 37, to the Thesen Island causeway (sample A6). A description of the Ashmead Channel samples (A1 to A6) is given in Table 2, Appendix 3. Sewage outlet sample 1 is located where the sewage-treatment-plant effluent flows into the Ashmead Channel, and sewage outlet sample 2 is nearer to the treatment plant.

A total of ten samples were taken from around Leisure Isle (Fig. 3c). Samples L1 to L9 were taken on a transect across the Leisure Isle sandflat, approximately 400m wide. Sample L0 was collected in a small channel behind/east of Leisure Isle. The sandflat is exposed at low tide and covered by sea water at high tide. The water at high tide increases from a depth of 0.1 m at sample L1, to approximately 1 m near sample L9, which is adjacent to the main channel (near sample 41). Beach and rock pool samples at Brenton-on-Sea beach west of the tidal inlet, Noetzie Beach east of the tidal inlet, and between the Knysna Heads were also analysed.

Table 1 in Appendix 3 contains the date and time that each of the main channel samples was collected, and includes the GPS coordinates, a description of the sample sites, sediment type and the ecological, hydrographical and micropalaeontological aspects of the sample sites. Table 2, Appendix 3 includes location descriptions, sediment types and the physical and micropalaeontological records for the extra samples collected around the Knysna Estuary. The ecological and hydrological (physical) parameters include: the salinity of the surface and bottom water, and whether there was a salinity gradient, the pH, turbidity, transparency and colour of the water column, as well as the depth, flow velocity and temperature of the water at each main channel sample location. The sedimentology includes the overall grain size, sorting, roundness of the grains and the sediment colour. The micropalaeontological information includes the number of individual foraminifera and species per 20 g of the sand fraction and the percentage littoral foraminifera in each sample.

Figure 3b. The Ashmead Channel and the locations of Ashmead Channel samples A1 - A6

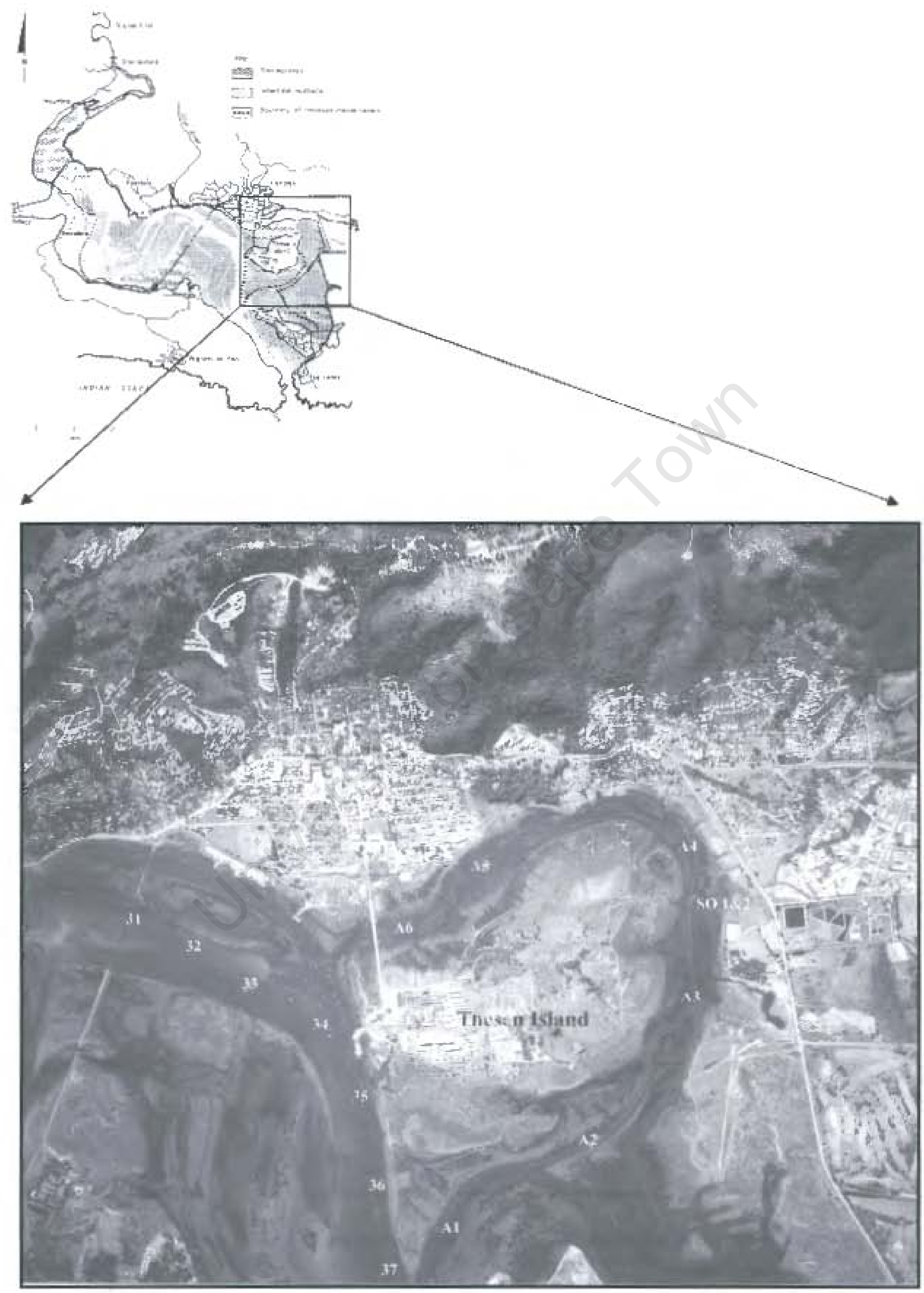
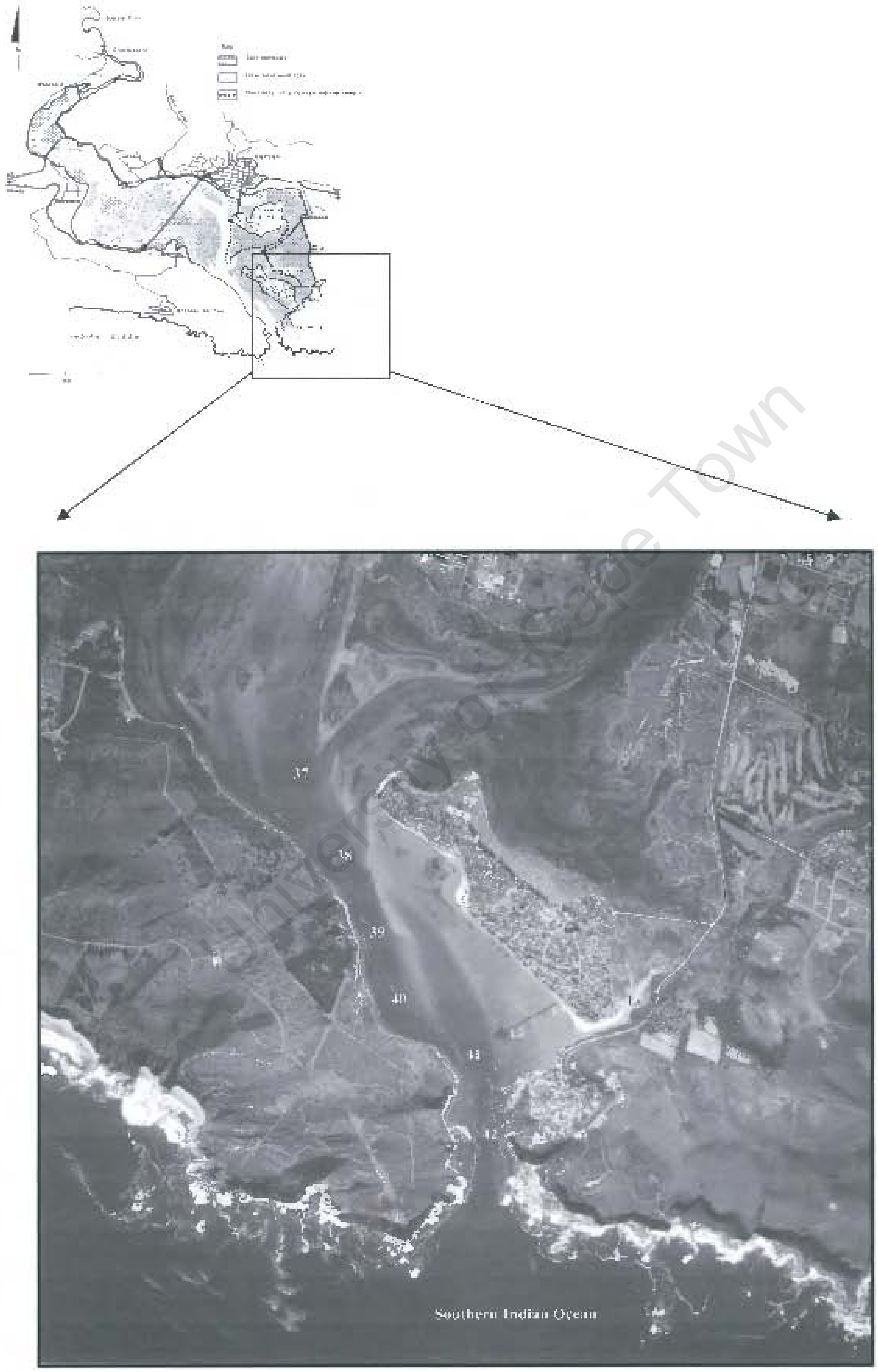


Figure 3c. Leisure Isle and its orientation in the Knysna Estuary

Locations of Leisure Isle sandflat samples L1-L9 and sample L0 behind/east of Leisure Isle



3.1 Physical Properties

The bathymetry of the Knysna Estuary varies from 0.5 m to >9 m in the deeper waters near the tidal inlet of the estuary (Fig. 3.1.1). The salinity increases rapidly downstream from the weir (0 ‰). In the upper estuary, bottom friction on the channel bed slows the lower part of the water column and lower-salinity water moves over the higher-density water, causing stratification of the water column. Salinity values reach a high of 36.5 ‰ at sample 17 (2 km downstream of the White Bridge), after which the salinity drops slightly, remaining between 30 ‰ and 33 ‰, until sample 39 (1.5 km from The Heads), where it rises to that of seawater (~35‰) and remains so to the mouth of the estuary (Fig. 3.1.2). The drop in salinity from sample 19 to sample 37 coincides with the developed area along the banks of the estuary, and may therefore be due to recent rains, resulting in fresh water runoff from the urban areas into the estuary. Figure 3.1.3 also illustrates a salinity gradient in the upper estuary from salinity measurements in the vertical water column. Results are similar to the salinity structure of the estuary illustrated by Allanson *et al.* (2000) and Largier *et al.* (2000). The pH decreases upstream, from more alkaline values (7.5 - 8.18) near the mouth of the estuary, to values of 5.5 – 7.5 in the brackish waters of the upper estuary (Fig. 3.1.4). A scatter plot of Salinity against pH for the main channel samples depicts an almost linear trend across the estuary from more acidic, lower salinity river water to more alkaline, higher salinity sea water (Fig. 3.1.5).

Figure 3.1.1 Bathymetry along the main channel of the Knysna Estuary

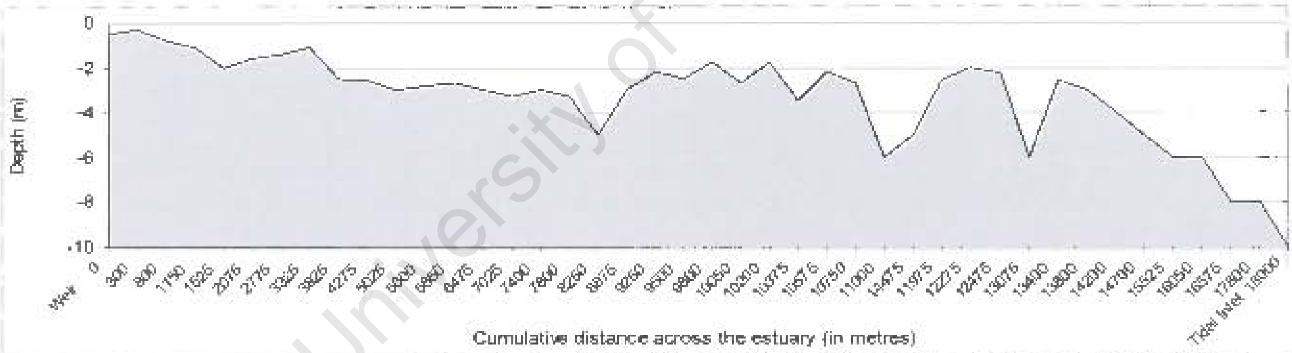


Figure 3.1.2 Salinity measurements along the main channel of the Knysna Estuary

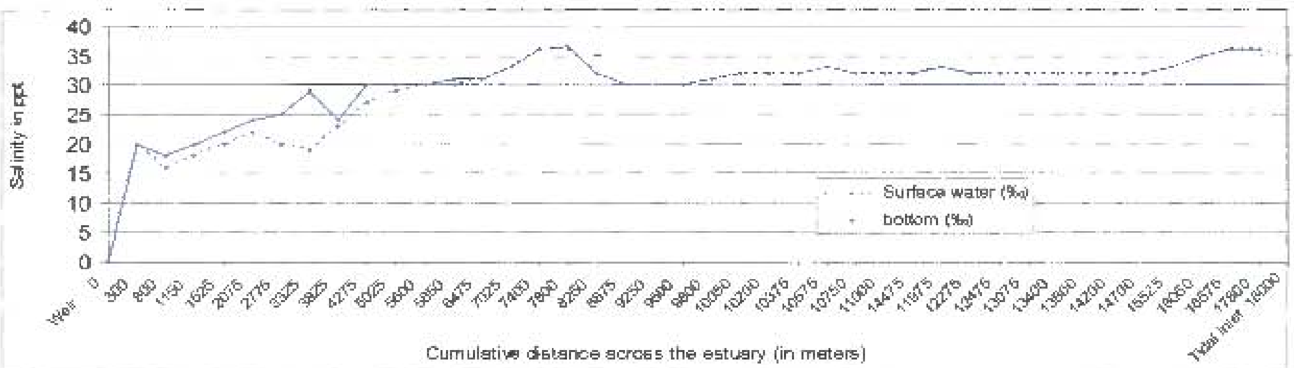


Figure 3.1.3 Salinity measurements in the vertical water column along the main channel of the Knysna Estuary. The lower and middle estuary are well mixed, while the upper estuary is stratified with respect to salinity

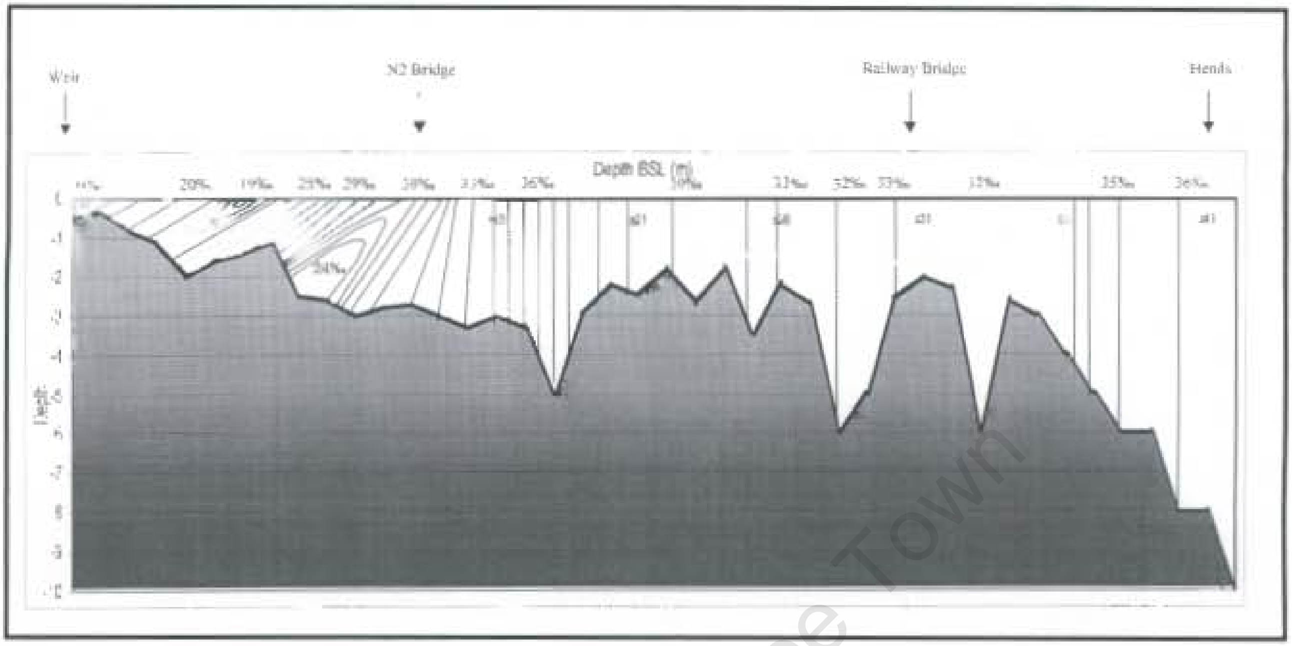


Figure 3.1.4 pH measurements of the surface waters along the main channel of the Knysna Estuary

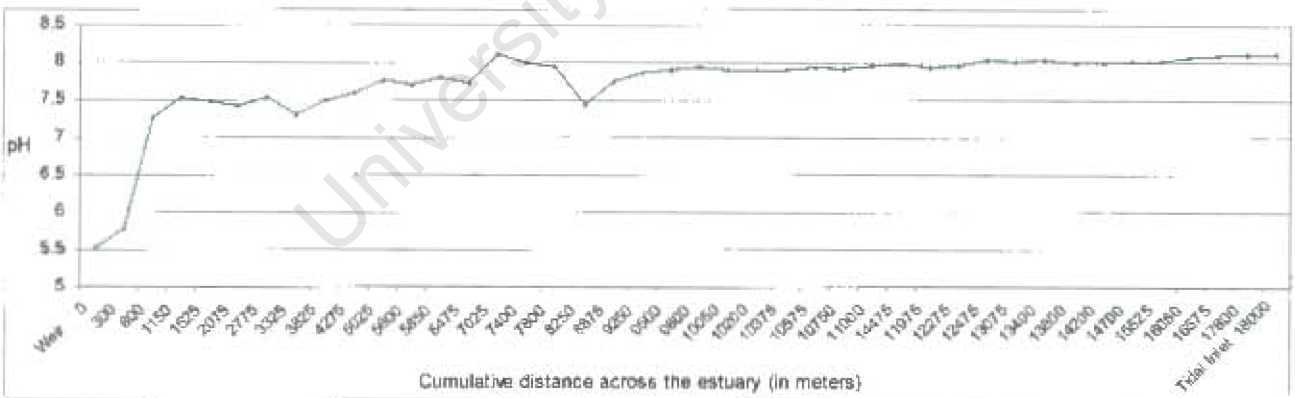


Figure 3.1.5 Scatter plot of salinity vs. pH across the Knysna Estuary

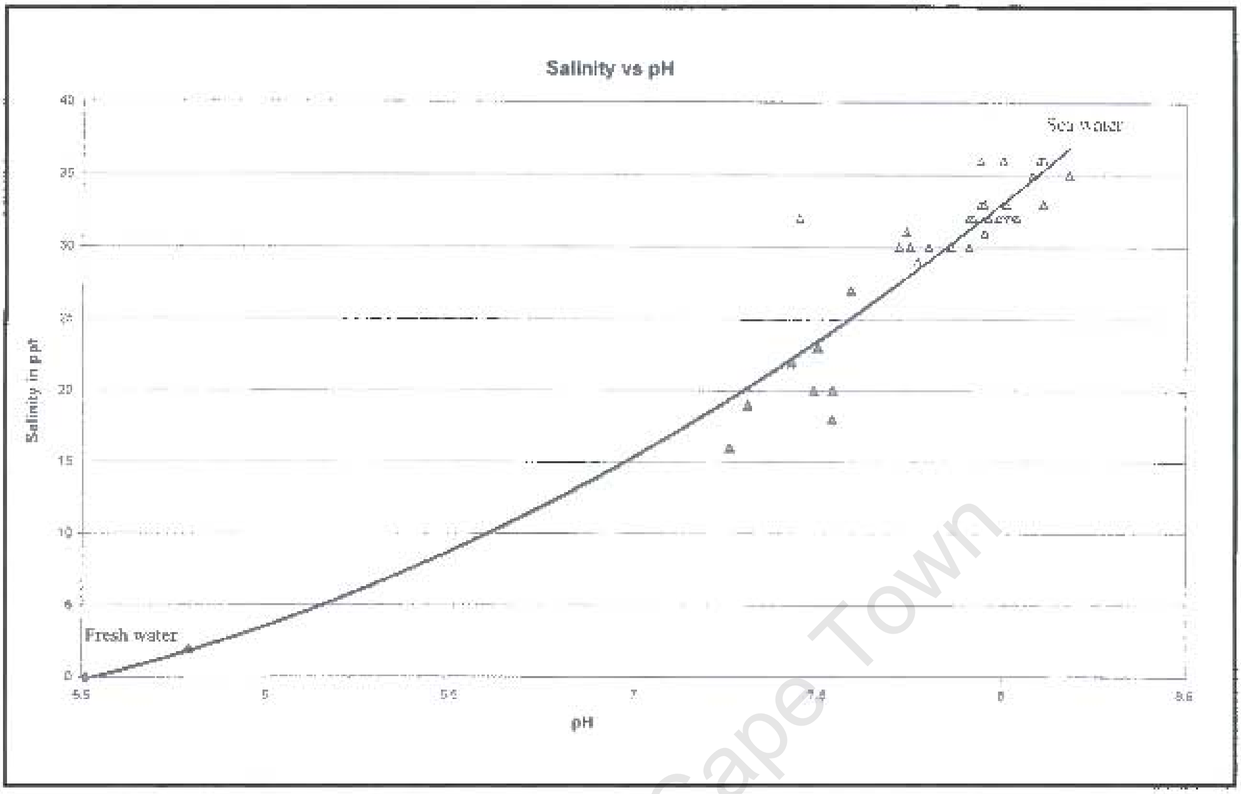


Figure 3.1.6 plots salinity vs. pH for the extra samples collected around the Knysna Estuary. Thesen Island causeway and the Railway Bridge side-channel are near the Knysna CBD area. These areas are therefore susceptible to runoff from the adjacent urban slopes. Relatively alkaline runoff flows into the channel north of Thesen Island and in the rainy season the waters east of the causeway become less saline. The Sout (Salt) River samples reflect middle-estuarine (slightly lower than sea water) salinities, due to flood-tide water from the Knysna Estuary pushing into this channel every tidal cycle. Sout River sample 1 is further upstream, where the channel is narrow and vegetation on the banks results in relatively acidic runoff into this area of the Sout River.

The sewage outlet brings fresh water into the Ashmead Channel surrounding Thesen Island. Sewage-outlet sample 2 is situated where the sewage effluent runs into the Ashmead Channel waters, and therefore has an elevated salinity relative to sewage-outlet sample 1. The pH values in the Ashmead Channel range from near marine to 7.86 (Fig. 3.1.7). Samples A3 and A4 in the Ashmead Channel show elevated pH values relative to the rest of the channel. This may be due to (fairly alkaline) inflow in this area from a combination of effluent from the sewage-treatment-plant outlet and runoff from the mainland.

The beach and rock pool areas include samples from the Leisure Isle sandflat near the tidal inlet, between the Knysna Heads, Brenton-on-Sea Beach (Western Head) and Noetzie Beach (Eastern Head). These areas are essentially 'marine' and all have salinity and pH values equivalent to sea water (salinity values range from 35-36 ‰ and pH ~ 8.1). The Leisure Isle sandflat is similar to a beach environment, although this area is, to some extent, protected from the harsh forces of breakers by the Knysna Heads.

Figure 3.1.6 Salinity vs. pH for extra samples around the Knysna Estuary

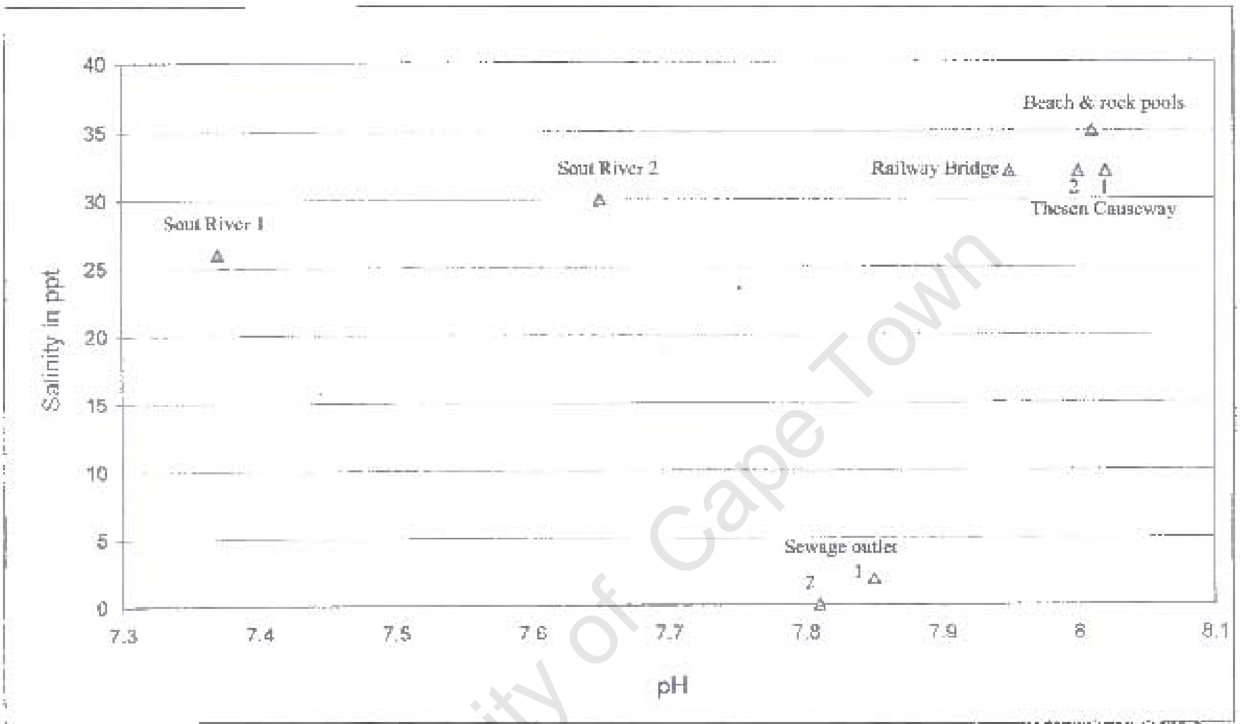
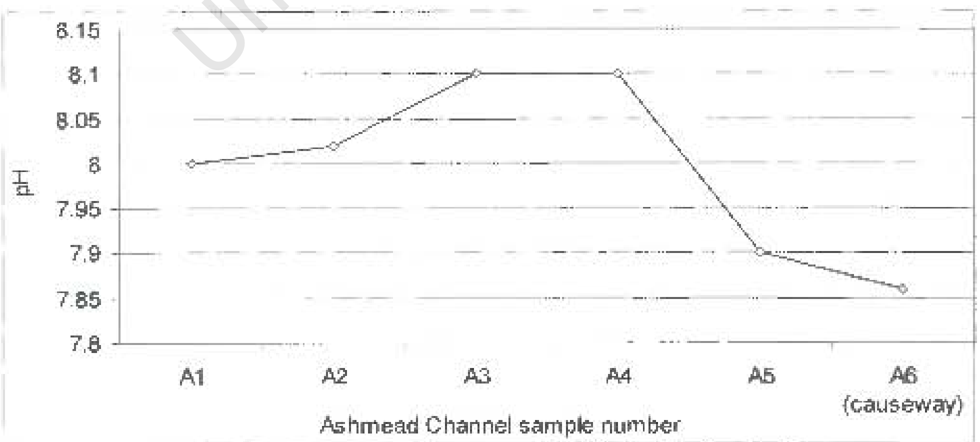


Figure 3.1.7 pH measurements in the Ashmead Channel



3.2 SEDIMENTS

The composition of the sediment varies across the estuary. Samples consist primarily of quartz grains, with subdominant clay minerals and organic material, as well as a few sandstone or rock fragments. Table 3 in Appendix 3 contains the results from the grain-size analyses across the Knysna Estuary. Variations in the percent gravel (>2 mm), very coarse to coarse sand (2 - 0.5 mm), medium to very fine sand (0.5 - 0.06 mm) and mud (<63 μm) of sediment from the main channel of the Knysna Estuary are presented in Figure 3.2.1. Sediment in the lower estuary, near the tidal inlet, is clean and consists predominantly of well sorted, rounded to sub-rounded quartz grains. The middle estuary varies in composition; the clay fraction and organic content increasing with decreasing grain size and current activity. Besides samples 17 and 11, which are very fine grained, resulting from erosion of the nearby saltmarsh areas, the rest of the estuary contains generally well sorted, fine-medium grained sand with sub-angular to sub-rounded quartz grains and occasional Peninsula Formation sandstone rock fragments derived from the catchment area. Samples 6 to 14 are poorly sorted with coarse sand and mud present. The channel bed of the upper estuary (samples 1-6) is poorly sorted and composed of angular to sub-rounded sandstone and quartz cobbles, pebbles, gravel and coarse sand.

The gravel fraction of the upper estuary samples contains only coarse rock fragments and pebbles with no shell material. However, the gravel fraction of samples 19, 29, 30 and 34 consists predominantly of mollusc shells including, predominantly, *Protomella capensis* (gastropod) and minor *Nassarius kraussianus* (gastropod), *Loripes clauses* (white bivalve) and *Solen capensis* (pencil bait). Appendix 2 contains light-microscope pictures illustrating variations in sediment types and shells from selected samples around the Knysna Estuary.

A grain-size analysis of the extra samples collected around the Knysna Estuary allows for characterisation of the sediment types (Fig. 3.2.2). Sediment from the channel behind Leisure Isle and Brenton-on-Sea beach is almost identical in composition, texture and colour. It consists predominately of quartz grains and calcareous shells and shell fragments, in addition to being well sorted, fine-medium grained sand with sub-angular to sub-rounded grains. The sewage-outlet samples consist predominantly of fine sand with <5 % mud content. The Ashmead Channel sediment is similar to that of the sewage outlet, but the mud fraction increases around the channel towards the causeway, where siltation is prevalent. The Railway Bridge side-channel contains abundant shell material, dominating the gravel fraction. *Protomella capensis* is the dominant shell species around the Railway Bridge, which is consistent with the shells from the surrounding main channel samples. The Sout River samples contain immature sediment with abundant angular catchment-derived rock fragments and rare marine material, such as shells. Figure 3.2.3 illustrates the general sedimentological changes across the estuary.

Figure 3.2.1 Grain-size analysis for the main channel samples plotted as a column graph

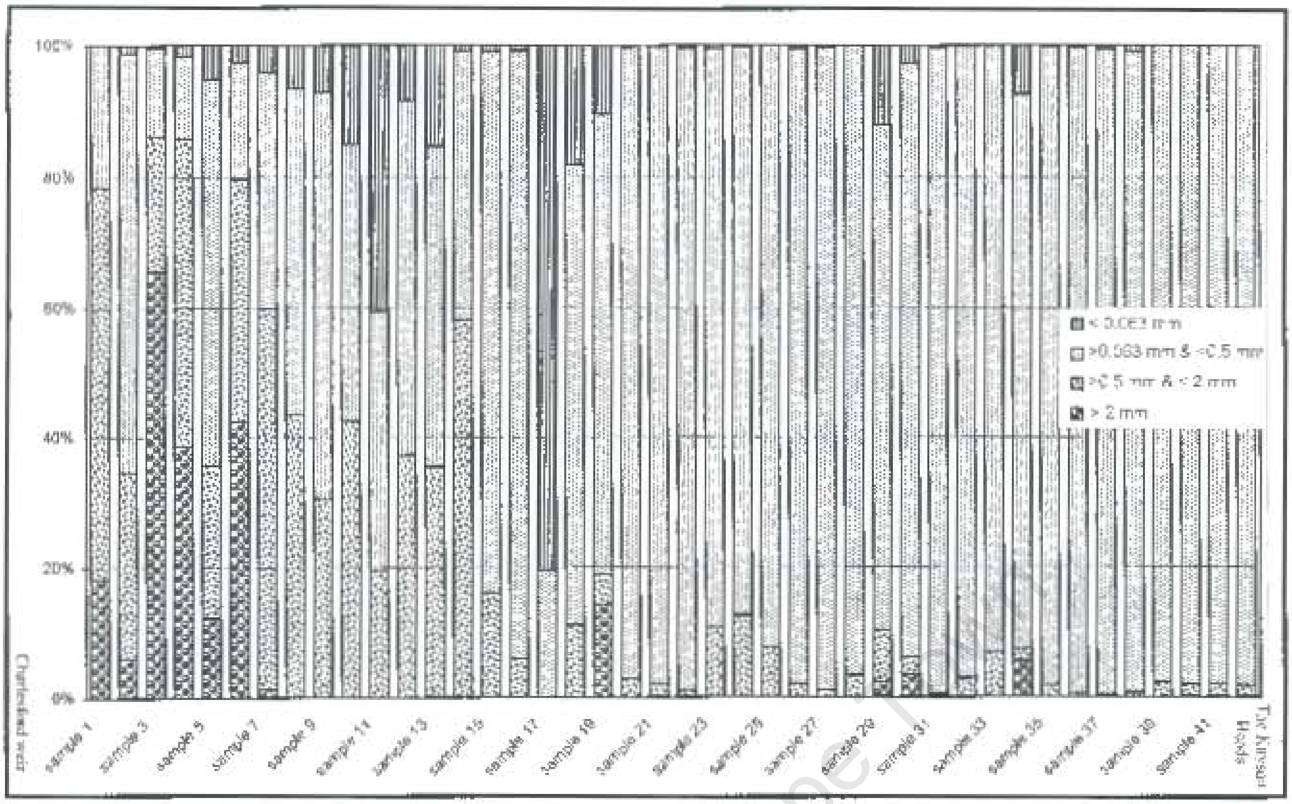


Figure 3.2.2 Grain size analysis of the extra samples collected around the Knysna Estuary

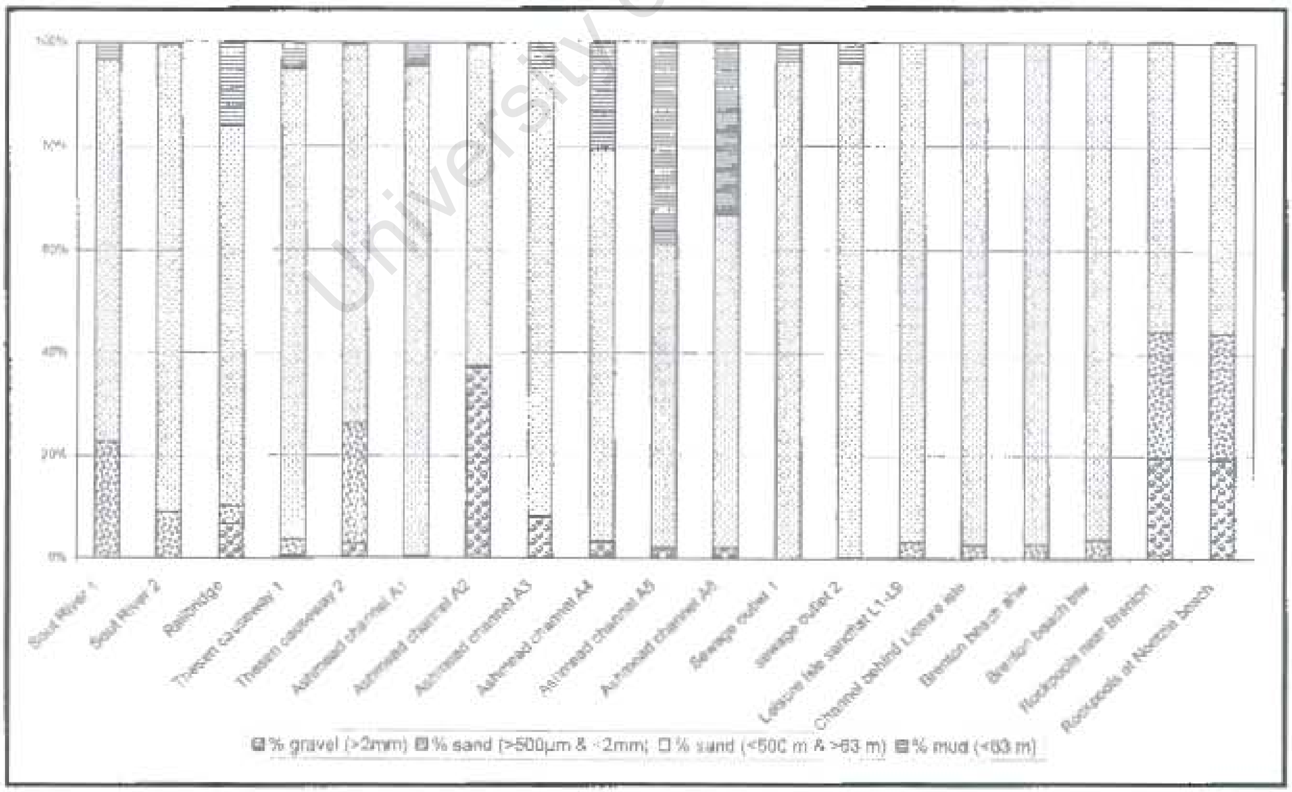
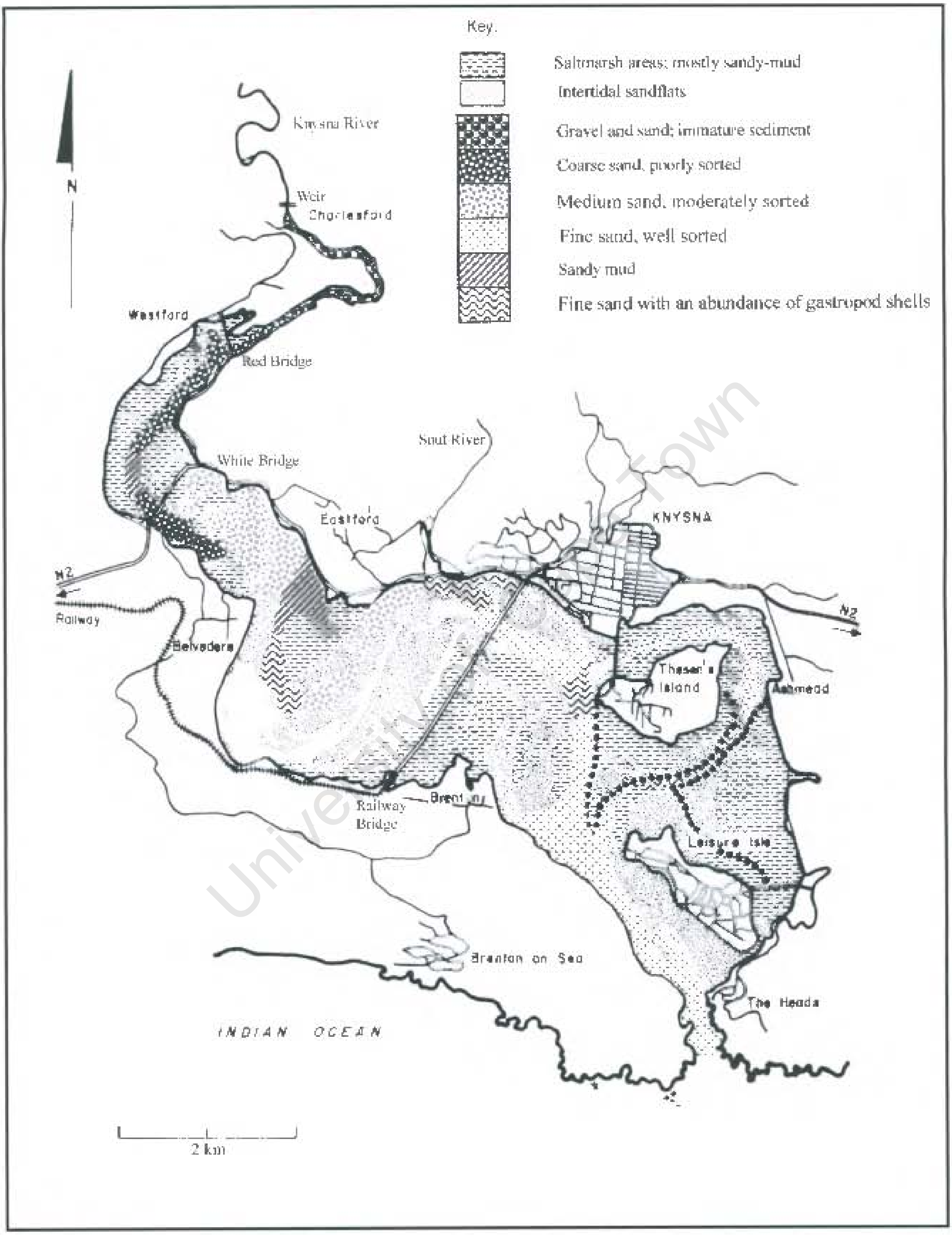


Figure 3.2.3 Grain-size analysis of the sediments in the Knysna Estuary. Adapted from Grindley (1985).



3.3 MICROFAUNAL ABUNDANCE

Individual numbers of foraminifera and ostracods per 20g of the sand fraction vary considerably across the estuary, with low numbers at the Knysna Heads (sample 42, tidal inlet), around the White Bridge and near the head of the estuary (samples 1-3) (Fig. 3.3.1). Samples 17, 19 and 37 contain abundant foraminifera, and samples 19, 27, 29 and 34 contain relatively high numbers of ostracods. Areas upstream of sample 17 (off Belvedere) and seaward of sample 38 have low numbers of ostracod tests. Samples 4-6, 17-19, 26-32 and 34-38 display a relatively high abundance of microfauna (Fig. 3.3.1). There are two dominant species of foraminifera from sample 1 to sample 16, after which species diversity of both foraminifera and ostracods rises considerably, reaching a maximum at sample 37 (south of Thesen Island), and then decreasing towards the mouth of the estuary (Fig. 3.3.2). A total of 105 species of foraminifera were recorded in the Knysna Estuary, whereas only 10 ostracod species were found. For the purpose of this study, ostracod data was not researched further than numbers of individuals and species.

Figure 3.3.1 Relative numbers of foraminifera and ostracod individuals in main channel samples

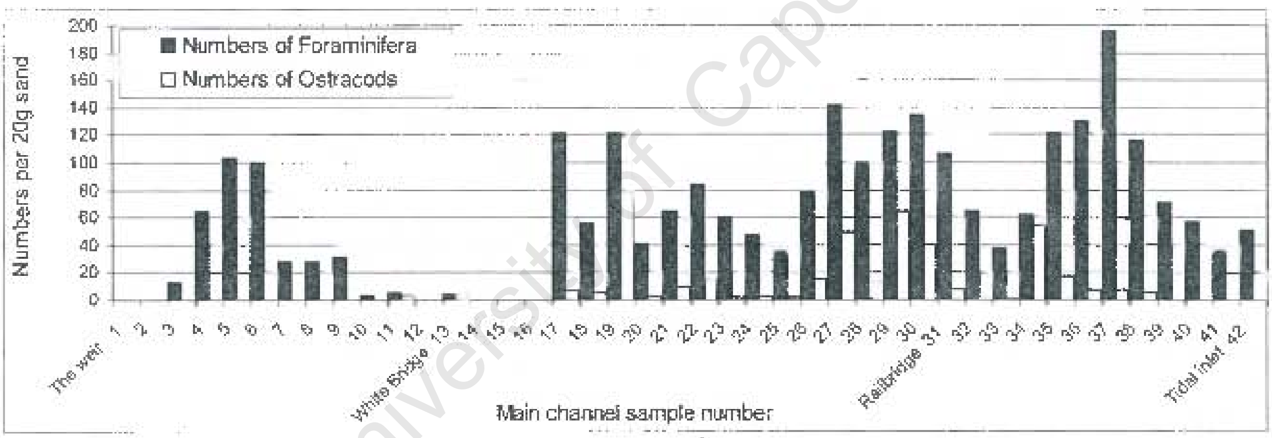
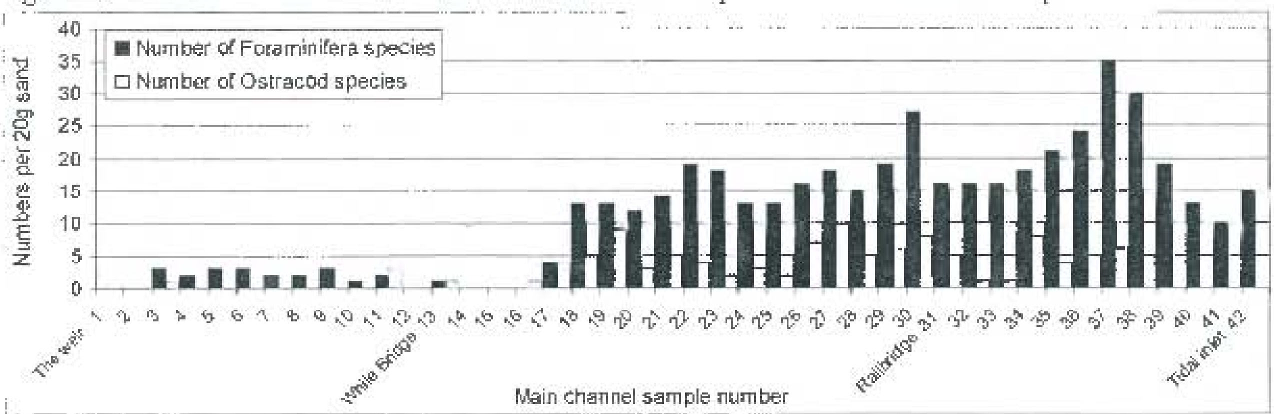
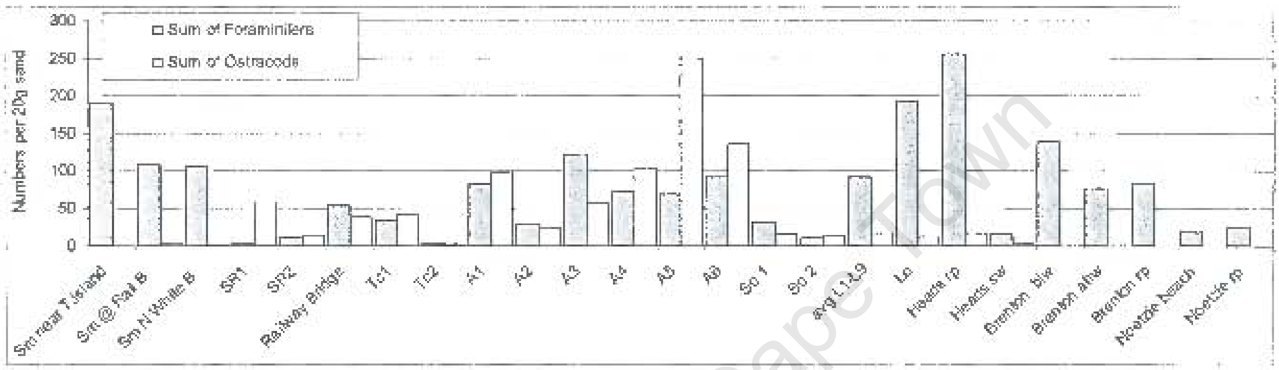


Figure 3.3.2 Relative numbers of foraminifera and ostracod species in main channel samples



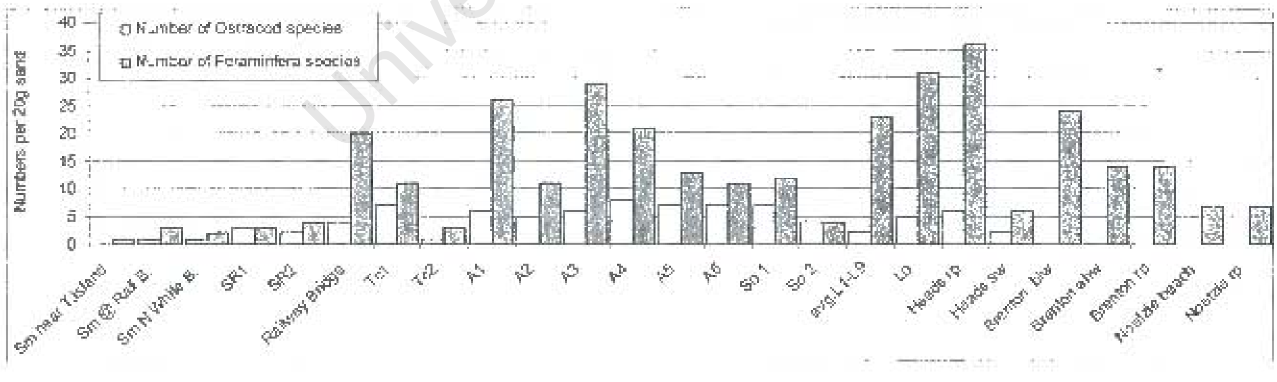
Numbers of foraminifera and ostracods, as well as species of foraminifera, vary considerably between the extra samples collected around the estuary, due to the differing environments (Fig. 3.3.3 and Fig. 3.3.4). The Ashmead Channel, especially sample A5 (north of Thesen Island), and the Railway Bridge side-channel contain ostracods in varying abundances, whereas the saltmarsh and marine-dominated samples do not contain ostracods. The Knysna Heads rock pools are rich in calcareous foraminifera, whereas the saltmarsh areas contain agglutinated foraminifera. Samples from the sewage-outlet channel, the Sout River, and just west of the causeway connecting Thesen Island to the mainland, are relatively devoid of microfauna.

Figure 3.3.3 Numbers of foraminifera and ostracods in the extra samples around the Knysna Estuary



Sm = Saltmarsh; SR = Sout River; Tc – Thesen Causeway; A = Ashmead Channel sample; So = Sewage outlet; L1-L9 = Leisure Isle sandflat samples; Lo = channel behind Leisure Isle; Heads rp = Knysna Heads rock pools; Heads sw = Knysna Heads surface water; blw = below low water; and ahw = above high water.

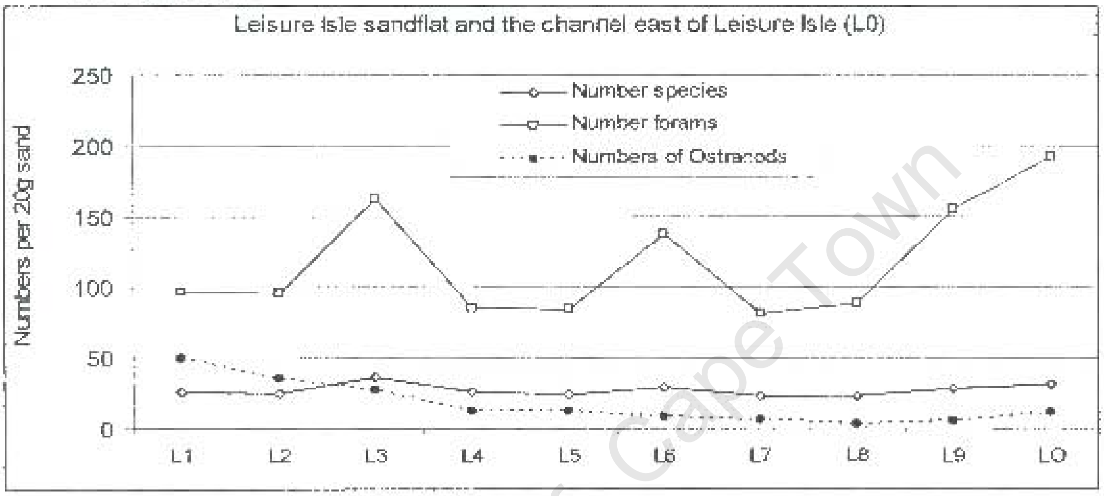
Figure 3.3.4 Numbers of foraminifera and ostracod species in the extra samples around the Knysna Estuary



Foraminifera found in the beach sediments are, almost certainly, not living there, but are non-living tests that have been transported onto the beach and deposited. Most of the living foraminiferal tests found in rock pools around the coast are more robust than ostracod carapaces and can therefore survive in turbulent waters. Ostracod carapaces (shells) may be destroyed in energetic littoral environments, such as the wave-dominated beach environments, rock pools and shallow-water sandflats around the mouth of the Knysna Estuary.

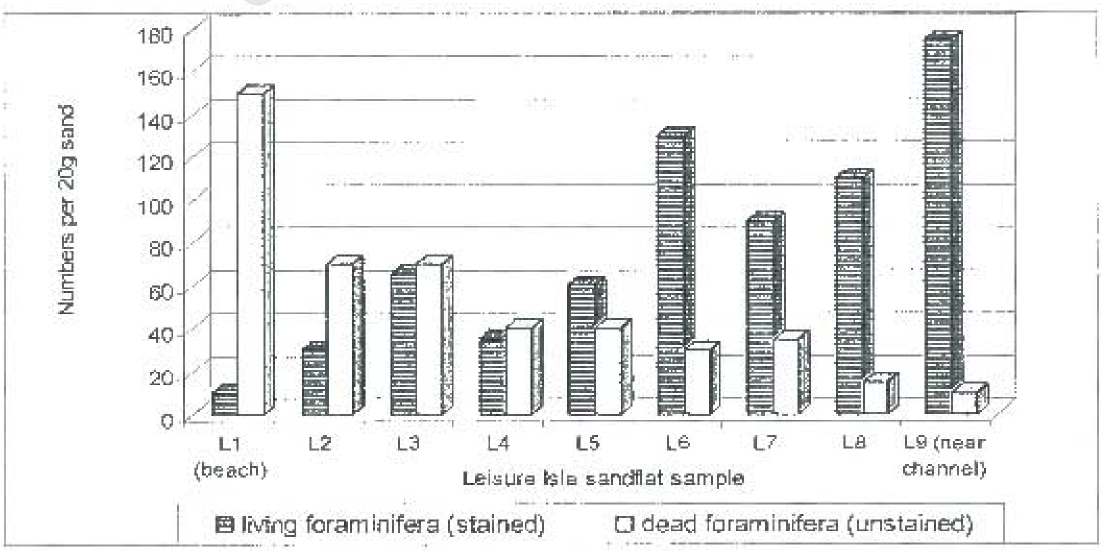
Quartz grains, foraminifera and calcareous marine material, which make up the sediment of the Leisure Isle sandflat are brought in through the tidal inlet and deposited in this area, due to flood-tides transporting and depositing sediment containing foraminifera. Deposition from the water column occurs with the reduction in current strength as the water moves up the sandflat. The numbers of foraminifera are considerably higher than ostracods on the Leisure Isle sandflat (Fig. 3.3.5) and, referring back to Figures 3.3.3 and 3.3.4, it is evident that ostracods are not found in marine-dominated areas such as beach environments and rock pools.

Figure 3.3.5 Numbers of foraminifera and ostracods across the Leisure Isle sandflat and in the channel east of Leisure Isle.



Numbers of living foraminifera (tests stained with Rose Bengal solution) increase across the sandflat, towards the main channel, whereas numbers of non-living tests decrease towards the main channel, illustrating a similar, but opposite, trend (Fig 3.3.6). This may be due to the susceptibility of dead tests to be transported onto the sandflat with the flood tide, thus accumulating away from the main channel.

Figure 3.3.6 Number of living and non-living foraminifera tests across the Leisure Isle sandflat



Contrary to the foraminifera, the numbers of living ostracods decrease steadily towards the main channel from sample L1 to sample L9 (Fig. 3.3.7). The percentage of living foraminifera vs. the percentage of living ostracods demonstrate opposing trends across the sandflat, possibly signifying competition between the microfauna (Table 3.3.1 and Fig. 3.3.8).

Figure 3.3.7 Numbers of living and non-living ostracod tests across the Leisure Isle sandflat

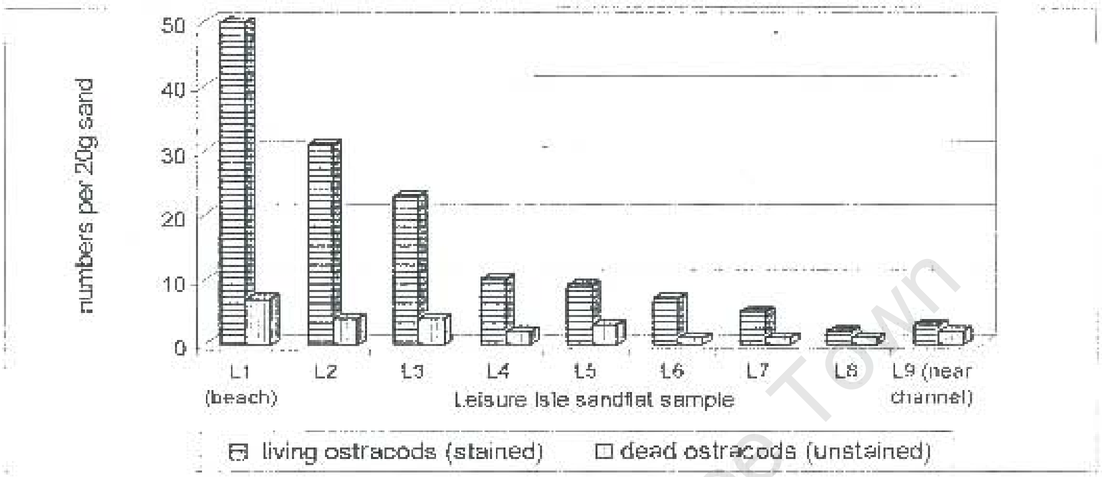
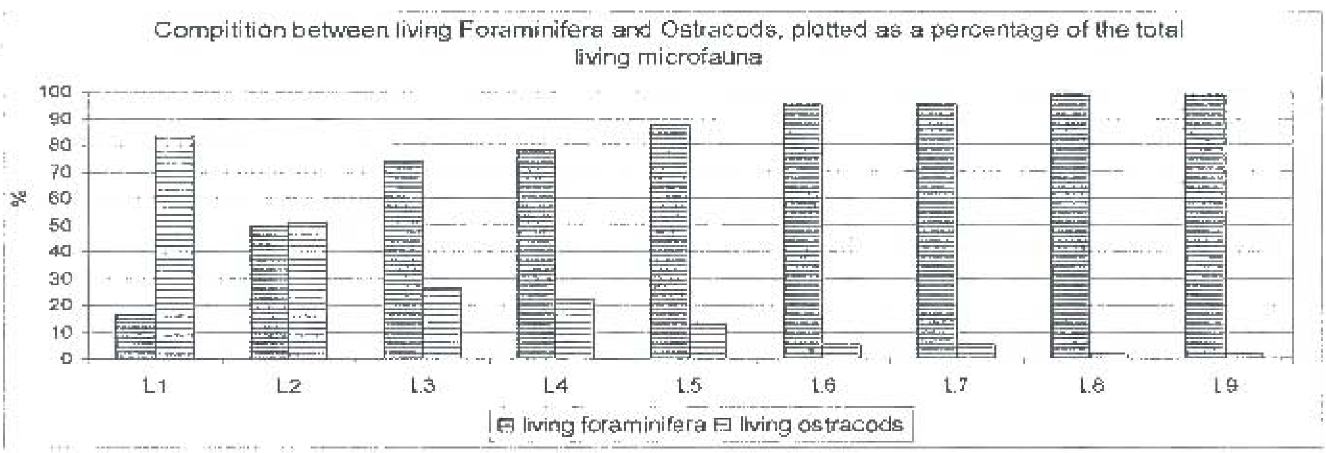


Table 3.3.1 Leisure Isle sandflat: Percentage foraminifera and ostracods stained with Rose Bengal solution.

	number stained ostracods	number stained forams	% living Ostracods	% living Foraminifera
L1	50	10	83.33	16.67
L2	31	30	50.82	49.18
L3	23	65	26.14	73.86
L4	10	35	22.22	77.78
L5	9	60	13.04	86.96
L6	7	130	5.11	94.89
L7	5	90	5.26	94.74
L8	2	110	1.79	98.21
L9	3	175	1.69	98.31

Figure 3.3.8 Percentage of living foraminifera and ostracods across the Leisure Isle sandflat



Microfauna are relatively abundant in the Ashmead Channel due to the nutrient-rich sediment in this area (Figures 3.3.9 and 3.3.10). Foraminiferal species numbers generally follow the same trend as the individual numbers of foraminifera. However, species diversity decreases near the causeway. Sample A5 (Fig. 3.3.10), approximately 100 m east of the causeway, is abnormally rich in ostracods (>300 individuals per ~20 g sand). Samples were stained with Rose Bengal solution to establish the numbers of living and dead foraminifera in the Ashmead Channel. Data from the centre of the Ashmead Channel revealed that there are generally more dead foraminifera than living foraminifera, and there are more living ostracods than dead ostracods in the Ashmead Channel, although no clear trends were portrayed (Figures 3.3.11 and 3.3.12). There is a higher percentage of living ostracods than living foraminifera in the Ashmead Channel (Table 3.3.2), indicating an environment that favours ostracod inhabitancy.

Figure 3.3.9 Foraminifera of the Ashmead Channel

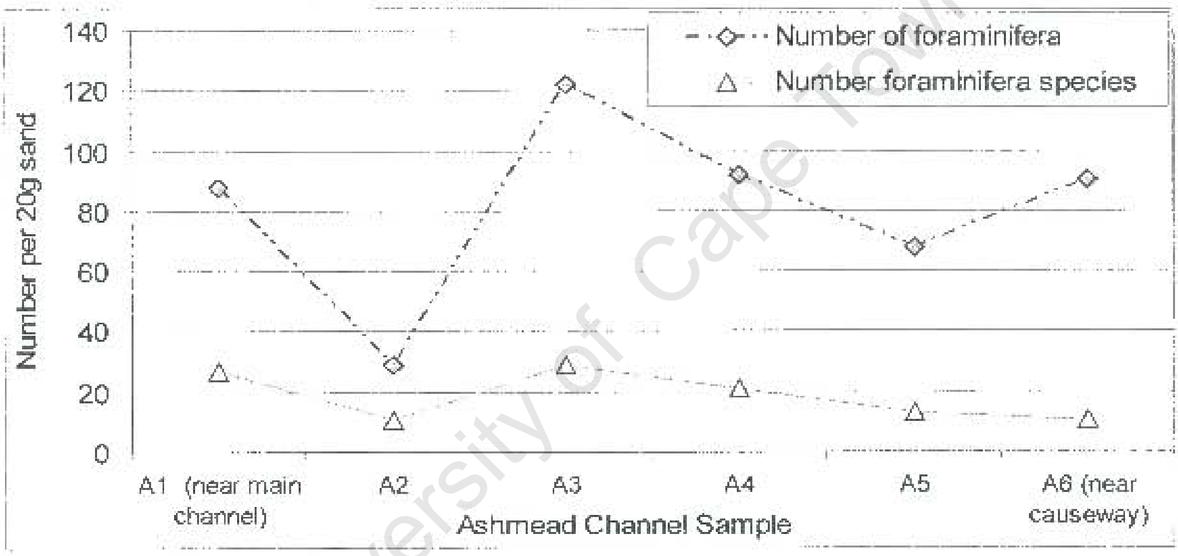


Figure 3.3.10 Numbers of foraminifera vs. numbers of ostracods in the Ashmead Channel

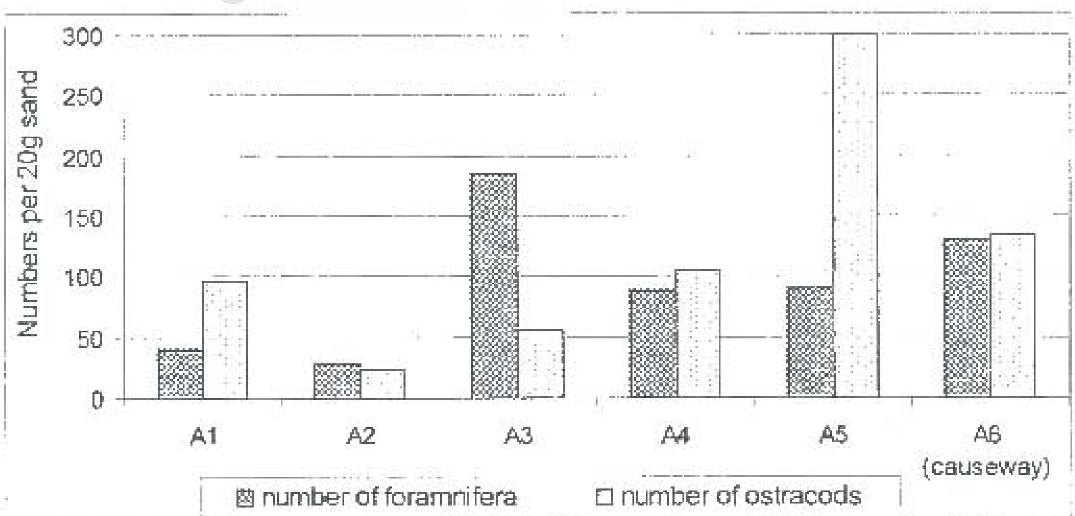


Table 3.3.2 Foraminifera and Ostracods from the Ashmead Channel; percentage stained with Rose Bengal

	Foraminifera % stained	Ostracods % stained
Sample A1	45	70
Sample A2	35	50
Sample A3	56	68
Sample A4	27	60
Sample A5	32	69
Sample A6	36	74

Figure 3.3.11 Ashmead Channel; Percentage of living to non-living (abiotic) foraminifera tests

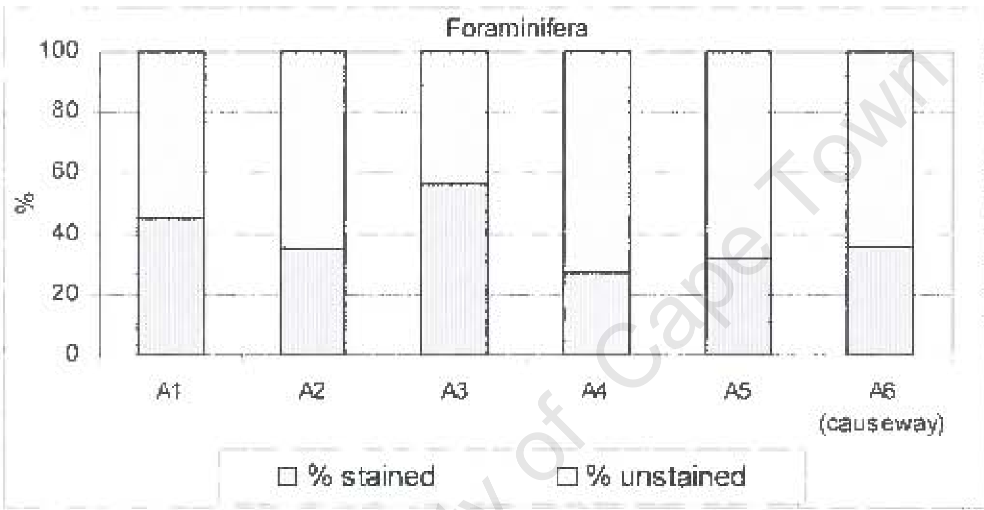
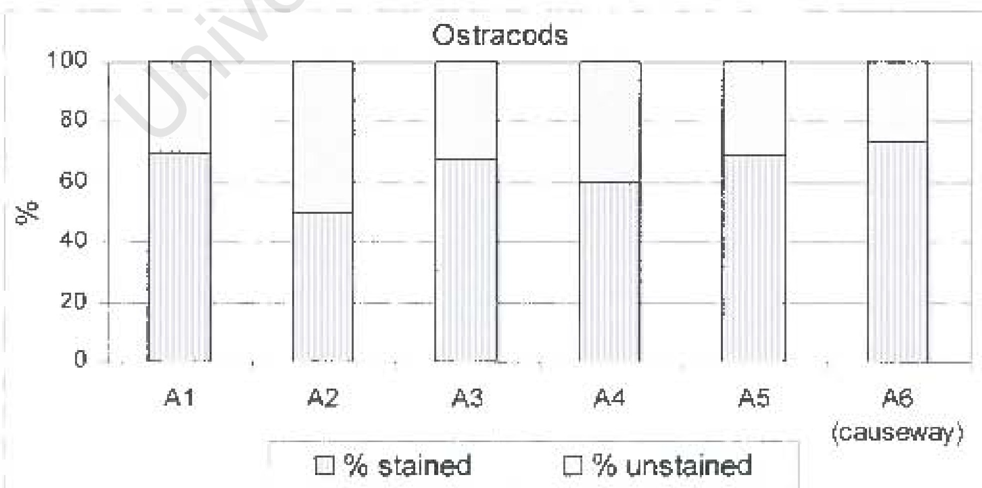


Figure 3.3.12 Ashmead Channel; Percentage of living to non-living ostracod tests



4. Distribution of Foraminifera in the Knysna Estuary

Calcareous Foraminifera

Planktic species are buoyant and may drift into the estuary (alive or dead) from the open ocean. *Nonion boueanus* is a calcareous benthonic, found in the open ocean on the continental shelf. Benthic *Lagena, Oolina* and *Bulimina* species are typical of the continental shelf environment. They live in shallow water (5 – 40 m depth) and can tolerate relatively low oxygen levels (McMillan, 2001. pers. comm.). *Ammonia japonica,* also benthic, lives in shallow-marine environments. *Planorbulina mediterranensis, Lobatula lobatula, Cibicides refulgens, Glabratella* and *Rosalina* species are characteristic of wave-dominated, littoral environments and attach their tests to the substrate. The *Elphidium* species are Holocene in age, benthic, and are generally found in the lower estuary (McMillan, 2001. pers. comm.). Their tests are planispiral and have distinctive septal bridges. *Elphidium crispum* and *Pararotalia nipponica* indicate littoral influence and some may be reworked from the Late Pleistocene, resulting in specimens being abraded and bleached. Miliolids can either have 5 chambers (*Quinqueloculina* spp.), 3 chambers (*Triloculina* spp.), or 2 chambers (*Pyrgo* spp.) and/or they arrange their chambers around each other; for example *Spiroloculina* and *Miliolinella* species. When in abundance, they generally indicate hypersaline conditions. Chambers are arranged at specific angles to each other and the aperture often has a tooth in it, which varies in shape and size between species (refer to plates 8-11 in Appendix 5). All these species may be washed further into the estuary by wave and tidal action. *Ammonia parkinsoniana* is a typical benthic, lower-estuarine species, abundant in the channels. This is the most abundant foraminiferal species found in the Knysna Estuary and is a common occurrence in estuaries all around the South African coastline (McMillan, 1987). When found in abundance this species indicates reduced salinity compared to ocean water and may be accompanied by other typically estuarine foraminifera such as *Haynesina germanica* and *Rotalia gaimardii.*

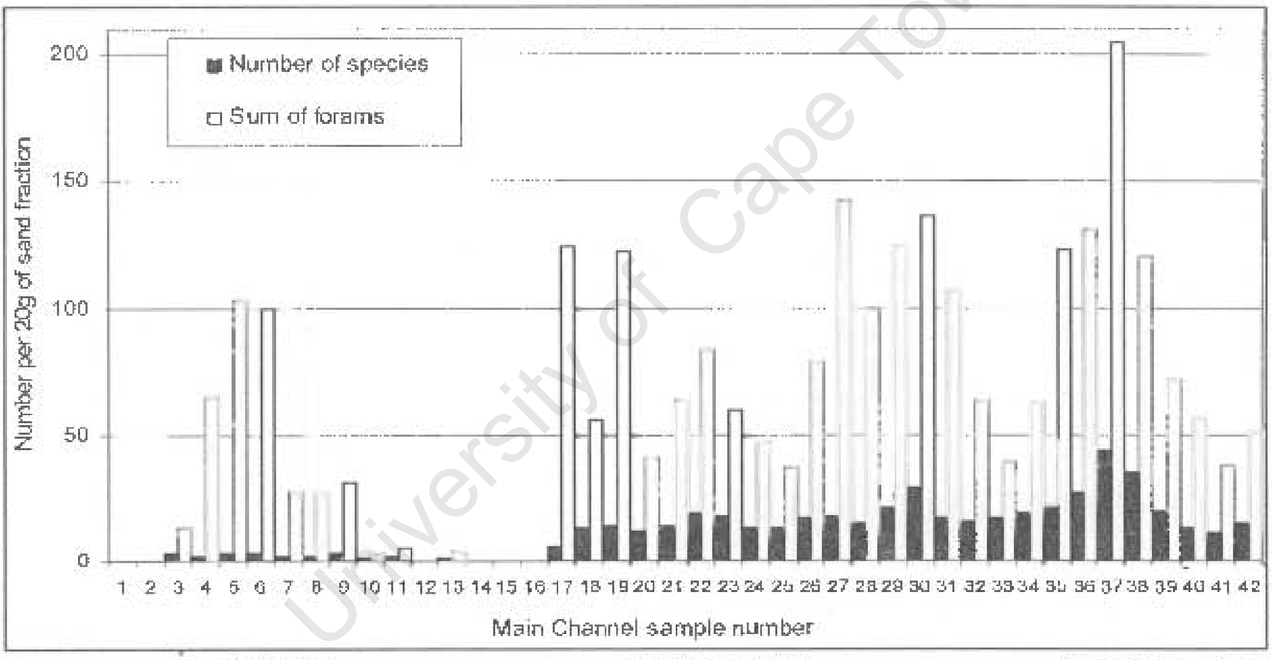
Agglutinated Foraminifera

Foraminifera that live on the intertidal saltmarsh areas are all agglutinated. *Trochammina inflata* are benthic and generally creamy-brown in colour. They are characteristic of saltmarshes in estuaries around southern Africa and globally. They can tolerate relatively low salinities in acidic soils and are associated with abundant organic material. *Haplophragmoides wilberti* and *Haplophragmoides canariensis* belong to the same family as *Trochammina inflata,* but the former can also be found in mangrove swamps and thrives on the warmer east coast of South Africa. The latter is more typical of the inner shelf sediments (McMillan, 2001. pers. comm.). They are planispiral (identical on both sides) and involute (can only see chambers of the last whirl). The species *Miliammina fusca,* also found world-wide, lives in low-salinity, upper-estuarine marsh environments, indicating fresh water influence (McMillan, 2001. pers. comm.). Marine or littoral agglutinated foraminifera include *Textularia conica, Gaudrina rudis* and *Spiroplectinella sp.*

4.1 DISTRIBUTION OF FORAMINIFERA IN THE MAIN CHANNEL SAMPLES

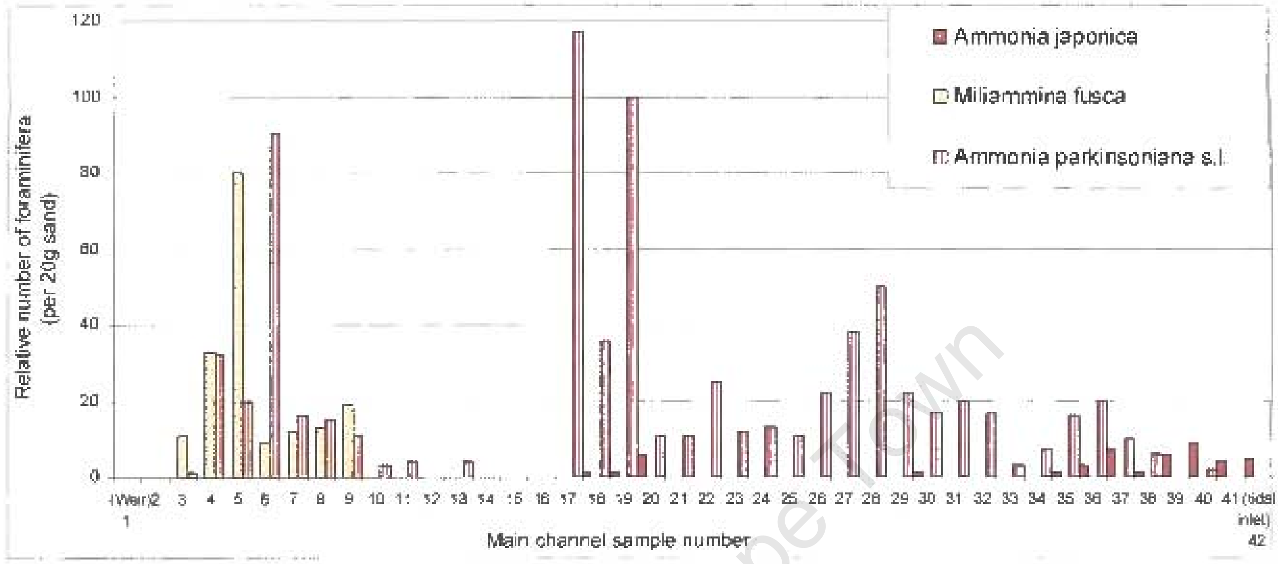
Total individual foraminifera numbers and foraminiferal species numbers vary considerably throughout the Knysna Estuary (Fig. 4.1.1 and Table 4.1.1). Species distributions in this chapter will be discussed from the weir at the head of the estuary to the Knysna Heads (tidal inlet), so as to correlate with the tables and illustrations. The upper estuary consists predominantly of two species of foraminifera. Samples 22 to 37, upstream and downstream of the Railway Bridge, display the richest foraminiferal diversity in the Knysna Estuary. Species typical of shallow-marine conditions are found in relatively low numbers in these samples and fifteen species dominate the sediments of this region of the estuary (Table 4.1.1). In the lower estuary, near the tidal inlet, species diversity in the sediments drops and foraminifera become scarcer. Eight species of foraminifera dominate the microfaunal assemblage near the Knysna Heads (Table 4.1.1).

Figure 4.1.1 Relative numbers of foraminifera individuals and species along the Knysna Estuary.



Samples 1 and 2, collected at the head of the estuary, where the water salinity is virtually zero, do not contain foraminifera. Samples 3-9, between the Charlesford Weir and the Old Bridge (Refer to Fig. 3a), are relatively rich in foraminifera, although only two species, *Miliammina fusca* and *Ammonia parkinsoniana s.l.*, thrive in this region of the estuary (Figure.4.1.2). Samples 11-16 appear to be inhospitable to foraminifera. Only ten *Ammonia* specimens were recorded in this section of the main channel (~2.7 km), in the vicinity of the White (N2) Bridge. Downstream of this barren area, foraminiferal diversity increases rather dramatically, with a sharp increase in *Ammonia parkinsoniana* numbers to ~117 per 20g sand (Fig. 4.1.2), and the foremost appearance of planktic species (2 recorded) in sample 17, after which no planktic species are recorded until sample 26, which is ~9 km from the tidal inlet (Table 4.1.1). The planktic species recorded in sample 17 were probably transported upstream during flood tides.

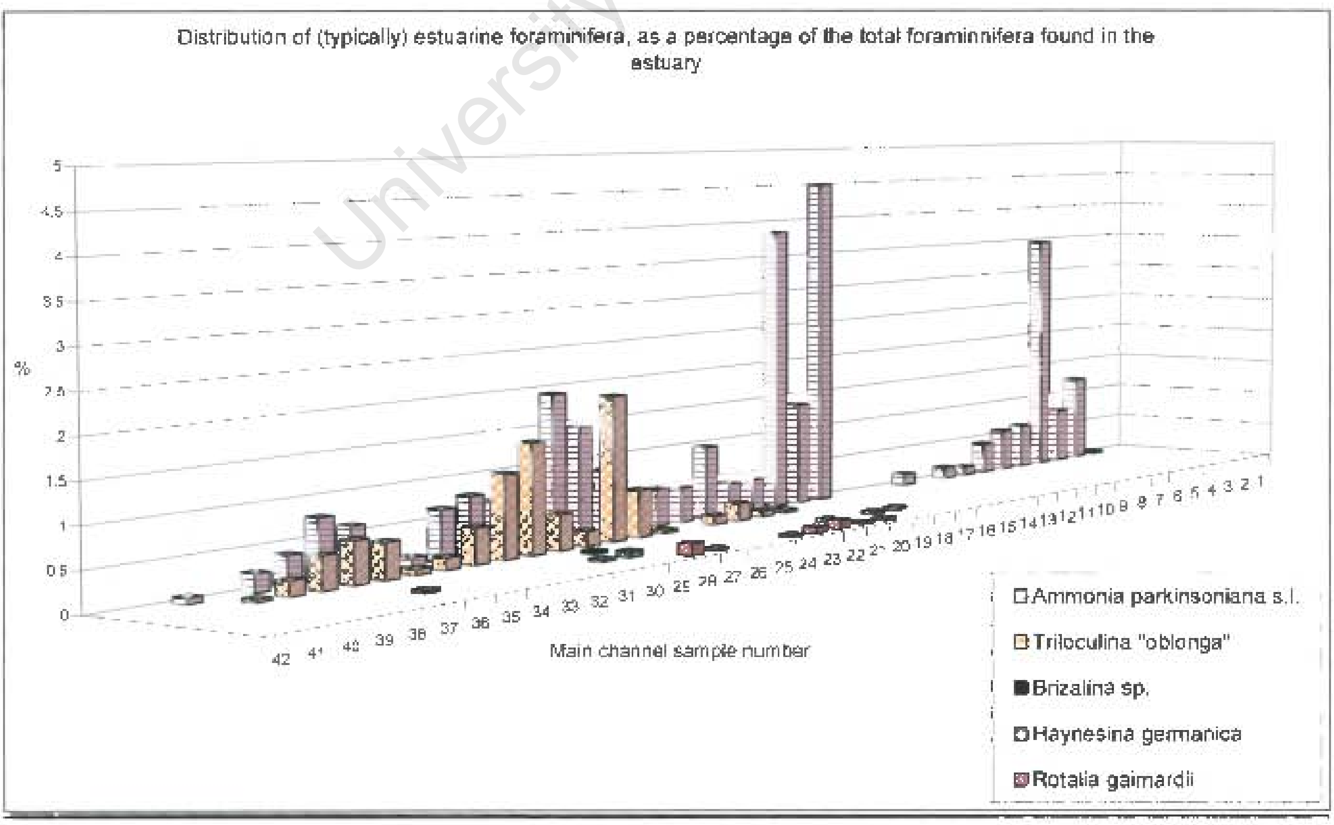
Figure 4.1.2 Distribution of *Miliammina fusca*, *Ammonia parkinsoniana* s.l., and *Ammonia japonica* across the Knysna Estuary.



Sample 18, off Belvedere, displays the first *Haynesina germanica*, a typically estuarine species (Fig. 4.1.3). *Elphidium crispum* emerge in the Knysna Estuary sediments at this point (Table 4.1.1) and remain present to the mouth of the estuary. In the middle estuary (sample 18 to ~ sample 30), most *Elphidium crispum* species are abraded and broken, indicating transportation of non-living tests. From the Railway Bridge to the tidal inlet of the estuary, the numbers of abraded *Elphidium crispum* become less and near The Heads *Elphidium crispum* tests are all large and well-preserved. Low numbers of foraminifera, that are typically indicative of littoral environments, were also documented in sample 18, such as *Lobatula lobatula, Pararotalia nipponica, Bulimina* sp., *Lagena* sp. and *Oolina* sp. (Table 4.1.1), but these specimens are most likely non-living tests that were transported upstream with flood tides. Downstream of sample 18, *Elphidium* species and miliolids such as *Quinqueloculina* and *Triloculina* species increase in abundance (Table 4.1.1). Sample 20 presents the appearance of *Rotalia gaimardii* and living *Quinqueloculina dunkerquiana*, *Triloculina "oblonga"* and *Triloculina trigonula*. *Rotalia gaimardii* is a typically estuarine species and in the Knysna Estuary it is found, in low numbers, from sample 20-28, therefore confined to an area in the main channel of just over 2 km, between the Railway Bridge and the White Bridge (Figure.4.1.3). In this region of the estuary, the subtidal main channel meanders between constrictive intertidal sandbanks, thus providing a more tranquil environment, compared to the area seaward of the Railway Bridge. Figure 4.1.3 illustrates the distribution of species of foraminifera that are estuarine in nature.

Quinqueloculina dunkerquiana is present in all samples from sample 20 to the tidal inlet of the estuary. However, seaward of the Railway Bridge most of the specimens, if not all of them, are orange in colour and abraded, indicating reworking from (possibly) the latest Pleistocene. *Quinqueloculina dunkerquiana*, therefore, thrives in waters slightly less saline than seawater. Seaward of the Railway Bridge, the sediments not only include more foraminifera of marine origin, but also become more enriched in marine material such as shells, echinoid spines, algal fragments etc. *Triloculina oblonga*, *Triloculina trigonula*, and *Triloculina tricarinata* are non-ornamented miliolids that exist in salinities a little lower than sea water. *Triloculina oblonga*, the dominant estuarine miliolid, and *Triloculina trigonula* can be found living in the main channel from sample 20 to sample 38 (Table 4.1.1), which is sited ~2 km inland from the Knysna Heads, where the main channel becomes constricted between the Western Head and the Leisure Isle sandflat. *Triloculina tricarinata* appears in sample 22 and its presence continues, in low numbers, until sample 32, just downstream of the Railway Bridge (Table 4.1.1). *Elphidium macellum* is found in low numbers from sample 20, approximately midway between the White Bridge and the Railway Bridge, to sample 32, just downstream of the Railway Bridge (Table 4.1.1). *Elphidium macellum* usually thrives in littoral environments and was probably washed upstream and deposited landward of the Railway Bridge. Species typical of shallow-marine settings are also found dispersed between some sediment samples of the middle estuary. For example, *Rosalina sp.*, *Gavelinopsis praegeri*, *Bulimina sp.*, *Oolina sp.*, *Lagena sp.* and agglutinated species such as *Textularia conica*, *Gaudrina rudis* and *Spiroplectinella sp* (Table 4.1.1).

Figure 4.1.3 Typically estuarine foraminiferal species and their abundance throughout the Knysna Estuary.



Fifteen species dominate the sediments of samples 22 to 37, between Belvedere and Leisure Isle (Table 4.1.1). Specifically, *Ammonia parkinsoniana, Elphidium crispum, Elphidium articulatum, Elphidium macellum, Elphidium advenum, Haynesina germanica, Rotalia gaimardii, Triloculina oblonga, Triloculina trigonula, Triloculina tricarinata, Quinqueloculina dunkerquiana, Cibicides refulgens, Pararotalia nipponica, Poroeponides lateralis* and *Lobatula lobatula* (Table 4.1.1). *Cibicides refulgens* and *Pararotalia nipponica* were first found in sample 20 and are recorded in all the subtidal samples, in increasing abundance, to the Knysna Heads. *Poroeponides lateralis* appears in sample 24 and is a constituent in all the samples seaward of this point. The first specimens of *Planorbulina mediterranensis* and *Spiroloculina communis* (miliolid) are found in sample 23, although *Planorbulina mediterranensis* is most abundant in samples 35 to 39, 4 km to 1.5 km upstream from The Heads respectively (Table 4.1.1). These species are typically littoral in nature, although they can evidently tolerate the lower mid-estuarine salinities of 30-33 ‰.

Sample 37 contained the most foraminifera recorded in the main channel of the Knysna Estuary (Fig. 4.1.1), as well as the highest diversity in foraminiferal species. This sample is located near the entrance to the Ashmead Channel, about 1.7 km upstream from the Knysna Heads. The Ashmead Channel illustrates relatively high numbers of foraminifera, and due to sample 37 being located at the confluence of these two channels, the sediments contain foraminifera that are transported from the Ashmead Channel, as well as living and non-living tests that are living in the main channel and those transported up and down the main channel by tidal currents.

Eight species dominate the turbulent sediments near the Knysna Heads (Table 4.1.1). These are *Ammonia japonica, Elphidium crispum, Pararotalia nipponica, Cibicides refulgens, Poroeponides lateralis, Lobatula lobatula, Planorbulina mediterranensis*, and *Miliolinella subrotunda*. *Ammonia japonica* is found in samples 18, 19 and 20, but was probably transported to this region of the estuary, since it thrives in more marine environments. From sample 35 to sample 42 (between The Heads), *Ammonia japonica* becomes the dominant *Ammonia* species, whilst *Ammonia parkinsoniana* numbers decrease rapidly in this region. *Ammonia parkinsoniana* is the classically estuarine *Ammonia* species, dominating the microfaunal communities over most of the estuary, but gives way to *Ammonia japonica* when littoral sea-waters prevail (refer back to Fig. 4.1.2). *Miliolinella subrotunda* is found living (well preserved) in samples 36 to 40, off Leisure Isle. Other miliolids that live in shallow-marine, littoral environments are *Quinqueloculina contorta, Quinqueloculina seminulum* and ornamented species of *Triloculina*, such as *Triloculina terquemiana* and *Triloculina bertheliniana*. Figure 4.1.4 displays the distribution and relative abundance of the most dominant foraminiferal species in the main channel of the Knysna Estuary.

Figure 4.1.4 Distribution and relative abundance of the most dominant foraminiferal species in the main channel of the Knysna Estuary.

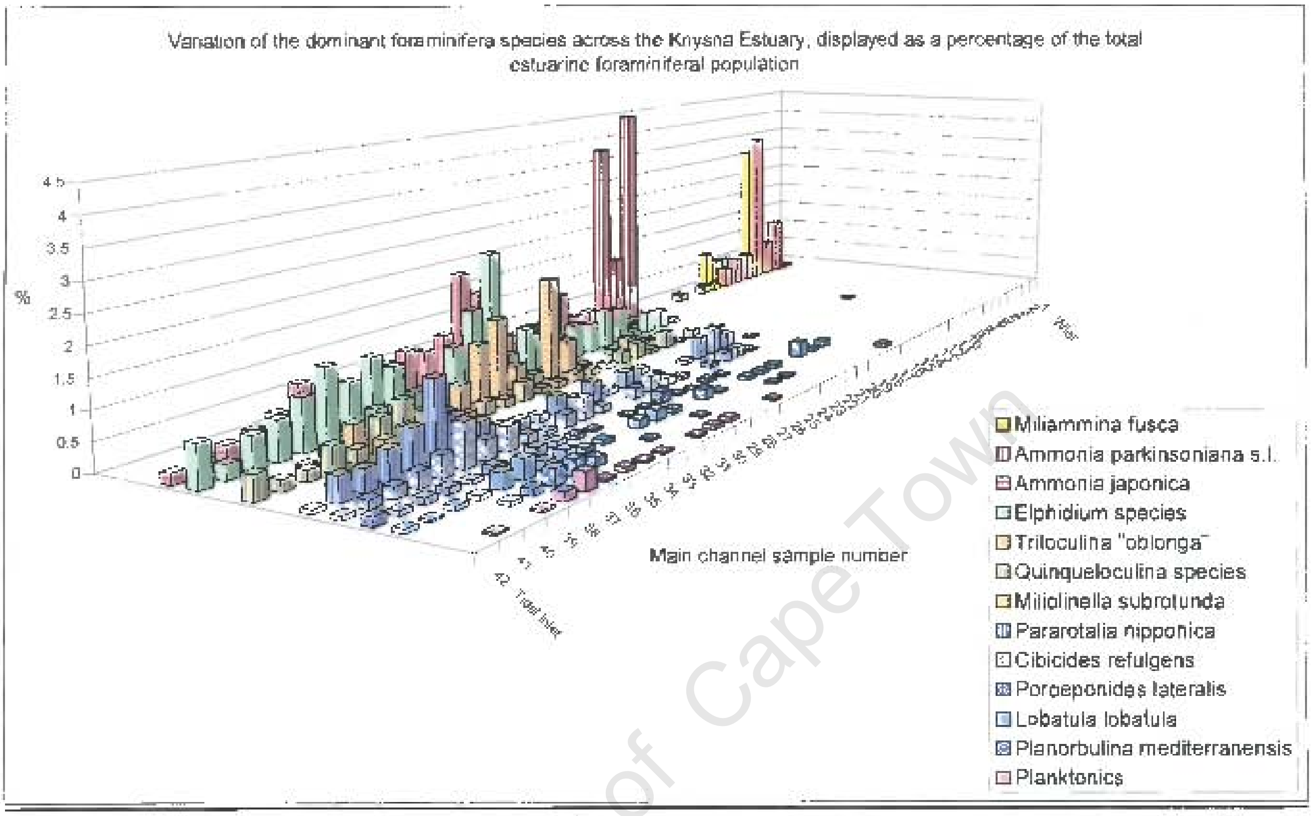


Table 4.1.1 Species of foraminifera recorded in the main channel samples of the Knysna Estuary

FORAMINIFERA / SAMPLE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Trochammina inflata					8													2	1																							
Haplophragmoides wilberti			1								1																															
Miliammina fusca			25	31	30	5	12	13	19																																	
Ammonia parkinsoniana s.l.			1	32	28	50	16	14	11	3	4		4				117	36	100	11	11	26	17	13	11	22	34	52	22	17	20	11	3	7	18	28	10	8		2		
Ammonia species																		1	1	4										1					1	1	7	5	6	9	4	5
Bolivina striatula																	1																									
Brizalina sp.																													1													
Haynesina germanica																		1	1		1								2	1						1						
Rotalia gaimardi																				1	1	3	2	1			1	4														
Elphidium cf. articulatum																	2				1																	6				
Elphidium articulatum																			3	1					1	2	1		46	15	2	1		1			2					
Elphidium advenum																		2		1		2			1					6	9	1		2	6	4	7	6	4			1
Elphidium cf. advenum																										1	5		6	15	3		1	2	2	2	7	6				
Elphidium cf. alvarezianum																		2	3										2	2						2	6				1	
Elphidium crispum																		4	4	1	12	14	14	16	11	16	12	12	6	2	10	6	9	20	24	14	13	7	14	16	6	19
Elphidium macellum																			1		6	3	1	1			1	1	1		1	1				1						
Elphidiella sp.																		1																								
Triloculina "oblonga"																				1	2	6	3		1	18	44	5	13	37	28	12	4	2	12	14	11	6	5			
Triloculina trigonula																				1		1	7	3		2	2			1	3	2	1	1	6	1		2				1
Triloculina tricarinata																						1			1	1	1	2				2										
Triloculina larquemiana																					1									2					1		1	1			2	
Triloculina bertheliniana																																					1					
Triloculina fichteliana																																					1					
other *Triloculina sp.*																						1	2					1	1				1	1			1				1	
Quinqueloculina cf. vulgaris																	1							1			1	1	1	1	1				2							2
Quinqueloculina bunkerguiana																				1	6		6	6	3	2	2	2	2	6	2	3	3	1	10	11	8	2	6	3	5	6
Quinqueloculina seminulum																										1				1	1			2			2	2	2	2		
Quinqueloculina contorta																						2	1				1			1			1			3	7	1	1			
Quinqueloculina cf. undulata																			1																							
Quinqueloculina lata																							1									1					1					
Quinqueloculina cf. curta																																				1						
other *Quinqueloculina* species																			3															3				1				
Spiroloculina communis																						1	1			1		4			1	1						2		3		1
Spiroloculina sp.																										1																
ribbed *Spiroloculina sp.*																														2							1	1				
Miliolinella subrotunda																																				2	14	12	1	1		
Sigmoilina sp.																																					1					
Textularia conica																			1							1	1	1		1					2				1			
Gaudryina rudis																							1	1			1								1					1		1
Spiroplectinella sp.																																	1				1					
Pararotalia nipponica									1									1		6	13	11	2		1	7	8	3	9	6	8	4	6	6	14	17	36	19	18	10	11	2
Cibicides refulgens																				1	5	6	2		2	4	8	6		3	10	6	2	4	11	9	28	18	7	5	4	2
Cibicidoides pseudoungerianus																					2				1			2		2		1	1	1		1	1	1		1		1
Cibicidoides sp.																								1											1							
[illegible] lateralis																								1	2		1	5	1	1		1	2	3	4	1	4	2	8	3	2	4
Glabratella patelliformis																						1				1																
Glabratella sp.																																					1					
Lagena species																		1												1							4	2	1			
oolina species																		1				1							2	2						2		3	1			
Lobatula lobatula																		3	2	2		2	2	2		1	5		2	6	4		2	2	6	4	6	7	2	2	1	3
Planorbulina mediterranensis																							1	1					1			1			4	7	7	3	2			
Rosalina bradyi						1																1								1							1		1			
Rosalina williamsoni																						1																				
Rosalina cf. globularis																																	1	1				1				
Gavelinopsis praegeri																									1				1	1							6		1			
Bulimina marginata																		1																								
Bulimina elongata																														2			1	1			2	2				
Bulimina [illegible]																																			1							
Hemisphaerammina bradyi																					1		1	1													2	1				
Acervulina sp.																																			1	1		2				1
Forams reworked from Pleistocene																			1		1	1	1		1				1		2				1	1						
Cassidulina laevigata																																				1	1	1				
Cancris auriculus																																					1					
Nonion [illegible]																																						2	1			
Chrysalidinella dimorpha																																					1					
Notorotalia clathrata																																										1
Planktonics																	2									1			2	2	1		1	1	2	1	4	4	1		1	
Sum of Foraminifera	0	0	13	65	109	100	28	26	31	3	6	0	4	0	0	9	121	56	122	41	64	84	60	47	37	78	142	100	129	134	106	64	38	82	121	130	106	116	71	57	37	51
Number of Foraminifera species	0	0	3	2	3	3	2	2	3	1	7	0	1	0	0	0	4	15	13	12	14	19	18	13	13	15	18	15	16	27	19	19	15	18	21	24	38	20	19	13	10	15
Number of Ostracods	0	0	0.5	0	0	0	0	0	0	0	3	0	5	0	0	0.5	8	5	40	3	10	15	2	3	2	13	50	13	65	40	7	0.5	1	55	17	8	3	5	0	0	0	0
number of Ostracod species	0	0	1	0	0	0	0	0	0	0	3	0	1	0	0	1	4	5	9	3	6	4	2	3	2	7	10	5	6	6	5	1	1	6	4	5	6	5	0	0	0	0

4.2 Foraminifera of the extra samples collected around the Knysna Estuary

Species numbers and diversity vary considerably around the Knysna Estuary (Table 4.2.1), particularly when evaluating localities such as the Sout River, which flows into the main channel of the estuary between the Railway Bridge and the White Bridge, a side channel beneath the Railway Bridge, the Ashmead Channel, which flows around Thesen Island, the sewage-outlet channel, which enters the Ashmead Channel, the Leisure Isle sandflat and the channel behind Leisure Isle, the coastal rockpool and beach environments between, and on either side of, the Knysna Heads, and the saltmarsh areas on the mudflats surrounding the estuary. The following subsections explain the foraminiferal assemblages recorded in these samples.

Figure 4.3.1., at the end of the chapter, illustrates a summary of foraminiferal distributions and relative abundance across the Knysna Estuary, demonstrating certain important foraminiferal species from the main-channel samples as well as the extra samples collected around the estuary.

Table 4.2.1 Species of foraminifera recorded in samples, other than the main channel, collected around the Knysna Estuary

	[illegible] samples			Sour Bank		Rail bridge	Thesen Causeway		Ashmead channel						Sewage outlet		Leisure Isle sandflat									[illegible]	Samples in marine conditions						
FORAMINIFERA / SAMPLES	Sw of Thesen I.	beside rail bridge	north of [illegible] bridge	1	2	side channel	1 (west)	2 (east)	A1	A2	A3	A4	A5	A6	1	2	L1	L2	L3	L4	L5	L6	L7	L8	L9	1a	Heads Blind pool	Heads a.w.	Brenton beach sand b.t.w	a.t.w	Brenton rock pool	Noetzie Beach sand	Noetzie Rock pool
Trochammina inflata	~190	~190	~190		1	2						1		3	1	1																	
Haplophragmoides wilberti						1																											
Haplophragmoides canariensis									1		1																						
Miliammina fusca		~2	~14		8								2	1																			
Ammonia parkinsoniana s.l.		~3	~1		3	2	11	1	8	1	9	15	38	52	2	3	1	5	5	1	1	2	4	1	2	7	3		1				
Ammonia japonica											2	4	3	2			2	4	8	5	2	10	5	6	10	22	46		86	8	3		
Brizalina striatula																																	
Brizalina pseudopunctata									3																								
Brizalina sp.																																	
Haynesina germanica						2			1							3			4		1												
Rotalia gaimardi																																	
Elphidium cf. *articulatum*							1		21	6	22	16	22	21			9	18	12	5	1	1	1		8	4							
Elphidium articulatum						4			8	7	16			1					1		1					2	1						
Elphidium advenum											1	2															8					2	1
Elphidium cf. *advenum*						9			1		1																						
Elphidium cf. *alvarezianum*									1	1	1				1		4	1	1	1	1		1	1	2	1	1						
Elphidium crispum						1	2		2	4	3	4	1	3	2		7	5	14	10	5	18	12	4	12	14	18		10	12	17	2	6
Elphidium macellum									1	1							2	1	7	1	3	1	2	4	7	14	10		5	3			
Elphidium gunteri																											1						
Elphidiella sp.									1		2		1																				
Triloculina "oblonga"									8		11	6	2													2							
Triloculina trigonula											2	4								2	1	1	2		2	8	14			2	4		
Triloculina tricarinata						4					3	1							1		1			4		2	3						
Triloculina terquemiana											2	1					1	1	8	1			1		1		3		1				
Triloculina berthelotiana																	1		1														
Triloculina bosciana																																	
other Triloculina species				1		2				5					8												1						
Quinqueloculina cf. *vulgaris*																										1			1				
Quinqueloculina duthiersi							1	1	3	1	5	2	1				4	4	6	4	4	9	5	2	8	8	3		27	3	5	1	1
Quinqueloculina seminulum									3	1	4	1					3		8		1	2	1	1	4	1					2		
Quinqueloculina costata							1										1	4	2		1		1	1	1	2	3		1		1		
Quinqueloculina lata						4					8	1					1			1		1											
Quinqueloculina cf. *undulata*																																	
Quinqueloculina cf. *cyclo*																																	
other Quinqueloculina species				11	1	1	1								3	4		1	1			1											
Spiroloculina communis									1								1					2				4	1		1				
Spiroloculina sp.																																	
ribbed *Spiroloculina* sp.												1							1														
Miliolinella subrotunda									3	1	11	5					8	8	6	1	4	4	1	1	2	4	11	1			2		
Miliolinella circularis											2						1									1							
Pyrgo sp.																						1											
Agglutinated *Siphonaperta* [illegible]																						1								1			
Sigmoilina sp.																																	
Textularia conica																	1		4	1		1		1	3	1	4		8				
Gaudryina rudis																	3				1	2	5		4	2	8		3				
Spiroplectinella sp.																						1											
Pararotalia nipponica						3	7	1	3	1	4	5	2	1	13		11	18	24	18	16	33	17	22	35	37	16	8	23	25	2	10	8
Cibicides refulgens							3				1	1			3		7	4	7	8	7	15	7	10	6	11	12	1	14	11	8	1	4
Cibicidoides pseudoungerianus																	3	1		1	1	1		1		1	4	2					
Cibicidoides sp.															1			1				1							1	1	1		
Poroeponides lateralis							1										4	5	6	7	5	5	5	6	13	12	13	1	14	4	20		1
Glabratella australensis																					1			1	1		1						
Glabratella sp.																						1											
Lagena species																			1							1	1						
Oolina species									3		1		2						1					4									
Lobatula lobatula						1	2		3						1		14	7	19	9	11	8	6	8	14	14	28	2	7	5			
Planorbulina mediterranensis																	8	1	10	1	6	5	2	4	12	16	49		4	4			
Rosalina bradyi																		1		1						3	1		1				
Rosalina williamsoni																		1											1				
Rosalina cf. *globularis*						1	1		3			1		1	1																		
Sigmoilopsis schlumbergeri						1					3								1				1		1								
Bulimina [illegible]																																	
Bulimina marginata						3							1																1				
Bulimina elegantissima																			1														
piece *Homotrema rubrum*																	8	1	8			2	1				4				1		
Acervulina sp.																	1	1	2	1	1	1	1	1	2	3	3		1				
Gypsina sp.																											1						
Usbekistania sp.																											1						
pink globular foram sp.						1			1									8	1	1	5		1	2	1	1	1		1				
Glandulina sp.									1																								
Planispirina sp.																						1											
Cycloforina orbicula											1	1																					
Cassidulina laevigata																																	
Cancris auriculus																				1						1					1		
Nonion boueanum									1				1							1													
Fursenkoina (?) from *Planorbulina*											3	1					1	4						1	1		1		1	8	11	3	7
planktonics						3			14		1			1	1				1						9	1	5			1		9	
Sum of forams	190	109	105	3	12	58	33	3	62	20	119	70	65	91	31	10	96	94	161	82	84	133	80	96	147	190	254	16	138	74	73	16	18
Number of species	1	3	3	3	4	19	11	3	25	11	28	18	12	10	12	4	25	23	34	25	24	28	22	21	25	31	35	6	23	13	13	5	6
Sum of ostracods	0	3	2	56	13	38	42	1	86	24	56	104	>200	>35	15	14	49	33	25	16	13	8	4	2	3	12	18	2	0	0	0	0	0
ostracod species	0	1	1	3	2	4	7	1	6	5	5	6	7	7	7	4	5	1	1	3	3	2	2	2	1	6	6	1	0	0	0	0	0

4.2.1 FORAMINIFERA OF THE SOUT RIVER

Foraminifera are scarce in the Sout River (Table 4.2.1). This may have something to do with the unsorted, angular, immature sediment and the frequently altering water depth and salinity conditions, due to the Sout River channelling rainfall runoff from the surrounding hills and being filled and emptied on the flood and ebb tides, respectively. Water salinity near the mouth of the Sout River (Sout River sample 2) is relatively saline (30 ‰), but decreases upstream towards Sout River sample 1 (26 ‰). Sout River sample 2 contains four species of foraminifera in comparatively low numbers, including *Ammonia parkinsoniana* (3), a small *Quinqueloculina* species with a two-pointed tooth (3 recorded), *Miliammina fusca* and *Trochammina inflata*. *Ammonia parkinsoniana* is probably washed into the Sout River from the Knysna Estuary, since it is not found upstream in Sout River sample 1. The *Quinqueloculina* species with the distinct two-pointed tooth is also found upstream in Sout River sample 1 (one specimen). It is also recorded, in low numbers, in two other areas of the estuary, such as in the sewage-outlet samples and in Thesen Island causeway sample 1 (east of the causeway). The relative abundance of *Miliammina fusca* (five) recorded in Sout River sample 2 indicates the influence of fresh water. *Trochammina inflata* was most likely washed into the Sout River from the surrounding saltmarshes. The Sout River has similar sediment texture and foraminiferal assemblages as the upper estuary, apart from the *Quinqueloculina* species. However, the salinity in the Sout River is higher than in the upper estuary, and similar to the middle-estuary, between the White Bridge and the Railway Bridge.

4.2.2 FORAMINIFERA UNDER THE RAILWAY BRIDGE

The side channel under the Railway Bridge is relatively rich in microfauna (Table 4.2.1). The most abundant foraminiferal species recorded is *Elphidium cf. advenum*. *Elphidium articulatum* is also relatively abundant and both these *Elphidium* species are indicative of estuarine conditions, where salinities are slightly lower than seawater. These *Elphidium* species, together with living estuarine species such as *Ammonia parkinsoniana* and *Haynesina germanica*, and a few marine species such as *Gavelinopsis praegeri*, *Rosalina cf. globularis*, *Lobatula lobatula*, *Pararotalia nipponica*, *Bulimina elongata* and planktic *Globigerina quinqueloba*, prove this area to be transitional, from more estuarine waters to marine waters with increased salinity. Furthermore, the downstream change in salinity coincides with a change in sediment texture, to more fine-grained, well-sorted, rounded grains, as well as a change in water colour, from murky-green to transparent blue-green water. There is also increased marine material in the sediments seaward of the Railway Bridge (Table 1 in Appendix 3).

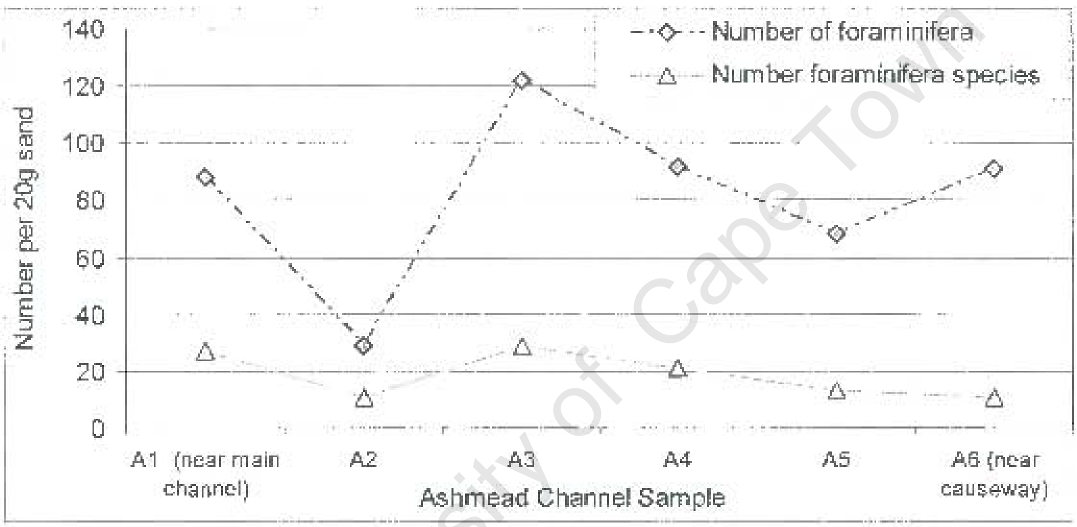
Miliolids are also particularly abundant in this sample below the Railway Bridge and some species were rather unique. These include numerous large, flat, ribbed *Quinqueloculina* species with the aperture on a neck, some large, flat *Triloculina* species with the aperture on a neck, a few keeled, finely grooved *Quinqueloculina* species, numerous *Quinqueloculina lata*, some *Triloculina tricarinata* and *Triloculina trigonula*, as well as a few globular *Miliolinella* species.

Trochammina inflata and *Haplophragmoides wilberti* were also recoded in the Railway Bridge side-channel. This region of the estuary is flanked by vast areas containing abundant saltmarsh vegetation (Refer back to Fig. 2.1), and due to precipitation runoff and tidal movement up and down the saltmarsh areas, agglutinated foraminifera are, most likely, washed into the estuary from the nearby saltmarshes. Four species of ostracods were collected under the Railway Bridge, with individual counts of ~ 40 per 20g sand.

4.2.3 FORAMINIFERA OF THE ASHMEAD CHANNEL

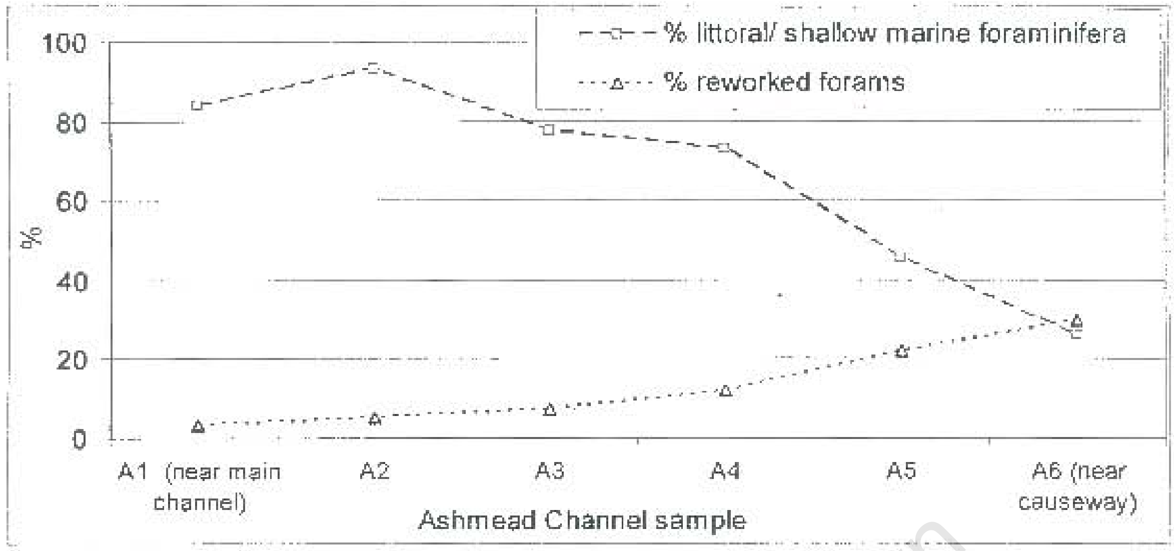
The Ashmead Channel surrounding Thesen Island is sheltered from the tidal currents experienced in the main channel of the estuary, as well as from prevalent boat and wind action on the water surface. This channel contains relatively calm, clear, alkaline (pH ~ 8.02) waters of moderate depth (~1.5 m), high organic and nutrient content, and middle-estuarine salinities (~33 ‰). The sediment is generally fine-grained, well-sorted and contains shells and other marine debris. Foraminifera numbers are high due to the protected nature of the Ashmead Channel as well as the constant, but adequate, nutrient supply from the sewage-treatment plant outlet and storm water drains (Fig. 4.2.1).

Figure 4.2.1 Variation in numbers and species of foraminifera in the Ashmead Channel.



Rapid deposition of marine material takes place when water enters the Ashmead Channel. Ashmead Channel sample A1 is located near the southern entrance of the Ashmead Channel from the main channel (Refer back to Fig. 3b) and therefore demonstrates the greatest littoral influence, calculated from the percent littoral foraminifera in each sample (Fig. 4.2.2). The percent littoral influence decreases, as expected, around the Ashmead Channel towards sample A6. The confined, relatively shallow channel area causes water to lose energy, and therefore holding capacity, resulting in deposition from the water column, with most marine material accumulating near the southern entrance of the channel where the change in hydrology is greatest. Due to accumulation occurring east of the causeway, one would expect the number of non-living tests to accumulate in this area. The percentage of reworked material increases around the Ashmead Channel towards sample A6 (Fig. 4.2.2), proving that dead material does accumulate east of the causeway, on the northern side of Thesen Island.

Figure 4.2.2 Variation in percent littoral foraminifera and reworked foraminifera in the Ashmead Channel.



Ammonia parkinsoniana is the dominant species in the Ashmead Channel, which is expected considering the typically-estuarine salinities in this region of the estuary. Numbers of *Ammonia parkinsoniana* are higher in the Ashmead Channel compared to main channel samples 34 – 37 collected west of Thesen Island (Figures 4.2.3 and 4.2.4). Main channel sample 37 is near to Ashmead Channel sample A1, and main channel sample 34 is west of the causeway (Refer back to Fig. 3b). Main channel sample 37 and Ashmead Channel sample A1 display similar numbers of *Ammonia parkinsoniana* species, which reflects the proximity of these sample sites. The number of *Ammonia parkinsoniana* species increase considerably from sample A1 to sample A6 near the causeway.

Numbers of miliolids are generally higher in the main channel of the estuary, compared to the Ashmead Channel, while *Elphidium* species do not show much variation in abundance between the main channel west of Thesen Island and the Ashmead Channel (Figure 4.2.5 and 4.2.6). The presence of miliolids normally indicates hypersaline conditions (McMillan, pers. comm. and Wright *et al.*, 1990) and therefore increase in abundance towards the Knysna Heads, where water salinities increase to that of sea water. *Quinqueloculina dunkerquiana* and *Triloculina "oblonga"*, found throughout the Ashmead Channel, as well as *Triloculina trigonula* and *Triloculina tricarinata*, found in sediments on the eastern side of Thesen Island, probably live in the Ashmead Channel, since these species thrive in waters with salinities slightly lower than sea water (Table 4.2.1). However, miliolid species such as *Miliolinella subrotunda, Spiroloculina communis*, ribbed *Spiroloculina sp.* and *Triloculina terquemiana*, which normally live in littoral marine environments, were probably washed into the Ashmead Channel from the main channel together with other littoral foraminifera and marine material.

Figure 4.2.3 *Ammonia parkinsoniana* numbers in the Ashmead Channel

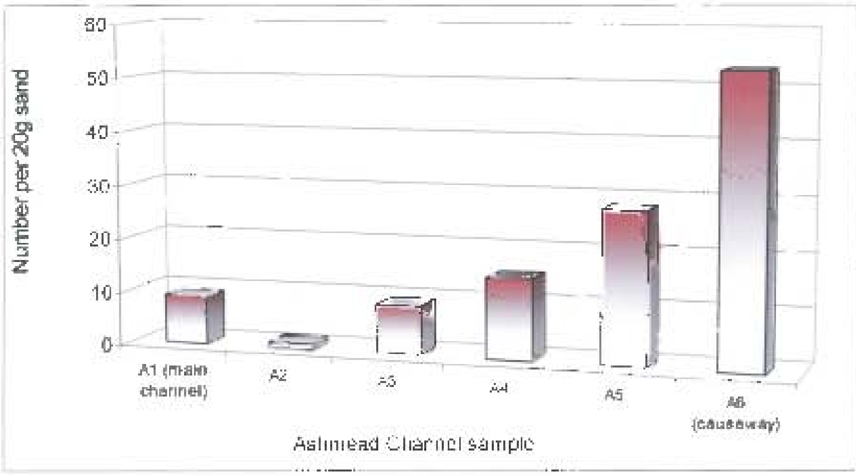


Figure 4.2.4 *Ammonia parkinsoniana* numbers in the main channel near the Ashmead Channel.

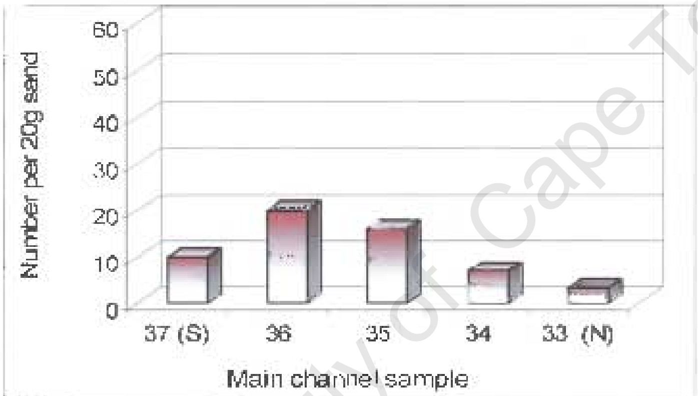


Figure 4.2.5 Numbers of miliolids and *Elphidium* species in the Ashmead Channel

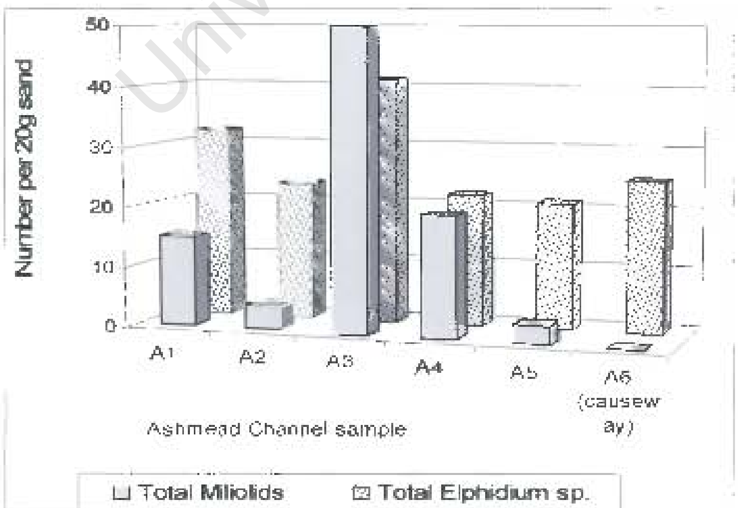
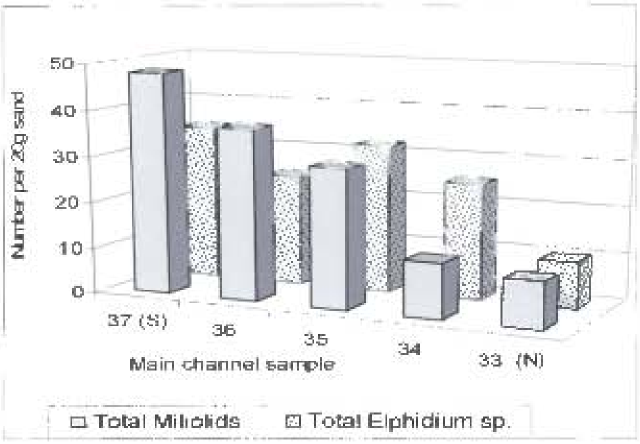


Figure 4.2.6 Numbers of Miliolid and Elphidium species in the main channel, samples 34 - 37



Foraminifera, typical of littoral, shallow-marine environments are more dominant in sediments of the main channel than in the Ashmead Channel (Fig 4.2.7). This is to be expected, since sediment type and water salinities, temperatures and current activity in the main channel are more comparable to the littoral shallow-marine environments. The Ashmead Channel is protected from turbulent current activity, has slightly lower water salinities, warmer temperatures and finer sediment.

Various saltmarsh species were found in the Ashmead Channel (Table 4.2.1), including *Haplophragmoides wilberti*, *Trochammina inflata*, and *Miliammina fusca* (sample A5 and A6). Both *Haplophragmoides* and *Trochammina* species are found living on the saltmarsh surrounding Thesen Island (Simpson, 2001), and were probably washed into the Ashmead Channel. Previous research in the Ashmead Channel by Simpson (2001) also recorded *Miliammina fusca* in the sediments north of Thesen Island, down-slope from the Knysna CBD area, coinciding with samples A5 and A6. Since the presence of *Miliammina fusca* in the sediments indicates freshwater influence, this area must be prone to precipitation runoff from the surrounding urban slopes. No saltmarsh foraminifera were recorded in the main channel samples near the Ashmead Channel (Table 4.2.2).

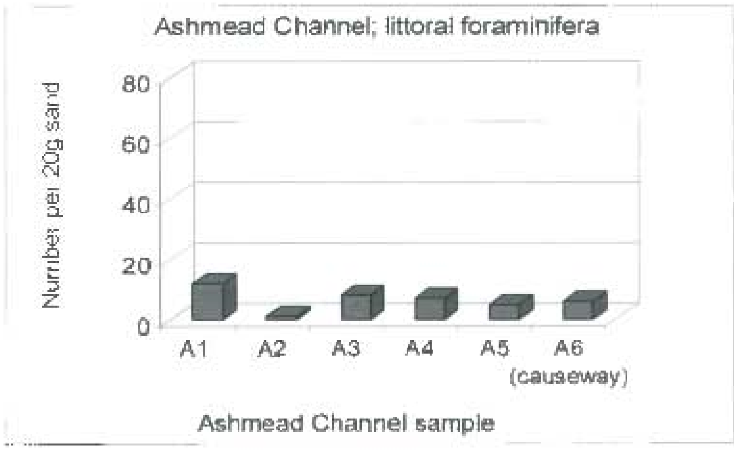
Although numbers of the *Elphidiella* species are relatively low in the Ashmead Channel, they are well preserved, and other than the one recorded in main channel sample 18, this is the only area in the Knysna Estuary where this species was recorded (Table 4.2.2).

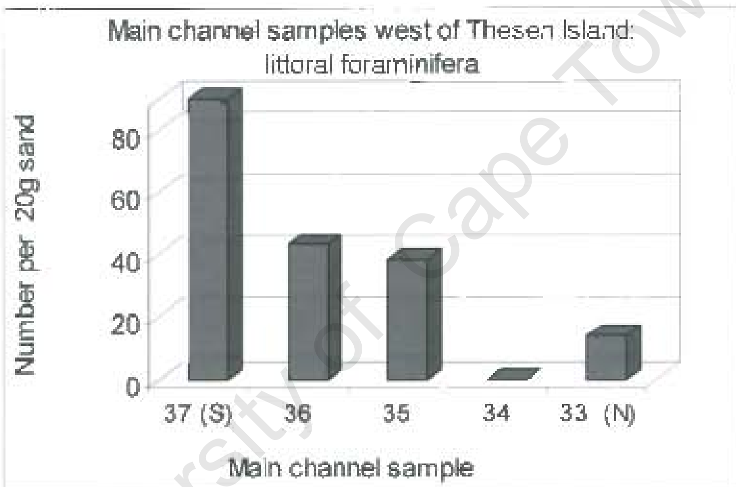
Table 4.2.2 Comparing Ashmead and nearby main channel samples; saltmarsh and *Elphidiella* species.

Ashmead Channel	A1	A2	A3	A4	A5	A6
Saltmarsh forams	10	0	0	0	1	0
Elphidiella sp.	1		2		5	

Main channel sample	33	34	35	36	37
Saltmarsh forams					
Elphidiella sp.					

Figure 4.2.7 Littoral foraminifera in the Ashmead Channel compared to nearby main channel samples





Littoral foraminifera include:

Ammonia japonica, Textularia conica, Gaudryina rudis, Spiroplectinella sp., Glabratella sp., Oolina species, *Homotrema rubrum, Lagena* species, *Bulimina* species, *Pararotalia nipponica, Cibicides refulgens, Lobatula lobatula, Cibicidoides sp., Planorbulina mediterranensis, Acervulina sp., Rosalina bradyi, Rosalina cf. globularis, Poroeponides lateralis*, and *Gavelinopsis praegeri.*

4.2.4 FORAMINIFERA OF THE SEWAGE OUTLET

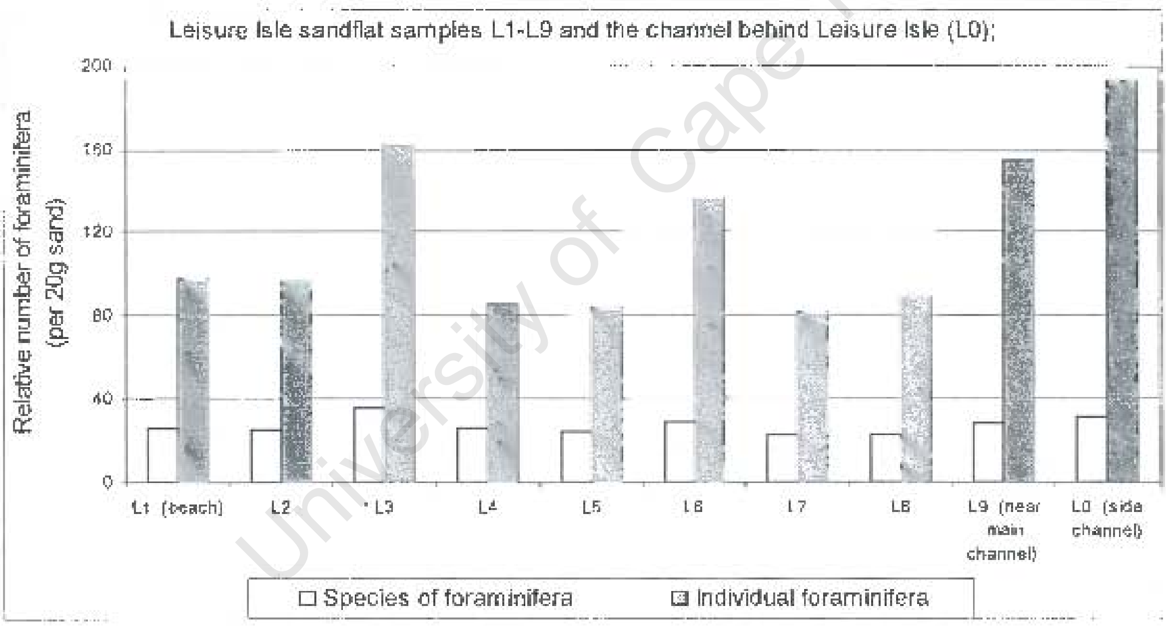
The sewage outlet is a small, shallow channel that drains the sewage-treatment-plant effluent into the Ashmead Channel. Sewage-outlet sample 1 is near to the Ashmead Channel and sewage-outlet sample 2, 80m from sewage-outlet sample 1, is nearer to the sewage-treatment plant. The channel water has 0 ‰ salinity, but increases slightly to 2 ‰ near the Ashmead Channel due to mixing with the Ashmead Channel water (~33 ‰). Sewage-outlet sample 1 contains much more foraminifera (33 individuals) and species (12) per 20g sand than sewage-outlet sample 2, which had 10 foraminifera consisting of 4 different species per 20g sand. In both samples, ostracod numbers per 20g of the sand fraction were relatively high, (18 in sample 1, and 15 in sample 2). Eight species of ostracods were recorded in sewage-outlet sample 1 and four species in sewage outlet sample 2. Most of the ostracods are living in both the sewage-outlet samples and flourish here because of the abundant organic matter and the high nutrient content of the sediments, as well as the protected nature of this region of the estuary.

Foraminifera recorded in these samples are, most probably, washed in from the Ashmead Channel and the surrounding intertidal banks. Foraminifera that are transported into the sewage-outlet channel include foraminifera from the saltmarshes on the intertidal banks, foraminifera that live in the Ashmead Channel, as well as some that are transported into the Ashmead Channel from the littoral/shallow-marine environments. Foraminifera washed from the saltmarsh areas include *Trochammina inflata*, which is found in relatively low abundance in both sewage-outlet samples. Foraminifera that may live in the Ashmead Channel include *Ammonia parkinsoniana*, a small *Quinqueloculina* species with a flat, two-pointed tooth in the aperture, *Haynesina germanica, Elphidium cf. advenum*, and a fat *Triloculina* species, which are all species that thrive in salinities slightly lower than seawater. Foraminifera that may be washed into the channel, via the Ashmead Channel, from marine waters near The Heads include *Pararotalia nipponica, Rosalina cf. globularis, Cibicides refulgens, Lobatula lobatula,* and *Cibicidoides sp.* Serpulid worm tubes and shell fragments recorded in the sediments are also evidence of marine material transported into this channel.

4.2.5 Foraminifera on Leisure Isle sandflat and the channel behind Leisure Isle

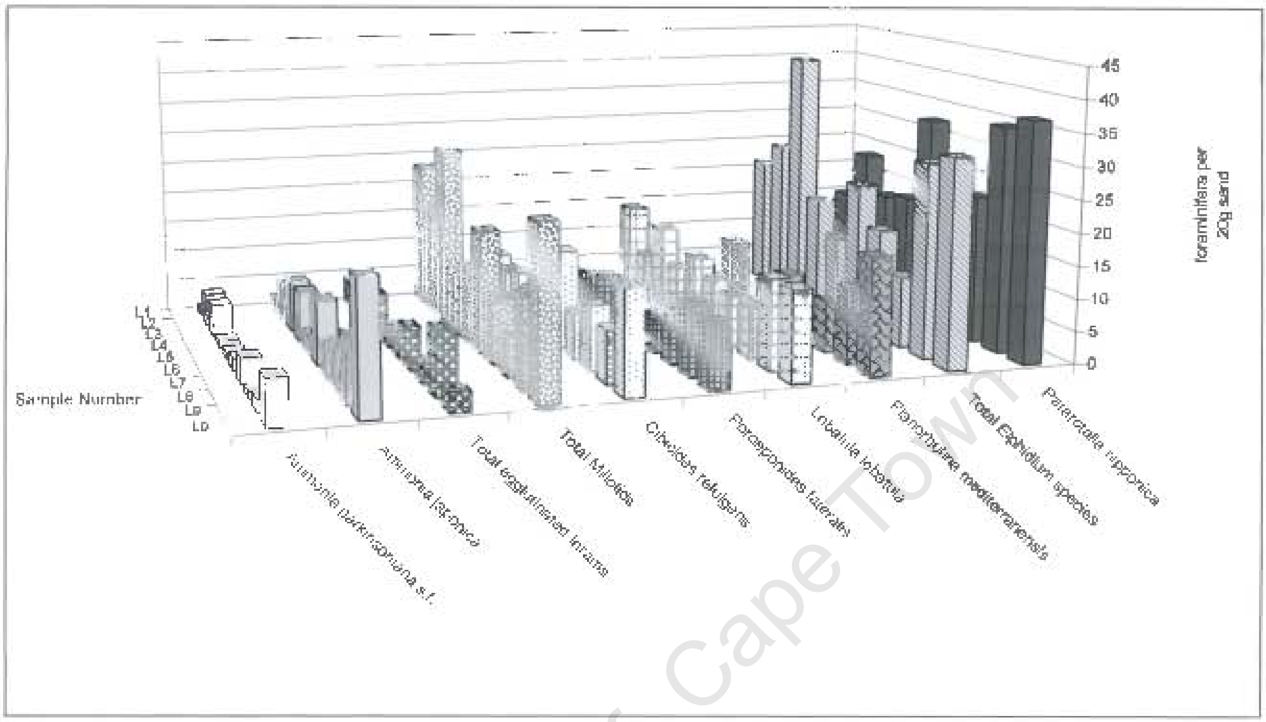
The numbers of species remains relatively constant across the sandflat, southwest of Leisure Isle, and in the channel behind Leisure Isle. However, the numbers of total foraminifera vary from sample to sample (Fig. 4.2.8). Foraminifera typical of littoral and shallow-marine environments are found in abundance around Leisure Isle. This is attributable to: Firstly, the marine salinities and constant supply of new ocean water with every tidal cycle favours the survival of foraminifera that live in shallow-marine/littoral environments. Secondly, the Leisure Isle sandflat was formed by the continuous deposition of sediment, resulting from decreased wave energy in this area when oceanic water is brought in through the tidal inlet on the flood-tide. Foraminifera are deposited on the sand-bank adjoining Leisure Isle, resulting in the accumulation of, mainly, littoral foraminifera. Few foraminifera may be transported by tidal action further upstream into the Knysna Estuary.

Figure 4.2.8 Numbers of foraminifera; individuals and species across the Leisure Isle sandflat.



Estuarine species such as *Ammonia parkinsoniana* (shown on Fig. 4.2.9), *Triloculina trigonula, Elphidium articulatum, Elphidium advenum* and *Quinqueloculina dunkerquiana* are relatively scarce, and some tests, especially *Quinqueloculina dunkerquiana*, are discoloured and abraded. In contrast, littoral species of foraminifera, such as *Pararotalia nipponica, Planorbulina mediterranensis, Lobatula lobatula, Poroeponides lateralis, Cibicides refulgens, Elphidium crispum, Elphidium macellum, Triloculina terquemiana, Triloculina bertheliniana, Miliolinella subrotunda, Ammonia japonica* and agglutinated *Textularia conica* and *Gaudrina rudis* are relatively abundant across the entire sandflat (Fig. 4.2.9). Well-preserved tests of shallow-marine foraminifera such as *Oolina, Lagena,* and *Bulimina* species are also recorded in the sediments of the Leisure Isle sandflat (Appendix 4). *Elphidium cf. alvarezianum*, which is relatively well preserved in some main-channel samples (18, 19, 29, 30, 36, and 37), is recorded and well preserved in all the Leisure Isle sandflat samples (Appendix 4).

Figure 4.2.9 Distribution of the dominant species recorded across the Leisure Isle sandflat



Sample L0 from the channel behind Leisure Isle and Leisure Isle sandflat sample L3 have the highest diversity of foraminifera, due to transport and deposition of sediment and foraminifera in these areas by the flood tides. The channel behind Leisure Isle is permanently filled with relatively shallow (<1m), transparent, oceanic water (>34 ‰). This channel is ideal for foraminifera on account of its adequate refuge from turbulent wave and current action, along with the relatively warm waters, particularly at low tide, as a result of being accessible to sunlight penetration and the shallow nature of the channel.

Sample L9 is relatively rich in foraminifera due to its location beside the main channel, near the mouth of the Knysna Estuary. Foraminifera that reside in shallow-marine habitats thrive in this area because of the constant supply of ocean water, and protection by The Heads, from the destructive action of breakers. Lower numbers of foraminifera further up the sandflat, away from the main channel, can be the result of two ecological factors: Firstly, living foraminifera in samples L1 to L3 seem to be competing with relatively high numbers of living ostracods, as mentioned in chapter 3.3 (Fig. 3.3.8). Secondly, this area is prone to desiccation during low tides, which is unfavourable for foraminifera, and therefore most of the foraminifera recorded on the upper sandflat are non-living (refer back to Fig. 3.3.6). *Pyrgo*, a two-chamber miliolid recorded in samples L3 and L6 was also found living on the Leisure Isle sandflat and was not recorded elsewhere in the estuary (Appendix 4).

4.2.6 FORAMINIFERA OF MARINE SAMPLES

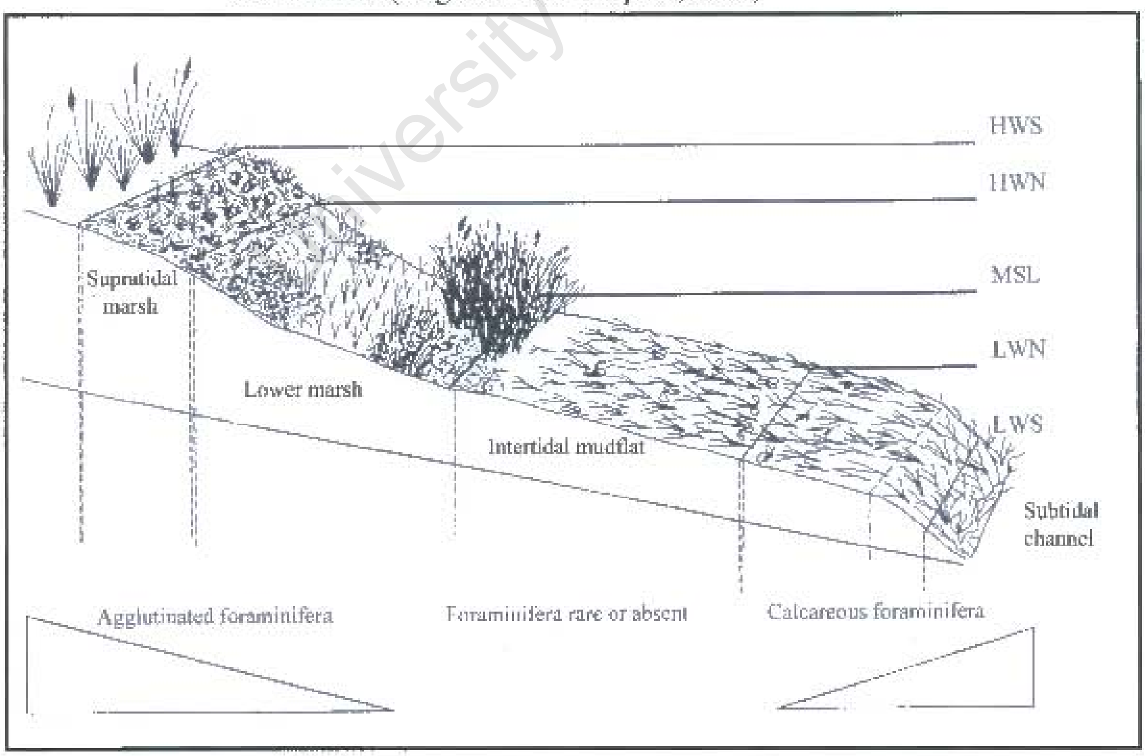
Marine samples collected for this study include the beach and rock pool samples from between the Knysna Heads, Brenton-on-Sea beach and Noetzie beach. These samples all contain entirely littoral foraminiferal assemblages. The Knysna Heads rock pools comprise a high-diversity assemblage (~35 species), with abundant living foraminifera (~254 per 20g sand fraction). The species recorded in the Knysna Heads rock pools were predominantly well preserved with few reworked or abraded specimens (Appendix 4). The Brenton-on-Sea and Noetzie rock pools contain foraminifera with relatively large tests. The sediment in these rock pools consists of moderate numbers of well-preserved *Poroeponides lateralis* and *Cibicides refulgens* specimens and a few large, abraded *Challengerella bradyi* that were, most likely, reworked from the Pleistocene beach-rock deposits. Other reworked material recorded in these rock pools, includes *Quinqueloculina dunkerquiana, Cancris auriculus* and a few abraded *Pararotalia nipponica, Ammonia japonica* and *Elphidium advenum* specimens.

The Brenton-on-Sea and Noetzie beach sediments contain littoral foraminifera similar to those from the Leisure Isle sandflat, as well as reworked foraminifera that were probably transported by wave action from the nearby rock pools. The beach samples collected below the waves contain a higher-diversity assemblage (>100 foraminifera per 20g sand, including ~24 species) than samples from above the wave base (<100 foraminifera per 20g sand, including ~14 species). Most of the foraminiferal tests in the beach sediments are abraded and/or broken, indicating transportation and accretion with coastal sediments, particularly since foraminiferal numbers and test preservation decreases from the rock pool environments to sediment below wave base, and in beach sediment above the high-water mark, respectively. The collection of foraminifera in the beach sediments is therefore, generally, a non-living assemblage.

4.2.7 FORAMINIFERA LIVING ON THE INTERTIDAL WETLANDS OF THE KNYSNA ESTUARY

Above the *Zostera* (eelgrass) meadows on the banks of the Knysna Estuary, is a rich assemblage of saltmarsh plants, which are variously inundated and exposed during the tidal cycle. The intertidal marsh areas of the estuary cover an area of 1000 hectares (ha) and are second in size only to Langebaan Lagoon on the west coast of South Africa (Maree, 2000). The plant-species diversity and distribution of these intertidal wetlands have been described by Maree (2000). The intertidal saltmarsh (850 ha), is dominated by *Spartina maritima* and halophytic marsh plants such as *Sarcocornia natalensis* and *Chenolea diffusa*; whereas the estuarine intertidal rush marsh (150 ha), is dominated by *Juncus kraussii*. The *Spartina*-dominated marsh areas generally occur in the lower reaches of the estuary at a level between mean sea level and mean high-water neaps, whereas the estuarine intertidal rush marshes in the middle to upper reaches of the estuary are characterised by reduced salinity, with the marsh surface occurring at a level between mean high-water neaps and mean high-water springs (Adams *et al.*, 1999). Studies by Simpson (2001), Horton *et al.* (1999), Jennings and Nelson (1992), Jennings *et al.* (1995), Scott and Medioli (1980a), Scott and Leckie (1990), Scott *et al.* (1996) and others, have proved that foraminiferal assemblages, in conjunction with changes in the sediment type and vegetation, also have characteristic zones of accumulation from the channel to the upper-marsh areas (Fig. 4.2.10).

Figure 4.2.10 Variations in foraminiferal assemblages from the subtidal channel to the supratidal marsh environment. (diagram from: Simpson, 2001)



LWS: low water, spring tide. LWN: low water, neap tide. MSL: mean sea level. HWN: high water, neap tide and HWS: high water, spring tide.

Three localities, labelled saltmarsh transects a, b and c were chosen to correlate with saltmarsh areas studied by Maree (2000). 'Transect a' is sited south-east of Thesen Island, opposite the Ashmead Channel and is representative of saltmarshes of the lower estuary. 'Transect b' located west of the Railway Bridge, is representative of the middle reaches of the estuary; and 'Transect c' is situated north of the White Bridge and is representative of saltmarshes of the hyposaline, upper-estuarine region of the Knysna Estuary (Fig. 4.2.11). Saltmarsh 'a' and Saltmarsh 'b' have similar vegetative cover, dominated by *Spartina maritima, Sarcocornia natalensis* and *Chenolea diffusa* (Fig. 4.2.11), and both transects consist of foraminiferal assemblages comparable to the intertidal saltmarsh areas surrounding Thesen Island (Simpson, 2001).

Figure 4.2.11 Saltmarsh sites selected for this study; located in the lower, middle and upper reaches of the Knysna Estuary; and the distribution of saltmarsh vegetation around the estuary.

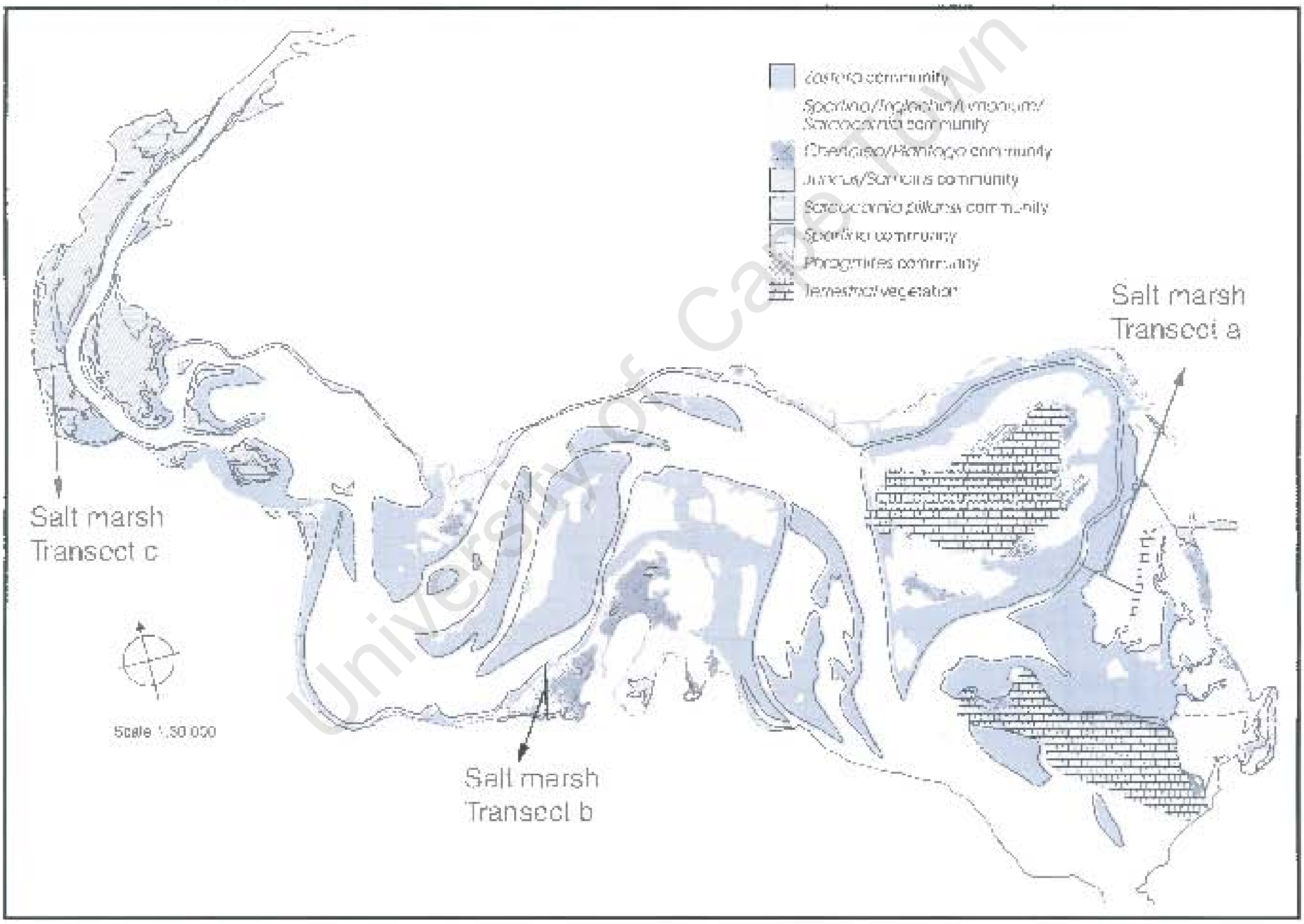


Diagram adapted from Maree (2000). Publication in Transactions of the Royal Society 55 (2), for the Knysna Basin Project (1995 – 1998).

Four samples were collected across Saltmarsh 'a'. Sample 'a' 1 is sited in *Zostera* vegetative cover, ~70 m from the centre of the Ashmead Channel. Sample 'a' 2 is surrounded by *Spartina maritima*, ~100 m from the channel. Samples 'a'3 and 'a'4 are approximately 150 m and 200 m, respectively, from the channel, located in halophytic marsh plants, *Sarcocornia natalensis* and *Chenolea diffusa* (Fig. 4.2.11). After sample 'a' 4 the vegetation becomes more terrestrial and foraminifera are scarce. Figure 4.2.12 illustrates the grain size analysis and percentage organics across Saltmarsh 'a'. The organics recovered from samples 'a' 3 and 'a'4, after washing and sieving the sediment, were different in colour and texture. The organic matter from sample 'a' 3 was fibrous and light brown in colour, while the organic matter from sample 'a'4 formed black clusters. However, the abundance of foraminifera (Fig. 4.2.13) and the species of foraminifera in both these samples was the same. Saltmarsh 'a' is dominated by one agglutinated species, *Trochammina inflata* (Fig. 4.2.14). *Haplophragmoides wilberti* was recorded, as a minor species, with the dominant *Trochammina inflata* on the saltmarsh area surrounding Thesen Island (Simpson, 2001), and therefore may be living in the lower- and middle-estuarine saltmarsh sediments, although not recorded in the samples collected for this study.

Five samples were collected across Saltmarsh 'b', west of the Railway Bridge. This transect was measured from a subsidiary channel, running parallel with the main channel of the Knysna Estuary. Sample 'b'1 is located ~50 m from the channel, within *Spartina maritima* vegetation. Samples 'b'2 and 'b'3 are ~70 m and ~250 m from the channel, respectively, with vegetative cover consisting of halophytic marsh plants such as *Sarcocornia natalensis* and *Chenolea diffusa*. Sample 'b'4 is sited within a tributary channel, with no vegetation, ~570 m from the channel, and sample 'b'5, ~ 650 m up the transect, is located within dry *Juncus*-type vegetation (Fig. 4.2.11). Organic matter collected from samples near to channel-type areas (i.e. samples 'b' 1, 4 and 5) is scarce, light brown and fibrous, whereas samples associated with halophytic marsh plants (samples 'b' 2 and 'b' 3) contain a large proportion of organic matter composed of black clusters (Fig. 4.2.15). Samples 'b' 2 and 'b' 3 are rich in foraminifera (Fig. 4.2.16), consisting only of *Trochammina inflata*, while samples 'b' 1, 4 and 5 contain far fewer foraminifera, and include *Miliammina fusca*, as well as a few calcareous *Elphidium spp.* and *Ammonia parkinsoniana* (Fig. 4.2.17). The samples analysed from Saltmarsh 'b', therefore, illustrate that foraminiferal species and abundance seem to be related to the abundance of organic matter, which, in this case, coincides with variation in type of organic matter. The presence of foraminifera such as agglutinated *Miliammina fusca* and calcareous *Ammonia parkinsoniana* (in low abundance) near the channel and in a sub-channel in the upper marsh of transect 'b' suggests some freshwater influence in the middle-estuary (Fig 4.2.17). In the wet season, enhanced flow from the Knysna River with additional surface and groundwater runoff from the urban slopes surrounding the estuary, results in lowered salinity conditions in the middle reaches of the estuary. The lower estuary is flushed every tidal cycle and, due to being readily open to the ocean, is not affected in the wet season.

Transect 'c' is distinct from the lower and middle reaches of the Knysna Estuary, in terms of vegetative cover and microfauna. Two samples were collected from Saltmarsh 'c', north of the White Bridge, due to the narrow intertidal area in this region of the estuary. Sample 'c' 1 was located closer to the main channel of the estuary than sample 'c' 2, which was ~50 m from the main channel. According to Maree (2000), the vegetation in this region of the estuary consists of the *Juncus/Samolus* community (Fig. 4.2.11). Both samples contain a moderate abundance of organics (Fig. 4.2.18). Sample 'c' 2 has a greater mud fraction and more foraminifera (Fig. 4.2.19) than sample 'c' 1. *Miliammina fusca* is the dominant saltmarsh species in this region of the estuary with *Trochammina inflata* as the sub-dominant species (Fig. 4.2.20). Figure 4.2.21 illustrates the variation in the dominating species of foraminifera for the three selected saltmarsh sites across the Knysna Estuary.

Saltmarsh 'a'; south east of Thesen Island

Figure 4.2.12 Saltmarsh 'a': Sediment grain size analysis.

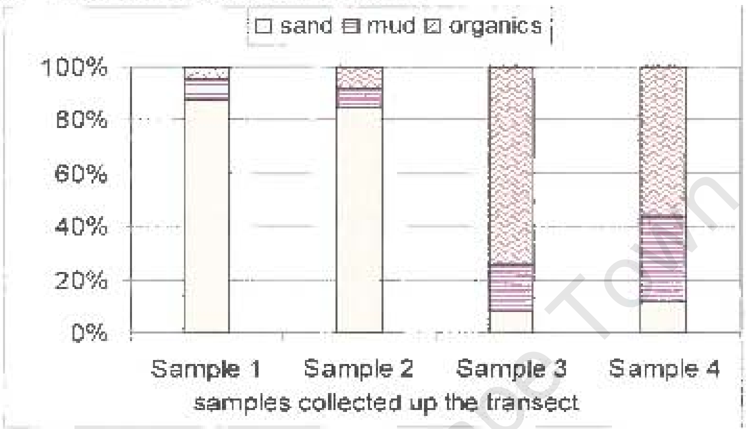


Figure 4.2.13 Saltmarsh 'a': Relative abundance of foraminifera across the saltmarsh

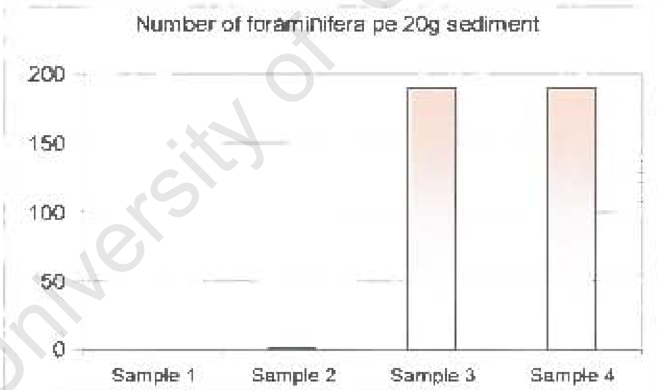
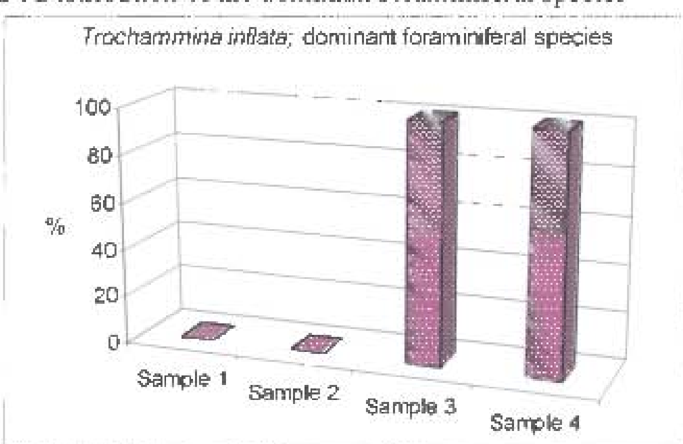


Figure 4.2.14 Saltmarsh 'a': Distribution of the dominant foraminiferal species



Transect 'b': Saltmarsh west of the Railway Bridge

Figure 4.2.15 Saltmarsh 'b': Grain size analysis

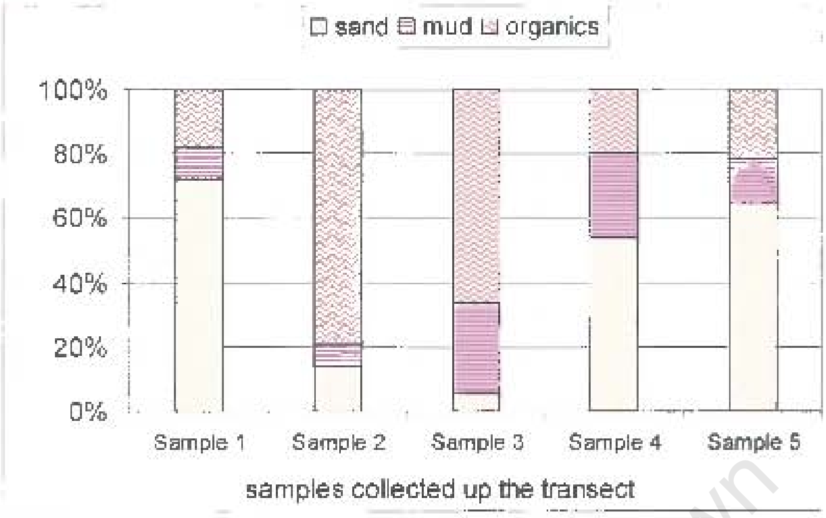


Figure 4.2.16 Saltmarsh 'b': Relative abundance of foraminifera up the saltmarsh

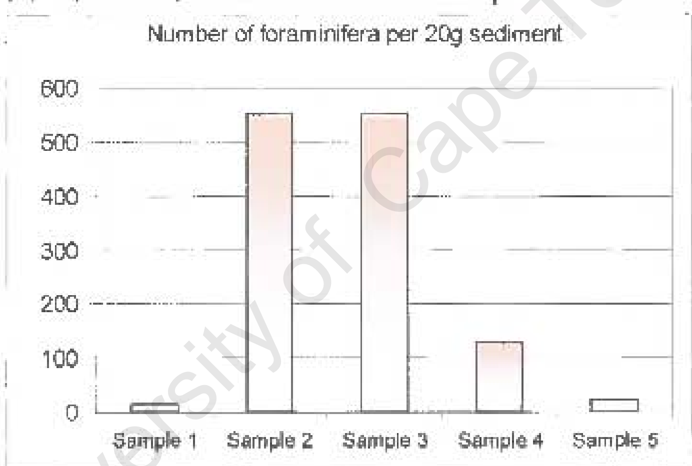
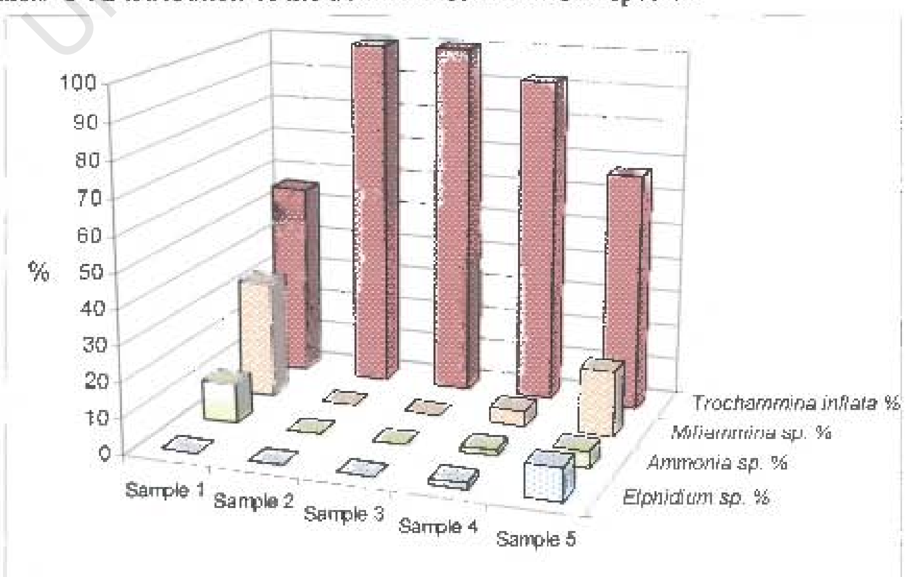


Figure 4.2.17 Saltmarsh 'b': Distribution of the dominant foraminiferal species



Transect c: Saltmarsh north of the White Bridge, in the upper reaches of the estuary

Figure 4.2.18 Saltmarsh 'c': Grain size analysis

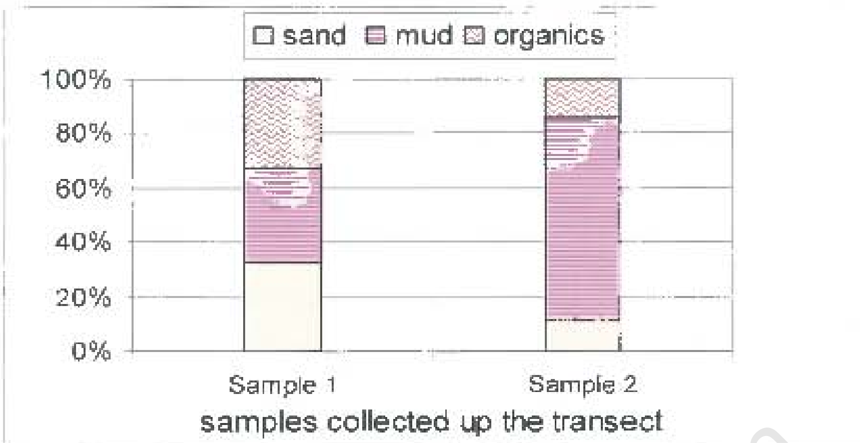


Figure 4.2.19 Saltmarsh 'c': Relative abundance of foraminifera across the marsh

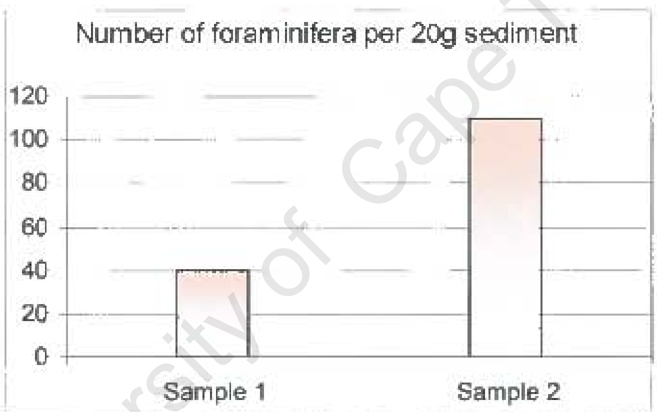


Figure 4.2.20 Saltmarsh 'c': Distribution of the dominant foraminiferal species

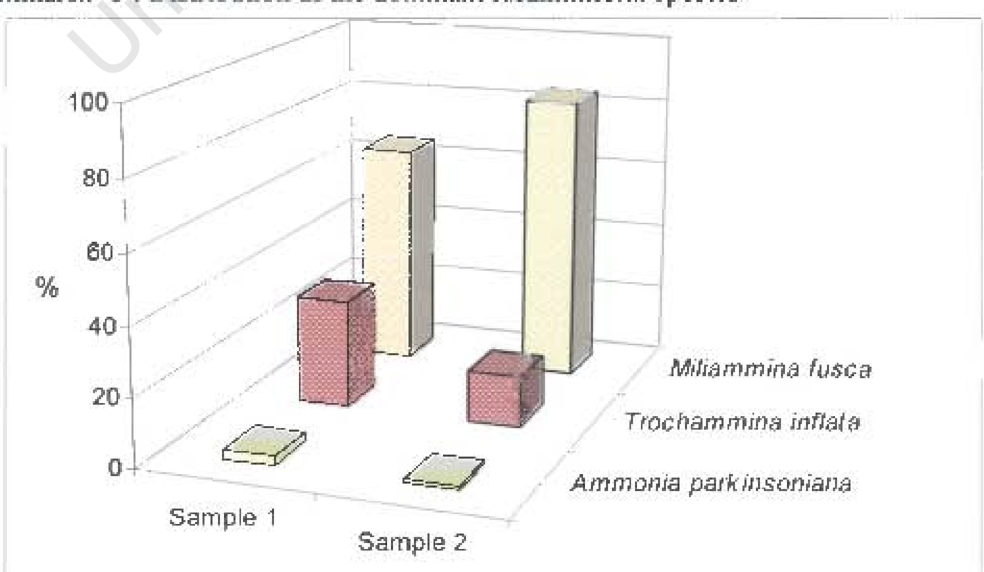
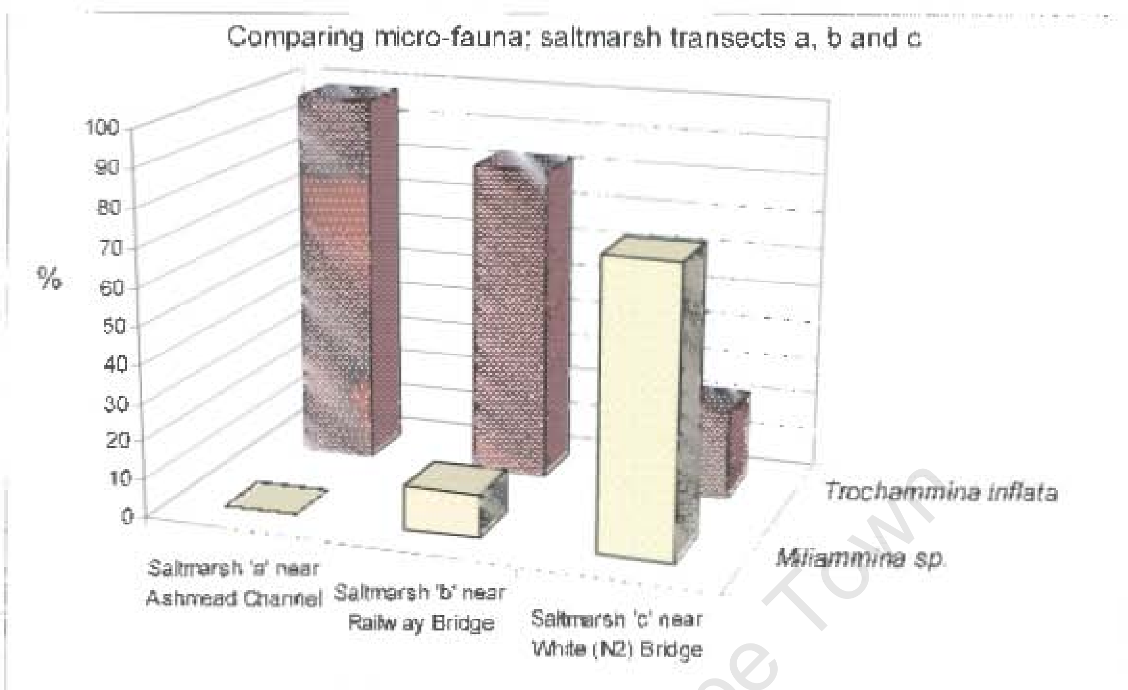


Figure 4.2.21 Foraminiferal species variation for selected saltmarsh sites across the Knysna Estuary



4.3 LIST OF FORAMINIFERA RECORDED IN THE KNYSNA ESTUARY

Total number of species = 105
Total number of genera = 56

Agglutinated intertidal marsh species
Miliammina fusca
Trochammina inflata
Haplophragmoides wilberti
Haplophragmoides canariensis
Ammonia species
Ammonia parkinsoniana s.l.
Ammonia japonica
Elphidium species
Elphidium cf. articulatum
Elphidium articulatum
Elphidium advenum
Elphidium cf. advenum
Elphidium cf. alvarezianum
Elphidium crispum
Elphidium macellum
Elphidiella sp.
Elphidium gunteri
Planktonics
Globigerina sp.
Globigerina bulloides
Globigerina quinqueloba
Globbigerinoides ruber
Globigerinella equilateralis
Globorotalia inflata
Globoquadrina dutertrei
Neogloboquadrina pachyderma
Estuarine species
Ammonia parkinsoniana s.l.
Haynesina germanica
Rotalia gaimardii
Triloculina "oblonga"
Quinqueloculina dunkerquiana
Relatively rare marine species
Gypsina sp.
Uvigerina sp.
Chrysalidinella dimorpha
Cassidulina laevigata
Planispirillina sp.
piece *of Nubecularia lucifuga*

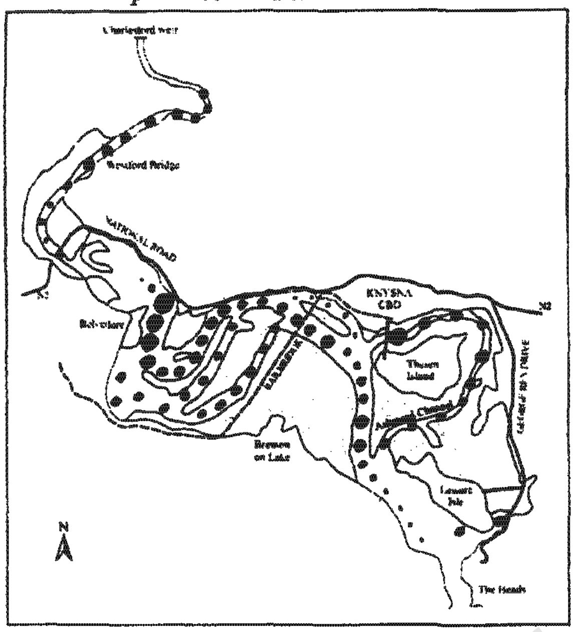
Littoral species
Pararotalia nipponica
Cibicides refulgens
Cibicidoides pseudoungerianus
Poroeponides lateralis
Lobatula lobatula
Planorbulina mediterranensis
Acervulina sp.
Acervulina inhaerens
Glabratella sp.
Glabratella australensis
Rosalina bradyi
Rosalina williamsoni
Rosalina cf. globularis
Gavelinopsis praegeri
Shallow-marine species
Lagena semilineata
Lagena striata
Lagena leavis
ribbed *Lagena sp.*
Lagena cf. lyelli-
Lagena sp.
Oolina melo
Oolina cf. melo
Oolina hexagona
finely ribbed *Oolina sp.*
Oolina sp. A (McMillan, 1987)
Oolina squamosa
Glandulina sp.
Cyclogyra orbicula
Bulimina marginata
Bulimina elongata
Bulimina orangensis
Brizalina striatula
Brizalina pseudopunctata
Agglutinated marine species
Siphonaperta martinae
Textularia conica
Graudryina rudis
Spiroplectinella sp.

Miliolids
Triloculina "oblonga"
Triloculina trigonula
Triloculina tricarinata
Triloculina terquemiana
Triloculina bertheliniana
Triloculina fichteliana
fat *Triloculina sp.*
flat, ribbed *Triloculina sp.*
elongate *Triloculina sp.*
Quinqueloculina cf. vulgaris
Quinqueloculina dunkerquiana
Quinqueloculina seminulum
Quinqueloculina contorta
Quinqueloculina lata
Quinqueloculina cf. curta (reworked)
little *Quinqueloculina sp.*
narrow *Quinqueloculina sp.*
finely ribbed *Quinqueloculina sp.*
Quinqueloculina sp. with no tooth
Spiroloculina communis
ribbed *Spiroloculina sp.*
Miliolinella subrotunda
Miliolinella circularis
thin elongate *Miliolinella sp.*
Pyrgo sp.
Reworked shallow-marine foraminifera
All Latest Pleistocene in age
Lenticulina sp.
Challengerella bradyi (latest Pleistocene)
Challengerella cf. bradyi
Hyalinea balthica
flat *Planularia sp.*
Notorotalia clathrata
Brizalina sp.
Orange *Quinqueloculina dunkerquiana*
Other reworked foraminifera
Nonion boueanus
Ehrenbergina cf. healyi (Early Miocene)
large *Cibicidoides sp. (Eocene)*
Cancris cf. auriculus(Miocene)

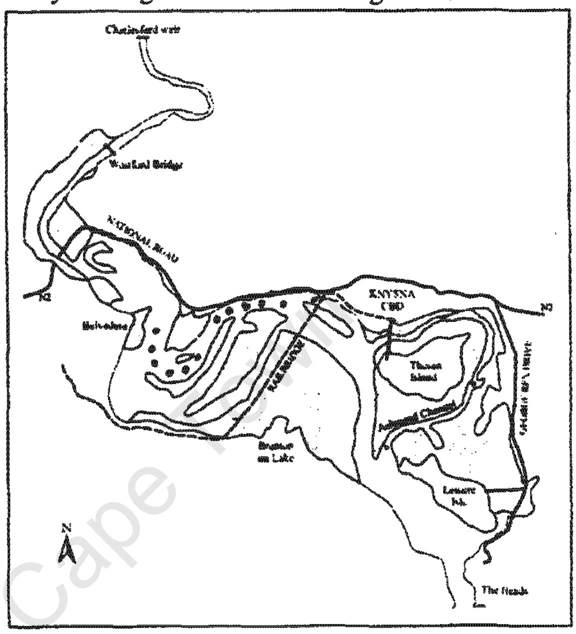
Figure 4.3.1 Distributions and relative abundance across the Knysna Estuary of some important species of foraminifera.

Solid dot represents species presence in sediment;
Size of dot represents relative abundance of that particular species

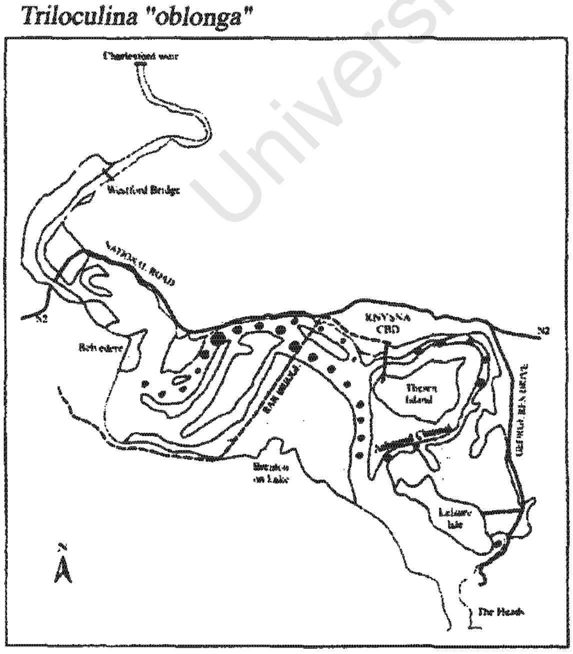
Ammonia parkinsoniana s.l.



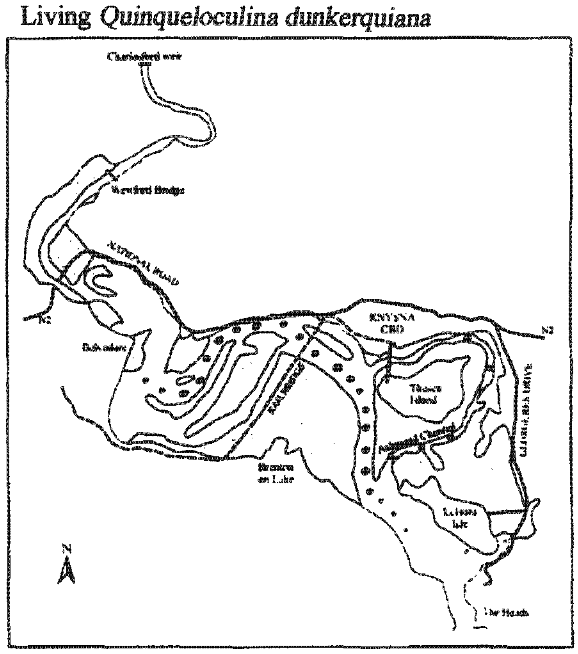
Haynesina germanica & Rotalia gaimardii



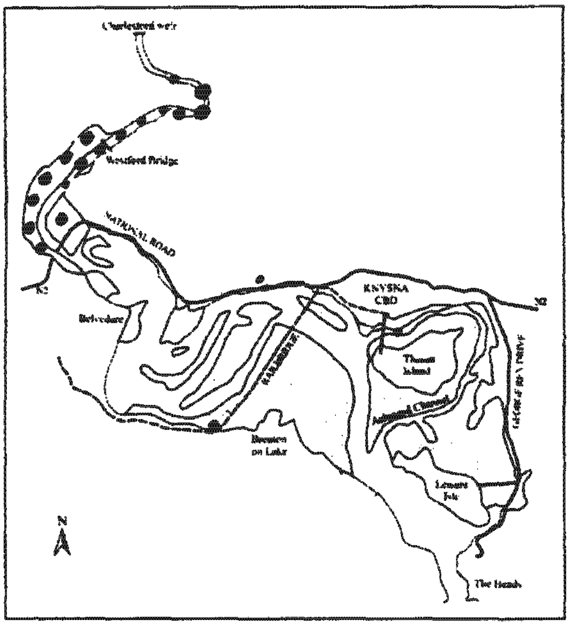
Triloculina "oblonga"



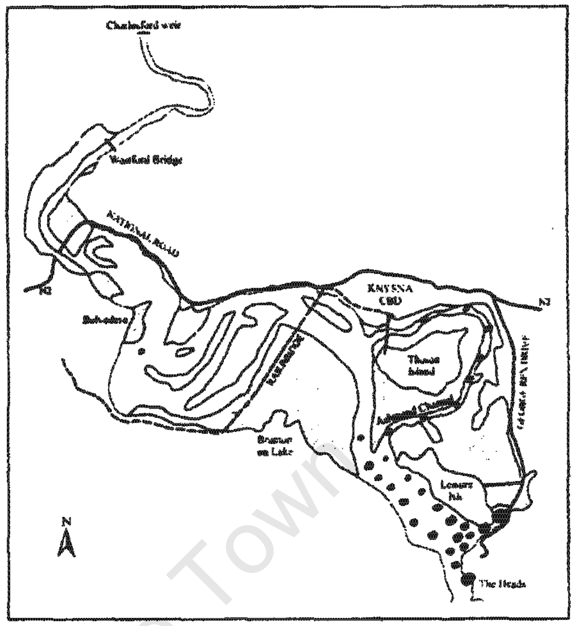
Living *Quinqueloculina dunkerquiana*



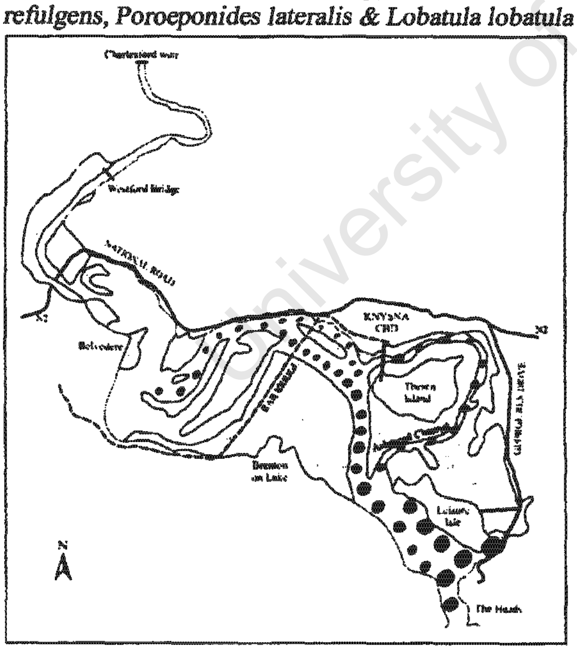
Miliammina fusca



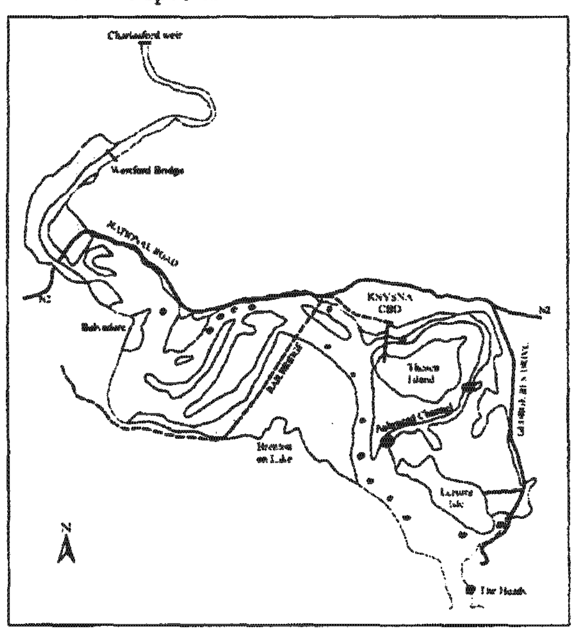
Ammonia japonica & Miliolinella subrotunda



Elphidium crispum, Pararotalia nipponica, Cibicides refulgens, Poroeponides lateralis & Lobatula lobatula



Planktic species



5. USING FORAMINIFERAL ASSEMBLAGES AS AN AID IN ESTABLISHING ECOLOGICAL REGIMES WITHIN THE KNYSNA ESTUARY

Foraminiferal assemblages from this study are primarily from the subtidal channel and include foraminifera that have been transported into the sample sites from other parts of the channel, such as from the saltmarsh environments and the open ocean or littoral environment; therefore rendering an assemblage including living, dead (recent) and reworked (fossil) tests. Variations in foraminiferal assemblages usually correlate to changes in environmental parameters, such as pH, salinity, depth, light intensity, dissolved oxygen concentrations, current strength, turbidity, calcium carbonate and trace element content, nutrient content and sediment type (Boltvoskoy and Wright, 1976). A study by Lidz and Rose (1989) concluded that faunal assemblages, rather than individual species of foraminifera, are diagnostic environmental indicators, since many species range over several faunal zones. Foraminifera found in the Knysna Estuary can be divided into the following assemblages: a littoral/ sub-littoral assemblage, from high energy beach and rock pool environments near the Knysna Heads and along the coast; a shallow-marine assemblage indicative of relatively sheltered environments that are constantly covered by seawater; an estuarine assemblage, containing species that live in fairly sheltered waters with relatively long residence times and salinities slightly lower than seawater; an upper-estuarine, hyposaline assemblage, influenced by fresh river inflow; a mudflat/ saltmarsh assemblage living on the intertidal wasteland areas surrounding the estuary; and a localized assemblage of *Elphidiella* species in the Ashmead Channel (Fig. 5.1). Cooper and McMillan (1987) recorded similar foraminiferal assemblages in the Mgeni Estuary, near Durban.

<u>The littoral/ sub-littoral assemblage</u>

This assemblage consists mainly of genera which are adapted to high-energy, surf-zone conditions. The dominant species in the littoral assemblage include *Cibicides refulgens, Lobatula lobatula, Poroeponides lateralis, Planorbulina mediterranensis, Glabratella sp., Pararotalia nipponica,* ornamented *Triloculina* and *Quinqueloculina* species, and *Elphidium* species such as *Elphidium crispum.* Most of these species live attached to a substrate of either rock or seaweed in the intertidal and subtidal zones (Haynes 1981, and Lipps, 1993), and have trochospiral and planoconvex tests, which are fairly strong, enabling them to live in these high-energy environments. *Elphidium* is a common inhabitant of marginal-marine and high-energy environments, and is a familiar resident in lower energy environments such as estuaries and lagoons (Boltovskoy and Wright, 1976). Foraminifera from this assemblage have been noted in the marine-derived sands near the mouth of the estuary, the Leisure Isle sandflat, in the channel behind Leisure Isle, in the beach sand at Brenton-on-Sea and Noetzie, as well as in rock pools at the Knysna Heads, Noetzie, and near Brenton-on-Sea. Sediments in these areas are generally fine, well sorted sands, consisting predominantly of sub-rounded to rounded quartz grains and abundant calcareous shell fragments and algal material.

Also associated with this assemblage are a moderate amount of reworked and broken foraminifera, many of which are Pleistocene in age (Cooper and McMillan, 1987). Some younger specimens of latest Pleistocene to early Holocene also occur. An abundance of reworked tests is generally indicative of high-energy environments, most of which derive from erosion of partly cemented Pleistocene highstand deposits at the base of the Knysna Heads and along the south coast. Their presence in the estuarine sediments is attributed to storm action and longshore drift (Cooper and McMillan, 1987).

Shallow-marine assemblage

This is generally a high-diversity assemblage of planktic and benthic foraminifera that generally have less robust tests than littoral species. Most of the benthic genera in this assemblage inhabit the shallow (<100 m depth) continental shelf areas, while the planktic species are open-ocean, as well as continental-shelf dwellers (Haynes, 1981). Typical benthic genera in the assemblage include *Planispirillina, Lagena, Oolina, Brizalina* and *Bulimina* species. Shallow-marine foraminifera are therefore less abundant in the mobile sands between the Knysna Heads, and are best preserved in the more sheltered areas in the lower reaches of the estuary, such as in the channel behind Leisure Isle and in the main subtidal channel near the Ashmead Channel. Planktic species such as *Globigerina bulloides, Globigerina calida, Globoquadrina dutertrei*, and *Globigerinoides ruber* are found in the Knysna Estuary, although they are generally scarce. Their tests are more porous than benthic tests and can be carried further up the estuary in suspension. Most planktic species are fully marine, although *Globigerina bulloides* and *Globigerinoides ruber* can tolerate salinities as low as 30.5 ‰ (Haynes, 1981). It is probable that the presence of planktic species in the Knysna Estuary is due to the death of these foraminifera, which have then been transported from the sea and into the estuary by the flood tides and deposited on the channel beds during the high-tide slack (Cooper and McMillan, 1987).

Estuarine assemblage

The estuarine assemblage is best established where the salinity drops to approximately 32 ‰ and waters are less turbulent. Characteristic foraminifera of this assemblage include *Ammonia parkinsoniana* (in high numbers), *Rotalia gaimardii* and *Haynesina germanica*, which are typical estuarine species of foraminifera. Other species that thrive in salinities slightly lower than seawater are *Elphidium articulatum, Elphidium cf. articulatum, Elphidium advenum, Triloculina "oblonga", Triloculina trigonula, Triloculina tricarinata* and *Quinqueloculina dunkerquiana*, which are well preserved and relatively abundant in samples that include the estuarine assemblage. Main channel samples, which best illustrate this assemblage are samples 18 – 28, which are situated from ~2 km seaward of the White Bridge to ~1 km downstream of the Railway Bridge. No *Rotalia gaimardii* were found upstream or downstream of this area and *Ammonia parkinsoniana* numbers were highest in this region of the Knysna Estuary.

Upper-estuarine, hyposaline assemblage

The low-salinity (0 ‰ - 20 ‰) of the brackish upper-estuarine waters results in a low-diversity foraminiferal assemblage (Murray, 1973; Haynes, 1981). The Upper-estuarine/ hyposaline assemblage is dominated by the rotaliid *Ammonia parkinsoniana* with some arenaceous *Miliammina fusca*. *Ammonia parkinsoniana* is common in estuarine and low-salinity environments around the world, whereas *Miliammina fusca* is generally most abundant in channel sediments and surrounding mudflats of the upper, hyposaline reaches of an estuary (Cooper and McMillan, 1987). Since *Miliammina fusca* was abundant on the marsh areas upstream of the White Bridge (N2), they were probably washed into the channel from the surrounding mudflats. Many of the *Miliammina* species found in the channel north of the White Bridge are bleached (cream colour, instead of orange), which is additional evidence of transport from the intertidal marshes.

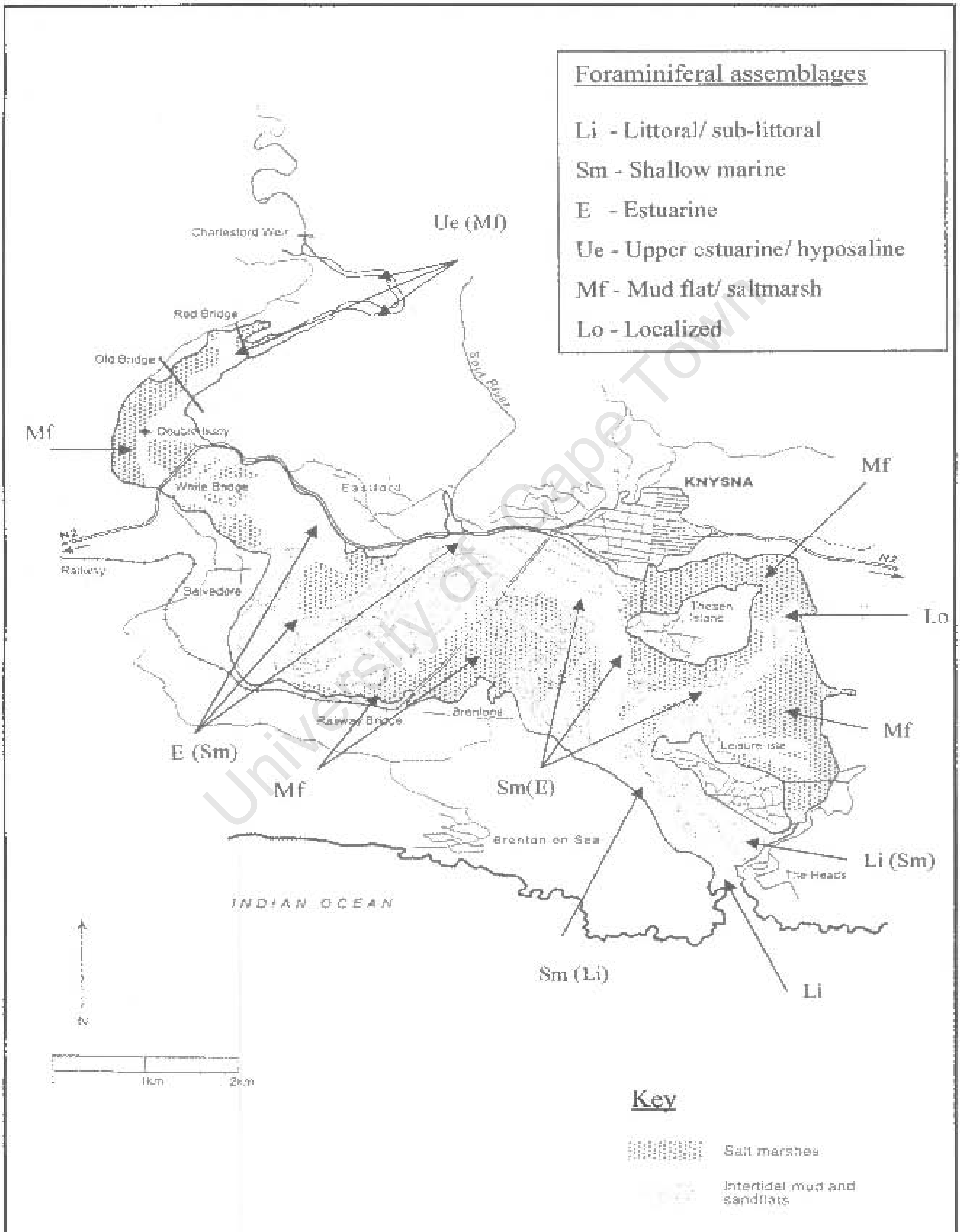
Mudflat / saltmarsh assemblage

Sediment in these areas consists of more than 90 % mud (< 63 μm), deposited by suspension settling from the estuarine waters when the banks of the estuary are covered with water during flood and spring tides. Saltmarsh vegetation on the mudflats effectively traps the fine grained sediment. These areas are prone to desiccation during low tide, creating relatively saline conditions, resulting in the disintegration of calcareous foraminiferal tests, which dissolve in these hypersaline conditions (Simpson, 2001; Boltvoskoy and Wright, 1976). The mudflat assemblage consists essentially of arenaceous foraminifera such as *Trochammina inflata* and some *Haplophragmoides wilberti* (recorded by Simpson, 2001), which thrive on saltmarsh areas in the middle and lower estuary. *Trochammina inflata* occurs globally on intertidal and estuarine mudflats (McMillan, pers. comm. 2001; Cooper and McMillan, 1987). *Miliammina fusca*, associated with *Juncus* or rush wetlands, is the dominant species in the upper reaches of the Knysna Estuary. These species are associated with mangroves and mudflats worldwide and are tolerant of lowered salinity and low-alkalinity conditions (Haynes, 1981). An inundation gradient occurs along the banks of the estuary and both the vegetation and the foraminifera experience different tidal regimes with regard to height above or below sea level. Foraminiferal assemblages on the intertidal mudflats are directly related to elevation above mean sea-level, with the duration and the frequency of intertidal exposure as the most important factors (Horton *et al.*, 1999; Scott and Medioli, 1980a).

Localized assemblages

A species of foraminifera, *Elphidiella sp.*, is only recorded living (very well preserved) in the Ashmead Channel. One *Elphidiella* species was found in the main channel of the Knysna Estuary in sample 18, ~2 km seaward of the White Bridge, but this specimen was probably transported upstream by tidal action. Unfortunately, records of the *Elphidiella* species are rare, especially around the South African coastline, and its preferred habitat is not clearly understood. It is therefore difficult to clarify why a small population of this species is living in the Ashmead Channel. An explanation may be the high nutrient content within the sediments and the sheltered, fairly shallow and relatively warm waters of the subtidal environment in the Ashmead Channel.

Figure 5.1 Foraminiferal assemblages and their distribution in the Knysna Estuary



ESTUARINE REGIMES OF THE KNYSNA ESTUARY

Studies of modern estuaries have shown that they are characterised by low-diversity assemblages of living benthic foraminifera (Wang and Murray, 1983). Offshore, living foraminiferal assemblages are generally more diverse than those of estuaries (Murray, 1973). According to Wang and Murray (1983), the transport of marine foraminifera into an estuary increases with an increase in tidal influence. Foraminiferal tests are transported as bedload and predominantly in suspension. Foraminifera that are carried in suspension are generally very small (<200 μm) and include many open-marine species. When they are dropped from suspension on the slack tide and deposited in the sediment of the estuary, they lead to higher-diversity assemblages in environments where the diversity of the living assemblage is low. As faunal dominance is partly related to diversity, species dominance generally decreases with increasing diversity (Wang and Murray, 1983). The abundance of exotic tests shows a progressive increase with increased tidal strength, and since the Knysna Estuary is open to the southern Indian Ocean, a large proportion of the estuarine sediment will include both local (estuarine) and exotic (marine) species. For that reason, samples collected upstream of the Knysna Heads vary, with decreasing oceanic influence, in the abundance and diversity of foraminifera. These variations in foraminiferal numbers and assemblages can be used to infer estuarine regimes within the Knysna Estuary.

Largier *et al.* (2000) divided the Knysna Estuary into three regimes according to their thermohaline or hydrographic character. The "bay regime" in the lower estuary, contains water that is primarily oceanic and negligibly influenced by river inflow or residence in the estuary. The "lagoon regime" in the mid-estuary (generally between the White Bridge and the Railway Bridge), consists of waters that are diluted little by river inflow, but are warmer and have salinities slightly lower than seawater, due to long residence times in the relatively shallow, meandering channel, resulting in retention of freshwater runoff from the slopes surrounding the estuary; and the "estuary regime" in the upper estuary, which is significantly influenced by river inflow.

These regimes correspond to changes in water type, tidal velocities, depth and sediments. Microfauna living in the channel sediments are influenced by these changes and foraminiferal assemblages reflect the changing environmental conditions and sediment types. For this study, regimes were determined across the Knysna Estuary according to the tolerance limits of certain species, which are indicated by the dominance and existence of particular species of foraminifera, total numbers of foraminifera, and the percentage of littoral foraminifera. Alterations in the foraminiferal assemblages recorded in the sediments of the main, subtidal channel are related to ecological changes across the estuary (Table 5.1, Fig. 5.2 and Fig. 5.3). The following regimes were established across the main channel of the Knysna Estuary:

The Bay Regime

Bay-regime waters are comparable to other bays along the South African coast and are characterised by near-oceanic salinities, generally above 34 ‰. This regime expands on the flood tide, filling the lower estuary to 7.5 km from the mouth during spring tides, and to 4 km during neap tides (Largier *et al.*, 2000). Flushed every tidal cycle by tidal pumping and tidal diffusion, the Bay regime exhibits a ready import and export of water-borne material, including nutrients, larvae, plankton, foraminifera and pollutants, regardless of the strength of river flow. The character of this regime is thus set more by offshore and shallow marine-waters than by estuarine hydrodynamics. Current velocity in the water column between the Knysna Heads reaches a maximum of ~1 m/s at spring low tide (Largier *et al.*, 2000). A combination of strong tidal currents and swell action suspends sediment particles from the channel bed, which, together with shelf-derived constituents and reworked material from the erosion of the surrounding coastal rocks, are transported into the estuary. Due to the high energy in this region of the estuary, fragile foraminifera do not survive and the sediment comprises a scarce, low-diversity, littoral assemblage of robust foraminifera. A small number of planktic species were recorded in the surface waters at the Knysna Heads (refer to Appendix 2), however they were absent in the channel sediments between The Heads (Table 4.1). Planktic foraminifera do not survive in the sediments of this area due to their fragile test structure. Instead, planktic foraminifera that float into the estuary are transported and deposited further upstream, and most of those documented are found in the Lagoon regime, seaward of the Railway Bridge.

Main channel samples 36 and 37, ~3 km landward of The Heads, contain the greatest diversity of foraminiferal species and this area appears to be the transition zone from the Bay regime to the Lagoon regime. Seaward of this area (in the Bay regime), species such as *Miliolinella subrotunda* and *Ammonia japonica* become prominent in the foraminiferal assemblage. *Elphidium crispum* tests are well preserved and relatively large. Littoral foraminifera such as *Poroeponides lateralis, Cibicides refulgens, Pararotalia nipponica, Planorbulina mediterranensis* and *Lobatula lobatula* dominate the microfaunal assemblage, and estuarine foraminifera such as *Triloculina "oblonga", Triloculina trigonula, Ammonia parkinsoniana, Quinqueloculina dunkerquiana, Elphidium articulatum* and *Elphidium advenum* decrease rapidly in abundance. *Cassidulina laevigata* and *Sigmoilina sp.* (foraminifera from the inner continental shelf) are recorded to be well preserved in this transition zone (Table 5.1).

The Lagoon Regime

The Lagoon regime is characterised by aged salt water with little direct freshwater influence. Salinities are of the order 30 - 34 ‰ (Figure 5.2). With limited river inflow, shallow depths and strong tidal flow, these waters are typically well mixed (Largier *et al.*, 2000). Long residence times of 1 – 2 weeks (Refer back to Fig. 1.3.4) in this region of the estuary are indicated by relatively high water temperatures observed during warm weather (Largier *et al.*, 2000). According to Largier *et al.* (2000), the seaward limit of the Lagoon regime extends close to the mouth during low tide, but is in the vicinity of the Railway Bridge at high tide.

The upstream limit of the Lagoon regime varies with tidal phase and variations in the rate of river discharge, but seldom extends upstream of the White Bridge (Largier *et al.*, 2000). Sediment on the channel bed consists of moderately to well sorted, fine-medium sand with relatively little marine material (Table 1, appendix 3). Sediment colour varies from one location to the next. Some samples are light grey in colour, consisting of fine-medium sand and may contain abundant estuarine gastropods, such as *Protomella capensis,* while others consist predominantly of very fine grained, dark-brown sediment that has been eroded from the nearby saltmarshes.

The Lagoon regime contains some shallow-marine and littoral species that have been transported upstream with the flood tides, but it is characterised by the occurrence of the estuarine foraminiferal assemblage including: *Ammonia parkinsoniana, Haynesina germanica, Rotalia gaimardii, Elphidium articulatum, Elphidium advenum, Triloculina "oblonga"* and *Quinqueloculina dunkerquiana. Ammonia parkinsoniana* is most abundant in the Lagoon regime and gives way to *Ammonia japonica* near the tidal inlet of the estuary, indicating the transition to the Bay regime (Table 5.1). The appearance, or disappearance, of some species in the foraminiferal assemblage subdivides the Lagoon regime into 4 zones (sub-regimes): the 'marginal Lagoon regime', which is essentially a transition zone from the Bay regime to the Lagoon regime, the 'lower Lagoon regime', the 'middle Lagoon regime' and the 'upper Lagoon regime', furthest upstream (Table 5.1 and Fig. 5.2). Diversity decreases from the 'marginal Lagoon regime' to the 'upper Lagoon regime'. The 'marginal Lagoon regime' contains the highest diversity of foraminifera in the Knysna Estuary. In order to correlate with the progression of samples, as shown in Table 5.1, the different zones/sub-regimes of the Lagoon regime shall be discussed downstream, from the 'upper Lagoon regime' to the 'marginal Lagoon regime.' Hence, observing the change in foraminiferal assemblages with an increase in tidal/marine influence.

The 'upper Lagoon regime' (samples 17 - 19) is characterised by abundant *Ammonia parkinsoniana*, sub-dominant estuarine foraminifera such as *Haynesina germanica, Elphidium articulatum, Elphidium advenum, Elphidium cf. alvarezianum*, minor abraded littoral species such as *Elphidium crispum, Pararotalia nipponica, Lobatula lobatula,*, minor shallow marine species such as a ribbed *Lagena sp., Oolina cf. melo, Bulimina marginata* and one planktic species (Table 5.1). The 'middle Lagoon regime' (samples 20 - 28) has a similar assemblage of foraminifera as the 'upper Lagoon regime', but is characterised by the appearance and limited extent of the estuarine species, *Rotalia gaimardii,* and the appearance of estuarine miliolids such as *Triloculina "oblonga", Triloculina trigonula, Triloculina tricarinata,* and *Quinqueloculina dunkerquiana.* Littoral species increase in abundance as well as diversity, and species such as *Spiroloculina communis, Quinqueloculina contorta, Quinqueloculina cf. vulgaris, Poroeponides lateralis* and agglutinated *Textularia conica* and *Gaudrina rudis* become apparent. Some Pleistocene (reworked) *Challengerella bradyi* are also recorded in the 'middle Lagoon regime' (Table 5.1). The 'lower Lagoon regime' (samples 29 - 34) shows decreasing numbers of *Ammonia parkinsoniana* and *Elphidium articulatum*, the greatest abundance of *Triloculina "oblonga"*, the termination of *Triloculina tricarinata* and contains no estuaarine *Haynesina germanica* or *Rotalia gaimardii*. The 'lower Lagoon regime' has increased diversity of littoral and shallow-marine foraminifera compared to the 'upper' and 'middle' Lagoon regime (Table 5.1). The 'marginal Lagoon regime' (samples 35 - 38) contains the highest diversity of foraminifera in the Knysna Estuary and shows a rapid increase, downstream, in the percent littoral foraminifera within the sediment samples of the Lagoon regime (Fig. 5.2). *Triloculina "oblonga"* and *Triloculina trigonula* decrease in abundance, compared to samples further upstream, and *Quinqueloculina dunkerquiana* specimens are predominantly reworked (abraded and orange in colour). *Ammonia japonica* and *Miliolinella subrotunda* appear in the sediment samples and *Pararotalia nipponica, Cibicides refulgens* and *Elphidium crispum* (all littoral foraminifera) dominate the assemblage with abundant, but sub-dominant, *Ammonia parkinsoniana.* Numbers of reworked foraminifera increase and some shallow-marine (*Lagena* and *Oolina* species) and planktic species are recorded in the 'marginal Lagoon regime'.

<u>The Barren Regime</u>

There is an absence of both foraminifera and ostracods in the main channel samples from approximately 1.5 km downstream to ~ 400 m upstream of the White Bridge (samples 10 - 16). However, the mudflat areas on the banks of the channel do contain relatively abundant agglutinated foraminifera consisting predominantly of *Miliammina fusca* with sub-dominant *Trochammina inflata*. Since this study focussed on the channel of the Knysna Estuary, this area has been termed the Barren regime. Foraminifera recorded in the channel sediments include two saltmarsh species and eleven specimens of *Ammonia parkinsoniana*. Foraminifera are therefore scarce in this region of the Knysna Estuary compared to the rest of the estuary. The reason for the absence of foraminifera is unknown, but contaminants from the N2 highway, which crosses the White Bridge, may possibly be polluting the water and adding toxic metals to the sediments under the bridge, since the roadside drains directly from the White Bridge into the estuary. Allanson *et al.* (2000) investigated the chemistry of the water column with particular reference to nutrients, suspended solids and the levels of toxic materials such as heavy metals, polynuclear hydrocarbons and polychlorinated biphenols in the estuary. However, their research was restricted to the Ashmead Channel and the oyster beds in the middle estuary.

<u>The Estuary Regime</u>

The Estuary regime has water with salinities of less than 30 ‰ and often exhibits stratification. The low salinities, particularly of the surface waters, are accounted for by the inflow of fresh water from the Knysna River and weak tidal currents. The channel sediment is dominated by fluvially-derived, poorly sorted, gravel, pebbles and cobbles, composed of Table Mountain Group (Peninsula Formation) sandstone and quartzite fragments. The Estuary regime is defined by two species of foraminifera (very low diversity) that make up the upper-estuarine/hyposaline assemblage. Calcareous *Ammonia parkinsoniana s.l.* and agglutinated *Miliammina fusca*, which may have been transported from the intertidal banks.

The River Regime

The River regime contains catchment-derived water and sediment that is transported into the estuary from the Knysna River. This regime dominates the area north of the Charlesford weir; ~18 km from the tidal inlet of the estuary, but since the Knysna River was not included in this study, representative samples for this regime were not collected. Main channel samples 1 and 2 consist of fresh (0 – 2 ‰), relatively acidic water, flowing on a poorly-sorted, immature channel bed and contain no foraminifera. These samples are therefore included into the lower limits of the River regime.

Figure 5.2 Determining regimes across the Knysna Estuary with respect to; salinity changes, percentage littoral foraminifera, and foraminifera species numbers.

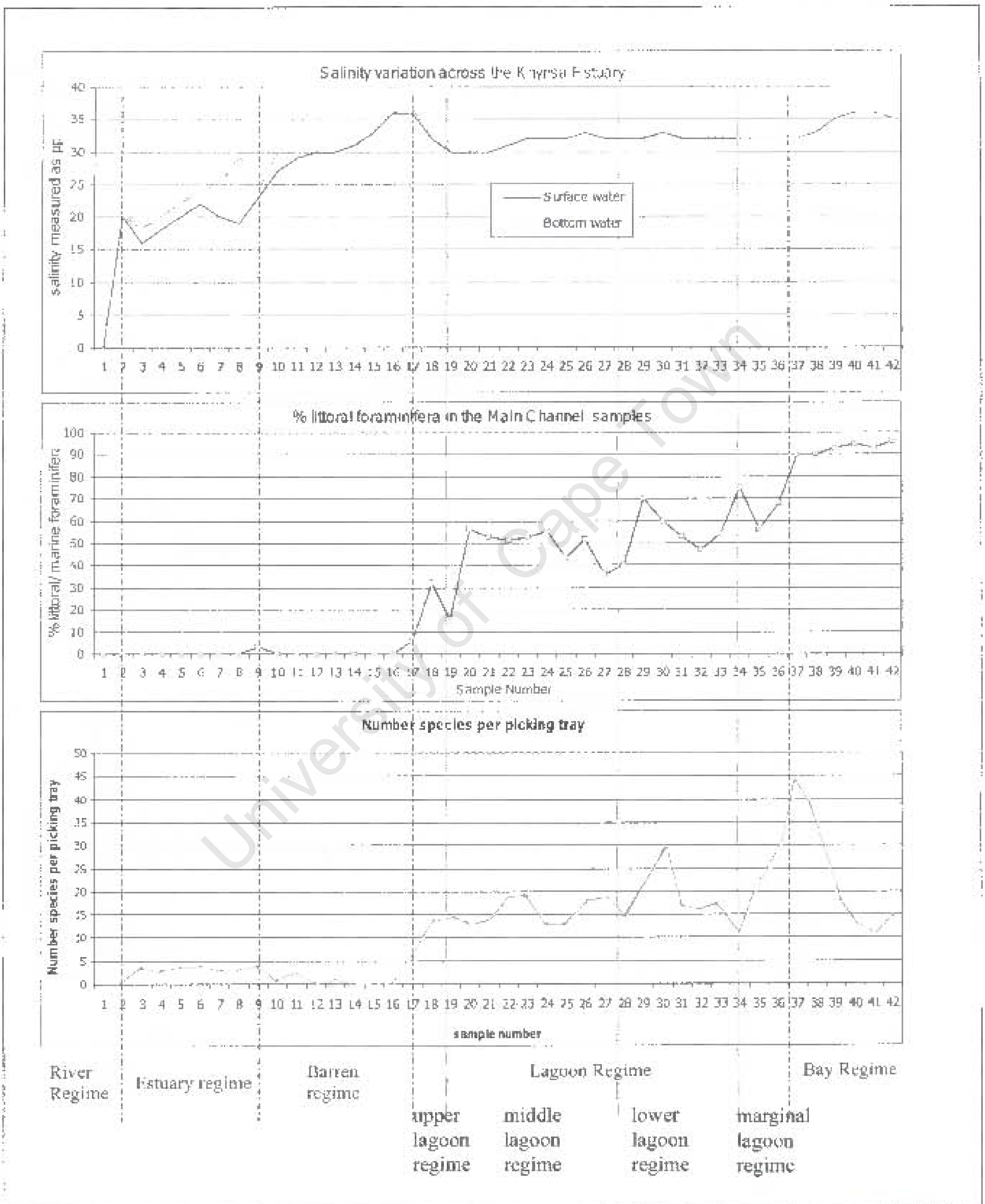
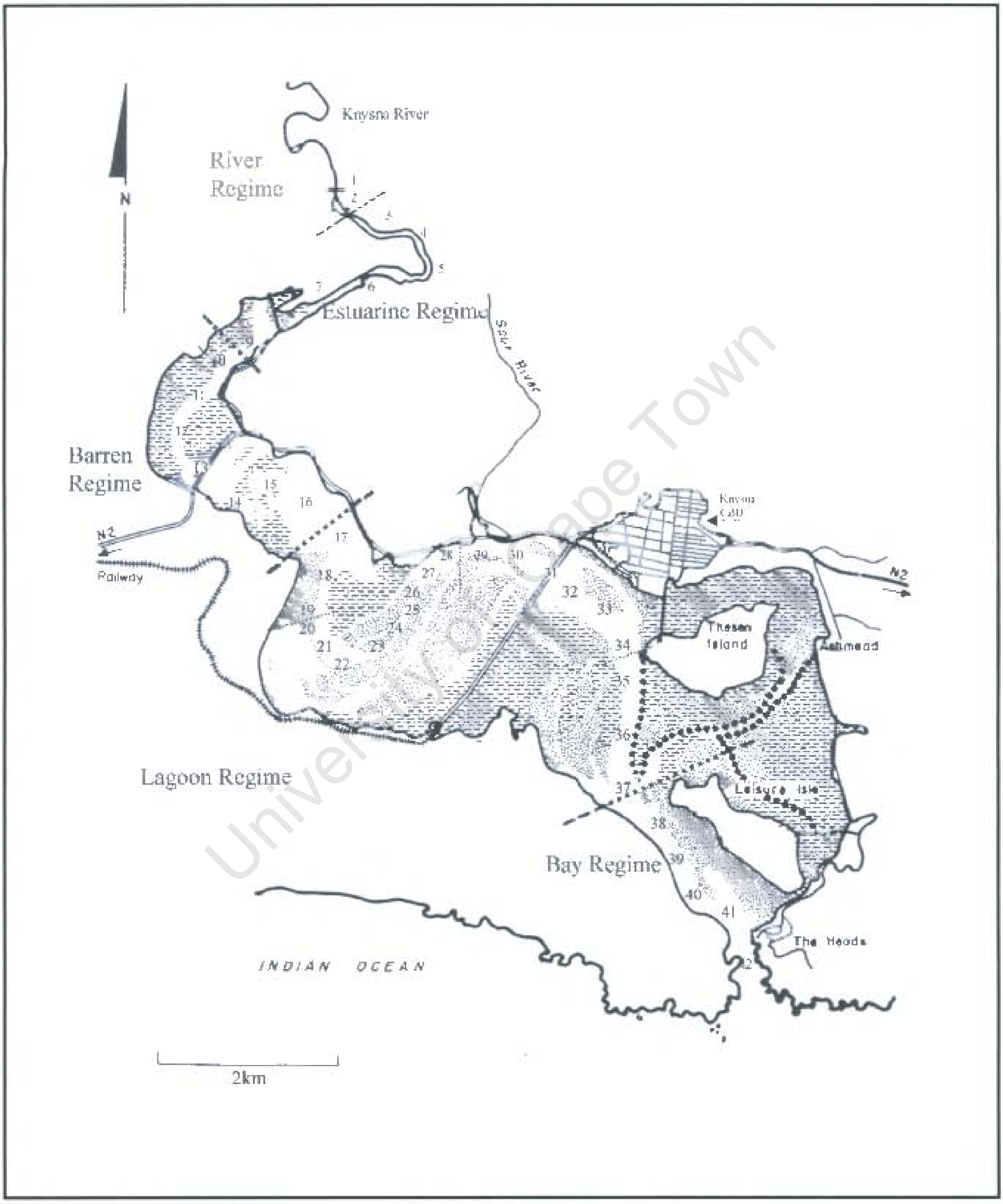


Table 5.1 Extrapolating estuarine regimes from species of foraminifera recorded in the main channel of the Knysna Estuary

	River regime		Estuarine regime							Barren Regime							Lagoon regime																				Bay regime					
																	Zone A			Zone B									Zone C					Zone D								
FORAMINIFERA / SAMPLE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Trochammina inflata					3													2	1																							
Haplophragmoides wilberti			1								1																															
Miliammina fusca			11	33	80	9	12	13	19																																	
Ammonia parkinsoniana s.l.			1	32	20	90	18	15	11	3	6		4				117	38	100	41	41	28	12	13	11	22	38	80	22	17	24	17	3	7	15	20	10	8		3		
Ammonia japonica																		1	3	6										1					1	3	7	8	8	9	4	5
Brizalina striatula																	1																									
Brizalina sp																													1													
Haynesina germanica																		1	1		1								2	1						1						
Rotalia gaimardi																				1	1	3	2	1			3	4														
Elphidium cf. articulatum																	2				1																	8				
Elphidium articulatum																			3	1					1	2	1		49	16	2	1		1			2					
Elphidium advenum																		2		1		2			1					6	8	1		2	8	6	7	3	4			1
Elphidium cf. advenum																										1	3		5	15	3		1	2	2	2	7	6				
Elphidium cf. alvarezianum																		2	3										2	2						2	6				1	
Elphidium crispum																		4	4	1	12	14	14	16	11	15	18	12	4	2	10	3	9	20	24	14	13	7	14	15	5	14
Elphidium macellum																			1		6	3	1	1			1	1	1		1	1				1						
Elphidiella sp																		1																								
Triloculina "oblonga"																				1	2	6	3		1	14	49	5	12	37	28	12	4	2	12	14	11	5	1			
Triloculina trigonula																				1		3	7	3		2	2			1	3	2	6	1	5	1		2				1
Triloculina tricarinata																						1			1	1	1	2				2										
Triloculina terquemiana																					1									2					1		1	1			2	
Triloculina bertheliniana																																					1					
Triloculina fichteliana																																					1					
other *Triloculina* sp																						1	2					1	1				1	1			1				1	
Quinqueloculina cf. vulgaris																	1							1			1	1	1	1	1				2							2
Quinqueloculina duthiersiana																				1	6		6	6	3	2	2	2	2	3	2	6	3	1	19	16	6	2	6	3	5	9
Quinqueloculina seminulum																										1				1	1			2			2	2	2	2		
Quinqueloculina costata																						2	1				1			1			1			3	7	1	1			
Quinqueloculina cf. undulata																			1																							
Quinqueloculina lata																							1									1					1					
Quinqueloculina cf. curta																																				1						
other *Quinqueloculina* species																			3															5				1				
Spiroloculina communis																						1	1			1		6			1	1						2		3		1
Spiroloculina sp.																										1																
ribbed *Spiroloculina sp*																														2							1	1				
Miliolinella subrotunda																																				2	14	12	1	1		
Sigmoilina sp.																																					1					
Textularia conica																			1							1	1	1		1					2				1			
Gaudryina rudis																							1	1			1								1					1		1
Spiroplectinella sp.																																	1				1					
Pararotalia nipponica									1									1		8	13	11	2		1	7	8	3	8	5	9	4	5	6	11	17	38	19	18	19	11	2
Cibicides refulgens																				1	6	5	2		2	4	8	5		3	10	6	2	4	11	9	20	10	7	5	4	2
Cibicidoides pseudoungerianus																					2				1			2		2		1	1	1		1	1	1		1		1
Cibicidoides sp.																								1											1							
Poroeponides lateralis																								1	2		1	3	1	1		1	2	3	4	1	4	2	3	3	2	4
Glabratella patelliformis																						1				1																
Glabratella sp.																																					1					
Lagena species																		1												1							4	2	1			
Oolina species																		1				1							2	2						3		3	1			
Lobatula lobatula																		3	2	8		2	2	2		1	6		2	6	4		2	2	6	4	9	7	2	3	1	7
Planorbulina mediterranensis																							1	1					1			1			4	7	7	3	2			
Rosalina bradyi						1																1								1							1		1			
Rosalina williamsoni																						1																				
Rosalina cf. globularis																																	1	1				1				
Gavelinopsis Praegeri																									1				1	1							4		1			
Bulimina marginata																		1																								
Bulimina elongata																														2			1	1			2	2				
Bolivina orangensis																																			1							
Homotrema rubrum																					1		1	1													2	1				
Acervulina sp.																																			1	1		2				1
Forams reworked from Pleistocene																			1		1	1	1		1				1		3				1	1						
Cassidulina laevigata																																				1	3	1				
Cancris auriculus																																					1					
Nonion acuenus																																						2	1			
Chrysalidinella dimorpha																																					1					
Notorotalia clathrata																																										1
Planktonics																	2									1			2	2	1		1	1	2	1	4	4	1		1	
Sum of Foraminifera	0	0	13	85	153	100	28	28	31	3	0	0	4	0	0	0	121	90	122	41	64	84	36	47	37	79	142	100	[illegible]	134	108	[illegible]	[illegible]	82	121	190	196	116	71	67	37	51
Number of Foraminifera species	0	0	3	2	3	3	2	2	3	1	2	0	1	0	0	0	4	13	13	12	14	19	12	18	18	15	14	16	18	27	16	16	16	12	21	24	35	30	19	13	13	16
Number of Ostracods	0	0	0.5	2	0	0	0	0	0	0	3	0	5	0	0	0.5	8	5	83	0	10	15	2	3	2	15	60	19	65	40	7	0.0	1	5	1	0	8	5	0	0	0	0
Number of Ostracod species	0	0	1	2	0	0	0	2	0	0	0	0	1	0	0	1	4	5	9	3	5	4	2	3	2	7	10	5	5	9	5	[illegible]	1	7	3	5	5	4	0	0	0	0

Figure 5.3 Regimes of the Knysna Estuary according to salinity gradients and foraminiferal data; Also indicating the main-channel sample locations relative to these regimes.



6. Discussion

Estuaries can be classified according to the degree of mixing of fresh water and seawater, into three categories: stratified, partially mixed and well mixed. (Largier *et al.*, 2000). Most of the Knysna Estuary is well mixed, since marine water is transferred readily through the Knysna Heads. It is perhaps more accurate to refer to this estuary as an embayment, which is almost entirely marine dominated (Largier *et al.*, 2000), receiving variable flow (0.09 m^3/s - >9 m^3/s) from the Knysna River at Charlesford, some 18 km upstream of the tidal inlet. The total area of the estuary is 1827 ha (Grindley, 1985), of which 1000 ha is intertidal and supratidal marsh (Maree, 2000). The Knysna Estuary is well suited for investigating microfossil assemblages, since it has an ideal climate, transparent water and a diversity of habitats, which sustain the richest abundance of fauna and flora along the South African coast (Day *et al.*, 1952 and Day, 1967). It is also open to the sea throughout the year, thus samples collected at a single time of the year are representative of the average conditions (Benson and Maddocks, 1964).

The distribution of foraminifera in the Knysna Estuary can be documented, but the reasons for those distributions are complex. A variety of interrelated biotic and abiotic factors control microfaunal distributions, and changing levels of importance of these factors from place to place have proven difficult to unravel (Lipps, 1993). A total of 105 Species from 56 Genera of foraminifera were recognised in the Knysna Estuary. Displaced and reworked tests of early Holocene to Pleistocene age include ~10 species (refer to chapter 4.3). Of the benthic foraminifera in the Knysna Estuary, 9 truly estuarine species were recorded, including *Ammonia parkinsoniana s.l., Elphidium articulatum, Elphidium advenum, Haynesina germanica, Rotalia gaimardii, Triloculina "oblonga", Triloculina trigonula, Triloculina tricarinata* and *Quinqueloculina dunkerquiana.* 4 Saltmarsh species were found, including abundant *Trochammina inflata*, and subdominant *Haplophragmoides wilberti* in the lower and middle estuary, and *Miliammina fusca* in the upper-estuarine marsh areas. 14 Calcareous littoral foraminifera and 4 agglutinated littoral foraminifera were recognized. 19 Calcareous shallow-marine foraminifera were recorded. 8 Species of *Elphidium* and 1 *Elphidiella* species were found. 25 Species of miliolids were documented, including 9 *Triloculina* species, 10 *Quinqueloculina* species, 3 *Spiroloculina* species, 3 *Miliolinella* species and 1 *Pyrgo* species. Although scarce and in low abundance, 8 planktic foraminifera were recorded within the sediments of the Knysna Estuary. These species have been illustrated in Appendix 5.

Wang and Murray (1983) were able to correlate foraminiferal assemblages with tidal range and the degree of mixing of fresh water and salt water in estuaries. Planktic tests are transported furthest in suspension, designating the landward limit of marine influence (tidal range) in the estuary. The most-upstream record of a planktic foraminifera in the Knysna Estuary is in sample 17, just downstream of the White Bridge. Wang and Murray (1983) divided estuarine foraminiferal assemblages into: (a) indigenous estuarine species, adapted to marginal-marine salinity conditions, living in the channels, on the tidal flats and on the marshes;

(b) open-marine (exotic) species, carried into estuaries by tidal currents, either as bedload or in suspension; and (c) reworked or transported foraminiferal tests derived from erosion of pene-contemporaneous or older sediments. Foraminifera from each of these categories have been recognised and recorded in the Knysna Estuary (refer to Ch. 5).

Day (1967) suggested five controlling factors responsible for species richness or poverty in estuaries. Among these, the erosion of the drainage basin, which determines the water clarity and hence the richness of aquatic vegetation, and the width and permanence of the estuary inlet, which affects the tidal range and wave action in the estuary, are of particular relevance to this study. Day (1967) also stresses the importance of shelter in the lives of estuarine animals. Calm-water species (including foraminifera) possess the ability to survive in sheltered water as well as a tolerance to reduced or varying salinity. The availability of food is another fundamental factor controlling species richness or poverty. The fundamental, and possibly primitive, role of foraminifera seems to be as consumers of minute organisms and detritus and once they have assimilated some of the energy available at this level, it can be passed onto larger organisms on higher trophic levels.

The largest numbers of foraminifera around the Knysna Estuary were recorded on the saltmarsh areas neighbouring the channels and in the rock pools near the mouth of the estuary. The intertidal marshes support many agglutinated foraminifera, but species diversity is very low. The rock pools between the Knysna Heads contained abundant calcareous, littoral foraminifera of moderate diversity. Marine marshes contain an abundance of organic detritus, bacteria and epiphytes of various kinds (Lipps and Valentine, 1970), which can sustain large numbers of foraminifera. The microcarnivores that feed on foraminifera in these muddy environments are diverse and some detritus feeders, such as some species of gastropods and possibly mud prawns, incidentally include foraminifera in their diet (Lipps and Valentine, 1970). Considering the foraminifera-rich rock pools near the Knysna Heads; rocky-bottom communities are generally associated with turbulent environments and there tends to be little fine detritus present. Nevertheless, organic detritus does collect in the rock cervices and mats of megascopic algae. Bacteria, diatoms and other unicellular algae live in these places and can sustain foraminiferal populations (Lipps and Valentine, 1970). Foraminifera living in these environments attach themselves to the substrate by use of either pseudopodia, an organic membrane, or by means of a calcite layer (Lipps, 1993). Some gastropods and small grazing metazoans regularly ingest foraminifera that live in the rock pools (Lipps and Valentine, 1970).

In general, as grain-size increases in sedimentary substrates, the amount of organic matter present declines. Therefore, as one traverses from the finer-grained mudflats to more sand-rich, subtidal channel communities there is less organic debris and bacterial abundance probably declines as well (Lipps and Valentine, 1970). Standing crops of foraminifera are therefore expected to decline in sand-rich sediments as their food sources diminish, which would help explain (together with the turbulent waters in the tidal inlet) the decrease in numbers of foraminifera near the mouth of the Knysna Estuary. Foraminifera are nevertheless present and locally diverse in coarse sands and many foraminifera that live in sandy sediments have special feeding habits which are almost certainly associated with the low food supply. For example, species of *Elphidium* extend pseudopodial nets which cover relatively large areas (Lipps and Valentine, 1970).

Ostracods were not found in the sand-rich sediments of the marine-dominated areas. Ostracods can move more efficiently than foraminifera, since they are arthropoda with appendages that extend beyond their microscopic bivalve shells, which can be used for swimming. They can therefore move to where food is more readily available (McMillan, pers. comm. 2002). Their shells (carapaces) may also be more fragile than littoral foraminiferal tests, forcing them to inhabit more sheltered, low-energy environments. The Ashmead Channel, which surrounds Thesen Island, is generally enriched in microfauna relative to the main channel of the Knysna Estuary. The Ashmead Channel is a shallow, low-energy, relatively warm environment, with sufficient light penetration, relatively large saltmarsh areas, a high dissolved organic content in the water column and the subtidal sediments are fine and muddy. It also receives a constant, but adequate, nutrient supply from the sewage-treatment plant and stormwater drains, which can support abundant algal and vegetative growth. These factors combined, allow foraminifera and ostracods to thrive in this region of the Knysna Estuary and would also explain the presence of the mud prawn, *Upogebia Africana*, throughout the Ashmead Channel, as noted by Hodgson *et al.* (2000).

Foraminiferal tests are composed of calcium carbonate or fine arenaceous material and after demise of the living protoplasm, this test acts as a sediment grain. Transported or reworked tests therefore often yield data on sediment provenances and transportation processes. According to Wright *et al.* (1990) who studied foraminifera and sedimentation patterns in the St. Lucia Estuary on the east coast of South Africa, the study of foraminiferal assemblages provides a quick, simple method of distinguishing between marine- and catchment-derived sediment, presenting an alternate method to sediment grain-size analysis. It is probable that most of the sediment containing littoral and reworked foraminifera originated in coastal rock pools around the Knysna Estuary, which contain recently eroded material. This sediment was then transported, together with some foraminifera from the continental margin, onto the beaches near the mouth of the estuary, and into the Knysna Estuary by wave action and longshore drift.

Many reworked or transported species recorded in the sediments of the estuary were identified on account of being abraded, broken and discoloured (see Appendix 2), such as *Elphidium crispum* and *Pararotalia nipponica* species in the middle estuary, which were transported from the lower estuary and *Quinqueloculina dunkerquiana* in the lower estuary, which was transported from the middle estuary. Specimens of *Quinqueloculina contorta, Triloculina terquemiana* and *Oolina melo* in the lower estuary were perhaps transported from other high-energy environments within or outside of the Knysna Estuary and most *Pararotalia nipponica, Elphidium crispum, Nonion boueanus* and *Triloculina terquemiana* species in the

Ashmead Channel were transported by flood tides from the high-energy, littoral environment near the Knysna Heads. Using foraminifera to recognise the different sedimentary facies enables a better understanding of sediment dynamics within the estuary and, because foraminifera are such sensitive ecological indicators, they ultimately provide data for improved estuarine management plans.

Changing environmental parameters across the estuary are reflected by contrasting foraminiferal assemblages. The zonation or variation of foraminiferal assemblages in the Knysna Estuary may be interpreted as a response to: (a) alterations in ecological conditions, (b) sediment-transport mechanisms, and (c) the erection of artificial structures on and around the Knysna Estuary. Foraminiferal assemblages in the Knysna Estuary have been discussed in Chapter 5 and include: a littoral assemblage, a shallow-marine assemblage, an estuarine assemblage, an upper estuarine/ hyposaline assemblage, a mudflat assemblage and a localized assemblage of *Elphidiella* species in the Ashmead Channel. Once salinities of >30 ‰ are reached in the estuary, ~7 km downstream from the weir, littoral and shallow-marine foraminifera appear in the channel sediments. The littoral and the shallow-marine assemblages are important in the Knysna Estuary, because oceanic waters and current activity controls a large proportion of the estuary. Marine influence, indicated by the presence of littoral, shallow-marine and planktic foraminifera, decreases from 100 % at the tidal inlet, to >40 % near main-channel sample 20 (essentially mid-estuary), to 0 % in the upper-most estuary. A large proportion of the littoral and shallow-marine foraminifera in the channel and on the sandflats in the lower estuary, were presumably transported to their present position from exposed beaches associated with medium-grained sandy substrates. Marine foraminifera are transported further upstream by storm surges and spring tides. Marine influence, indicated by a large quantity of planktic, littoral and shallow-marine foraminifera, gastropods, bivalves, echinoid spines and sponge spicules is evident in the sediments of the Ashmead Channel. Samples A1 and A2 (south of Thesen Island) contain abundant shell material, including slightly abraded and relatively bleached estuarine shells such as *Protomella capensis, Loripes clausius* and *Solen capensis* that were possibly transported from the Knysna Heads rock pools. As one progresses anticlockwise around Thesen Island towards the causeway, both marine influence and shell abundance decreases. The sediments at the causeway demonstrate the least marine influence, with an assemblage of abraded and somewhat bleached marine foraminifera and shells.

Shallow-marine assemblages and foraminifera from the continental shelf indicate an onshore-offshore movement of sand, in addition to the coastal longshore movement. Near the Knysna Heads, a combination of strong tidal currents and vigorous wave action causes suspension of sediment particles, which are transported into the Knysna Estuary, together with shelf-derived and reworked material derived from erosion of the surrounding coastal rocks. Thus, species diversity and the proportion of exotic, marine species in the channel sediments can be used as criteria for the recognition of tidal strength in estuaries. This is clearly of value in the interpretation of fossil estuarine deposits, since there is an obvious correlation between tidal amplitude, estuary type and the resultant foraminiferal assemblages.

Largier *et al.* (2000) divided the Knysna Estuary into three regimes. The "Bay regime" in the lower estuary, The "Lagoon regime" in the mid-estuary (generally between the White Bridge and the Railway Bridge), and the "Estuary regime" in the upper estuary. By studying the changing environmental conditions and the associated foraminiferal assemblages, the Knysna Estuary has been divided further. A "Barren regime" has been included in the vicinity of the White Bridge and the "Lagoon regime" has been subdivided into four zones/sub-regimes. Hence, subtle changes that are not clearly reflected in the oceanography are reflected by the microfauna (Figure 5.2 and 5.3). This study focussed on the main subtidal channel of the estuary. A Saltmarsh regime would be included if one were to look at the estuary as a whole. The boundary of regimes within the estuary usually demonstrates an area of enriched foraminiferal diversity relative to the surrounding channel areas. A good example is the confluence of the Lagoon regime and the Bay regime near main channel samples 36 and 37, which contains the greatest diversity of foraminifera within the Knysna Estuary.

The Bay regime, near the tidal inlet of the estuary, consists of a relatively low-diversity, littoral assemblage of foraminifera. The low-diversity littoral assemblage is attributed to the turbulent nature of this area. The disruption of sediments by tidal currents destroys the feeding nets of foraminifera and results in the destruction of more fragile foraminiferal tests. Only foraminifera whose tests have adaptive features enabling them to withstand turbulent conditions are preserved. Studies by Guilcher *et al.* (1965), Murray (1965b) and Brooks (1973) prove that current action directly affects the distribution of living tests in shallow-water, high-energy zones. Phleger (1967), Murray (1968a, 1969) and Haynes and Dobson (1969) all noted that where tidal currents are rapid the specimen abundance is low.

Upstream of the Bay regime is the Lagoon regime, which is established from just seaward of the Railway Bridge to ~2 km seaward of the White Bridge. The Lagoon regime consists of waters that are warmer and slightly less saline than seawater, due to relatively long water-residence times. The Lagoon regime consists of 4 zones according to the tolerance limits and abundance of specific species. The Lagoon regime generally contains a high-diversity assemblage of predominantly estuarine foraminiferal species, with some shallow-marine and commonly abraded littoral foraminifera. The high-diversity assemblage in the Lagoon regime, compared to the rest of the estuary, could be due to the presence of a more favourable habitat in this region and/or the inaccessibility of this area to the public and especially to bait collectors. Hodgson *et al.* (2000a), determined that the numbers of the mud prawn, *Upogebia africana* (Crustacea: *Thalassinidae*), showed a peak in abundance in the middle estuary, particularly near the oyster beds, and considered reasons for the density of *Upogebia africana* in this part of the estuary. Factors contributing to the favourability of this habitat may include the less variable and higher water temperature (particularly in the summer months) in this area when compared to the lower and upper reaches of the estuary. In addition, the salinity of the middle reaches is less variable than higher up in the estuary and the amount of <63 μm (mud) sediments and organic matter is slightly higher (Hodgson *et al.* 2000a). Korringa (1956) suggests that oyster spat and older oysters might thrive above the Railway Bridge in the middle reaches of the estuary because of the high food content of the water. Both foraminifera and the mud-prawn populations may benefit from the relatively abundant organic detritus produced by the oysters, though the mud-prawn population possibly also include foraminifera into their diets. Another factor contributing to increased foraminiferal numbers and diversity in this regime is the transport of foraminifera into this area from the open ocean, the littoral environment, as well as from the surrounding mudflats. It has long been known that open-sea foraminifera may be transported progressively into estuaries with increased tidal influence (Wang and Murray, 1983). Illing (1950) demonstrated that dead test behave as sediment grains and are so subject to transport by current movements. Living and fossil marine foraminiferal tests are thus transported upstream, adding to the estuarine assemblage of foraminifera and therefore increasing microfaunal diversity of the Lagoon regime.

A Barren regime exists around the White Bridge, where microfossils within the main channel are scarce. The area around the White Bridge may be absent of foraminifera due to pollutants draining into the estuary from the national road (N2), contaminating the sediments in this region of the estuary. *Juncus* vegetation growing on the mudflats around the White Bridge also appears unhealthy (fairly sparse and a bit dilapidated). The diversity of macrofauna living in the soft, muddy intertidal sediments of the estuary as a whole has not decreased since the enumeration by Day *et al.* in 1952 (Allanson *et al.*, 2000). In fact, macrofaunal diversity has actually increased in the Knysna Estuary due to more fine sediments being incorporated into the intertidal sediments through anthropogenic activities in the catchment area and on the banks of the estuary (Allanson *et al.*, 2000). However, compared to intertidal mudflats in the middle and lower reaches of the estuary, the area around the White Bridge does show fewer numbers of macrofauna (Allanson *et al.*, 2000). This area needs more attention and the levels of toxic metals need to be investigated carefully, either within the sediments beneath the bridge, or within the plant tissue of *Juncus* growing on the surrounding mudflats.

More than 12 km upstream of the mouth, upstream of the White Bridge, fluvial currents play an important role, causing a salinity gradient in the vertical water column. The channel bed comprises abundant cobbles and generally >30 % gravel (coarser than -1phi grain size). This region of the estuary is termed the Estuary regime. It is composed of catchment-derived sediment and brackish water with low salinity and pH values. The Estuary regime consists of relatively high numbers of only two species of foraminifera, *Ammonia parkinsoniana* and *Miliammina fusca.* Environments such as this, where foraminiferal faunas are characterised by large numbers of a few species, are generally considered as stressful habitats (McMillan, 1987). *Miliammina fusca* is the dominant species on the mudflats in this region and a large number are washed into the subtidal channel from the mudflats on the banks. Upstream of the Estuary regime is the River regime, which was not included in this study, although main channel samples 1 and 2 do fall within the lower limits of this regime. These samples consist of fresh river water and contain no foraminifera.

Foraminiferal assemblages on the marsh areas of the estuary, together with a sedimentological and ecological analysis of these areas, provides evidence that the foraminiferal assemblages, in conjunction with the sediment type and changes in vegetation, also have characteristic zones of accumulation from the channel to the upper-marsh areas (Simpson, 2001). Considering the results from saltmarsh 'a' near Thesen Island in the lower estuary and from saltmarsh 'b' near the Railway Bridge in the middle estuary, we can assume that the abundance, as well as the prevailing species of foraminifera, are related primarily to variations in the abundance of organic matter on the intertidal saltmarshes. Since the abundance of vegetative cover coincides with the type of vegetation, foraminiferal assemblages are thus associated with elevation-related changes in the saltmarsh plants. Abundant organic matter, not only provides food, but protects foraminifera from predators and harsh sunlight. The prawn banks (intertidal mudbanks), which have limited plant cover, are prone to desiccation during low tide and are therefore devoid of foraminifera relative to the adjacent subtidal channel and supratidal saltmarsh environments (Simpson, 2001). Diatom assemblages across the intertidal zone can also be divided into three groups correlating to the upper marsh, lower marsh and tidal flat areas (Zong and Horton, 1998), which correlates with the foraminiferal data.

Saltmarsh areas downstream of the White Bridge are dominated by *Trochammina inflata* and *Haplophragmoides wilberti*. Their preservation potential is enhanced by the lack of competition with calcareous foraminifera and the low energy conditions prevailing in the muddy areas in which they live. *Miliammina fusca*, associated with *Juncus* or rush wetlands, is the dominant species in the upper reaches of the estuary. The rush (*Juncus*) wetlands have been built by the Knysna River over the last 6000 years (Holocene transgression) in the vicinity of the White Bridge and upstream to the Red Bridge (Maree, 2000). Le Quesne (2000) demonstrated that these wetlands play an essential role in providing breeding grounds and nursery areas for a number of fish species such as the checked goby *Redigobius dewaalii*.

The need for sustained river flow to maintain estuarine conditions in the sector above the White Bridge and to allow some variation in salinity across the estuary has been stressed in the Knysna Basin Project (Allanson, 2000). While the overwhelming magnitude of the tidal volume is acknowledged (average tidal flow through The Heads is ~1 000 m^3/s, compared to 0.09 - >9 m^3/s from the Knysna River (Largier *et al.*, 2000)), it is the river inflow which is of importance if the estuarine character of the ecosystem is to be maintained. The first requirement is to maintain a salinity gradient in the upper estuary. If salinities are established near to that of seawater in the upper estuary, the *Juncus* wetlands will become replaced by less productive saltmarsh and the biological character of both the macro- and the microfauna above the White Bridge would change (Allanson, 2000). The upper estuarine foraminiferal assemblage of *Ammonia parkinsoniana* and *Miliammina fusca* would be replaced by hypersaline species of foraminifera such as miliolids. In addition, cues for the upstream migration of fish and planktic animals would be reduced in intensity and these rich feeding grounds would become under-utilised (Le Quesne, 2000). Estuarine fish are preyed upon by fish-eating birds and other fish, such as "Garrick/Leervis" and "kob", which will therefore also be affected. River-borne organic particles contribute significantly to the food of suspension feeders such as oysters, razor clams, mud prawns and foraminifera, which are all very important in the estuarine food web. In times of severe drought the salinity in this area would rise to above that of seawater, creating a hypersaline environment, which is inimical to many estuarine species.

It is essential, therefore that the estuarine reserve for the Knysna Estuary be properly established in terms of the requirements of the National Water Act of 1998. Allanson (2000) discusses the fact that, whilst the present invertebrate reserve in the south-east of the estuary and the intertidal area adjacent to the Featherbed Reserve affords protection to some habitats and the associated organisms, other habitats around the estuary are not protected. Future management plans should consider expanding the current reserve areas to include sections of the middle and upper reaches of the estuary, the subtidal as well as the intertidal environments. Of crucial importance is the further protection of the supratidal marshes and the continued regulation of boating. Marsh areas are important to the ecology of the estuary for a number of reasons, which include acting as a nutrient sink during the recycling of phosphates and nitrates within the system and providing a habitat for numerous estuarine organisms, birds, fish, the endangered seahorse *Hippocampus capensis*, as well as a diverse number of invertebrates (Day *et al.*, 1952 and Maree, 2000) and foraminifera. The use of marsh areas for recreation, development, bait collection and demand for fresh water, are just a few pressures that are likely to increase in the future and one cannot overstress the function and conservational importance of these wetlands in the entire system.

We cannot escape the reality that urbanisation and expansion of greater Knysna will increase the volume of sewage-treatment-plant effluent and stormwater discharge, which will affect the loading of nutrients and toxic materials, if not throughout the estuary, then certainly in the Ashmead Channel. The potential for large growths of floating macro-algae such as *Enteromorpha* and *Ulva* is increasing and, if not dealt with correctly, will interfere with navigation, destroy the feeding grounds of waders, decrease the aesthetic appearance of the channel and most certainly affect the microfauna. The levels of toxic materials in the water column show some change with respect to copper and zinc in stormwater outflows from the Knysna industrial area, Thesen Island and discharge from the sewage-treatment-plant into the Ashmead Channel. However these enhanced values are not, as yet, a threat. These sources are diluted by the huge volume of daily tidal flow through The Heads, coupled with utilisation and mineralization in the sediments by the microfauna, preventing a build-up of nutrients in the water column (Allanson *et al.*, 2000). In the rest of the estuary, these values have not changed overall since the 1982 surveys by Watling and co-workers (Allanson *et al.*, 2000), however measurements were not taken under the White Bridge, which appears to be unsuitable for microfauna. What is important to note is that, if the sediments beneath the White Bridge are contaminated, these contaminants are not affecting the estuary seaward of the barren regime, since the levels of metals within the soft tissue of the Knysna commercial oysters, *Crassostrea gigas*, were not above the maximum tolerable standards for heavy metals in the water column (Allanson *et al.*, 2000).

Thesen Island has been the location of Thesen and co. (Pty) Ltd timber processing works since the 1920s when the Thesen family raised the level of the island to introduce industrial activities. Other activities on the Thesen Island include the National Parks Board offices, a scientific laboratory for environmental sciences, and the Knysna Oyster Company. The causeway, constructed in 1883, connects Thesen Island to the mainland (Viljoen, 2000). The causeway reduced flow to approximately 15% of the natural flow prior to its construction and even though culverts were emplaced in 1972 to improve circulation, siltation persisted in this area (CSIR Environmentek, 2000). Studies of tidal movement have shown that the exchange of water in the Ashmead Channel, between the mainland and Thesen Island, is poor. The limited tidal exchange east of the causeway contributed to the deterioration of the water quality in that area and a number of effects gave cause for concern (Grindley, 1985). Fluctuations in dissolved oxygen (relatively deoxygenated), the high percentage of sub-sieve particles (<63 μm) and high nitrogen values in this area all result from the accumulation of fine sediments with a high organic content east of the causeway, in contrast to the unaffected area west of the causeway (Grindley and Snow, 1983 and Grindley, 1985). *Ulva* vegetation and algal growth on the tidal flats east of the causeway indicates raised nutrient levels (Simpson, 2001). Sponges were found on the tidal flats of both the southern and eastern sides of Thesen Island, but were not present near the causeway due to the virtually anaerobic nature of the sediment (Simpson, 2001). Sediments near the causeway include some *Miliammina fusca* species, indicating lowered salinities, which may result from runoff from the slopes of the urban area north of Thesen Island (Simpson, 2001). According to Allanson *et al.* (2000), effluent from the sewage-treatment plant and the stormwater drains produces pulses of nutrient-rich water into the Ashmead Channel. However, harmful levels of nutrients in the water column are prevented (at present) by the large daily volume of tidal flow into the estuary.

The seawall, built in 1930, which surrounds Thesen Island, has resulted in the loss of much of the intertidal habitat. It intercepts the lower marsh area on the south of the island, inhibiting the transport of both sediment and foraminifera from the channel to the saltmarsh and vice versa. A site-characterisation study of the soil in the pole-yard (12 hectares) on Thesen Island demonstrated contamination by toxic wood treatment chemicals (GIBB Africa, 1999), posing a threat, by groundwater contamination, to the intertidal saltmarsh areas, not more than 100 m away (Fig. 6.1). In October 1993, an application for rezoning on the island, from industrial to township development was submitted to the Knysna Town Council and at present the island is being redeveloped for recreational and residential use. Islands are to be created within the existing island, with canals forming a number of interlinked waterways around residential plots. This will enhance the appearance of the island and increase tourism and recreational benefits in the area (Fig. 6.2). The causeway will be reconstructed to allow natural circulation around the island (Fig. 6.3). If monitored properly, the creation of sub-channels within Thesen Island could create a perfectly sheltered environment in which the microfauna can flourish, and considering their importance in the estuarine food-web, the macrofauna and the ecosystem as a whole will also benefit.

There is much potential for continued investigation into the marshland and channel areas of the Knysna Estuary. A geochemical analysis involving heavy metal concentrations within the microfossil tests and a detailed study on morphological (test) deformities could be done to establish the degree to which the microfauna are being affected by pollution associated with development on the shores of the estuary, especially around the White Bridge and in the Ashmead Channel. Metal concentrations should be attempted in *Ammonia parkinsoniana* specimens, since this is the most widespread single species of benthic foraminifera in the Knysna Estuary and this species can be compared within other estuarine environments around the South African coast, as well as globally.

Research by Samir (2000) and Samir and El-Din (2001) on the response of foraminifera and ostracods to various pollution sources, including contaminants containing heavy metals, agricultural waste and domestic sewage effluent, conclude that foraminifera are more sensitive to wastes containing heavy metals than sewage effluent and agricultural waste. This might explain why several foraminifera survive living in the sediments near the sewage treatment plant outflow in the Ashmead Channel, while foraminifera are rare in the subtidal area around the White Bridge. Samir and El-Din (2001) also state that increasing pollution results in low species diversity and population density, and the survival of tolerant and opportunistic species. We can therefore assume that agglutinated saltmarsh species and calcareous *Ammonia parkinsoniana* are more tolerant to heavy metal contaminants than other estuarine microfauna, since these species, although scarce, were found in the sediments below the White Bridge. Samir (2000) also noted that benthic foraminifera are less tolerant to pollution than ostracods and molluscs, which can move more efficiently to more favourable areas.

Increasing environmental stresses are likely to lead to the disruption and dynamic restructuring of communities, as well as localised extinctions of both rare and abundant species, and total extinctions of rare species (Culver and Buzas, 1995). The role of benthic foraminifera in the trophic structure of shallow-marine communities dictates that many other organisms will be affected by environmental degradation caused by the activities of humans. This research provides a valuable reference to evaluate the impact that urban sprawl and tourism has had, and will have, on the microfauna of the Knysna Estuary.

Figure 6.1. Previous industrial activities on Thesen Island. (Modified from GIBB Africa, 1999. *Site Characterisation Study – Pole yard and Associated Wood Treatment Facilities*. Previously from a CSIR document)

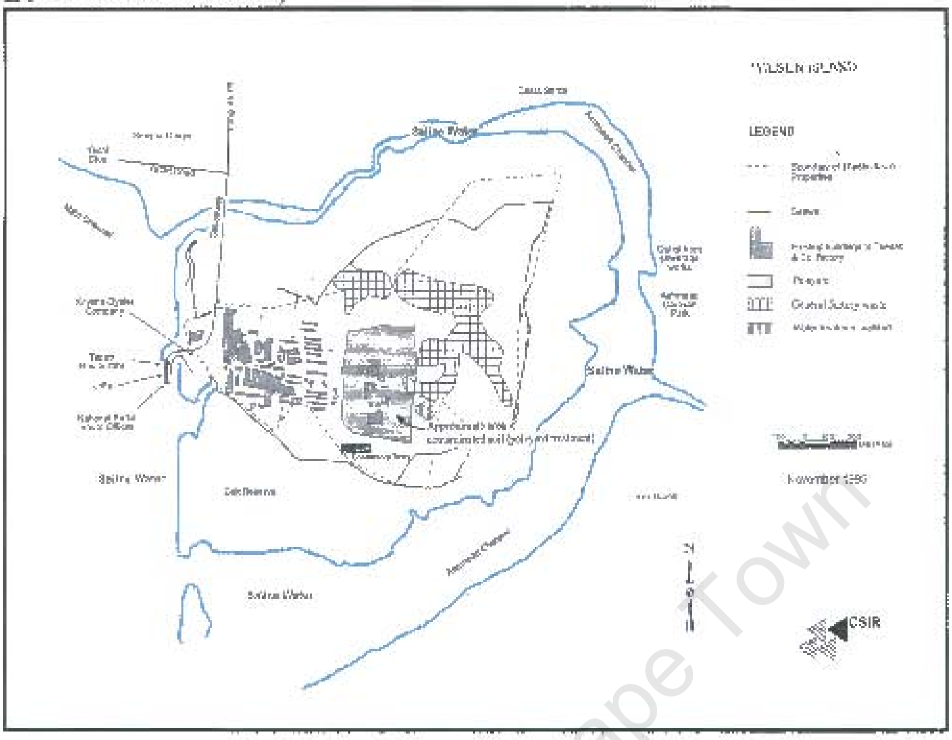


Figure 6.2 Proposed redevelopment of Thesen Island (From GIBB Africa, 1999). Facing south. The Eastern Head, Leisure Isle and the main channel all appear in the view.

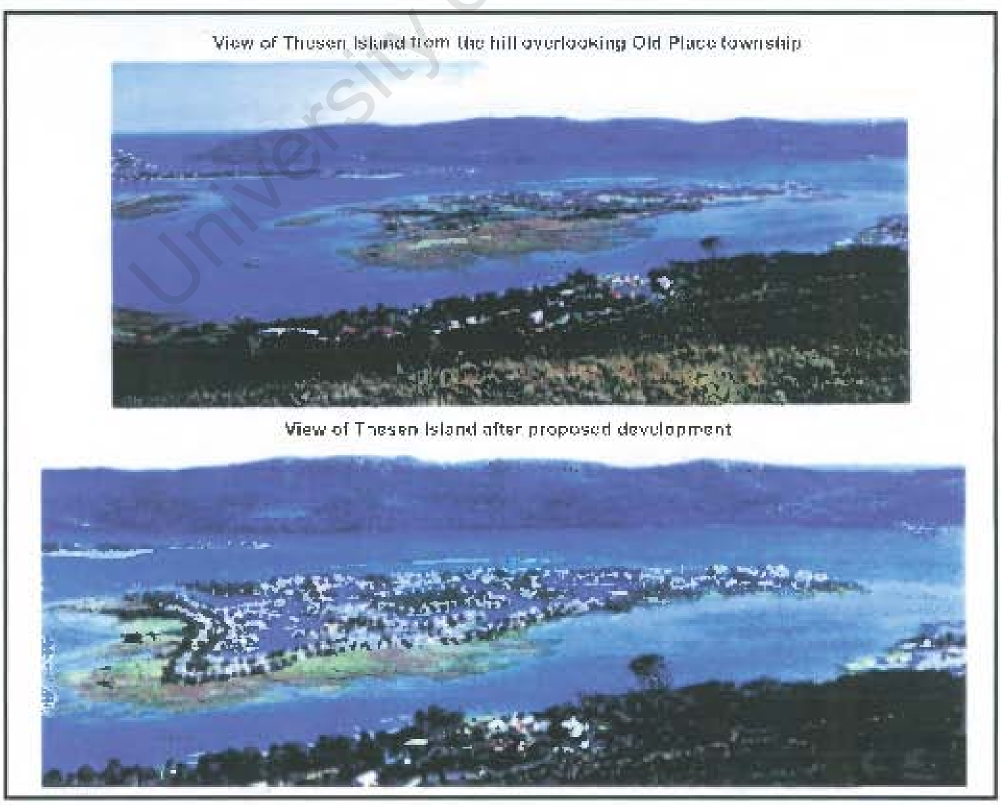


Figure 6.3 Proposed reconstruction of Thesen Island causeway
Photograph by K. Simpson (2002), facing south.

COMPARING THE FORAMINIFERA OF THE KNYSNA ESTUARY WITH OTHER ESTUARINE AND OFFSHORE ENVIRONMENTS ALONG THE SOUTH AFRICAN COAST.

Many of the genera recorded in this study occur around much of the South African coast and are typical temperate-water dwellers (Murray, 1973; McMillan, 1974). The presence of warm- and temperate-water dwellers is a function of the latitudinal position of the estuary. Warm-water planktic foraminifera are carried southward by the Agulhas Current and become mixed with species more typical of the temperate areas of the west and south coast. They may then be transported into the Knysna Estuary by longshore drift and wave action. This section compares the foraminifera found in the Knysna Estuary with foraminifera recorded in the Mgeni Estuary and the St Lucia Estuary on the east coast, as well as on the Agulhas Bank on the continental shelf off the south coast of South Africa.

According to Cooper and McMillan (1987), the Mgeni Estuary on the east coast of South Africa has similar foraminiferal assemblages to the Knysna Estuary. Ninety-seven species of 54 genera were recorded in the Mgeni Estuary, which is similar to the 105 species and 56 genera recorded in the Knysna Estuary. However, only 46 species, 44% of the Knysna species from the south coast, are also found in the warmer waters of the Mgeni Estuary on the east coast. Species common to both the Mgeni Estuary and the Knysna Estuary include: estuarine species such as *Ammonia parkinsoniana* and *Haynesina germanica*; all the saltmarsh species, *Trochammina inflata*, *Haplophragmoides wilberti* and *Miliammina fusca*; most *Elphidium* species, *Elphidium crispum*, *Elphidium macellum*, *Elphidium advenum*, *Elphidium alvarezianum* and *Elphidium cf. gunteri*; many miliolids, such as *Quinqueloculina dunkerquiana*, *Quinqueloculina seminulum*, *Quinqueloculina lata*, *Quinqueloculina curta*, *Triloculina trigonula*, *Triloculina terquemiana*, *Triloculina* *tricarinata, Triloculina fichteliniana, Spiroloculina sp.* and *Spiroloculina communis*; littoral and shallow-marine species such as *Ammonia japonica, Pararotalia nipponica, Poroeponides lateralis, Cibicides refulgens, Cibicides pseudoungerianus, Planorbulina mediterranensis, Glabratella sp., Miliolinella subrotunda, Rosalina globularis, Lagena semilineata* and *Oolina squamosa*; and most of the planktic species that were recorded in the Knysna Estuary, including *Globorotalia inflata, Globigerina bulloides, Globigerina calida, Globigerinoides ruber, Globoquadrina dutertrei, Globigerina sp.* and *Globigerinoides triloba*. We can therefore infer that most of the planktic species in the Knysna Estuary are transported from the east coast via the Agulhas Current into the estuary.

According to Wright *et al.* (1990), 45 species of 31 genera were recorded in the St Lucia Estuary, Zululand, also on the east coast of South Africa, but further north than the Mgeni Estuary. Only Twenty-four of these species, 23% of the Knysna species from the south coast, were common to both the St Lucia Estuary and the Knysna Estuary, which one might expect since the distance from Knysna increases. The dominant foraminifera in the St. Lucia Estuary (Wright *et al.*, 1990) and the Mgeni Estuary (Cooper and McMillan, 1987) are *Ammonia, Elphidium* and *Quinqueloculina* species with subordinate *Triloculina* and *Cibicides species* (Wright *et al.*, 1990) and the Knysna Estuary reveals similar results. Foraminiferal Species that are common to all three estuaries (Mgeni and St Lucia on the east coast and Knysna Estuary on the south coast) are *Ammonia parkinsoniana, Haynesina germanica, Haplophragmoides wilberti, Elphidium advenum, Elphidium crispum, Elphidium macellum, Elphidium gunteri, Pararotalia nipponica, Poroeponides lateralis, Cibicides refulgens, Glabratella sp., Miliolinella subrotunda, Quinqueloculina dunkerquiana, Triloculina trigonula, Triloculina tricarinata, Triloculina sp., Quinqueloculina cf. vulgaris, Quinqueloculina cf. curta, Lenticulina sp, Cassidulina laevigata* and the planktic species *Globigerinoides triloba.*

Considering the saltmarsh foraminiferal assemblages, Cooper and McMillan (1987) noted the same mudflat microfauna in the Mgeni Estuary on the east coast of South Africa and *Trochammina inflata* and *Jadammina macrescens* were recorded as the dominant species of the Langebaan Lagoon saltmarsh, on the south west coast of South Africa (Franceschini, 2003). *Trochammina inflata* is therefore found on saltmarshes all around the South African coastline, but species such as *Jadammina macrescens, Haplophragmoides wilberti* and *Miliammina fusca* are more localised.

Offshore, on the Agulhas Bank, 115 species of foraminifera, of 57 genera were recorded (McMillan, 1974). These numbers are similar to those in the Knysna Estuary, but only 25 of these species, 24% of the Knysna species from the south coast, were also found on the Agulhas Bank, indicating an onshore movement of some species of foraminifera. Species common to the Knysna Estuary and the Agulhas Bank include: *Elphidium crispum, Elphidium macellum, Elphidium cf. advenum, Cassidulina laevigata, Cibicides refulgens, Cibicides pseudoungerianus, Hyalina balthica, Orbulina sp., Pararotalia nipponica, Ammonia japonica, Spirillina sp., Cancris auricular, Rosalina cf. bradyi, Uvigerina sp., Bulimina marginata, Bulimina elongata, Lenticulina* *sp., Lagena sp., Miliolinella circularis, Miliolinella subrotunda* and possible *Challengerella bradyi* (All *Ammonia*-type species were mistakenly identified as *Ammonia beccarii* in McMillan, 1974).

Ammonia parkinsoniana is the only estuarine species of foraminifera common to estuaries all around the South African coast, though *Ammonia* appears to decrease in species diversity northwards towards tropical Mozambique (Wright *et al.*, 1990). The genus appears in the South African fossil record in the Early Pliocene and remains widespread and abundant to the present day (McMillan, 1987). The genus, *Ammonia*, is best represented in shallow-marine, intertidal and lower-estuarine environments, where it may, on occasion, constitute almost the entire foraminiferal assemblage. In such environments, foraminiferal faunas are usually characterised by large numbers of few species, a feature generally considered to be indicative of stressful habitats (McMillan, 1987). Further offshore, other *Ammonia* species occur, such as *Ammonia japonica*, which is typical of more marine environments, but these are much less numerous and only rarely dominate the diverse and abundant foraminiferal assemblages of the continental shelf (McMillan, 1987). This would explain why *Ammonia parkinsoniana* numbers decrease towards the mouth of the Knysna Estuary, while *Ammonia japonica* appears in the foraminiferal assemblage in this region of the estuary.

The tests of *Ammonia parkinsoniana* show some variation in the Knysna Estuary. All specimens of this species have been referred to as *Ammonia parkinsoniana senso lato* for the purposes of this study. Variations in test morphology may be influenced by water salinity and temperature or they may be reflective of the energy, and thus the type of substrate, of the environment in which the species live. Still, attempts to relate test morphology with environment have not been successful in explaining the distribution of variants of *Ammonia parkinsoniana* around the South African coast at the present day (McMillan, 1987). Nevertheless, the relationship of test form to temperature is of significance, since it has been established by laboratory experiments (McMillan, 1987). This study did not focus on variations of test morphology, but further, precise studies on variation of *Ammonia parkinsoniana s.l.* in the Knysna Estuary would be of value, since they may clarify how test morphology of one species may vary relative to changing environmental parameters.

Understanding relative sea-level change is an important topic in many environmental studies. Accurate knowledge of relative sea-level (RSL) change is relevant to a wide variety of regional and global environmental studies including: coastal-evolution models, ice-sheet history and global-circulation models, and for practical matters related to coastal engineering, mining and exploration in marine environments and global environmental management. One of the records of RSL change comes from microfossil data (e.g. diatoms, foraminifera and pollen) contained in a range of Holocene sedimentary deposits (Horton *et al.*, 1999). Although pollen and diatom assemblages are used successfully as sea-level indicators and to infer palaeo-environmental, the use of foraminifera have become increasingly important. Foraminiferal assemblages are usually well preserved, easily detectable and occur in high numbers (100 – 200 tests per cm^3) in both contemporary and fossil deposits, thereby providing a good statistical base for palaeo-environmental interpretations (Horton *et al.*, 1999).

The results in the Knysna Estuary demonstrate that tidally influenced sediments can be recognised from their foraminiferal faunas. Where changes in tidal effects take place, there may be a similar change in foraminiferal assemblages and the general correlation demonstrated between tidal strength, estuary type and resultant foraminiferal death assemblages (thanacoenoses), is clearly of value in the interpretation of fossil estuarine deposits (Wang and Murray, 1983). It is possible that by studying the sequence of deposits laid down during a rapid rise of sea level, the increase in tidal/marine influence across the estuary could be recognised.

The Knysna Estuary preserves considerable evidence for sea level fluctuations. In-situ *Loripes clauses* shells from a subtidal mud bank deposit near the Knysna Estuary indicates a +2.8 m to +3.8 m sea level at 6.30 ka (Marker and Miller, 1993 and Marker and Miller, 1995). At the Knysna Heads, wave-cut caves provide evidence for older high sea-levels at +5 m and +15 m (Marker, 1986). The Heads provide free access to the ocean so that sea level change is immediate in the estuary. A rise in sea level would have resulted in marine foraminifera being transported further upstream in the Knysna Estuary and the microfauna and vegetation living on the supratidal marshes would have been replaced by species that inhabit the intertidal mudflat and subtidal channel environments. A Holocene low sea level stand is evident from an exposed palaeosol containing roots and tree stumps, about 1 m below neap high tide, on the Brenton shore (Marker, 1997). This exposure has been interpreted as a freshwater swamp deposit in which trees reached maturity and the wood is typical of land indigenous timber. A much earlier, mid-Pleistocene, low sea-level stand has also been identified at the Knysna Heads. A well jointed and planed aeolianite exists as a shore platform in the subtidal zone immediately below the Western Head within the entrance to the estuary (Marker, 1997). Its position below sea level, implies a reduction of sea level so that subaerial lithification would occur. These changes in sea level would have affected areas all around the South African coast, as well as globally. Studies have shown that Holocene sea-level fluctuations, similar to those observed in the Knysna Estuary, occurred in the Langebaan Lagoon on the southwest coast of South Africa (Compton, 2001).

Sea-level fluctuations can be observed best by studying microfaunal variations from the subtidal channel, across the intertidal sand- and mudflats to the upper (supratidal) marsh areas, since foraminiferal assemblages exhibit a strong correlation with elevation above mean sea level (Simpson, 2001) (Figure 4.2.10, Chapter 4.2.7). Channel sediments contain calcareous foraminifera, while foraminifera on the intertidal mudflats are scarce, due to an unfavourable habitat caused by repeated exposure, desiccation and flooding with tidal fluctuations (Simpson, 2001). The lower and upper marsh areas are relatively rich in agglutinated foraminifera and it has been stated that assemblages of agglutinated saltmarsh foraminifera are the most accurate sea-level indicators of temperate coastlines. The distribution of foraminifera in the intertidal zone is generally a direct function of elevation in relation to mean sea level, with the duration and frequency of intertidal exposure as the most important factors (Horton *et al.*, 1999).

7. CONCLUSIONS

A total of 105 Species and 56 Genera of Recent foraminifera were recognised in the Knysna Estuary. Displaced and reworked tests of Pleistocene to Early Holocene age included 10 species. Of the benthic foraminifera in the Knysna Estuary, 9 truly estuarine species were recorded, including: *Ammonia parkinsoniana s.l., Elphidium articulatum, Elphidium advenum, Haynesina germanica, Rotalia gaimardii, Triloculina "oblonga", Triloculina trigonula, Triloculina tricarinata* and *Quinqueloculina dunkerquiana.* Four agglutinated saltmarsh species, 14 calcareous littoral foraminifera and 4 agglutinated littoral foraminifera, 19 calcareous shallow-marine foraminifera, 8 *Elphidium* species and 1 *Elphidiella* species were found. Twenty-five miliolids were documented, including: 9 *Triloculina* species, 10 *Quinqueloculina* species, 3 *Spiroloculina* species, 3 *Miliolinella* species and 1 *Pyrgo* species. Although sparse, and in low abundance, 8 planktic species of foraminifera were recorded within the sediments of the Knysna Estuary, most of which were also recorded in the Mgeni Estuary on the east coast of South Africa. Hence, the majority of the planktic foraminifera found in the sediments of the Knysna Estuary were carried southward by the warm Agulhas Current and transported into the estuary by longshore drift, tidal currents and wave action.

Variations concerning foraminiferal assemblages in the Knysna Estuary have been interpreted as a response to (a) alterations in ecological conditions, (b) sediment-transport mechanisms, and (c) the construction of artificial structures on and around the Knysna Estuary. This study provides ecological parameters for each of the samples collected in the main channel, and around the Knysna Estuary, enabling relationships to be depicted between foraminiferal faunas and their environment. Variations in foraminiferal assemblages usually correlate to changes in environmental parameters, such as pH, salinity, depth, light intensity, dissolved-oxygen concentrations, current strength, turbidity, calcium carbonate and trace element content, nutrient content and sediment type. The most important factors controlling foraminiferal distributions in the Knysna Estuary seem to be: 1) the abundance and availability of food, which relates to the abundance of organic matter and therefore sediment grain size, since the fine intertidal marsh sediments provide abundant organic material, 2) turbulence, wave and tidal current action (i.e. energy of the environment), 3) relatively constant water conditions (temperature, salinity, and pH), and 4) protection from desiccation and predators. Consequently, foraminiferal assemblages have assisted in establishing ecological regimes within the Knysna Estuary according to variations in environmental parameters, foraminiferal abundance and species diversity. Where changes in tidal effects take place, a similar change in foraminiferal assemblages is observed. Foraminiferal assemblages in the Knysna Estuary include: a littoral assemblage, a shallow-marine assemblage, an estuarine assemblage, an upper estuarine/ hyposaline assemblage, a mudflat or saltmarsh assemblage, and a localized assemblage of *Elphidiella* species in the Ashmead Channel. Littoral and shallow-marine foraminifera can be used to define tidal strength and oceanic limits in estuaries. The main subtidal channel of the Knysna Estuary has been divided into the following regimes or zones, according to changing environmental conditions and the associated foraminiferal assemblages: A Bay Regime in the lower estuary, which is comparable to other bays along the South African coast and has moderate species diversity, including littoral and shallow-marine assemblages of foraminifera, a Lagoon Regime in the middle reaches of the estuary, exhibits high foraminiferal species diversity and relatively stable conditions with long water residence times compared to the rest of the estuary, a Barren Regime around the White Bridge, an Estuary Regime upstream of the White Bridge, which is influence by river inflow and contains very low species diversity, and a River Regime upstream of the Charlesford weir. If one were to consider the estuary as a whole we would include an Intertidal Saltmarsh Regime, accommodating high numbers of agglutinated foraminifera, comprising predominantly three species. Regions of enriched foraminiferal diversity relative to the surrounding channel areas are evident between different ecological regimes.

The general correlation demonstrated between the amplitude of the tides, estuary type and resultant dead foraminiferal assemblages is clearly of value in the interpretation of fossil estuarine deposits, especially with regard to understanding changes in sea-level. Sea-level fluctuations can be observed best by studying foraminiferal variations across intertidal areas and an accurate knowledge of relative sea-level change is relevant to a wide variety of regional and global environmental studies, including coastal-evolution models, ice-sheet history and global circulation models. The understanding of past sea-level changes is also important for practical matters related to coastal engineering, mining and exploration in marine environments and global environmental management. Furthermore, foraminiferal assemblages provide a quick, simple method of distinguishing between marine and catchment-derived sediment, enabling a better understanding of the sediment dynamics in the Knysna Estuary. A large proportion of the littoral and shallow-marine foraminifera in the channel and on the sandflats in the lower estuary were presumably transported to their present position from exposed beaches, which are associated with medium-grained, sandy substrates. Foraminifera from these marine-dominated assemblages can be found over most of the Knysna Estuary due to immense oceanic exchange at the mouth (tidal inlet) of the estuary. Marine foraminifera are transported further upstream by storm surges and spring tides.

Foraminifera common to the Mgeni Estuary and the St Lucia Estuary on the east coast of South Africa, and the Knysna Estuary on the south coast of South Africa are: *Ammonia parkinsoniana, Haynesina germanica, Haplophragmoides wilberti, Elphidium advenum, Elphidium crispum, Elphidium macellum, Elphidium gunteri, Pararotalia nipponica, Poroeponides lateralis, Cibicides refulgens, Glabratella sp., Miliolinella subrotunda, Quinqueloculina dunkerquiana, Triloculina trigonula, Triloculina tricarinata, Triloculina sp., Quinqueloculina cf. vulgaris, Quinqueloculina cf. curta, Lenticulina sp, Cassidulina laevigata* and the planktic species *Globigerinoides triloba.* Twenty-five species that were found in the Knysna Estuary were also recorded offshore on the Agulhas Bank. Species common to the Knysna Estuary and the Agulhas Bank include: *Elphidium crispum, Elphidium macellum, Elphidium cf. advenum, Cassidulina laevigata, Cibicides refulgens, Cibicides pseudoungerianus, Hyalina balthica, Orbulina sp., Pararotalia nipponica, Ammonia japonica and possible Challengerella bradyi* (All *Ammonia*-type species were identified as *Ammonia beccarii), Spirillina sp., Cancris auricular, Rosalina cf. bradyi, Uvigerina, Bulimina marginata, Bulimina elongata, Lenticulina sp., Lagena sp., Miliolinella circularis* and *Miliolinella subrotunda.* By comparing the microfauna of the Knysna Estuary with other estuaries around the coast, and offshore, one can obtain an idea of oceanographic circulation around the South African coastline and how far foraminifera can travel and survive.

Although the Knysna Estuary is considered to be in an acceptable environmental condition (Allanson, 2000), pressures of development and tourism in the area are likely to cause substantial deterioration. Economic demand has led to increasing encroachment onto the saltmarsh areas all around the Knysna Estuary, leading to the destruction and relocating of the pristine intertidal vegetation, as well as to the associated macro- and microfaunal communities. Studying the microfossil assemblages in the Knysna Estuary has proved to be very important with regard to understanding the ecology and dynamics of the Knysna Estuary and other estuarine environments and will expand the currently limited database of micropalaeontological research in southern Africa. This study has also shown that foraminifera serve as essential environmental indicators and can be used as indicators of pollution, eutrophication and siltation. Accordingly, foraminifera have been used to specify vulnerable areas within the estuary, such as under the White Bridge and in the Ashmead Channel. This study provides a valuable reference to evaluate the impact that increasing development and economic demand will have on the Knysna Estuary, and particularly, to the microfauna. Future management plans should consider expanding the current reserve areas to include regions of the middle and upper reaches of the estuary. Of crucial importance is the further protection of supratidal marshes and the continued regulation of both stormwater discharge into the estuary and boat activities.

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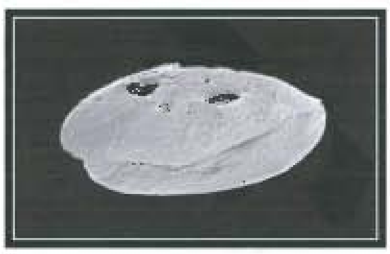
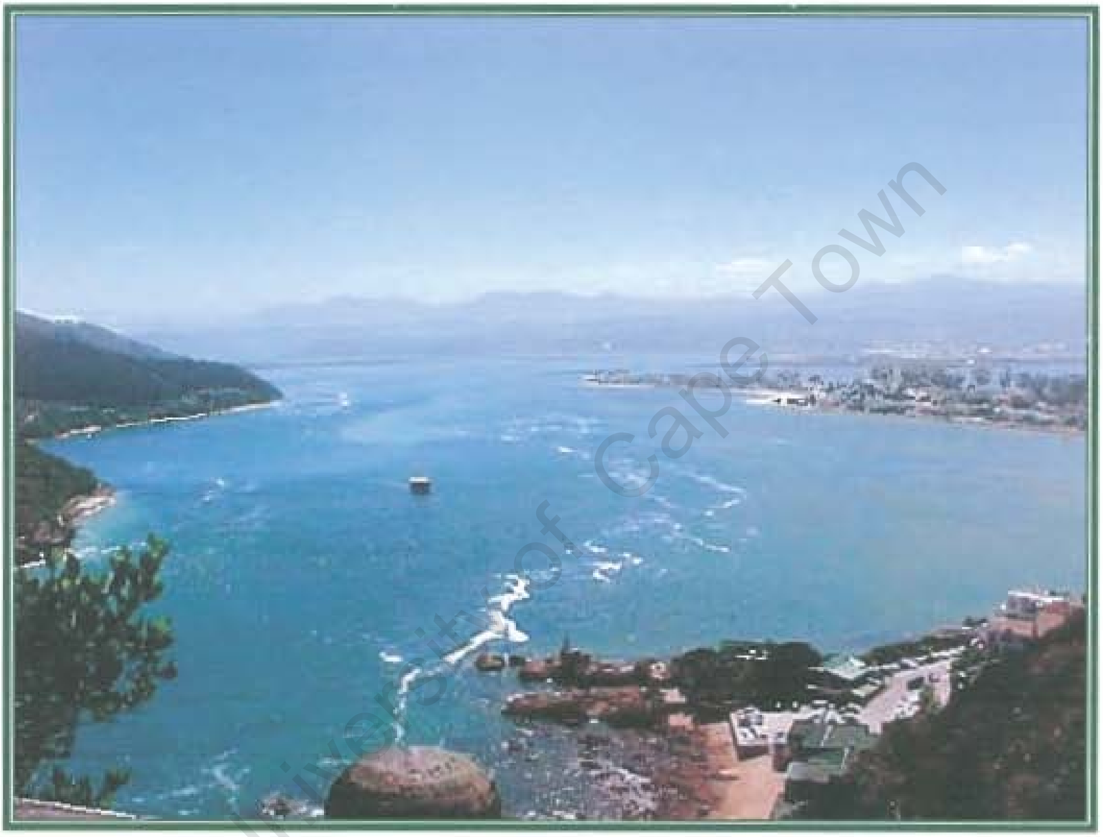


Abraded *Quinqueloculina sp.*

APPENDICES

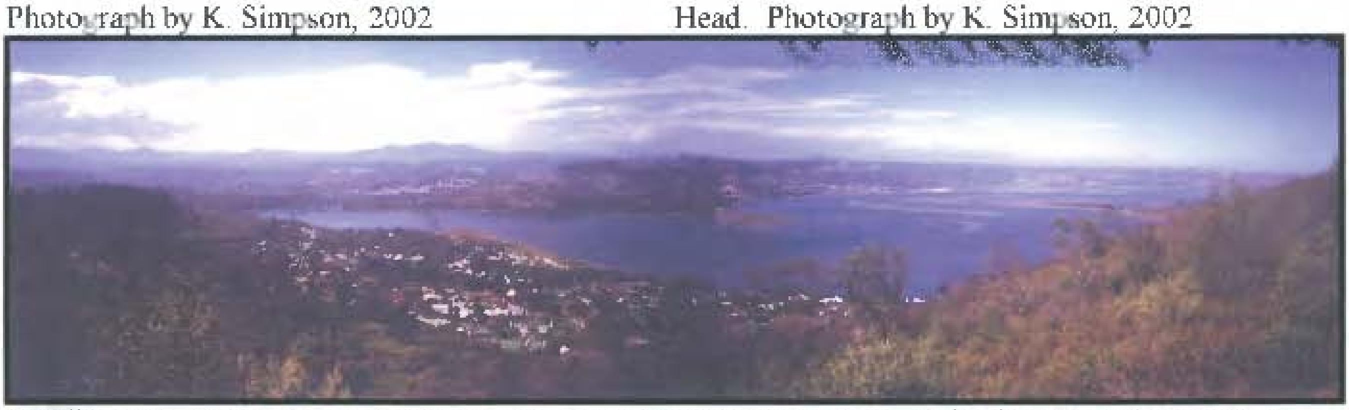


APPENDIX 1

Aerial Photograph of the Knysna Estuary, with the Knysna Heads in the foreground. Brenton-on-Sea beach is visible along the coast. Photograph modified from a 2001 issue of Getaway magazine. Looking towards the east.

The Knysna Heads. Facing south. Photograph by K. Simpson, 2002

Looking down to Brenton beach from the western Head. Photograph by K. Simpson, 2002



Middle reaches of the Knysna Estuary as seen from the western Head. Belvedere residential area on foothill. Facing north-east. Photograph by K. Simpson, 2002

Aerial photograph of Thesen Island and the Knysna CBD. Photograph from CSIR, Stellenbosch. Note the main subtidal channel in lower left quadrant and the Ashmead Channel around Thesen Island.

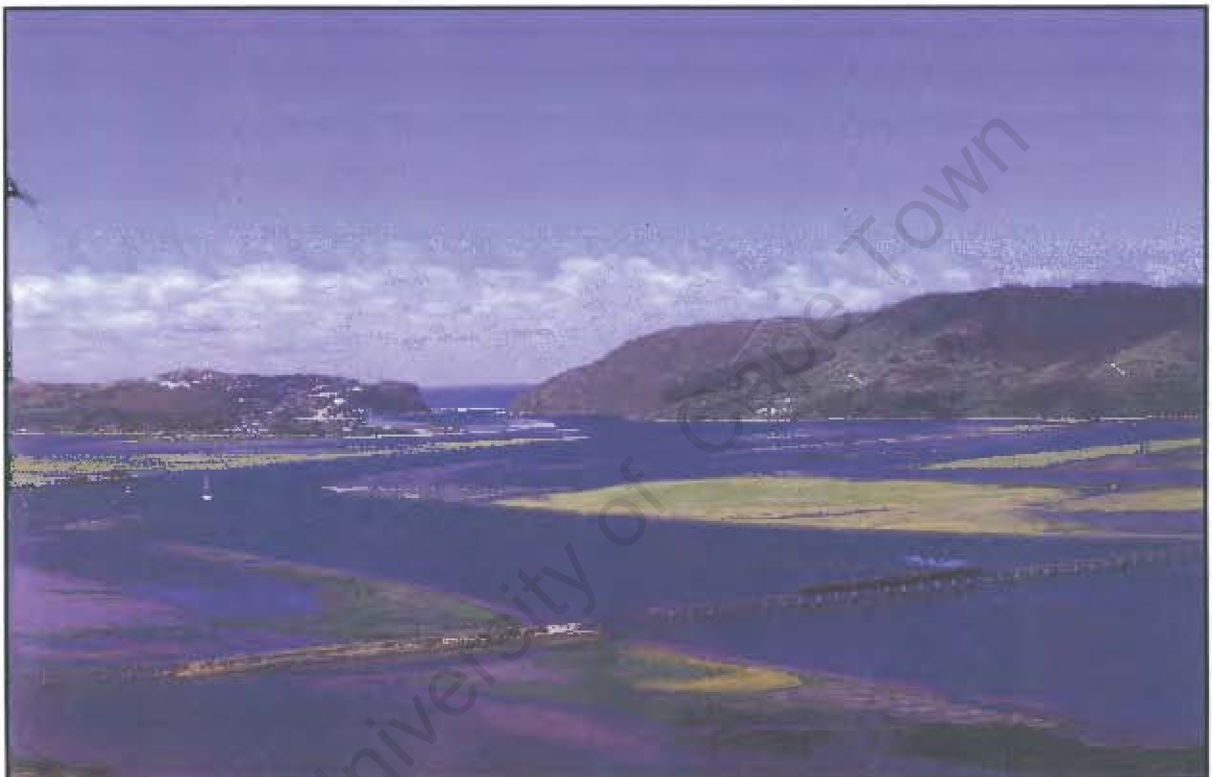
Proposed redevelopment of the Thesen Island Causeway. Photograph by K. Simpson (2002).

The Ashmead Channel at the Thesen Island causeway. Thesen Island in the background. Facing south. Photograph by K. Simpson, during low tide (2002). Note accumulation of sediment.

Right; Aerial photograph of the Knysna Heads, Leisure Isle and the Leisure Isle sandflat. Photograph from CSIR, Stellenbosch.

Below; Sewage treatment plant outlet channel. Facing east. Photograph by K. Simpson, 2002

Leisure Isle sandflat. Facing south towards the Knysna Heads. Right: sandflat at high tide. Left: sandflat at low tide. Photographs taken from Leisure Isle by K. Simpson, 2002.



Lower reaches of the Knysna Estuary. Facing south-southeast. Railway Bridge in foreground, Railway Bridge side-channel in lower right quadrant. Knysna Heads and Southern Indian Ocean in the background. Photograph adapted from "Out There" magazine (July, 2001 issue).

Shallow channel of the Sout River. Facing north. Photograph by K. Simpson, 2002.

Mouth of the Sout River, where it flows into the Knysna Estuary. Facing south. Photograph by K. Simpson, 2002

The weir on Charlesford farm. Note the fresh water lilies on the water surface. Facing north. Photograph by K. Simpson, 2002.

The weir on Charlesford farm. Facing west. Photograph by K. Simpson, 2002.

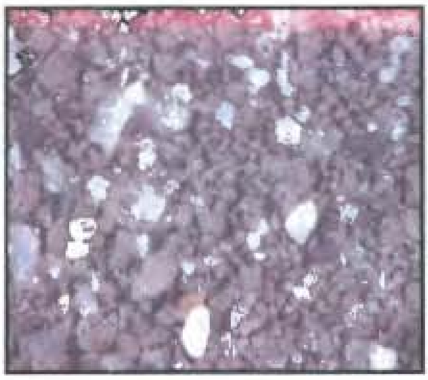
Near main channel sample 2, ~100 m downstream of the weir. Note the dark, peat-stained water, the pebbles and cobbles making up the channel bed and the vegetation on the banks. There are no intertidal marshes in the upper-most reaches of the Knysna Estuary. Facing south. Photograph by K. Simpson, 2002.

APPENDIX 2

Variation in sediment texture and colour across the Knysna Estuary.

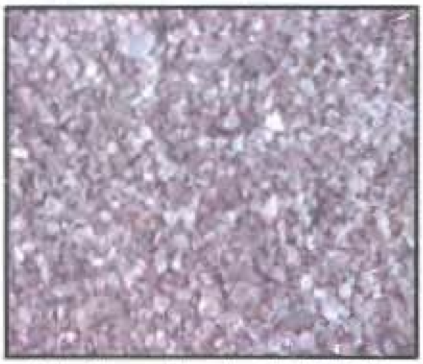
Samples with most distinct variation were selected

Main Channel S4, Sand fraction; Upper reaches of the estuary. (magnification x12.75)

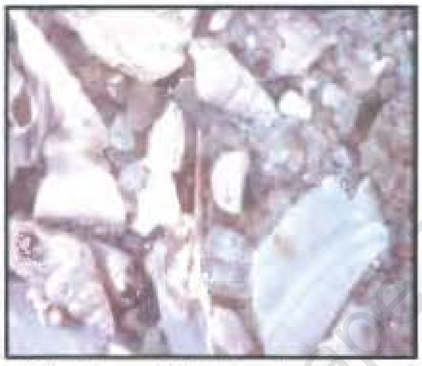


Main Channel S11, Sand fraction; Upstream of the White Bridge (magnification x12.75)

Main Channel S13, Sand fraction; Under the White Bridge (N2). (magnification x12.75)

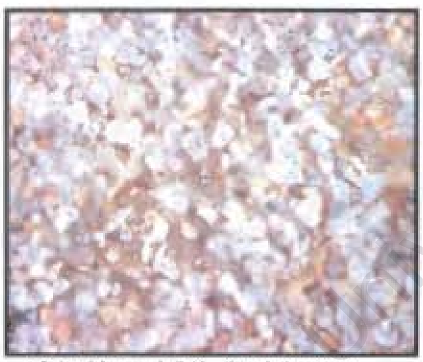


Main Channel Samples 17, 18 & 19 Sand fraction; off Belvedere. (magnification x12.75)

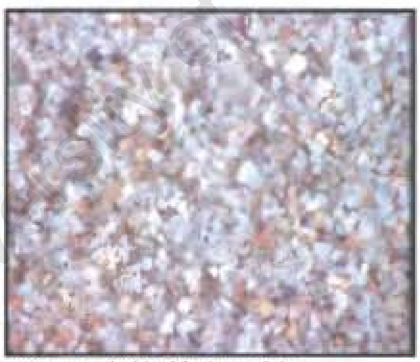


Main Channel S23, Sand fraction; above the Railway Bridge. (magnification x12.75)

Main Channel S33, Sand fraction; downstream of the Railway Bridge. (magnification x12.75)



Main Channel S42, Sand fraction; Knysna Heads tidal inlet. (magnification x12.75)

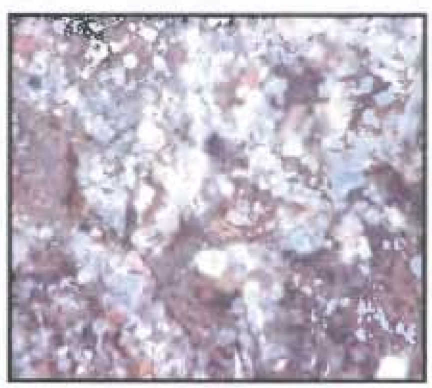


Channel behind Leisure Isle, Sand fraction. (Magnification 12.75x)

Sewage-outlet channel, flows into the Ashmead Channel, Sand fraction. (Magnification 12.75x)

Sout River, Sand fraction. (Magnification 12 75x)

Saltmarsh sediment: lower and middle estuary saltmarsh areas. (Magnification 3.15x).

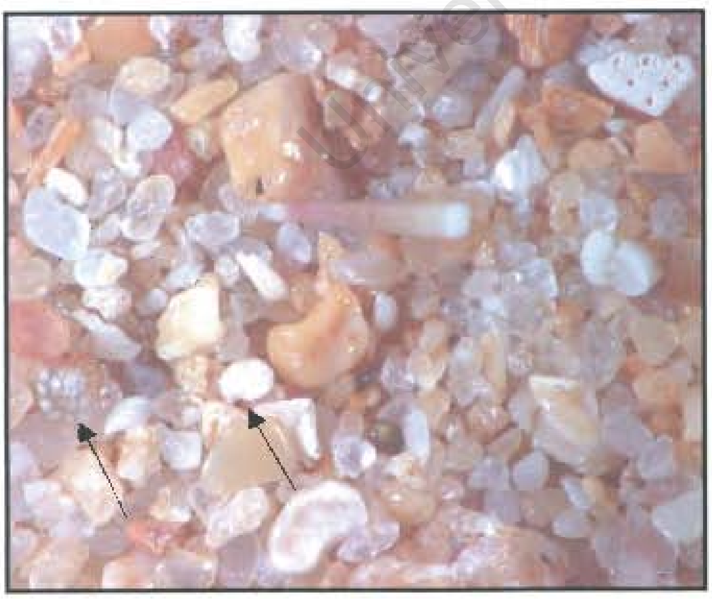


Railway Bridge side channel, Sand fraction. (Magnification 12.75x)

Rock pool sediments; Knysna Estuary

Brenton rock pools, sand fraction. Note *Elphidium crispum*.
(Magnification 12.75x)

Brenton rock pools, sand fraction. Note miliolid and elongate echinoid spines.
(Magnification 12.75x)



Brenton rock pools, sand fraction. Note *Elphidium crispum* and *Challengerella bradyi*.
(Magnification 12.75x)

Shells of the Knysna Estuary

Brenton rock pools; calcareous marine material abundant. (Magnification 3.15x)

Brenton rock pools; Sandstone rock fragments, calcareous fragments & *Fissurella mutabilis* gastropod in centre. (Magnification 3.15x)

Brenton rock pools; Sandstone rock fragments and bivalve shells. (Magnification 3.15x)

Ashmead Channel S2. Pink staining by Rose Bengal solution. *Protomella capensis* is dominant shell species. Bivalve in bottom right corner (Magnification 3.15x)

West of Thesen Island Causeway, Abraded shells (*Protomella capensis* and *Nassarius kraussianus*), shell fragments, wood and sandstone fragments. (Magnification 3.15x)

Railway Bridge side channel. *Protomella capensis* dominant shell species. (Magnification 3.15x)

Main channel sample 19. Slightly abraded *Protomella capensis* with bivalve shell to left. (Magnification 3.15x)

Main channel samples 29, 30 and 34. Well preserved and abraded *Protomella capensis*, *Nassarius kraussianus* and sub-angular quartzite grains. (Magnification 3.15x)

APPENDIX 3

Table 1:

Main Channel samples; Description table

Sample	1	2	3	4	5	6	7
Date	16/01/2002	16/01/2002	16/01/2002	16/01/2002	16/01/2002	16/01/2002	14/01/2002
Low Tide	11:26	11:26	11:26	11:26	11:26	11:26	10:22
	23:41	23:41	23:41	23:41	23:41	23:41	22:44
High Tide	17:42	17:42	17:42	17:42	17:42	17:42	16:41
	05:39	05:39	05:39	05:39	05:39	05:39	04:36
Time	13:59	13:38	12:00	11:48	11:08	10:47	11:46
GPS Reading (°S)	33.99831	33.99786	34.00585	34.00703	34.01089	34.00998	34.01473
(°E)	23.00305	23.00396	23.01028	23.01604	23.01824	23.01247	23.00474
Location Description	Just upstream of weir Fresh water lillies abundant	~100m before weir On Charlesford farm	~ 500m upstream of S.4 Near cobblestone rapids	~ 500m upstream of S.5	~900m upstream of s.6 Hairpin bend in channel	~850m NE of Red Bridge Bend in the channel	~500m upstream of Red Bridge (near nature reserve area)
Depth (m)	0.5	0.5	0.8	1.1	2	1.6	1.4
Surface Salinity (‰)	0	2	16	18	20	22	20
Bottom Salinity (‰)	0	2	18	20	22	24	25
Flow Velocity (m/s)	0.13333	0.5	0.3	0.1	0.1	0.2	0.2
Water Temperature (°C)	24.5	24	26.5	27	25	25	26
Water Colour	Brown	Brown	Brown	Brown	Brown	Brown	Brown
Water clarity	transparent	transparent	transparent	transparent	transparent	transparent	transparent
pH	5.51	5.79	7.26	7.54	7.49	7.43	7.54
Sediment type	immature gravel and sand	immature gravel and sand	immature gravel and sand	immature gravel and sand	immature gravel and sand	immature gravel and sand	coarse sand
Sorting	very poorly sorted	very poorly sorted	very poorly sorted	very poorly sorted	very poorly sorted	very poorly sorted	poorly sorted
Roundness of grains	very angular to subangular	very angular to subangular	very angular to subangular	very angular to subangular	very angular to subangular	very angular to subangular	angular to subangular
Comments	pebbles & cobbles present	pebbles & cobbles present	pebbles & cobbles present	pebbles & cobbles present	pebbles abundant	gravel abundant	gravel abundant
	some organics present	some organics present	some organics present	very few organics	very few organics	no shells or organics	no shells or organics
Sediment colour	off-white	medium brown-grey	Brown	light medium brown	dark brown	dark brown	medium brown
Number forams /20g sand	0	0	13	65	103	100	28
Number species /20g sand	0	0	3	2	3	3	2
Littoral forams/influence (%)	0	0	0	0	0	0	0

Main Channel samples; Description table (cont.)

Sample	8	9	10	11	12	13	14
Date	14/01/2002	14/01/2002	14/01/2002	14/01/2002	14/01/2002	14/01/2002	14/01/2002
Low Tide	10:22	10:22	10:22	10:22	10:22	10:22	10:22
	22:44	22:44	22:44	22:44	22:44	22:44	22:44
High Tide	16:41	16:41	16:41	16:41	16:41	16:41	16:41
	04:36	04:36	04:36	04:36	04:36	04:36	04:36
Time	12:15	12:38	13:03	13:25	13:42	13:58	15:32
GPS Reading (°S)	34.01622	34.01811	34.02104	34.0265	34.03027	34.03133	34.03288
(°E)	23.00101	22.99748	22.99323	22.98809	22.99007	22.99151	22.99401
Location Description	Under Red Bridge	Betw. Red & Old Bridge	At Old Bridge	Channel marker 1	Channel marker 2	Under N2 Bridge	Channel Marker 3
Depth (m)	1.1	2.5	2.6	3	2.8	2.7	3
Surface Salinity (‰)	19	23	27	29	30	30	31
Bottom Salinity (‰)	29	24	30	30	30	31	31
Flow Velocity (m/s-1)	0.2	0.2	0.2	0.2	0.4	0.4	0.2857
Water Temperature (°C)	26	27	24.5	24	25	24	25
Water Colour	Brown	Brown	Brown	Brown	Brown, but clearer	Almost clear	Dark blue-grey green
Visibility	transparent	transparent	transparent	transparent	transparent	1m visibility	1m visibility
pH	7.5	7.31	7.59	7.77	7.72	7.8	7.74
Sediment type	coarse sand	coarse sand	coarse sand	sandy mud	coarse sand	medium sand	medium sand
Sorting	poorly sorted	poorly sorted	poorly sorted	moderately sorted	poorly sorted	moderately sorted	moderately sorted
Roundness of grains	angular to subangular	angular to subangular	angular to subangular	subangular to subrounded	angular to subangular	angular to subangular	angular to subangular
Comments	gravel abundant	gravel abundant	gravel abundant	high organic content	quartz + rock fragments	quartz + rock fragments	quartz + rock fragments
	no shells or organics	no shells or organics	few shell fragments	eroding saltmarsh sediment	few shell fragments	few shell fragments	no shells or organics
Sediment colour	medium brown	light brown	light brown-grey	dark brown-charcoal	medium brown	brown	medium brown
Number forams /20g sand	28	31	2	5	0	4	0
Number species /20g sand	2	3	1	2	0	1	0
Littoral forams/influence (%)	0	3.2	0	0	0	0	0

Main Channel samples; *Description table* (cont.)

Sample	15	16	17	18	19	20	21
Date	14/01/2002	14/01/2002	14/01/2002	15/01/2002	15/01/2002	15/01/2002	15/01/2002
Low Tide	10:22	10:22	10:22	10:54	10:54	10:54	10:54
	22:44	22:44	22:44	23:12	23:12	23:12	23:12
High Tide	16:41	16:41	16:41	17:12	17:12	17:12	17:12
	04:36	04:36	04:36	05:08	05:08	05:08	05:08
Time	15:46	16:10	16:21	09:41	09:54	10:02	10:14
GPS Reading (°S)	34.03367	34.03345	34.03493	34.0368	34.04264	34.0473	34.0491
(°E)	22.9971	23.00157	23.00469	23.00825	23.00634	23.00625	23.00915
Location Description	Channel Marker 4	Channel Marker 5	Channel Marker 6	Channel Marker 7	Channel Marker 8	Channel Marker 9 Near sandbank	Channel Marker 10 Next to sandbank.
Depth (m)	3.3	3	3.3	5	3	2.2	2.5
Surface Salinity (‰)	33	36	36	32	30	30	30
Bottom Salinity (‰)	33	36	36.5	32	30	30	30
Flow Velocity (m/s-1)	0.3333	0.3333	0.3333	0.1666	0.5	0.8	0.8
Water Temperature (°C)	25	24	24	23	24	23	23.5
Water Colour	Dark blue-grey green	Dark blue-grey green	Dark blue-grey green	Dark blue-grey green	Dark blue-grey green	Dark green-brown	Dark green-brown
Visibility	poor - 20cm visibility	transparent	transparent	transparent	transparent	1m visibility	1m visibility
pH	8.11	8	7.94	7.45	7.75	7.86	7.91
Sediment type	medium sand	medium-fine sand	silt	fine sand	fine sand	fine sand	medium - fine sand
Sorting	moderately sorted	moderately sorted	very well sorted	moderately sorted	well sorted	moderately sorted	moderately sorted
Roundness of grains	angular to subangular	angular to subangular	rounded	subangular to subrounded	subangular to subrounded	generally subrounded	generally subrounded
Comments	quartz dominant	quartz rich	high organic content	gastropod shells present	gastropod shells abundant	some gastropods & bivalves	some gastropods & bivalves
	no shells or organics	no shells or organics	forams are tiny	organics present	lots organics	forams show abrasion	forams show abrasion
Sediment colour	light-medium brown	medium brown	charcoal	medium brown - dark grey	dark yellow-grey	light brown	light brown
Number forams /20g sand	0	0	124	56	122	41	64
Number species /20g sand	0	0	6	13	14	12	14
Littoral forams/influence (%)	0	0	5.65	32.1	15.6	56.1	52.6

Main Channel samples; Description table (cont.)

Sample	22	23	24	25	26	27	28
Date	15/01/2002	15/01/2002	15/01/2002	15/01/2002	15/01/2002	15/01/2002	15/01/2002
Low Tide	10:54	10:54	10:54	10:54	10:54	10:54	10:54
	23:12	23:12	23:12	23:12	23:12	23:12	23:12
High Tide	17:12	17:12	17:12	17:12	17:12	17:12	17:12
	05:08	05:08	05:08	05:08	05:08	05:08	05:08
Time	10:21	10:29	10:39	10:46	10:53	11:02	11:11
GPS Reading (°S)	34.04944	34.04834	34.04684	34.04479	34.04179	34.03978	34.03829
(°E)	23.01139	23.01442	23.01596	23.0172	23.01812	23.02011	23.02303
Location Description	Channel Marker 11 Betw. Sandbanks	Channel Marker 12 Betw. Sandbanks	Channel Marker 13 Betw. Sandbanks	Channel Marker 14 Betw. Sandbanks	Channel Marker 15 Betw. Sandbanks	Channel Marker 16 Betw. Sandbanks	Channel Marker 17 Next to N2 Road
Depth (m)	1.8	2.7	1.8	3.5	2.2	3	6
Surface Salinity (‰)	31	32	32	32	33	32	32
Bottom Salinity (‰)	31	32	32	32	33	32	32
Flow Velocity (m/s-1)	0.8888	1	1	0.8	0.8	0.333	0.30769
Water Temperature (°C)	24.2	24.2	23	23.5	24.5	24	24.5
Water Colour	Dark green-brown	Dark green-brown	Dark green-brown	Green-brown-blue	Green-brown-blue	Green-brown-blue	dark green
Visibility	1m visibility	1m visibility	1m visibility	1m visibility	1.5m visibility	30cm visibility	30cm visibility
pH	7.95	7.91	7.91	7.91	7.94	7.92	7.96
Sediment type	medium - fine sand	medium - fine sand	medium - fine sand	medium - fine sand	medium - fine sand	medium - fine sand	medium sand
Sorting	moderately sorted	moderately sorted	moderately sorted	well sorted	well sorted	well sorted	well sorted
Roundness of grains	generally subrounded	generally subrounded	generally subrounded	generally subrounded	generally subrounded	generally subrounded	generally subrounded
Comments	some gastropods & bivalves	some gastropods & bivalves	some gastropods & bivalves	various shells & echinoid spine	various shells & echinoid spine	various shells & echinoid spine	gastropods abundant
	forams show abrasion	calcareous fragments abundant	calcareous fragments abundant	calcareous fragments abundant	calcareous fragments abundant	calcareous fragments abundant	no organics
Sediment colour	light brown- grey	light brown- grey	light brown- grey	light brown	light brown- grey	light brown- grey	light brown
Number forams /20g sand	84	61	47	37	79	142	100
Number species /20g sand	19	19	13	13	17	18	15
Littoral forams/influence (%)	51.2	52.5	55.3	43.2	51.9	35.9	40

Sample	29	30	31	32	33	34	35
Date	15/01/2002	15/01/2002	15/01/2002	15/01/2002	15/01/2002	15/01/2002	15/01/2002
Low Tide	10:54	10:54	10:54	10:54	10:54	10:54	10:54
	23:12	23:12	23:12	23:12	23:12	23:12	23:12
High Tide	17:12	17:12	17:12	17:12	17:12	17:12	17:12
	05:08	05:08	05:08	05:08	05:08	05:08	05:08
Time	11:17	11:24	11:39	11:42	11:50	11:58	12:10
GPS Reading (°S)	34.03768	34.03982	34.04162	34.04154	34.04468	34.04748	34.0507
(°E)	23.0269	23.03045	23.03349	23.03456	23.0383	23.04198	23.04353
Location Description	Channel Marker 18 Near Sout River outlet	Channel Marker 19 Upstream of Railbridge	Under Railbridge	Channel Marker 20	Channel Marker 21	Near Channel Marker 22 Near sandbank	Near red sandbar marker
Depth (m)	5	2.6	2	2.3	6	2.6	3
Surface Salinity (‰)	32	33	32	32	32	32	32
Bottom Salinity (‰)	32	33	32	32	32	32	32
Flow Velocity (m/s-1)	0.3333	0.2666	0.1	0.1	0	0.57143	0.666
Water Temperature (°C)	24	24	24	24.2	24	24	24
Water Colour	dark green	dark green	dark merky green	dark green	dark green	dark green	dark green
Visibility	30cm visibility	relatively transparent	poor	relatively transparent	1m visibility	1m visibility	moderate
pH	7.99	7.95	7.98	8.03	8.01	8.04	8
Sediment type	fine sand	fine sand	fine sand	fine sand	medium - fine sand	fine sand	fine sand
Sorting	well sorted	well sorted	well sorted	well sorted	well sorted	well sorted	very well sorted
Roundness of grains	subrounded	subrounded	subrounded	subrounded	subrounded	subrounded	subrounded to rounded
Comments	gastropods abundant	gastrop. & forams abundant	some gastropods	gastropods abundant	no organics	organics present	qtz & calcareous fragm.
	organics present	organics presnt	quartz slightly gritty	quartz slightly gritty	quartz slightly gritty	gastropods abundant	very clean sediment
Sediment colour	medium brown-grey	medium brown-grey	light brown- grey	light brown- grey	light brown- grey	medium brown-grey	light brown- grey
Number forams /20g sand	125	136	107	64	39	44	123
Number species /20g sand	21	29	17	16	17	11	22
Littoral forams/influence (%)	70	59.6	53.3	46.9	53.9	75	56.1

Sample	36	37	38	39	40	41	42
Date	15/01/2002	15/01/2002	15/01/2002	15/01/2002	15/01/2002	15/01/2002	17/01/2002
Low Tide	10:54	10:54	10:54	10:54	10:54	10:54	11:59
	23:12	23:12	23:12	23:12	23:12	23:12	
High Tide	17:12	17:12	17:12	17:12	17:12	17:12	18:11
	05:08	05:08	05:08	05:08	05:08	05:08	06:10
Time	12:17	12:34	12:42	13:13	13:26	13:44	13:38
GPS Reading (°S)	34.05489	34.06099	34.06447	34.0689	34.07251	34.0754	34.07743
(°E)	23.04334	23.04544	23.04816	23.05135	23.0534	23.05617	23.06062
Location Description	Near Channel Marker 24 2nd sandbar marker	Near Channel Marker 25 Near green sandbar marker	Near Channel Marker 26 Near green sandbar marker	Near Channel Marker 27 Near green sandbar marker	Just past Channel Marker 28 Near The Heads	Entrance to The Heads	Between The Heads
Depth (m)	4	5	6	6	8	8	10
Surface Salinity (‰)	32	32	33	35	36	36	35
Bottom Salinity (‰)	32	32	33	35	36	36	35
Flow Velocity (m/s-1)	0.666	0.666	0.57143	0.57143	0.8	1	1.2
Water Temperature (°C)	24	23	23	23	22.5	22.2	23
Water Colour	dark green	Green-blue	Green-blue	Crystal green-blue	Crystal green-blue	Crystal green-blue	Crystal green-blue
Visibility	transparent	transparent	transparent	transparent	transparent	transparent	transparent
pH	8	8.02	8.01	8.08	8.1	8.11	8.18
Sediment type	fine sand	fine sand	fine sand	fine sand	fine sand	fine sand	fine sand
Sorting	very well sorted	very well sorted	very well sorted	very well sorted	very well sorted	very well sorted	very well sorted
Roundness of grains	subrounded to rounded	subrounded to rounded	subrounded to rounded	subrounded to rounded	subrounded to rounded	subrounded to rounded	subrounded to rounded
Comments	qtz & calcareous fragm.	qtz & calcareous fragm.	qtz & calcareous fragm.	qtz & calcareous fragm.	qtz & calcareous fragm.	qtz & calcareous fragm.	qtz & calcareous fragm.
	very clean sediment	very clean sediment	some organics	very clean sediment	very clean sediment	very clean sediment	very clean sediment
Sediment colour	light brown- grey	light brown- grey	light brown- grey	beige	beige	beige	beige
Number forams /20g sand	131	203	121	72	57	38	51
Number species /20g sand	27	44	36	20	13	11	15
Littoral forams/influence (%)	68	89.8	90.1	93	94.7	93	96.1

Table 2: Extra Samples collected around the Knysna Estuary

Sample	Sout River sample 1	Sout River sample 2	Railbridge side channel	Thesen island causeway 1	Thesen island causeway 2	Sewage outlet 1	Sewage outlet 2
Date	17/01/2002	17/01/2003	17/01/2004	17/01/2005	17/01/2006	17/01/2007	17/01/2008
Time	10:00	10:19	10:39	10:55	11:08	11:55	12:00
GPS Reading (°S)	34.03293	34.03698	34.03774	34.04337	34.04346	34.04642	34.04659
(°E)	23.02486	23.02466	23.03645	23.04826	23.04813	23.06751	23.06817
Location Description *(locations on figure 2.1)*	100m upstream of Sout River mouth	At Sout River mouth	Near N2 road, under Railbridge	Just east of Causeway	Just west of Causeway	~80m from sewage outlet	At the sewage outlet
Depth (m)	0.2m	0.6	2	3.5	2	0.3	1.5
Surface Salinity (‰)	26	30	32	32	32	2	0
Bottom Salinity (‰)	26	30	32	32	32	2	0
Salinity Gradient	No	No	No	No	No	No	No
Flow Velocity (m/s^{-1})	Zero	0.13	0.4	0.15	~0.6 (fast under causeway)	~0.15	~0.15
Water Temperature (°C)	25	24.5	25	25	25	26	25
Water Colour	Clear	Clear	Blue-green	Brownish blue	Browmish blue	light brown-clear	Light brown
pH	7.37	7.65	7.95	8.02	8	7.85	7.81
Water clarity	transparent	poor	poor	poor	poor	relatively clear	poor
Sediment type	coarse sand	medium grained sand	Fine sand	fine sand	medium grained sand	fine sand	fine-medium grained sand
Sorting	poorly sorted	poorly sorted	well sorted	well sorted	moderately sorted	well sorted	well sorted
Roundness of grains	angular to subangular	angular to subangular	subangular to subrounded	subangular to subrounded	subangular to subrounded	subangular to subrounded	subangular to subrounded
Comments	no organics or shells	no organics or shells	organics & shells present	abundant organics & shells	some shell fragments	few shell fragments	very few shells & organics
	ostracods ~30/tray	microfauna rare	microfauna small, but abundant	sediment looks gritty	sediment looks gritty	some organics present	microfauna rare
Sediment colour	Light brown	Light brown	light grey	light brown-grey	light brown-grey	light grey	light brown-grey
Foraminifera /20g sand	3	12	55	33	3	33	10
Foraminiferal Species /20g sand	3	4	21	11	3	12	4
% littoral/ shallow marine forams	0%	0%	63.60%	57.58	60%	87.88%	40%

Ashmead Channel

Ashmead channel sample	A1	A2	A3	A4	A5	A6
Location	Entrance to Ashmead channel	1km from A1	750m from A2	1km from A3	800m from A4	100m from A5
						near causeway
Depth (m)	~1.7m	~1.5m	~1.5m	~1.5m	0.75m	1m
Surface Salinity (‰)	33	33	33	33	33	33
Relative flow velocity	moderate	moderate	moderate	moderate	Slower	Very slow
Water Temperature (°C)	23	23	23	23	23	23
Water Colour	clear-green	clear-green	clear green-brown	clear green-brown	green-brown	brown
pH	8	8.02	8.1	8.1	7.9	7.86
Water clarity	good	moderate	moderate	moderate	poor	very poor
Sediment type	medium-fine grained sand	fine sand	very fine sand	very fine sand	mud-rich sand	mud-rich sand
Sorting	well sorted	well sorted	well sorted	well sorted	well sorted	well sorted
Roundness of grains	subangular- subrounded	subangular- subrounded	subangular- subrounded	subangular- subrounded	subangular- subrounded	subangular- subrounded
Comments	Eelgrass present (lots organics) Sand fraction dominant abundant marine material	few organics Shell -rich abundant marine material	Eelgrass present (lots organics) mud-rich some marine material	moderate amt organics mud-rich some marine material	organics abundant sediment gritty marine components - few and abraded	organics abundant sediment gritty marine components - few and abraded
Foraminifera /20g sand	88	29	122	92	68	91
Foraminiferal Species /20g sand	27	11	29	21	13	11
% littoral/ shallow marine forams	84.09	93.01	77.68	72.82	45.58	26.37
% reworked forams	3.04	5	7.4	11.96	22.06	29.67

Distance from sample 1 to sample 6 = 4km
Marine material = echinoid spines, sponge spicules, gastropods, bivalves, etc.

Sample A2 contains abundant shell material, including *Protomella capensis, Loripes clausius* and *Solen capensis.*

Marine dominated samples Collected in March 2002

Sample	Leisure isle sandflat (L1-L9)	channel behind Leisure isle (Lo)	Knysna Heads rock pools	Brenton beach	Brenton rock pools	Noetzie beach	Noetzie rock pools
GPS Reading (°S)(°E)	/	/	/	/	/	/	/
locations on figure 2.1							
Depth (m)	0 -1m at low tide	30cm at low tide	~15cm at low tide	above water	~20cm at low tide	above water	~20cm at low tide
Salinity (‰)	marine (~35‰)	marine (~35‰)	marine (~35‰)	marine (~35‰)	marine (~35‰)	marine (~35‰)	marine (~35‰)
Water Temperature (°C)	fluctuates with seasonal ocean temperatures; generally range from 15°C to 25°C from winter to summer months respectively						
Water Colour	blue-green (clear)	blue-green (clear)	blue-green (clear)	blue-green (clear)	blue-green (clear)	blue-green (clear)	blue-green (clear)
pH	oceanic (~8.0)	oceanic (~8.0)	oceanic (~8.0)	oceanic (~8.0)	oceanic (~8.0)	oceanic (~8.0)	oceanic (~8.0)
water clarity	transparent	transparent	relatively clear	moderate	relatively clear	moderate	relatively clear
Turbulence	relatively high energy environ.	moderate to low energy	high energy environment	high energy environ.	high energy environ.	high energy environ.	high energy environ.
Sediment type	generally fine grained sand	fine sand	medium grained sand	fine sand	medium grained	fine sand	medium grained
Sorting	well sorted	well sorted	well sorted	well sorted	well sorted	well sorted	well sorted
Roundness of grains	generally sub-rounded	generally sub-rounded	generally sub-rounded	generally sub-rounded	generally sub-rounded	generally sub-rounded	generally sub-rounded
Comments	abundant marine material	abundant marine material	abundant marine material	abundant marine material	abundant marine material	abundant marine material	abundant marine material
Sediment colour	light-brown	light-brown	light-brown	light-brown	light-brown	light-brown	light-brown
Foraminifera /20g sand	109 avg.	193	254	107 avg.	84	19	25
Foraminiferal Species /20g sand	26 avg.	31	35	14 avg.	14	7	7
% littoral/ shallow marine forams	100%	100%	100%	100%	100%	100%	100%

Marine material (gastropods, bivalves, echinoid spines, sponge-spicules, bryozoa, ophioroid oscicles, serpulid worm tubes, algal fragments, etc.)

Table 3

	>2mm	>500µm and <2mm	<500µm and >63µm	<63µm
Main channel sample	% gravel	% sand	%sand	% mud
sample 1	18.224	60.048	21.690	0.038
sample 2	6.143	28.579	63.957	1.321
sample 3	65.576	20.535	13.550	0.340
sample 4	38.715	47.103	12.457	1.725
sample 5	12.272	23.373	59.189	5.165
sample 6	42.438	37.295	17.748	2.519
sample 7	1.303	58.604	35.973	4.119
sample 8	0.000	43.423	50.029	6.548
sample 9	0.000	30.500	62.322	7.178
sample 10	0.000	42.428	42.607	14.965
sample 11	0.000	19.467	39.976	40.557
sample 12	0.000	37.256	54.447	8.297
sample 13	0.000	35.485	49.197	15.318
sample 14	0.000	58.162	41.006	0.832
sample 15	0.000	16.103	82.893	1.005
sample 16	0.000	5.961	93.243	0.796
sample 17	0.000	0.000	19.551	80.449
sample 18	0.000	11.057	70.780	18.164
sample 19	14.163	4.608	70.802	10.428
sample 20	0.000	2.776	96.930	0.294
sample 21	0.000	1.970	97.728	0.302
sample 22	0.000	0.931	98.632	0.437
sample 23	0.000	10.761	88.691	0.548
sample 24	0.000	12.609	87.092	0.299
sample 25	0.000	7.661	92.285	0.054
sample 26	0.000	2.030	97.508	0.462
sample 27	0.000	1.112	98.461	0.427
sample 28	0.000	3.368	96.632	0.000
sample 29	2.372	7.934	77.668	12.026
sample 30	3.410	2.658	91.239	2.693
sample 31	0.000	0.349	99.371	0.281
sample 32	0.000	2.950	96.880	0.170
sample 33	0.000	6.897	93.103	0.000
sample 34	5.490	1.911	85.285	7.314
sample 35	0.000	1.825	98.059	0.116
sample 36	0.000	0.561	99.120	0.319
sample 37	0.000	0.323	99.198	0.478
sample 38	0.000	0.676	98.375	0.949
sample 39	0.000	2.228	97.772	0.000
sample 40	0.000	1.904	98.096	0.000
sample 41	0.000	2.019	97.981	0.000
sample 42	0.000	1.743	98.257	0.000

Extra samples	% gravel (>2mm)	% sand (>500µm & <2mm)	% sand (<500µm & >63µm)	% mud (<63µm)
Sout River 1	0.000	22.779	73.692	3.529
Sout River 2	0.000	8.977	90.289	0.734
Railbridge	6.685	3.451	73.817	16.046
Thesen causeway 1	0.422	3.182	91.318	5.077
Thesen causeway 2	2.810	23.428	73.482	0.279
Ashmead channel A1	0.000	0.351	95.150	4.499
Ashmead channel A2	37.235	0.220	61.853	0.692
Ashmead channel A3	7.947	0.200	86.872	4.981
Ashmead channel A4	3.133	0.150	76.018	20.699
Ashmead channel A5	1.926	0.053	59.378	38.643
Ashmead channel A6	1.956	0.000	65.076	32.968
Sewage outlet 1	0.000	0.000	96.412	3.588
sewage outlet 2	0.000	0.127	95.873	4.000
Leisure Isle sandflat L1-L9	0.000	3.161	96.839	0.000
Channel behind Liesure is	0.000	2.615	97.385	0.000
Brenton beach ahw	0.000	2.651	97.349	0.000
Brenton beach blw	0.000	3.707	96.293	0.000
Rockpools near Brenton	19.843	24.419	55.738	0.000
Rockpools at Noetzie bea	19.500	24.470	56.030	0.000

APPENDIX 4

MAIN CHANNEL SAMPLES

Forams sorted in decending order according to relative abundance

Sample 1

no forams

Sample 2

no forams

Sample 3

Miliammina fusca	11	
Haplophragmoides wilberti	1	
Ammonia parkinsoniana s.l.	1	
Sum of forams per sample	*13*	
Number of species per sample	*3*	
% littoral influence	*0*	

Sample 4

Miliammina fusca (Broad)	33	
Ammonia parkinsoniana s.l.	32	
Sum of forams per sample	*65*	
Number of species per sample	*2*	
% littoral influence	*0*	

Sample 5

Miliammina fusca (Broad)	80	(55% cream coloured/ leached)
Ammonia parkinsoniana s.l.	20	
Trochammina inflata	3	
Sum of forams per sample	*103*	
Number of species per sample	*3*	
% littoral influence	*0*	

Sample 6

Ammonia parkinsoniana s.l.	90	(size & morphology varies)
Miliammina fusca	9	(90% cream/ leached)
Rosalina bradyi	1	
Sum of forams per sample	*100*	
Number of species per sample	*3*	
% littoral influence	*0*	

Sample 7

Ammonia parkinsoniana s.l.	16	(size & morphology varies)
Miliammina fusca	12	(25% cream/ leached)
Sum of forams per sample	*28*	
Number of species per sample	*2*	
% littoral influence	*0*	

Sample 8

Ammonia parkinsoniana s.l.	15	(large and well preserved)
Miliammina fusca	13	(62% cream/ leached)
Sum of forams per sample	*28*	
Number of species per sample	*2*	
% littoral influence	*0*	

Sample 9

Miliammina fusca	19	(26% cream/ leached)
Ammonia parkinsoniana s.l.	11	
Pararotalia nipponica	1	
Sum of forams per sample	*31*	
Number of species per sample	*3*	
% littoral influence	*3.2*	

Sample 10

Ammonia parkinsoniana s.l.	2	
Sum of forams per sample	*2*	
Number of species per sample	*1*	
% littoral influence	*0*	

Sample 11

Ammonia parkinsoniana s.l.	4	
Haplophragmoides wilberti	1	
Sum of forams per sample	*5*	
Number of species per sample	*2*	
% littoral influence	*0*	

Sample 12

no forams

Sample 13

Ammonia parkinsoniana s.l.	4	
Sum of forams per sample	*4*	
Number of species per sample	*1*	
% littoral influence	*0*	

Sample 14,15 and 16

no forams

Sample 17

Ammonia parkinsoniana s.l.	117	
Elphidium cf. articulatum	2	(Well preserved)
Globigerina sp.	2	
Brizalina striatula	1	
Quinqueloculina cf. vulgaris	1	(Y tooth in apeture)
Miliolinella (fat) sp.	1	
Sum of forams per sample	*124*	
Number of species per sample	*6*	
% littoral influence	*5.645*	

Sample 18

Ammonia parkinsoniana s.l.	36	
Elphidium crispum	4	
Lobatula lobatula	3	
Trochammina inflata	2	
Elphidium advenum	2	
Elphidium cf. alvarezianum	2	
Ammonia japonica	1	
Haynesina germanica	1	
Elphidiella sp.	1	
Pararotalia nipponica	1	
Ribbed Lagena sp.	1	
Oolina cf. melo	1	
Bulimina marginata	1	
Sum of forams per sample	*56*	
Number of species per sample	*13*	
% littoral influence	*32.1*	

Sample 19

Ammonia parkinsoniana s.l.	100	
Elphidium crispum	4	(abraded)
Elphidium articulatum	3	(abraded)
Elphidium cf. alvarezianum	3	(abraded)
Broad Quinqueloculina sp.	2	
Lobatula lobatula	2	
Trochammina inflata	1	
Ammonia japonica	1	
Haynesina germanica	1	
Elphidium macellum	1	
Quinqueloculina cf. undulata	1	
Narrow Quinqueloculina sp.	1	
Textularia conica	1	
Hyalinea balthica	1	(Reworked from Pleistocene)
Sum of forams per sample	*122*	
Number of species per sample	*14*	
% littoral influence	*15.6*	

Sample 20

Ammonia parkinsoniana s.l.	11	
Pararotalia nipponica	8	(some reworked, abraded)
Lobatula lobatula	8	
Ammonia japonica	6	
Rotalia gaimardii	1	
Elphidium articulatum	1	
Elphidium advenum	1	
Elphidium crispum	1	(Reworked, abraded)
Triloculina "oblonga"	1	
Triloculina trigonula	1	
Quinqueloculina dunkerquiana	1	
Cibicides refulgens	1	
Sum of forams per sample	*41*	
Number of species per sample	*12*	
% littoral influence	*56.1*	

Sample 21

Pararotalia nipponica	13	(Reworked from Pleistocene)
Elphidium crispum	12	(Reworked, abraded)
Ammonia parkinsoniana s.l.	11	
Quinqueloculina dunkerquiana	8	
Elphidium macellum	5	
Cibicides refulgens	5	
Triloculina "oblonga"	2	
Cibicidoides pseudoungerianus	2	
Haynesina germanica	1	
Rotalia gaimardii	1	
Elphidium cf. articulatum	1	
Triloculina terquemiana	1	
Homotrema rubrum (piece)	1	
Challengerella bradyi	1	(Reworked from Pleistocene)
Sum of forams per sample	*64*	
Number of species per sample	*14*	
% littoral influence	*52.6*	

Sample 22

Ammonia parkinsoniana s.l.	25	
Elphidium crispum	14	(some reworked, abraded)
Pararotalia nipponica	11	(some reworked, abraded)
Triloculina "oblonga"	6	
Cibicides refulgens	5	
Rotalia gaimardii	3	(Well preserved)
Elphidium macellum	3	
Triloculina trigonula	3	
Elphidium advenum	2	
Quinqueloculina contorta	2	
Lobatula lobatula	2	
Triloculina tricarinata	1	
fat Triloculina sp.	1	
Spiroloculina communis	1	
Glabratella cotralensis	1	
finely ribbed Oolina sp.	1	
Rosalina bradyi	1	
Rosalina williamsoni	1	
Challengerella bradyi	1	(Reworked from Pleistocene)
Sum of forams per sample	*84*	
Number of species per sample	*19*	
% littoral influence	*51.2*	

Sample 23

Elphidium crispum	14	(78% broken & abraded)
Ammonia parkinsoniana s.l.	12	
Triloculina trigonula	7	
Quinqueloculina dunkerquiana	6	
Triloculina "oblonga"	3	
Rotalia gaimardii	2	
flat Triloculina sp.	2	
Pararotalia nipponica	2	
Cibicides refulgens	2	
Lobatula lobatula	2	
Elphidium macellum	1	
Quinqueloculina contorta	1	
Quinqueloculina lata	1	
Spiroloculina communis	1	
Graudryina rudis	1	
Planorbulina mediterranensis	1	
Homotrema rubrum (piece)	1	
Challengerella cf. bradyi	1	(Reworked from Pleistocene)
flat Planularia sp.	1	(Reworked from Pleistocene)
Sum of forams per sample	*61*	
Number of species per sample	*19*	
% littoral influence	*52.45*	

Sample 24

Elphidium crispum	16	(50% broken & abraded)
Ammonia parkinsoniana s.l.	13	
Quinqueloculina dunkerquiana	5	
Triloculina trigonula	3	
Lobatula lobatula	2	
Rotalia gaimardii	1	
Elphidium macellum	1	
Quinqueloculina cf. vulgaris	1	
Graudryina rudis	1	
Cibicidoides sp.	1	
Poroeponides lateralis	1	
Planorbulina mediterranensis	1	
Homotrema rubrum (piece)	1	
Sum of forams per sample	*47*	
Number of species per sample	*13*	
% littoral influence	*55.3*	

Sample 25

Ammonia parkinsoniana s.l.	11	(50% broken & abraded)
Elphidium crispum	11	(72% broken & abraded)
Quinqueloculina dunkerquiana	3	
Cibicides refulgens	2	
Poroeponides lateralis	2	
Elphidium articulatum	1	
Elphidium advenum	1	
Triloculina "oblonga"	1	
Triloculina tricarinata	1	
Pararotalia nipponica	1	(Reworked)
Cibicidoides speudoungerianus	1	
Gavelinopsis Praegeri	1	
Challengerella bradyi	1	(Reworked from Pleistocene)
Sum of forams per sample	*37*	
Number of species per sample	*13*	
% littoral influence	*43.2*	

Sample 26

Ammonia parkinsoniana s.l.	22	(5 reworked from Pleistocene)
Elphidium articulatum	2	
Elphidium cf. advenum	1	
Elphidium crispum	15	(50% broken & abraded)
Triloculina "oblonga"	16	
Triloculina trigonula	2	
Triloculina tricarinata	1	
Quinqueloculina dunkerquiana	2	
Quinqueloculina seminulum	1	
Spiroloculina communis	1	
Spiroloculina sp.	1	
Textularia conica	1	
Pararotalia nipponica	7	
Cibicides refulgens	4	
Glabratella ostralensis	1	
Lobatula lobatula	1	
Globbigerinoides ruber	1	
Sum of forams per sample	*79*	
Number of species per sample	*17*	
% littoral influence	*51.9*	

Sample 27

Ammonia parkinsoniana s.l.	38	
Rotalia gaimardii	1	
Elphidium articulatum	1	
Elphidium cf. advenum	3	
Elphidium crispum	18	(few broken & abraded)
Elphidium macellum	1	
Triloculina "oblonga"	49	
Triloculina trigonula	2	
Triloculina tricarinata	1	
Quinqueloculina cf. vulgaris	1	
Quinqueloculina dunkerquiana	2	
Quinqueloculina contorta	1	
Textularia conica	1	
Graudryina rudis	1	
Pararotalia nipponica	8	
Cibicides refulgens	8	
Poroeponides lateralis	1	
Lobatula lobatula	5	
Sum of forams per sample	*142*	
Number of species per sample	*18*	
% littoral influence	*35.9*	

Sample 28

Ammonia parkinsoniana s.l.	50	
Rotalia gaimardii	4	
Elphidium crispum	12	(30% broken & abraded)
Elphidium macellum	1	
Triloculina "oblonga"	5	
Triloculina tricarinata	2	
flat Triloculina sp.	1	
Quinqueloculina cf. vulgaris	1	
Quinqueloculina dunkerquiana	2	
Spiroloculina communis	6	
Textularia conica	1	
Pararotalia nipponica	3	
Cibicides refulgens	5	
Cibicidoides speudoungerianus	2	
Poroeponides lateralis	5	
Sum of forams per sample	*100*	
Number of species per sample	*15*	
% littoral influence	*40*	

Sample 29

Elphidium articulatum	49	
Ammonia parkinsoniana s.l.	22	
Triloculina "oblonga"	12	
Pararotalia nipponica	9	
Elphidium crispum	8	
Elphidium cf. advenum	5	
Haynesina germanica	2	
Elphidium cf. alvarezianum	2	
Quinqueloculina dunkerquiana	2	
Lobatula lobatula	2	
Globbigerinoides ruber	2	
Brizalina sp.	1	(Reworked from late Pleistocene)
Elphidium macellum	1	
flat, ribbed Triloculina sp.	1	
Quinqueloculina cf. vulgaris	1	
Poroeponides lateralis	1	
Oolina cf. melo	1	
finely ribbed Oolina sp.	1	
Planorbulina mediterranensis	1	
Gavelinopsis Praegeri	1	
Lenticulina sp. (living)	1	
Sum of forams per sample	*125*	
Number of species per sample	*21*	
% littoral influence	*70*	

Sample 30

Triloculina "oblonga"	37	
Ammonia parkinsoniana s.l.	17	
Elphidium articulatum	15	
Elphidium cf. advenum	15	
Elphidium advenum	6	
Quinqueloculina dunkerquiana	6	
Pararotalia nipponica	5	
Lobatula lobatula	5	
Cibicides refulgens	3	
Elphidium cf. alvarezianum	2	
Elphidium crispum	2	
Triloculina terquemiana	2	
ribbed Spiroloculina sp.	2	
Cibicidoides speudoungerianus	2	
Oolina melo	2	
Bufimina elongata	2	
Ammonia japonica	1	
Haynesina germanica	1	
Triloculina trigonula	1	
Quinqueloculina cf. vulgaris	1	
Quinqueloculina seminulum	1	
Quinqueloculina contorta	1	(Reworked from Pleistocene)
Textularia conica	1	
Poroeponides lateralis	1	
Lagena cf. lyelli-	1	
Rosalina bradyi	1	
Gavelinopsis Praegeri	1	
Globorotalia inflata	1	
Globoquadrina dutertrei	1	
Sum of forams per sample	*136*	
Number of species per sample	*29*	
% littoral influence	*59.6*	

Sample 31

Triloculina "oblonga"	28	
Ammonia parkinsoniana s.l.	20	
Elphidium crispum	10	
Cibicides refulgens	10	
Elphidium advenum	9	
Pararotalia nipponica	9	
Lobatula lobatula	4	
Elphidium cf. advenum	3	
Triloculina trigonula	3	
Elphidium articulatum	2	
Quinqueloculina dunkerquiana	2	
Lenticulina sp. (fossil)	2	(Reworked)
Elphidium macellum	1	
Quinqueloculina cf. vulgaris	1	
Quinqueloculina seminulum	1	
Spiroloculina communis	1	
Globoquadrina dutertrei	1	
Sum of forams per sample	*107*	
Number of species per sample	*17*	
% littoral influence	*53.27*	

Sample 32		
Ammonia parkinsoniana s.l.	17	
Triloculina "oblonga"	12	
Elphidium crispum	8	
Cibicides refulgens	6	
Quinqueloculina dunkerquiana	5	(Reworked from Pleistocene)
Pararotalia nipponica	4	
Triloculina trigonula	2	
Triloculina tricarinata	2	
Elphidium articulatum	1	
Elphidium advenum	1	
Elphidium macellum	1	
Quinqueloculina lata	1	
Spiroloculina communis	1	
Cibicidoides pseudoungerianus	1	
Porosponides lateralis	1	
Planorbulina mediterranensis	1	
Sum of forams per sample	*64*	
Number of species per sample	*16*	
% littoral influence	*46.87*	

Sample 33		
Elphidium crispum	9	(60% broken & abraded)
Pararotalia nipponica	5	(Reworked from Pleistocene)
Triloculina "oblonga"	4	
Ammonia parkinsoniana s.l.	3	
Quinqueloculina dunkerquiana	3	(Reworked)
Cibicides refulgens	2	
Porosponides lateralis	2	(Reworked)
Lobatula lobatula	2	
Elphidium cf. advenum	1	
Triloculina trigonula	1	
fat Triloculina sp.	1	(Reworked)
Quinqueloculina contorta	1	(Reworked)
Spiroplectinella sp.	1	
Cibicidoides pseudoungerianus	1	
Rosalina cf. globularis	1	
Bulimina elongata	1	
Globoquadrina dutertrei	1	
Sum of forams per sample	*39*	
Number of species per sample	*17*	
% living littoral influence	*53.85*	

Sample 34		
Elphidium crispum	20	
Ammonia parkinsoniana s.l.	7	
little Quinqueloculina sp.	5	
Elphidium advenum	2	
Elphidium cf. advenum	2	
Triloculina "oblonga"	2	
Quinqueloculina seminulum	2	
Elphidium articulatum	1	
Triloculina trigonula	1	
fat Triloculina sp.	1	
Quinqueloculina dunkerquiana	1	(Reworked)
Sum of forams per sample	*44*	
Number of species per sample	*11*	
% littoral influence	*75*	

Sample 35		
Elphidium crispum	24	(45% broken & abraded)
Ammonia parkinsoniana s.l.	16	
Triloculina "oblonga"	12	
Pararotalia nipponica	11	
Cibicides refulgens	11	
Quinqueloculina dunkerquiana	10	(Reworked)
Elphidium advenum	6	
Triloculina trigonula	5	
Lobatula lobatula	5	
Porosponides lateralis	4	
Planorbulina mediterranensis	4	(3 Reworked)
Elphidium cf. advenum	2	
Quinqueloculina cf. vulgaris	2	(Reworked)
Textularia conica	2	
Globigerina sp.	2	(1 Reworked)
Ammonia japonica	1	(Reworked)
Triloculina terquemiana	1	(Reworked from Pleistocene)
Grandryina rudis	1	
Cibicidoides sp.	1	(Reworked)
Bulimina orangensis	1	
Acervulina sp.	1	
Challengerella bradyi	1	(Reworked from Pleistocene)
Sum of forams per sample	*123*	
Number of species per sample	*22*	
% living littoral influence	*56.1*	

Sample 36		
Ammonia parkinsoniana s.l.	20	
Pararotalia nipponica	17	
Quinqueloculina dunkerquiana	16	(Reworked from Pleistocene)
Elphidium crispum	14	
Triloculina "oblonga"	14	
Cibicides refulgens	9	
Planorbulina mediterranensis	7	
Elphidium advenum	5	
Lobatula lobatula	4	
Ammonia japonica	3	
Quinqueloculina contorta	3	
Elphidium cf. advenum	2	
Elphidium cf. alvareziamum	2	
Miliolinella subrotunda	2	
Haynesina germanica	1	
Elphidium macellum	1	
Triloculina trigonula	1	
Quinqueloculina cf. curta	1	(Reworked)
Cibicidoides pseudoungerianus	1	
Porosponides lateralis	1	
Oolina melo	1	
finely ribbed Oolina sp.	1	(Reworked)
Oolina sp. A (McMillan, 1987)	1	
Acervulina sp.	1	
Challengerella bradyi	1	(Reworked from Pleistocene)
Cassidulina laevigata	1	
Globigerina sp.	1	
Sum of forams per sample	*131*	
Number of species per sample	*27*	
% littoral influence	*68*	

Sample 37		
Pararotalia nipponica	36	
Cibicides refulgens	20	
Miliolinella subrotunda	14	
Elphidium crispum	13	
Triloculina "oblonga"	11	
Ammonia parkinsoniana s.l.	10	
Lobatula lobatula	9	
Ammonia japonica	7	
Elphidium advenum	7	
Elphidium cf. advenum	7	
Quinqueloculina contorta	7	
Planorbulina mediterranensis	7	
Quinqueloculina dunkerquiana	6	(some reworked)
Elphidium cf. alvareziamum	5	
Gavelinopsis Praegeri	5	
Porosponides lateralis	4	
Cassidulina laevigata	3	
Globigerinoides ruber	3	
Elphidium articulatum	2	
Quinqueloculina seminulum	2	
Bulimina elongata	2	
Homotrema rubrum	2	
Globorotalia inflata	2	
flat, ribbed Triloculina sp.	1	
Triloculina terquemiana	1	
Triloculina berthiniana	1	
Triloculina fichteliana	1	
Quinqueloculina lata	1	
ribbed Spiroloculina sp.	1	
Miliolinella (fat) sp.	1	
sigmoilina sp.	1	
Spiroplectinella sp.	1	
Cibicidoides pseudoungerianus	1	
Glabratella sp.	1	
Lagena sp.	1	
Lagena striata	1	
Lagena semilineata	1	
Lagena laevis	1	
Rosalina bradyi	1	
Canoris sariculus	1	(deep water foram)
Chrysalidinella dimorpha	1	
Globigerina sp.	1	
Globigerina bulloides	1	
Globoquadrina dutertrei	1	
Sum of forams per sample	*205*	
Number of species per sample	*44*	
% littoral influence	*89.75*	

Sample 38		
Pararotalia nipponica	19	
Miliolinella subrotunda	12	
Cibicides refulgens	10	
Elphidium crispum	7	
Lobatula lobatula	7	
Ammonia parkinsoniana s.l.	6	
Elphidium cf. articulatum	6	
Elphidium cf. advenum	6	
Elphidium advenum	5	
Triloculina "oblonga"	5	
Planorbulina mediterranensis	3	
Triloculina trigonula	2	
Quinqueloculina dunkerquiana	2	
Quinqueloculina seminulum	2	
Spiroloculina communis	2	
Porosponides lateralis	2	
Lagena sp.	2	
Bulimina elongata	2	
Nonion boueanum	2	
Globigerina bulloides	2	
Globigerinoides ruber	2	
Ammonia japonica	1	
Triloculina terquemiana	1	
Quinqueloculina contorta	1	
finely ribbed Quinqueloculina sp.	1	
ribbed Spiroloculina sp.	1	
Cibicidoides pseudoungerianus	1	
Oolina melo	1	(Reworked from Pleistocene)
finely ribbed Oolina sp.	1	
Oolina squamosa	1	
Rosalina cf. globularis	1	
Homotrema rubrum	1	
Acervulina inhaerens	1	
Acervulina sp.	1	
Cassidulina laevigata	1	
Pteropod	1	Gastropod-like planktonic
Sum of forams per sample	*121*	
Number of species per sample	*36*	
% littoral influence	*90.08*	

Sample 39		
Elphidium crispum	14	
Pararotalia nipponica	14	
Quinqueloculina dunkerquiana	8	(some reworked)
Cibicides refulgens	7	
Ammonia japonica	6	
Elphidium advenum	4	
Porosponides lateralis	3	
Quinqueloculina seminulum	2	
Lobatula lobatula	2	
Planorbulina mediterranensis	2	
Triloculina "oblonga"	1	
Quinqueloculina contorta	1	
Miliolinella subrotunda	1	
Textularia conica	1	
Lagena sp.	1	
Oolina sp. A (McMillan, 1987)	1	
Rosalina bradyi	1	
Gavelinopsis Praegeri	1	
Nonion boueanum	1	
Globoquadrina dutertrei	1	
Sum of forams per sample	*72*	
Number of species per sample	*20*	
% littoral influence	*93*	

Sample 40		
Elphidium crispum	15	(large & well preserved)
Pararotalia nipponica	10	
Ammonia japonica	9	
Cibicides refulgens	5	
Quinqueloculina dunkerquiana	3	(Reworked)
Spiroloculina communis	3	
Porosponides lateralis	3	
Ammonia parkinsoniana s.l.	2	
Quinqueloculina seminulum	2	
Lobatula lobatula	2	
Miliolinella subrotunda	1	
Gaudryina rudis	1	
Cibicidoides pseudoungerianus	1	
Sum of forams per sample	*57*	
Number of species per sample	*13*	
% littoral influence	*94.7*	

Sample 41		
Pararotalia nipponica	11	
Elphidium crispum	6	(large & well preserved)
Quinqueloculina dunkerquiana	5	(3 reworked)
Ammonia japonica	4	
Cibicides refulgens	4	
Triloculina terquemiana	2	
Porosponides lateralis	2	
Elphidium cf. alvarezianum	1	
Triloculina sp.	1	
Lobatula lobatula	1	
Globigerina sp.	1	
Sum of forams per sample	*38*	
Number of species per sample	*11*	
% littoral influence	*93*	

Sample 42		
Elphidium crispum	18	(large & well preserved)
Quinqueloculina dunkerquiana	9	
Ammonia japonica	5	
Porosponides lateralis	4	
Quinqueloculina cf. vulgaris	2	
Pararotalia nipponica	2	
Cibicides refulgens	2	
Lobatula lobatula	2	
Elphidium advenum	1	
Triloculina trigonula	1	
Spiroloculina communis	1	
Gaudryina rudis	1	
Cibicidoides pseudoungerianus	1	
Acervulina sp.	1	
Notorotalia clathrata	1	(Reworked from Pleistocene)
Sum of forams per sample	*51*	
Number of species per sample	*15*	
% littoral influence	*96.07*	

EXTRA SAMPLES AROUND THE KNYSNA ESTUARY

SOUT RIVER SAMPLES 1 AND 2

Qtz immature, unsorted, angular.
Same foram assemblage and sediment texture as upper estaury
sample 2 closer to the main estuary

sample 1 components
ostracods 3 species
sample 2 components
ostracods 2 species

Foraminifera of Sample 1	
Miliammina fusca	1
narrow Triloculina sp.	1
rounded quinqu sp with no tooth	1
Number species	*3*
Number forams	*3*

Foraminifera of Sample 2		
Miliammina fusca	5	
Ammonia parkinsoniana s.l.	3	
small Quinqueloculina sp.	3	flat tooth with two points
Trochammina inflata	1	
Number species	*4*	
Number forams	*12*	

RAILBRIDGE SIDE CHANNEL

sample components
ostracods 4 species.

Foraminifera		
Elphidium cf. advenum	8	
large flat ribbed Quinqueloculina sp.	6	(aperture on neck)
Pararotalia nipponica	5	(mainly reworked)
Elphidium articulatum	4	
Triloculina tricarinata	4	
Quinqueloculina lata	4	
Elphidium crispum	3	(1 reworked)
Bulimina elongata	3	
Trochammina inflata	2	
Ammonia parkinsoniana s.l.	2	(small)
Large flat Triloculina sp.	2	(aperture on neck)
Haynesina germanica	2	
Globigerina quinqueloba	2	
Haplophragmoides wilberti	1	
Triloculina trigonula	1	
keeled finely grooved quinqu sp.	1	(Y tooth)
globular miliolinella sp.	1	
Lobatula lobatula	1	
Rosalina cf. globularis	1	
Gavelinopsis praegeri	1	
Pink globular foram sp.	1	
Number species	*21*	
Number forams	*55*	

SEWAGE OUTLET SAMPLES 1 AND 2

Ostracods abundant with various species
Some serpulid worm tubes and shell fragments

Foraminfera of sample 1	
Pararotalia nipponica	12
fat Triloculina sp.	3
Lobatula lobatula	3
Trochammina inflata	2
Ammonia parkinsoniana s.l.	2
Elphidium crispum (1 reworked)	2
small Quinqueloculina sp.	2
Cibicides refulgens	2
Rosalina cf. globularis	2
Elphidium cf. advenum	1
Cibicidoides sp.	1
Globigerina calida	1
Number species	*12*
Number forams	*33*

Foraminifera of sample 2		
small Quinqueloculina sp.	4	
Ammonia parkinsoniana s.l.	3	
Haynesina germanica	2	flat tooth with two points
Trochammina inflata	1	
Number species	*4*	
Number forams	*10*	

ASHMEAD CHANNEL SAMPLES

collected 30/03/2002

Foraminifera listed from most abundant in each sample, to least abundant.

Extra components

- gastropods
- bivalve shells
- copopods
- organics
- Broken echinoid spines & sponge spicules

All Elphidium crispum are broken and abraded
All Ammonia japonica (med size) abraded; washed into channel
Elphidiela sp. are perfect in sample 5, however one broken elphidiella in sample 1.
Milliolids all abraded, thus probably washed into channel

Sample A1

Elphidium cf. articulatum (glob. chambers)	21
Ammonia parkinsoniana s.l. (small)	9
Neogloboquadrina pachyderma (juveniles)	7
Elphidium articulatum	6
Triloculina "oblonga"	5
Globigerina quinqueloba (juveniles)	5
Quinqueloculina seminulum	3
Quinqueloculina dunkerquiana	3
Pararotalia nipponica (2 reworked)	3
Brizalina pseudopuntata	3
Rosalina cf. globularis	2
Oolina melo	2
Miliolinella subrotunda	2
Lobatula lobatula	2
Globorotalia inflata	2
Elphidium crispum	2
Spiroluculina communis	1
Pink globular foram sp.	1
Oolina hexagona	1
Nonion boueanus (reworked)	1
Haynesina germanica	1
Haplophragmoides canariensis (from saltmarsh)	1
Galandulina	1
Elphidium macellum	1
Elphidium cf. alvarezianum	1
Elphidium cf. advenum	1
Elphidiella sp.	1
Number species	27
Number Foraminifera	88
% littoral influence	*84.09*

Sample A2

Elphidium crispum (abraded)	8
Elphidium articulatum	7
Elphidium cf. articulatum (glob. chambers)	6
Ammonia parkinsoniana s.l. (small)	1
Elphidium cf. alvarezianum	1
Elphidium macellum	1
fat Triloculina sp.	1
Quinqueloculina dunkerquiana	1
Quinqueloculina seminulum	1
Miliolinella subrotunda	1
Pararotalia nipponica (reworked)	1
Number species	11
Number Foraminifera	29
% littoral influence	*93.01*

Sample A3

Elphidium cf. articulatum (glob. chambers)	20
Elphidium articulatum	13
Triloculina "oblonga"	11
Miliolinella subrotunda	11
Ammonia parkinsoniana s.l. (small)	9
Quinqueloculina lata	8
Quinqueloculina seminulum	6
Quinqueloculina dunkerquiana	5
Pararotalia nipponica (reworked)	4
Globigerina sp. (juveniles)	4
Elphidium crispum (reworked)	3
Triloculina tricarinata	3
Ammonia japonica	2
Elphidium cf. articulatum (rounded shape)	2
Elphidiella sp.	2
Triloculina trigonula	2
Triloculina terqueniana	2
Miliolinella circularis	2
Gavelinopsis praegeri	2
Lenticulina sp.	2
Haplophragmoides canariensis (from saltmarsh)	1
Elphidium advenum	1
Elphidium cf. advenum	1
Elphidium cf. alvarezianum	1
Cibicides refulgens	1
Oolina sp. A (McMillan, 1987)	1
Cyclogyra orbicula	1
Globbigerinoides ruber	1
flat Planularia sp.	1
Number species	29
Number Foraminifera	122
% littoral influence	*77.86*

Sample A4

Ammonia parkinsoniana s.l. (med-large)	15
Elphidium cf. articulatum (rounded shape)	11
Miliolinella subrotunda	5
Pararotalia nipponica (reworked)	5
Ammonia japonica	4
Elphidium cf. articulatum (glob. chambers)	4
Elphidium crispum (reworked)	4
Triloculina "oblonga"	4
Triloculina trigonula	4
Elphidium advenum	3
Quinqueloculina dunkerquiana	2
Trochammina inflata (from saltmarsh)	1
Triloculina tricarinata	1
Triloculina terquemiana (reworked)	1
Quinqueloculina seminulum	1
Quinqueloculina lata	1
ribbed Spiroloculina sp.	1
Cibicides refulgens	1
Rosalina cf. globularis	1
Lenticulina sp.	1
Cyclogyra orbicula	1
Number species	21
Number Foraminifera	92
% littoral influence	*72.82*

Sample A5

Ammonia parkinsoniana s.l. (most large, various sizes)	28
Elphidium cf. articulatum (rounded shape)	13
Elphidium cf. articulatum (glob. chambers)	7
Elphidiella sp. (well preserved)	5
Ammonia japonica	3
Miliammina fusca (from upper estuary mudflats ?)	2
Triloculina "oblonga"	2
Pararotalia nipponica (reworked)	2
Oolina melo	2
Elphidium crispum (reworked)	1
Quinqueloculina dunkerquiana (reworked)	1
Bulimina elongata (well peserved)	1
Nonion boueanus (reworked)	1
Number species	13
Number Foraminifera	68
% littoral influence	*45.58*

Sample A6

Ammonia parkinsoniana s.l. (large in size)	53
Elphidium cf. articulatum (rounded shape)	18
Pararotalia nipponica (reworked)	5
Trochammina inflata (from saltmarsh)	3
Elphidium cf. articulatum (glob. chambers)	3
Elphidium crispum (reworked)	3
Ammonia japonica	2
Miliammina fusca (from upper estuary mudflats ?)	1
Elphidium articulatum	1
Rosalina cf. globularis	1
Globigerina sp.	1
Number species	11
Number Foraminifera	91
% littoral influence	*26.37*

THESEN ISLAND CAUSEWAY FORAMS

Thesen island sample 1 (east of /next to causeway)
Thesen island sample 2 (west of causeway)

Foraminifera of Sample 1

Ammonia parkinsoniana s.l.	11
Pararotalia nipponica	7
Elphidium crispum	3
small Quinqueloculina sp.(tooth = flat & two point	3
Cibicides refulgens	2
Lobatula lobatula	2
Elphidium cf. articulatum	1
Quinqueloculina dunkerquiana	1
Quinqueloculina contorta	1
Poroeponides lateralis	1
Rosalina cf. globularis	1
Number species	*11*
Number Foraminifera	*33*

Foraminifera of sample 2

Ammonia parkinsoniana s.l.	1
Quinqueloculina dunkerquiana	1
Pararotalia nipponica	1
Number species	*3*
Number Foraminifera	*3*

LEISURE ISLE SANDFLAT SAMPLES (Sample L1 near Leisure isle. Sample L9 at the main channel)

Number of foraminifera per 20g sand

Other sample components

- serpulid worm tubes
- ostracods
- glass sponge spicules
- various gastropods
- bivalves
- calcareous algal fragments
- echinoid spines
- bryozoans
- ophioroid oscicles

Sediment discription

- fine-medium grained
- similar to Brenton beach samples
- angular to subangular grains
- clean sediment
- well sorted
- calcareous fragments abundant

Sample L1	
Lobatula lobatula	14
Pararotalia nipponica	11
Elphidium cf. articulatum	9
Quinqueloculina dunkerquiana	8
Elphidium crispum	7
Cibicides refulgens	7
Miliolinella subrotunda	5
Poroeponides lateralis	4
Elphidium cf. alvarezianum	3
Quinqueloculina lata	3
Graudryina rudis	3
Planorbulina mediterranensis	3
piece of Homotrema rubrum	3
Ammonia japonica	2
Elphidium macellum	2
Quinqueloculina seminulum	2
Cibicidoides speudoungerianus	2
Ammonia parkinsoniana s.l.	1
Triloculina terquemiana	1
Triloculina bertheliniana	1
Quinqueloculina contorta	1
Spiroluculina communis	1
Miliolinella circularis	1
Textularia conica	1
Acervulina sp.	1
Hyalinea balthica (reworked)	1
Number species	*26*
Number forams	*97*

Sample L2	
Pararotalia nipponica	16
Elphidium cf. articulatum	15
Lobatula lobatula	7
Ammonia japonica	6
Elphidium crispum	6
Quinqueloculina dunkerquiana	6
Miliolinella subrotunda	6
Cibicides refulgens	6
Ammonia parkinsoniana s.l.	5
Quinqueloculina contorta	3
Poroeponides lateralis	3
Pink globular foram sp.	3
Elphidium macellum	2
Elphidium advenum	1
Elphidium cf. alvarezianum	1
Triloculina terquemiana	1
finely ribbed Quinqueloculina sp.	1
Cibicidoides speudoungerianus	1
Cibicidoides sp.	1
Planorbulina mediterranensis	1
Acervulina sp.	1
Rosalina bradyi	1
Rosalina williamsoni	1
piece of Homotrema rubrum	1
flat Planularia sp. (reworked)	1
Number species	*25*
Number forams	*96*

Sample L3	
Pararotalia nipponica	24
Elphidium cf. articulatum	17
Elphidium crispum	14
Lobatula lobatula	13
Planorbulina mediterranensis	10
Ammonia japonica	8
Elphidium macellum	7
Cibicides refulgens	7
Quinqueloculina seminulum	6
Poroeponides lateralis	6
Ammonia parkinsoniana s.l.	5
Miliolinella subrotunda	5
Quinqueloculina dunkerquiana	4
Textularia conica	4
Triloculina terquemiana	3
Narrow Quinqueloculina sp.	3
piece of Homotrema rubrum	3
Quinqueloculina contorta	2
Acervulina sp.	2
Haynesina germanica	2
Pink globular foram sp.	2
Globigerinella equilateralis	2
Elphidium articulatum	1
Elphidium advenum	1
Elphidium cf. alvarezianum	1
Triloculina tricarinata	1
Triloculina bertheliniana	1
Triloculina sp.	1
ribbed Spiroloculina sp.	1
Pyrgo sp.	1
Graudryina rudis	1
Lagena sp.	1
Oolina melo	1
Gavelinopsis praegeri	1
Bulimina orangensis	1
Globorotalia inflata	1
Number species	*36*
Number forams	*163*

Sample L4

Pararotalia nipponica	18
Elphidium crispum	10
Ammonia japonica	8
Lobatula lobatula	8
Poroeponides lateralis	7
Cibicides refulgens	6
Quinqueloculina dunkerquiana	4
Elphidium cf. articulatum	3
Elphidium advenum	3
Triloculina trigonula	2
Ammonia parkinsoniana s.l.	1
Elphidium cf. alvarezianum	1
Elphidium macellum	1
Triloculina terquemiana	1
Quinqueloculina lata	1
Miliolinella subrotunda	1
Textularia conica	1
Cibicidoides speudoungerianus	1
Planorbulina mediterranensis	1
Acervulina sp.	1
Rosalina bradyi	1
Rosalina cf. globularis	1
Bulimina elongata	1
Pink globular foram sp.	1
Cancris auriculus	1
Nonion boueanus (reworked)	1
Number species	*26*
Number forams	*85*

Sample L5

Pararotalia nipponica	19
Lobatula lobatula	11
Elphidium crispum	8
Cibicides refulgens	7
Planorbulina mediterranensis	6
Poroeponides lateralis	5
Quinqueloculina dunkerquiana	4
Miliolinella subrotunda	4
Ammonia japonica	3
Elphidium macellum	2
Pink globular foram sp.	2
Ammonia parkinsoniana s.l.	1
Elphidium cf. articulatum	1
Elphidium articulatum	1
Elphidium cf. alvarezianum	1
Triloculina trigonula	1
Triloculina tricarinata	1
Quinqueloculina seminulum	1
Quinqueloculina contorta	1
Graudryina rudis	1
Cibicidoides speudoungerianus	1
Acervulina sp.	1
Haynesina germanica	1
Glabratella australensis	1
Number species	*24*
Number forams	*84*

Sample L6

Pararotalia nipponica	33
Elphidium crispum	16
Cibicides refulgens	15
Ammonia japonica	10
Lobatula lobatula	9
Planorbulina mediterranensis	9
Quinqueloculina dunkerquiana	5
Poroeponides lateralis	5
Elphidium advenum	4
Miliolinella subrotunda	4
angular quinqu sp with no tooth	3
Ammonia parkinsoniana s.l.	2
Elphidium macellum	2
Quinqueloculina seminulum	2
Spiroluculina communis	2
Graudryina rudis	2
piece of Homotrema rubrum	2
Elphidium cf. articulatum	1
Triloculina trigonula	1
Quinqueloculina lata	1
Pyrgo sp.	1
Agglutinated Siphanaperta martinae	1
Textularia conica	1
Spiroplectinella sp.	1
Cibicidoides speudoungerianus	1
Cibicidoides sp.	1
Acervulina sp.	1
Glabratella sp.	1
Planispirillina sp.	1
Number species	*29*
Number forams	*137*

Sample L7

Pararotalia nipponica	17
Elphidium crispum	12
Lobatula lobatula	8
Cibicides refulgens	7
Ammonia japonica	5
Quinqueloculina dunkerquiana	5
Poroeponides lateralis	5
Ammonia parkinsoniana s.l.	4
Elphidium macellum	2
Triloculina trigonula	2
Planorbulina mediterranensis	2
Elphidium cf. articulatum	1
Elphidium advenum	1
Elphidium cf. alvarezianum	1
Triloculina terquemiana	1
Quinqueloculina seminulum	1
Miliolinella subrotunda	1
Graudryina rudis	1
Cibicidoides speudoungerianus	1
Acervulina sp.	1
Gavelinopsis praegeri	1
piece of Homotrema rubrum	1
Pink globular foram sp.	1
Number species	*23*
Number forams	*81*

Sample L8

Pararotalia nipponica	23
Cibicides refulgens	10
Poroeponides lateralis	8
Lobatula lobatula	8
Planorbulina mediterranensis	8
Ammonia japonica	6
Elphidium crispum	4
Elphidium macellum	4
Elphidium advenum	2
Quinqueloculina dunkerquiana	2
Pink globular foram sp.	2
Ammonia parkinsoniana s.l.	1
Elphidium cf. alvarezianum	1
Triloculina tricarinata	1
Quinqueloculina seminulum	1
Quinqueloculina contorta	1
Miliolinella subrotunda	1
Textularia conica	1
Cibicidoides speudoungerianus	1
Acervulina sp.	1
Glabratella australensis	1
Oolina melo	1
Challengerella bradyi	1
Number species	*23*
Number forams	*89*

Sample L9

Pararotalia nipponica	35
Lobatula lobatula	14
Elphidium crispum	12
Planorbulina mediterranensis	12
Poroeponides lateralis	11
Ammonia japonica	10
Cibicides refulgens	8
Elphidium macellum	7
Elphidium advenum	6
Textularia conica	6
Quinqueloculina dunkerquiana	5
Graudryina rudis	4
Elphidium cf. articulatum	3
Quinqueloculina seminulum	3
Ammonia parkinsoniana s.l.	2
Elphidium cf. alvarezianum	2
Triloculina trigonula	2
Miliolinella subrotunda	2
Acervulina sp.	2
Triloculina terquemiana	1
Quinqueloculina contorta	1
Glabratella australensis	1
Gavelinopsis praegeri	1
Pink globular foram sp.	1
Globigerina sp.	1
Globorotalia inflata	1
Chrysalidinella dimorpha	1
Ehrenbergina cf. healyi (reworked)	1
Number species	*28*
Number forams	*155*

CHANNEL BEHIND LEISURE ISLE (L0)

Pararotalia nipponica	37
Ammonia japonica	20
Planorbulina mediterranensis	18
Cibicides refulgens	16
Elphidium crispum	14
Lobatula lobatula	14
Elphidium macellum	11
Poroeponides lateralis	10
Triloculina trigonula	8
Ammonia parkinsoniana s.l.	7
Elphidium cf. articulatum	4
Spiroluculina communis	4
Miliolinella subrotunda	4
Rosalina bradyi	3
Elphidium articulatum	2
Triloculina "oblonga"	2
Triloculina tricarinata	2
Quinqueloculina contorta	2
Graudryina rudis	2
Acervulina sp.	2
Elphidium cf. alvarezianum	1
Quinqueloculina cf. vulgaris	1
Quinqueloculina dunkerquiana	1
Quinqueloculina seminulum	1
Miliolinella circularis	1
Textularia conica	1
Cibicidoides speudoungerianus	1
Lagena sp.	1
Pink globular foram sp.	1
Globigerina sp.	1
Cancris auriculus	1
Number species	*31*
Number forams	*193*

SURFACE WATER AT THE HEADS

Foraminifera		
Pararotalia nipponica	9	
Neogloboquadrina pachyderma	3	abraded, reworked
Cibicidoides speudoungerianus	2	
Lobatula lobatula	2	recrystalized and recalcified
Miliolinella subrotunda	1	
Cibicides refulgens	1	
Poroeponides lateralis	1	
Glabratella australensis	1	
Pink globular foram sp.	1	juviniles, unknown species
Number species	*9*	
Number forams	*21*	

Other components
qtz grains angular
sponge spicules
shell fragments
gastropods
algal and coral fragments
seaweed
broken echinoid spines
ostracods: 2 specimens, same species

KNYSNA HEADS ROCK POOLS

Foraminifera	
Planorbulina mediterranensis	48
Lobatula lobatula	26
Pararotalia nipponica	18
Ammonia japonica	16
Elphidium crispum	15
Triloculina trigonula	14
Elphidium macellum	13
Miliolinella subrotunda	13
Cibicides refulgens	13
Poroeponides lateralis	12
elongate Triloculina sp.	8
Graudryina rudis	8
Spiroluculina communis	7
Elphidium advenum	4
Textularia conica	4
piece of Homotrema rubrum	4
Ammonia parkinsoniana s.l.	3
Quinqueloculina dunkerquiana	3
Quinqueloculina contorta	3
Acervulina sp.	3
Triloculina tricarinata	2
Triloculina terquemiana	2
Cibicidoides speudoungerianus	2
Rosalina bradyi	2
Elphidium articulatum	1
Elphidium cf. alvarezianum	1
Elphidium gunteri	1
thin elongate miliolinella sp.	1
large Cibicidoides sp. (Eocene)	1
Lagena semilineata	1
Gypsina sp.	1
Uvigerina sp.	1
Globbigerinoides ruber	1
Globoquadrina dutertrei	1
piece Nubecularia lucifuga	1
Number species	*35*
Number forams	*254*

Other sample components
lots calcareous algal fragments
shells - gastropods and bivalves
bryozoans
ophioroid oscicles
echinoid spines
brachiopod shell
ostracods ~ 6 species
serpulid worm tubes
glass sponge spicules
Barnicle plates

Sediment discription
coarse grained
angular- subangular grains
quartz dominant
shells and shell fragments abundant
clean sediment

BRENTON ROCK POOLS

Forams from cemented Pleistocene deposits

Foraminifera		
Poroeponides lateralis	20	large and well preserved
Elphidium crispum	17	(large and well preserved)
Challengerella bradyi	11	(Reworked: latest Pleistocene)
Cibicides refulgens	8	
large Cibicidoides sp.	6	(Reworked from the Eocene)
Quinqueloculina dunkerquiana	5	
Triloculina trigonula	4	
Ammonia japonica	3	(large, reworked)
Quinqueloculina seminulum	3	
Miliolinella subrotunda	2	
Pararotalia nipponica	2	
Quinqueloculina contorta	1	
piece of Homotrema rubrum	1	
Cancris auriculus	1	(Reworked from Miocene)
Number species	*14*	
Number forams	*84*	

BRENTON BEACH SAMPLES

Below low water; wave dominated littoral zone

Foraminifera below low water/ littoral zone	
Quinqueloculina dunkerquiana	27
Pararotalia nipponica	22
Elphidium crispum	18
Cibicides refulgens	14
Poroeponides lateralis	14
Ammonia japonica	10
Lobatula lobatula	7
Planorbulina mediterranensis	6
Elphidium macellum	3
Graudryina rudis	3
Textularia conica	2
Ammonia parkinsoniana s.l.	1
Triloculina terquemiana	1
Quinqueloculina cf. vulgaris	1
Quinqueloculina contorta	1
Spiroluculina communis	1
large Cibicidoides sp. (Eocene)	1
Acervulina sp.	1
Glabratella australensis	1
Rosalina bradyi	1
Rosalina williamsoni	1
Bulimina elongata	1
Pink globular foram sp.	1
Lenticulina sp.	1
Number species	*24*
Number forams	*139*

Sample components
serpulid worm tubes (ornamented)
serpulid worm tubes (unornamented)
abundant calcareous algal fragments
shells - gastropods and bivalves
bryozoa abundant

Sediment discription
Quartz dominant
subangular- subrounded grains
fine-medium grained
shells and shell fragments abundant
abundant marine material
clean sediment

Beach sand sample; below storm water mark

Severely wave swept area, only thick walled forams preserved

Foraminifera in beach sand, above high water mark		
Pararotalia nipponica	25	
Elphidium crispum	12	
Cibicides refulgens	11	2 reworked
Ammonia japonica	5	
Poroeponides lateralis	4	
Planorbulina mediterranensis	4	40% reworked
Quinqueloculina dunkerquiana	3	typical of continental shelf
Lobatula lobatula	3	
Challengerella bradyi	2	
Elphidium macellum	2	
Triloculina trigonula	2	
Agglutinated Siphanaperta martinae	1	
large Cibicidoides sp. (Eocene)	1	
Globigerina sp.	1	
Number species	*14*	
Number forams	*76*	

NOETZIE BEACH SAND

Foraminifera

Pararotalia nipponica	10 (80% reworked)
Elphidium crispum	2 (large, reworked)
Elpidium advenum	2 (abraded/ reworked)
Challengerella bradyi	2 (Reworked from late Pleistocene)
Cibicides refulgens	1
Quinqueloculina dunkerquiana	1 (abraded, orange, reworked)
hyalinea balthica	1
Number species	*7*
Number forams	*19*

<u>Sediment discription</u>

Quartz dominant
Well sorted
subangular- subrounded grains
fine-medium grained
shells and shell fragments abundant
abundant marine material
clean sediment

<u>Sample components</u>

serpulid worm tubes (ornamented)
serpulid worm tubes (unornamented)
abundant calcareous algal fragments
shells - gastropods and bivalves
bryozoa abundant

NOETZIE ROCK POOLS

Foraminifera

Challengerella bradyi	7 (Reworked: late Pleistocene)
Pararotalia nipponica	5 (reworked)
Elphidium crispum	5 (rounded/ abraded)
Cibicides refulgens	4 (living)
Poroeponides lateralis	2 (living)
Elpidium advenum	1 (rounded/ abraded)
Quinqueloculina dunkerquiana	1 (abraded, orange, reworked)
Number species	*7*
Number forams	*25*

<u>Sediment discription</u>

Quartz dominant
moderately well sorted
subrounded-rounded grains
medium grained
shells and shell fragments abundant
abundant marine material
clean sediment
similar to Brenton rock pools

APPENDIX 5

APPENDIX 5

Scanning Electron Microscope (SEM) images of identified foraminifera species of the Knysna Estuary

PLATE 1

Row 1a *Ammonia parkinsoniana*, ventral view
Row 1b *Ammonia parkinsoniana*, ventral view
Row 1c *Ammonia parkinsoniana*, ventral view
Row 2a *Ammonia parkinsoniana*, ventral view
Row 2b *Ammonia parkinsoniana*, ventral view
Row 2c *Ammonia parkinsoniana*, oblique-ventral view
Row 3a *Ammonia parkinsoniana*, ventral view
Row 3b *Ammonia parkinsoniana*, ventral view
Row 3c *Ammonia parkinsoniana*, ventral view
Row 4a *Ammonia parkinsoniana*, ventral view
Row 4b *Ammonia parkinsoniana*, ventral view
Row 4c *Ammonia parkinsoniana*, dorsal view
Row 5a *Ammonia parkinsoniana*, dorsal view
Row 5b *Ammonia parkinsoniana*, dorsal view
Row 5c *Ammonia parkinsoniana*, dorsal view
Row 6a *Ammonia parkinsoniana*, dorsal view
Row 6b *Ammonia parkinsoniana*, dorsal view
Row 6c *Ammonia parkinsoniana*, dorsal view

PLATE 1

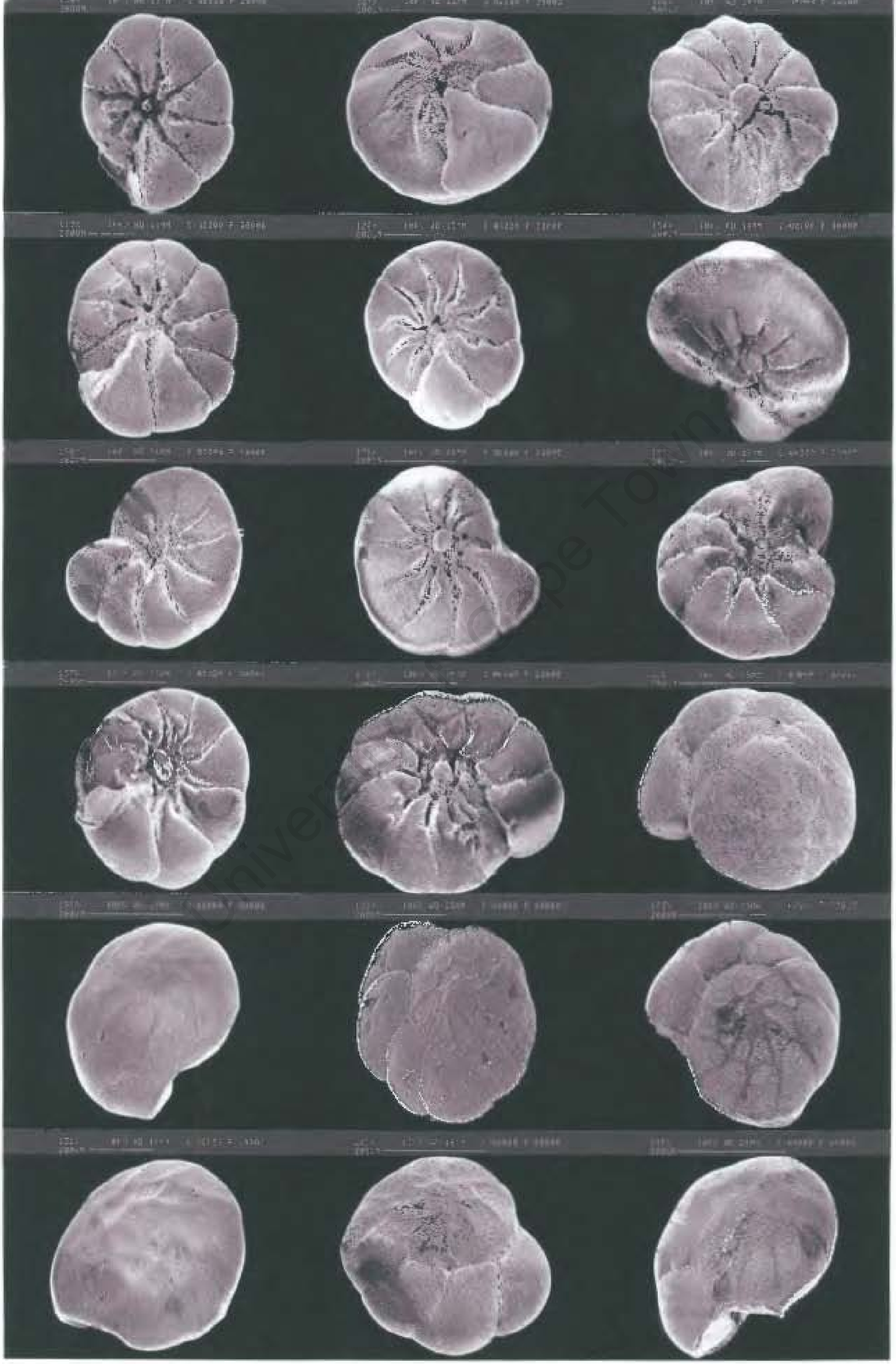


PLATE 2

Row 1a *Elphidium crispum*, side view

Row 1b *Elphidium crispum*, side view

Row 1c *Elphidium crispum*, side view

Row 2a *Elphidium crispum*, septal bridges, high magnification

Row 2b *Elphidium crispum*, septal bridges, high magnification

Row 2c *Elphidium crispum*, septal bridges, high magnification

Row 3a *Elphidium crispum*, edge view

Row 3b *Elphidium macellum*, side view

Row 3c *Elphidium macellum*, umbilical area, high magnification

Row 4a *Elphidium cf. alvarezianum*, side view

Row 4b *Elphidium cf. advenum*, side view

Row 4c *Elphidium advenum*, side view

Row 5a *Elphidium cf. articulatum*, side view

Row 5b *Elphidium articulatum*, side view

Row 5c *Elphidium cf. articulatum*, side view

Row 6a *Elphidium cf. articulatum*, side view, high magnification

Row 6b *Elphidium cf. articulatum*, apertural view

Row 6c *Elphidium cf. articulatum*, apertural view, high magnification

PLATE 2

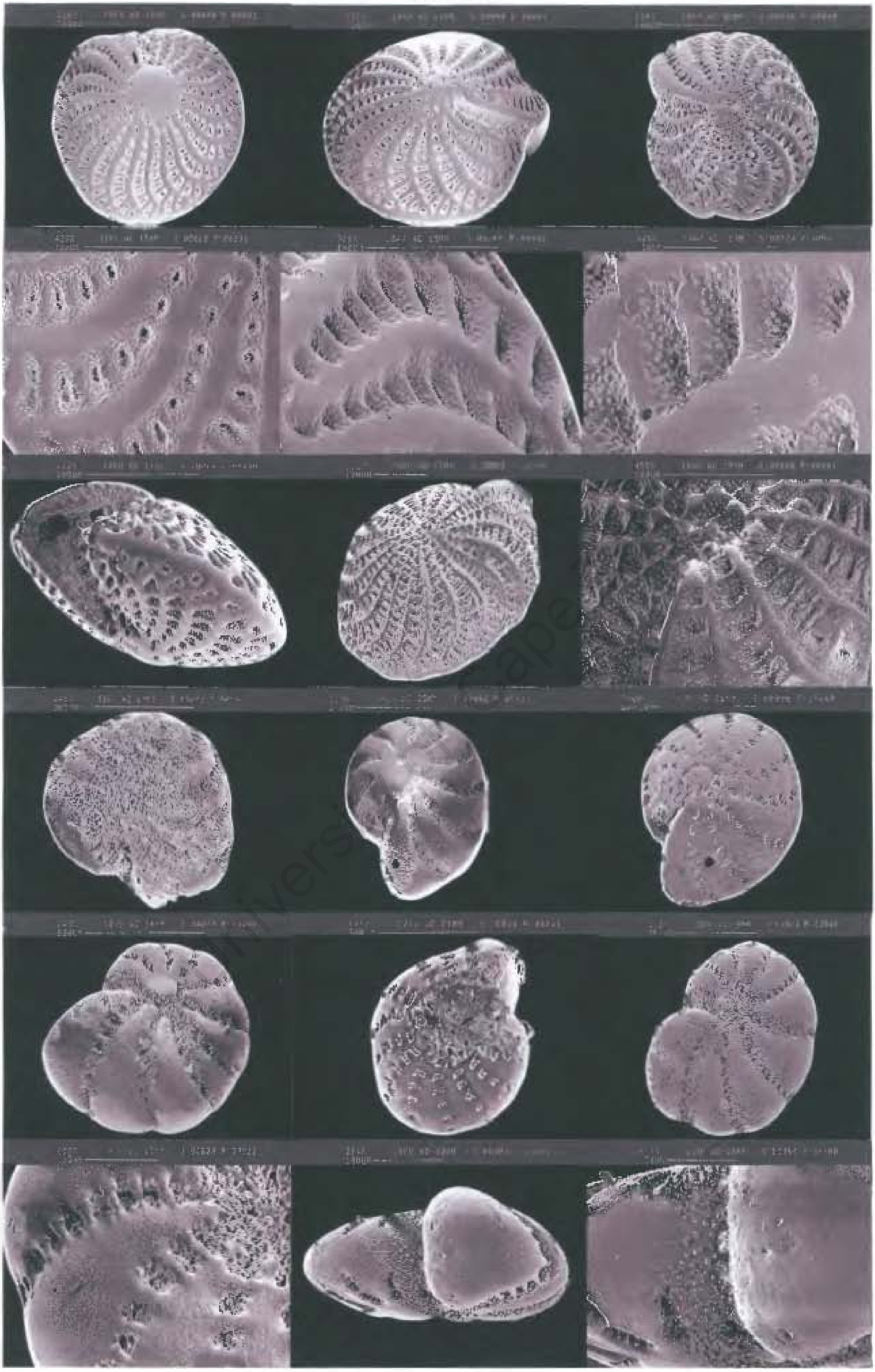


PLATE 3

Row 1a *Elphidium cf. articulatum*, side view

Row 1b *Elphidium cf. articulatum*, side view

Row 1c *Elphidium cf. articulatum*, apertural view

Row 2a *Elphidium gunteri*, side view

Row 2b *Elphidiella species*, side view

Row 2c *Elphidiella species*, high magnification

Row 3a *Elphidiella species*, side view

Row 3b *Elphidiella species*, side view

Row 3c *Elphidiella species*, edge view

Row 4a *Haynesina germanica*, side view

Row 4b *Haynesina germanica*, side view

Row 4c *Haynesina germanica*, umbilical area, high magnification

Row 5a *Ammonia japonica*, dorsal view

Row 5b *Ammonia japonica*, dorsal view

Row 5c *Ammonia japonica*, ventral view

Row 6a *Ammonia japonica*, ventral view

Row 6b *Rotalia gaimardii*, ventral view

Row 6c *Rotalia gaimardii*, ventral view

PLATE 3

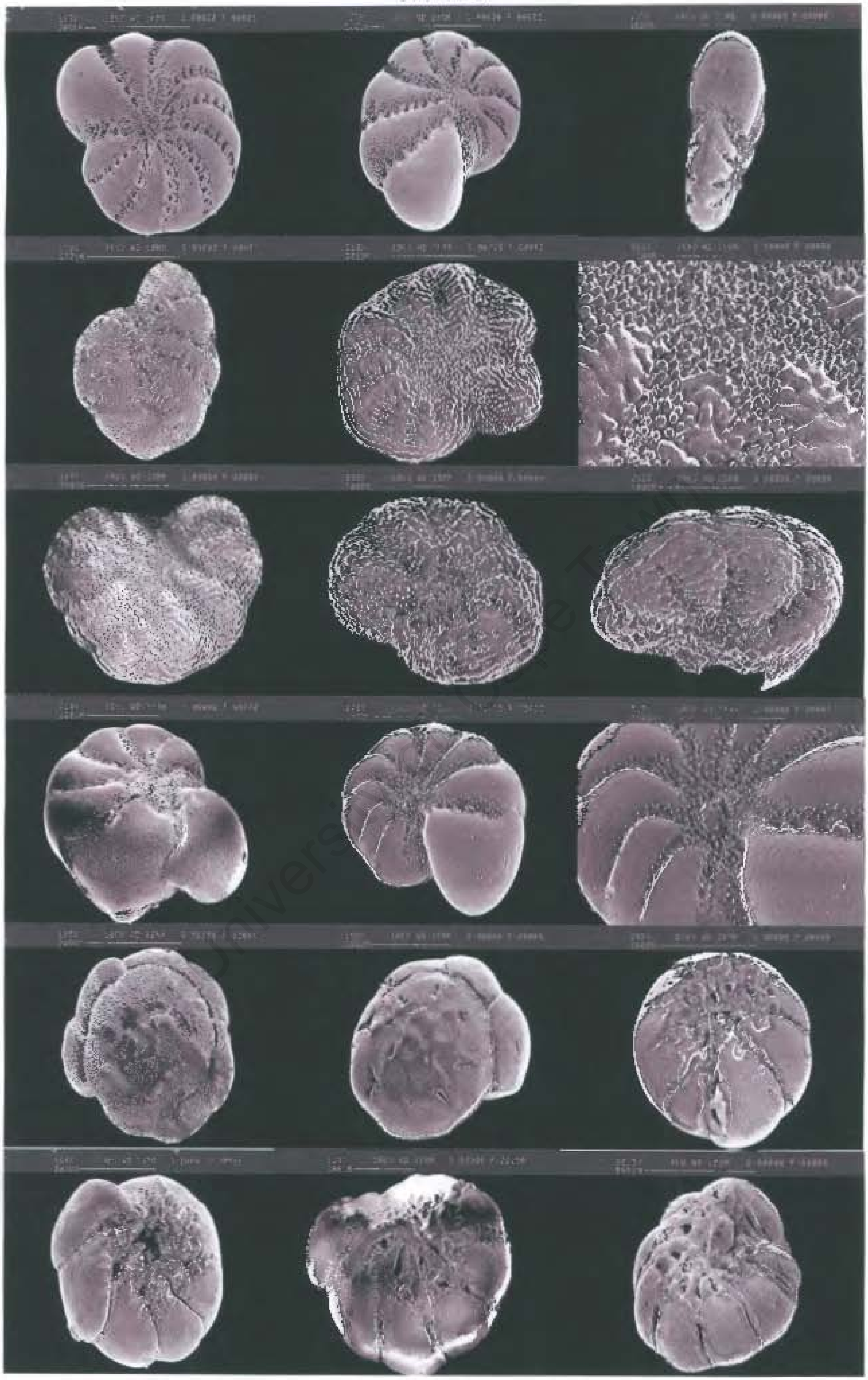


PLATE 4

Row 1a *Lobatula lobatula,* ventral view

Row 1b *Lobatula lobatula,* ventral view

Row 1c *Lobatula lobatula,* dorsal view

Row 2a *Lobatula lobatula,* dorsal view

Row 2b *Lobatula lobatula,* apertural view or edge view

Row 2c *Cibicides refulgens,* ventral view

Row 3a *Cibicides refulgens,* ventral view

Row 3b *Cibicides refulgens,* ventral view

Row 3c *Cibicides refulgens,* dorsal view

Row 4a *Poroeponides lateralis,* dorsal view

Row 4b *Poroeponides lateralis,* ventral view, and aperture with pores

Row 4c *Poroeponides lateralis,* oblique-dorsal view

Row 5a *Poroeponides lateralis,* dorsal view

Row 5b *Poroeponides lateralis,* perforations, medium magnification

Row 5c *Poroeponides lateralis,* perforations, high magnification

Row 6a *Cibicidoides speudoungerianus*, dorsal view

Row 6b *Cibicidoides speudoungerianus*, oblique-ventral view

Row 6c Piece of *Homotrema rubrum*

PLATE 4

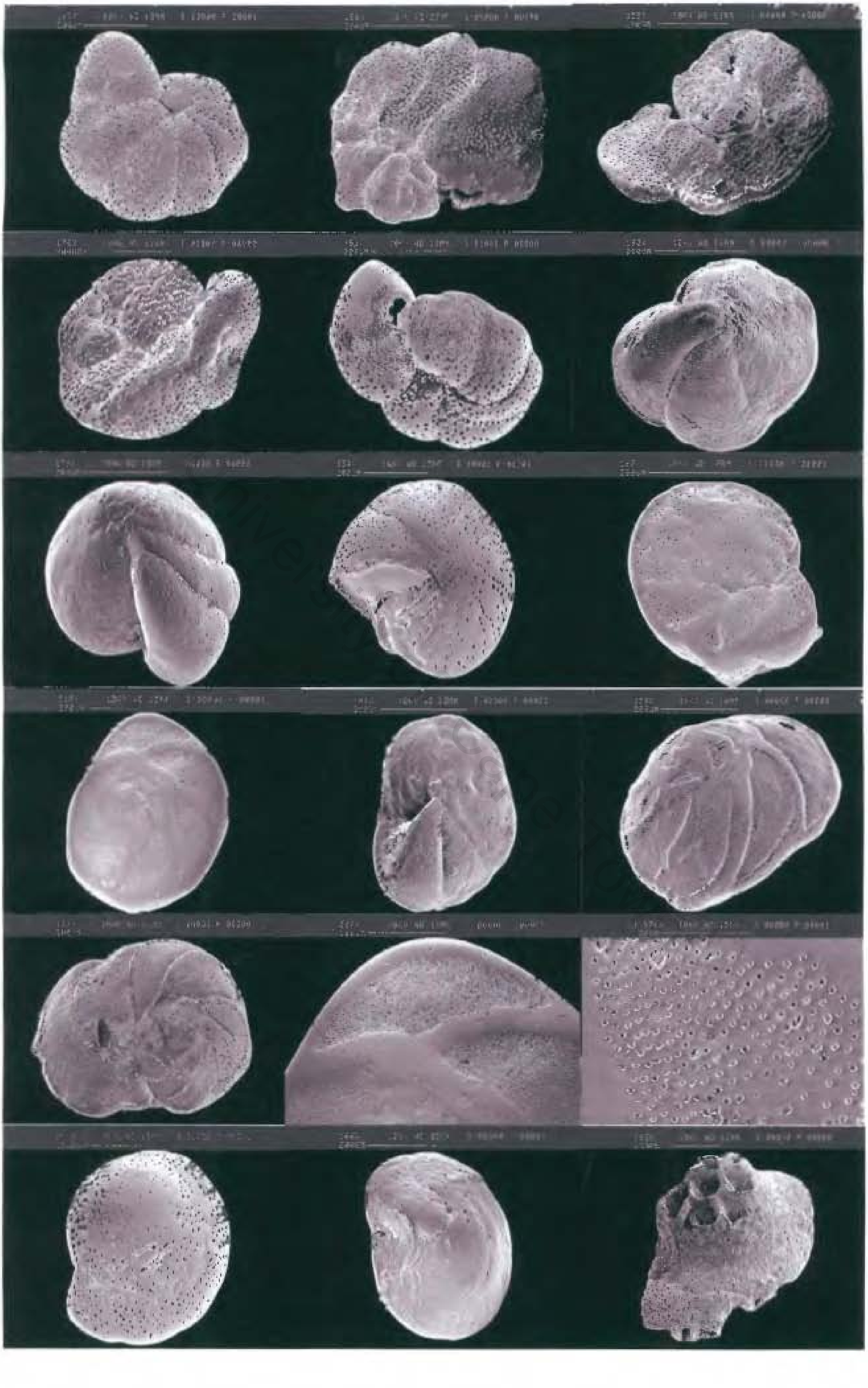


PLATE 5

Row 1a *Pararotalia nipponica*, dorsal view

Row 1b *Pararotalia nipponica*, dorsal view

Row 1c *Pararotalia nipponica*, ventral view

Row 2a *Pararotalia nipponica*, ventral view

Row 2b *Rosalina cf. globularis*, dorsal view

Row 2c *Rosalina cf. globularis*, ventral view

Row 3a *Rosalina bradyi*, dorsal view

Row 3b *Rosalina bradyi*, dorsal view

Row 3c *Rosalina bradyi*, ventral view

Row 4a *Rosalina bradyi*, ventral view

Row 4b *Rosalina bradyi*, ventral view

Row 4c *Rosalina bradyi*, ventral view

Row 5a *Glabratella australensis*, ventral view

Row 5b *Glabratella australensis*, dorsal view

Row 5c *Glabratella australensis*, dorsal view

Row 6a *Planorbulina mediterranensis*, ventral view

Row 6b *Planorbulina mediterranensis*, ventral view

Row 6c *Planorbulina mediterranensis*, ventral view, high magnification

PLATE 5

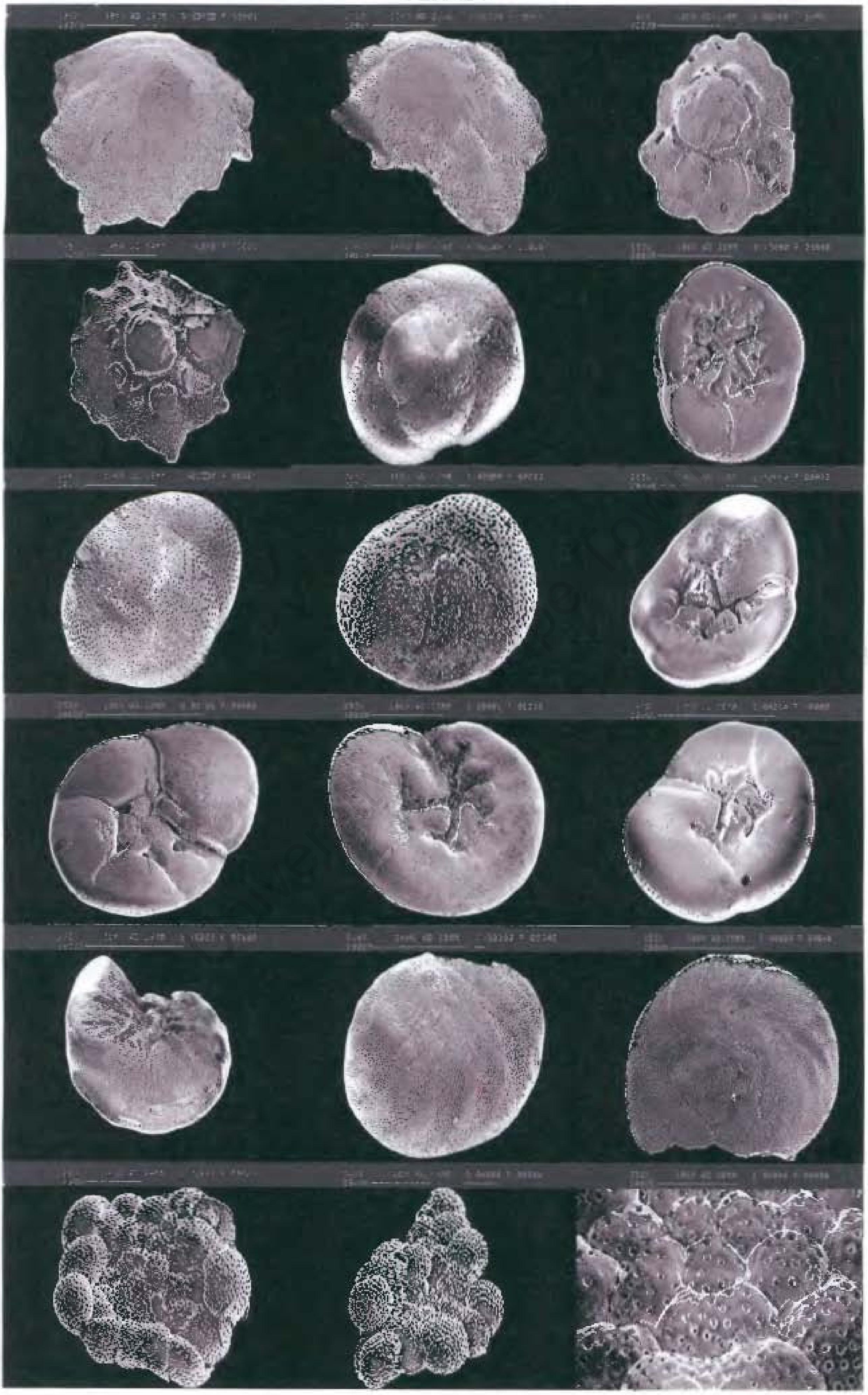


PLATE 6

Row 1a *Planorbulina mediterranensis*, ventral view
Row 1b *Planorbulina mediterranensis*, ventral view
Row 1c *Planorbulina mediterranensis*, ventral view
Row 2a *Planorbulina mediterranensis*, ventral view
Row 2b *Planorbulina mediterranensis*, ventral view
Row 2c *Planorbulina mediterranensis*, ventral view
Row 3a Indeterminate pink globular species
Row 3b Indeterminate pink globular species
Row 3c Indeterminate pink globular species
Row 4a *Brizolina speudopunctata*, side view
Row 4b *Bulimina orangensis*, side view
Row 4c *Bulimina orangensis*, side view
Row 5a *Bulimina elongata*, side view
Row 5b *Bulimina elongata*, side view
Row 5c *Bulimina elongata*, side view
Row 6a *Oolina melo*, apical view
Row 6b *Oolina melo*, side view
Row 6c *Oolina melo*, side view

PLATE 6

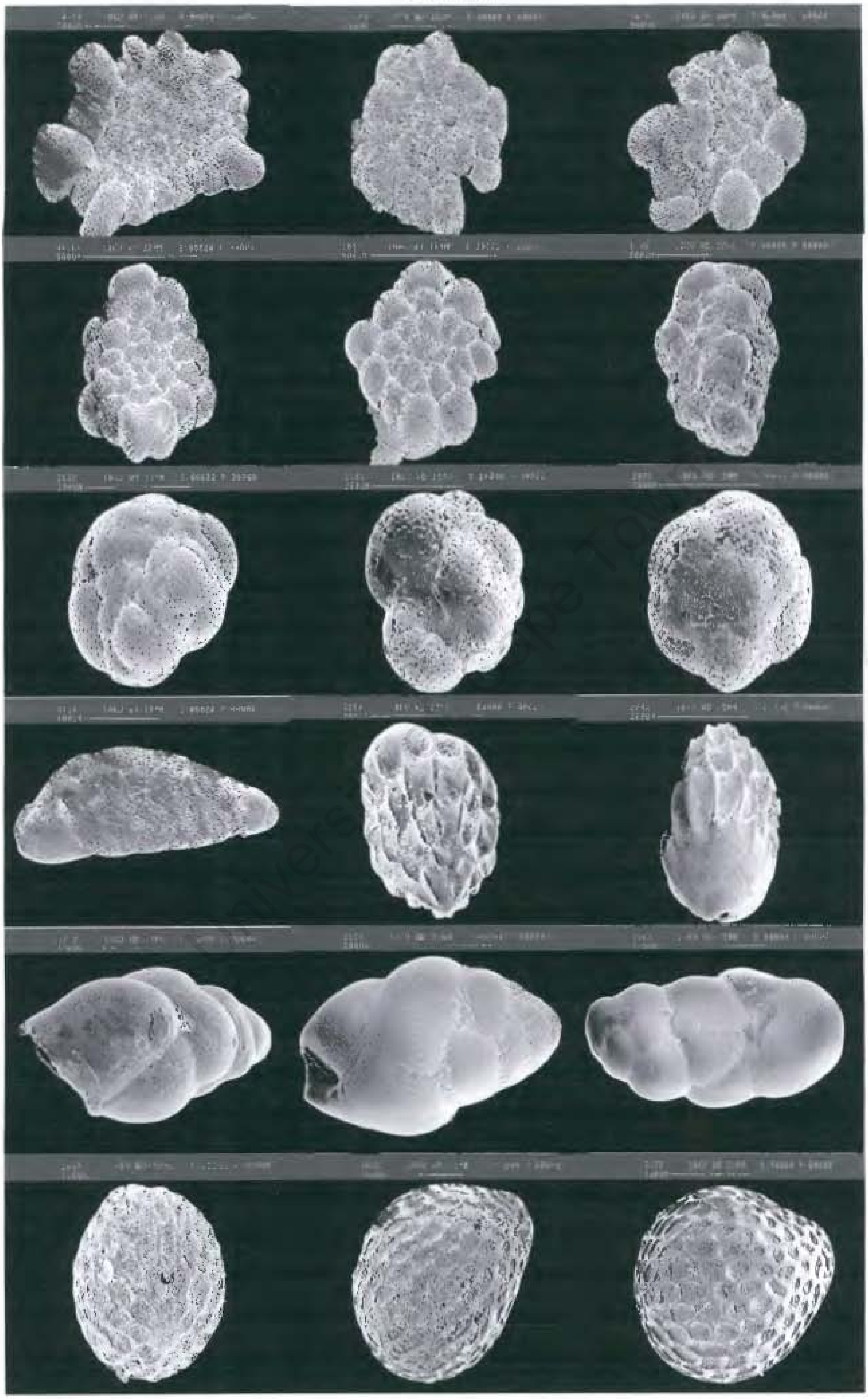


PLATE 7

Row 1a *Oolina hexagona*, apical view

Row 1b *Oolina hexagona*, side view

Row 1c *Oolina hexagona*, side view

Row 2a *Oolina squamosa*, oblique-side view

Row 2b *Oolina sp. A* (McMillan, 1987), side view

Row 2c *Lagena striata*, side view (multiple embryo, or possibly damaged during test growth)

Row 3a *Lagena semilineata, apical view*

Row 3b narrow *Lagena semilineata*, side view

Row 3c *Lagena cf. lyellii*, apical view

Row 4a ribbed *Lagena sp.* apical view

Row 4b ribbed *Lagena sp.* apical view

Row 4c ribbed *Lagena sp.* apical view

PLATE 7

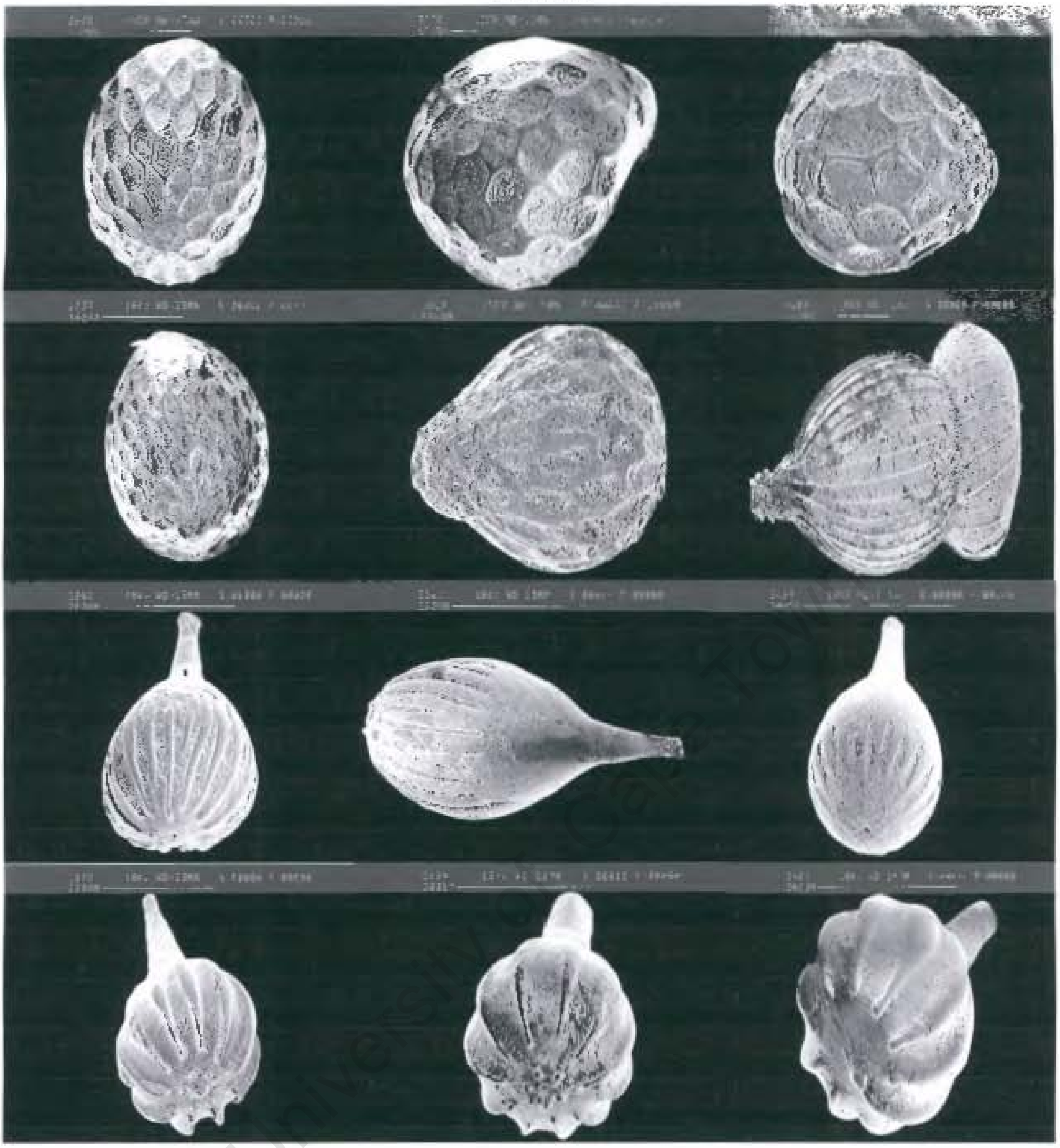


PLATE 8

Row 1a *Quinqueloculina dunkerquiana,* side view

Row 1b *Quinqueloculina dunkerquiana,* apertural view

Row 1c *Quinqueloculina dunkerquiana,* apertural view

Row 2a *Quinqueloculina dunkerquiana,* tooth in aperture, high magnification

Row 2b *Quinqueloculina dunkerquiana,* tooth in aperture, high magnification

Row 2c *Quinqueloculina dunkerquiana,* tooth in aperture, high magnification

Row 3a *Quinqueloculina seminulum,* oblique view

Row 3b *Quinqueloculina seminulum,* apertural view

Row 3c *Quinqueloculina lata,* side view

Row 4a *Quinqueloculina contorta,* side view

Row 4b *Quinqueloculina contorta,* apertural view

Row 4c *Quinqueloculina contorta,* side view

Row 5a *Quinqueloculina contorta,* side view

Row 5b *Quinqueloculina cf. vulgaris,* side view

Row 5c *Quinqueloculina cf. vulgaris,* side view

Row 6a *Quinqueloculina cf. undulate,* side view

Row 6b large broad *Quinqueloculina sp.* with Y-shaped tooth in aperture, side view

Row 6c large broad *Quinqueloculina sp.* with Y-shaped tooth in aperture, apertural view

PLATE 8

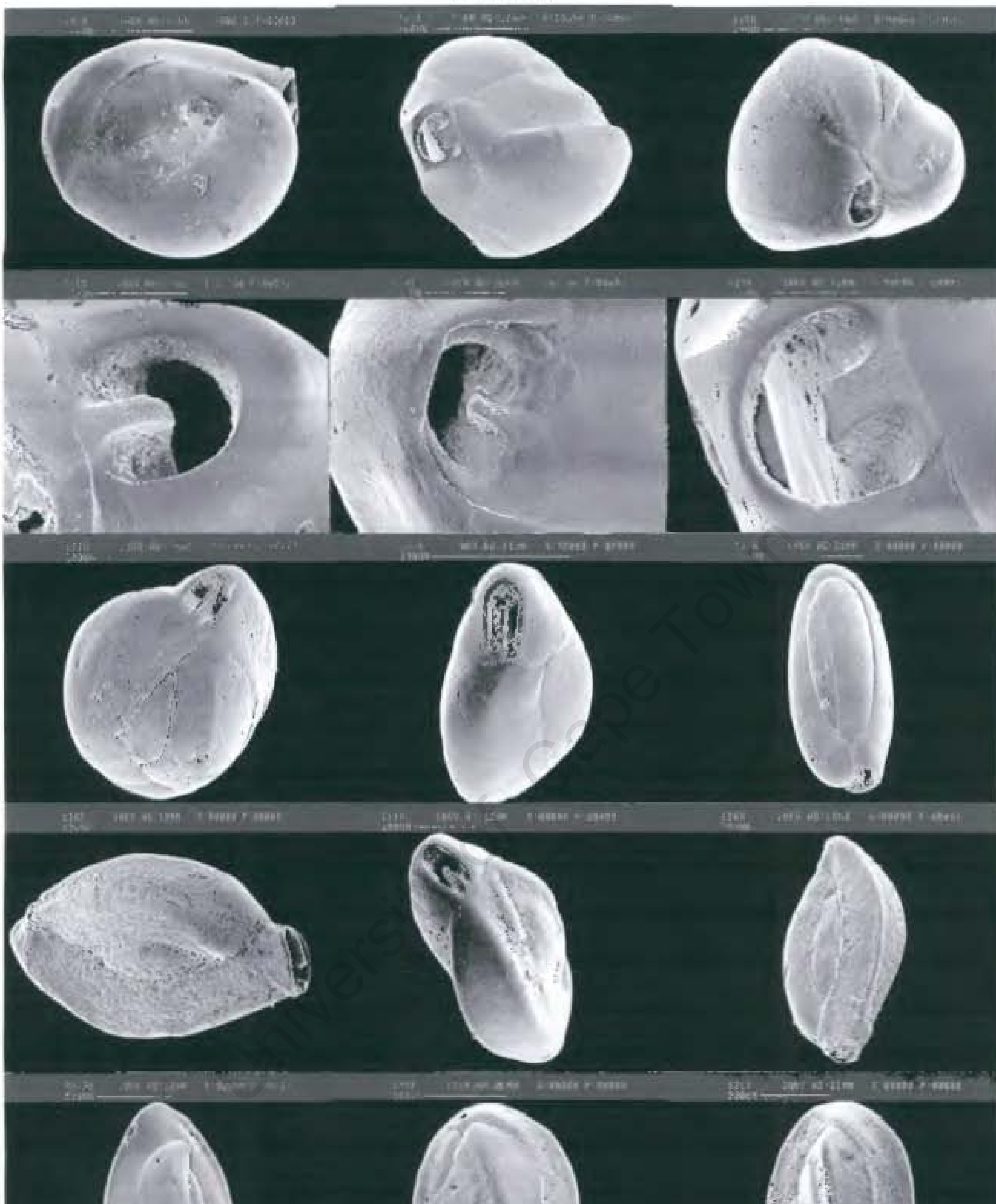


PLATE 9

Row 1a Small, broad *Quinqueloculina sp.* (tooth has two points), apertural view

Row 1b Small, broad *Quinqueloculina sp.* (tooth has two points), high magnification

Row 1c finely ribbed *Quinqueloculina sp.*, side view

Row 2a *Quinqueloculina sp.* with no tooth, side view

Row 2b *Spiroloculina communis*, side view

Row 2c *Spiroloculina communis*, side view

Row 3a *Spiroloculina communis*, apertural view

Row 3b *Spiroloculina communis*, tooth in aperture, high magnification

Row 3c Ribbed/ grooved *Sprioloculina sp.*, side view

Row 4a Ribbed/ grooved *Sprioloculina sp.*, side view (quartz grain on specimen)

Row 4b *Pyrgo*, apertural view

Row 4c *Pyrgo*, side view

Row 5a *Triloculina trigonula*, apertural view

Row 5b *Triloculina trigonula*, apertural view

Row 5c *Triloculina trigonula*, apertural-oblique view

Row 6a *Triloculina trigonula*, apertural view, Y-shaped tooth

Row 6b *Triloculina trigonula*, apertural view

Row 6c *Triloculina trigonula*, tooth in aperture, high magnification

PLATE 9

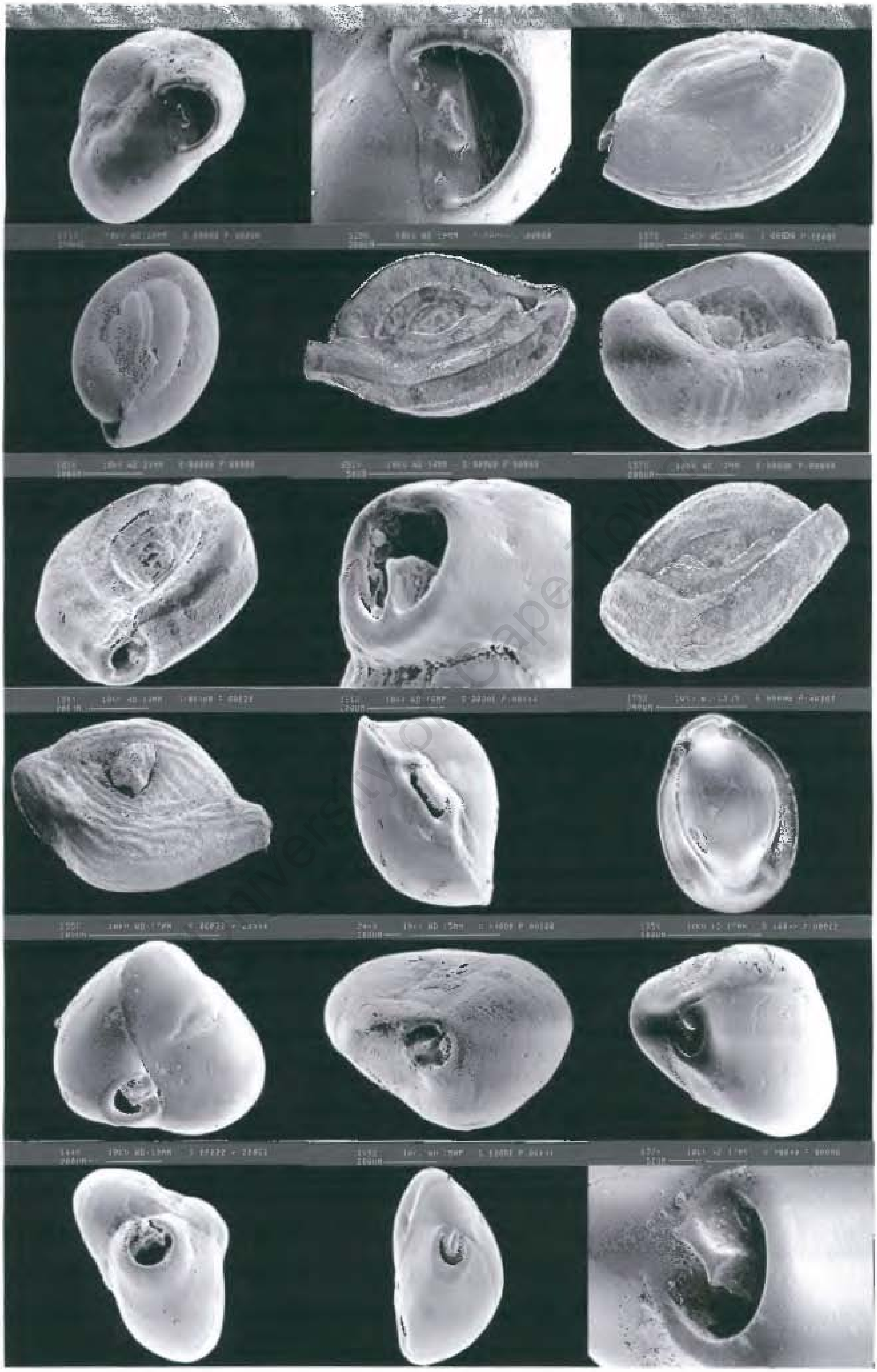


PLATE 10

Row 1a *Triloculina trigonula*, apertural view

Row 1b *Triloculina trigonula*, apertural view

Row 1c *Triloculina trigonula*, apertural view

Row 2a Elongate *Triloculina sp.*, side view

Row 2b *Triloculina oblonga*, apertural view

Row 2c *Triloculina oblonga*, apertural view

Row 3a *Triloculina oblonga*, apertural view

Row 3b *Triloculina oblonga*, oblique view

Row 3c *Triloculina oblonga*, apertural view

Row 4a *Triloculina oblonga,* Y-shaped tooth in aperture, high magnification

Row 4b *Triloculina oblonga,* Y-shaped tooth in aperture, high magnification

Row 4c *Triloculina oblonga,* Y-shaped tooth in aperture, high magnification

Row 5a *Triloculina sp.*, apertural view

Row 5b *Triloculina tricarinata*, apertural view

Row 5c *Triloculina tricarinata*, apertural view

Row 6a Large, flat *Triloculina sp.*, with aperture on neck, side view

Row 6b flat, ribbed *Triloculina sp.*, side view

Row 6c Large, broad *Triloculina sp.*, apertural-edge view

PLATE 10

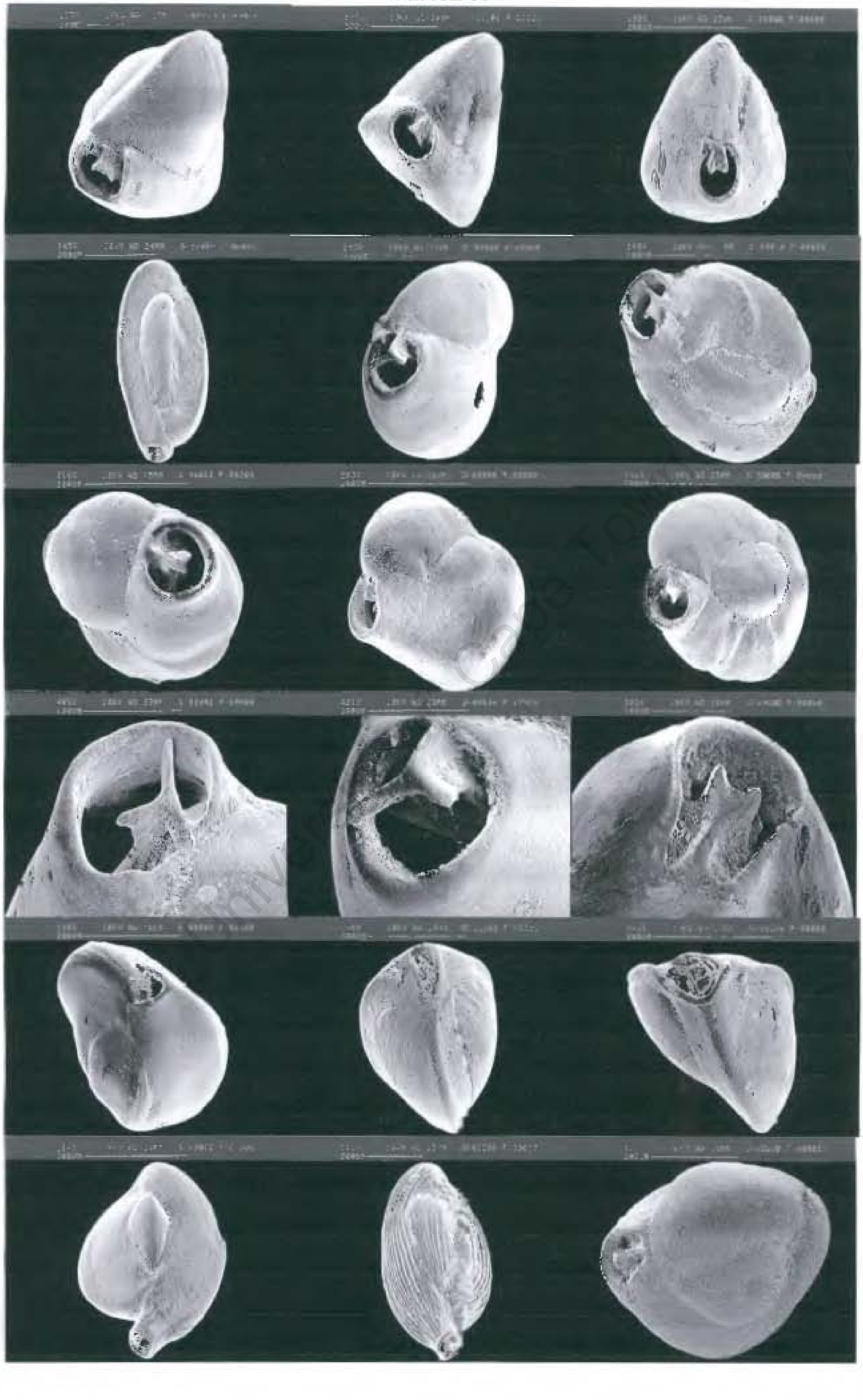


PLATE 11

Row 1a *Triloculina terquemiana*, side view
Row 1b *Triloculina terquemiana*, apertural view
Row 1c *Triloculina terquemiana*, oblique-aperture view
Row 2a *Triloculina terquemiana*, side view
Row 2b *Triloculina terquemiana*, apertural view
Row 2c *Triloculina terquemiana*, side view
Row 3a *Triloculina terquemiana*, oblique view
Row 3b *Triloculina terquemiana*, tooth in aperture, high magnification
Row 3c *Triloculina terquemiana*, tooth in aperture, high magnification
Row 4a *Triloculina terquemiana*, tooth in aperture, high magnification
Row 4b *Triloculina terquemiana*, tooth in aperture, high magnification
Row 4c *Triloculina terquemiana*, tooth in aperture, high magnification
Row 5a *Triloculina berthiliniana*, side view
Row 5b *Triloculina berthiliniana*, apertural view
Row 5c *Triloculina berthiliniana*, tooth in aperture, high magnification
Row 6a *Miliolinella subrotunda*, apertural view
Row 6b *Miliolinella subrotunda*, apertural view
Row 6c *Miliolinella subrotunda*, oblique view

PLATE 11

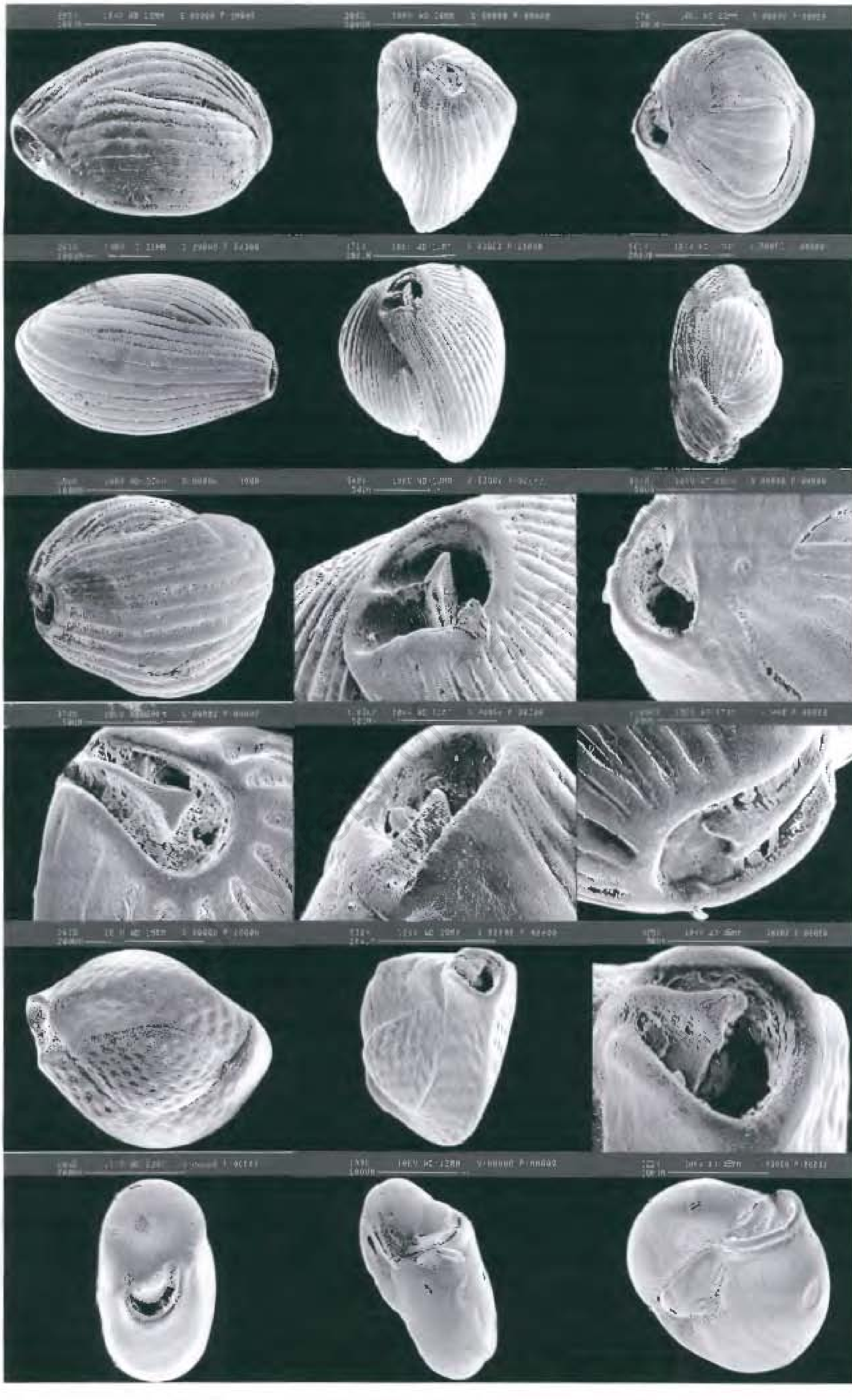


PLATE 12

Row 1a *Miliolinella subrotunda*, oblique view

Row 1b *Miliolinella subrotunda*, side view (abnormal growth)

Row 1c *Miliolinella subrotunda*, side view

Row 2a *Miliolinella subrotunda*, side view

Row 2b *Miliolinella circularis*, side view

Row 2c *Miliolinella circularis*, side view

Row 3a *Miliammina fusca*, side view

Row 3b *Miliammina fusca*, opposite side view

Row 3c *Miliammina fusca*, agglutinated surface, high magnification

Row 4a *Miliammina fusca*, side view

Row 4b *Miliammina fusca*, oblique-apertural view

Row 4c *Miliammina fusca*, oblique-apertural view

Row 5a *Siphanaperta martinae*, (agglutinated miliolid)

Row 5b *Trochammina inflata*, dorsal view

Row 5c *Trochammina inflata*, ventral view

Row 6a *Haplophragmoides wilberti*, side view

Row 6b *Haplophragmoides sp.*, side view

Row 6c *Haplophragmoides canariensis*, side view

PLATE 12

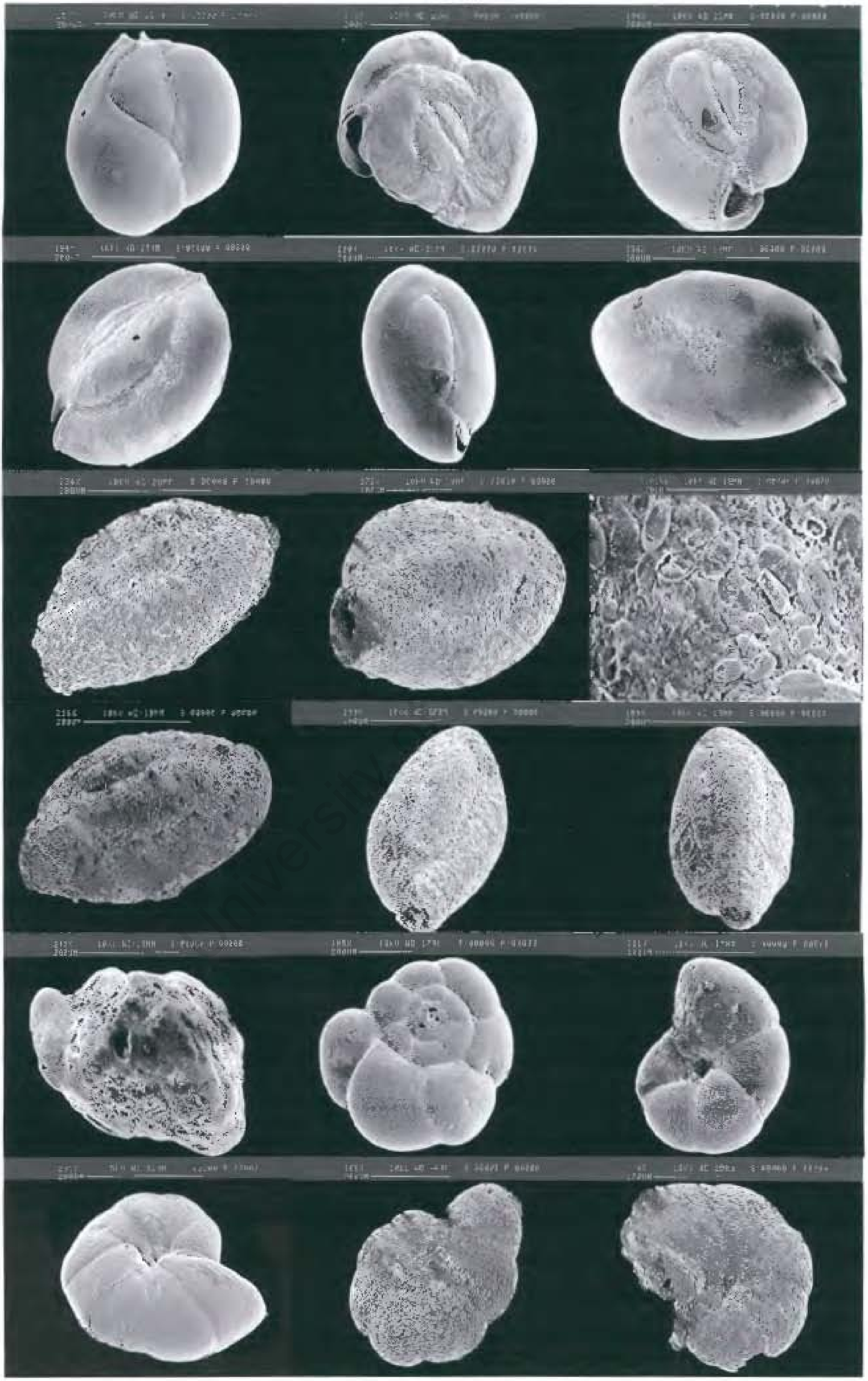


PLATE 13

Row 1a *Textularia conica*, side view

Row 1b *Textularia conica*, side view

Row 1c *Textularia conica*, side view

Row 2a *Textularia conica*, apical view

Row 2b *Textularia conica*, apertural view

Row 2c *Textularia conica*, oblique-apical view

Row 3a *Textularia conica*, apical-side view

Row 3b *Textularia conica*, apical-side view

Row 3c *Textularia conica*, agglutinated surface, high magnification

Row 4a *Gaudrina rudis*, apical view

Row 4b *Gaudrina rudis*, apical view

Row 4c *Gaudrina rudis*, apertural view

Row 5a *Gaudrina rudis*, apical view

Row 5b *Gaudrina rudis*, oblique-apical view

Row 5c *Gaudrina rudis*, agglutinated surface, high magnification

Row 6a *Gaudrina rudis*, apertural view

Row 6b *Spiroplectinella sp.*, side view

Row 6c *Spiroplectinella sp.*, agglutinated surface, high magnification

PLATE 13

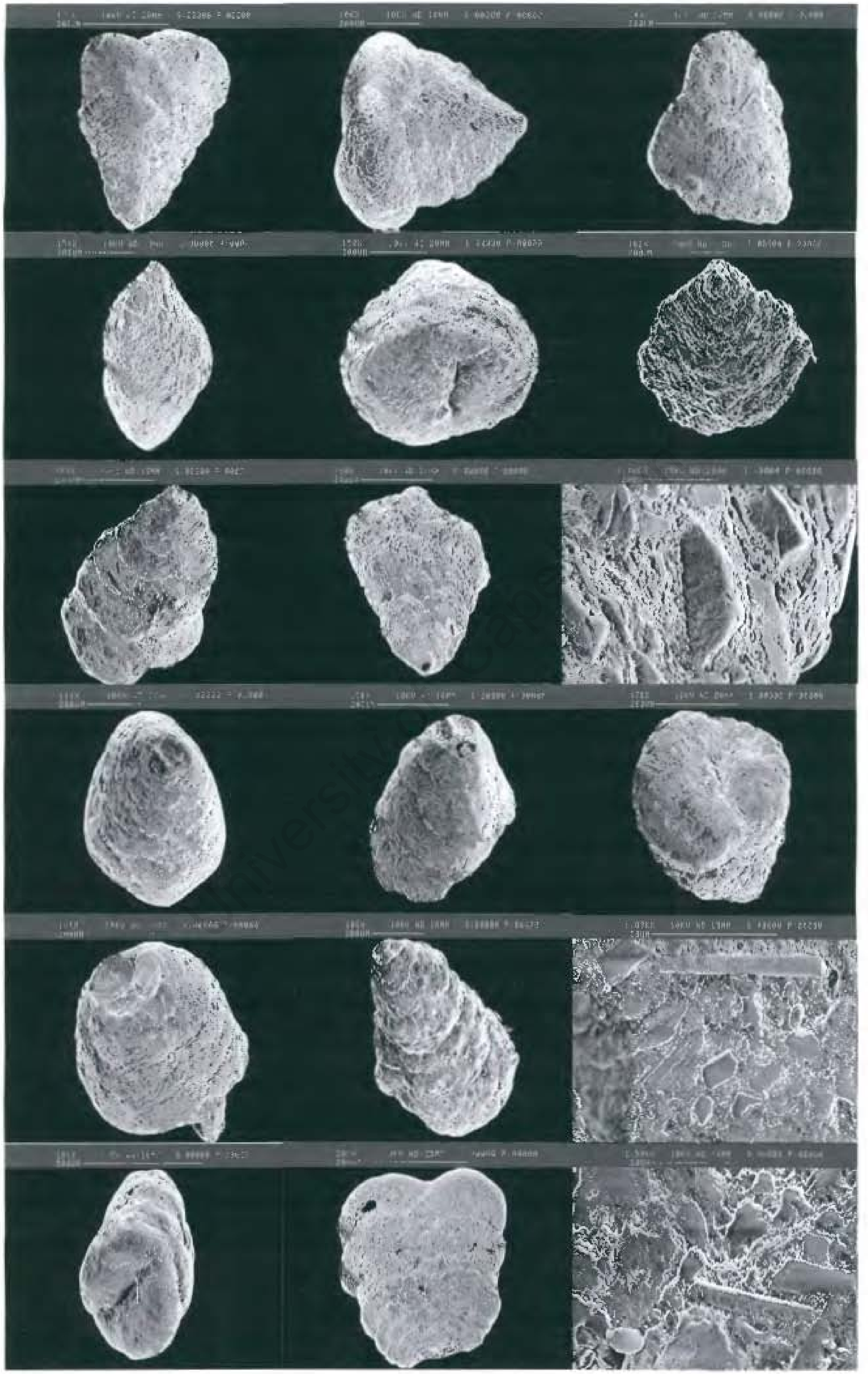


PLATE 14

Row 1a *Cyclogyra orbicular*, side view
Row 1b *Globulina,* side view
Row 1c *Glandulina*, side view
Row 2a *Lenticulina sp,* side view
Row 2b *Lenticulina sp,* side view
Row 2c *Nonion boueanus,* side view
Row 3a *Chrysalidinella dimorpha,* side view
Row 3b *Cassidulina laevigata,* side view
Row 3c *Cancris auriculus,* ventral view
Row 4a *Challengerella bradyi,* dorsal view
Row 4b *Challengerella bradyi,* ventral view
Row 4c *Challengerella bradyi,* ventral view
Row 5a flat *Planularia sp.* (Pleistocene)
Row 5b *Planispirillina sp.*, side view
Row 5c *Hyalina balthica* (Pleistocene)

PLATE 14

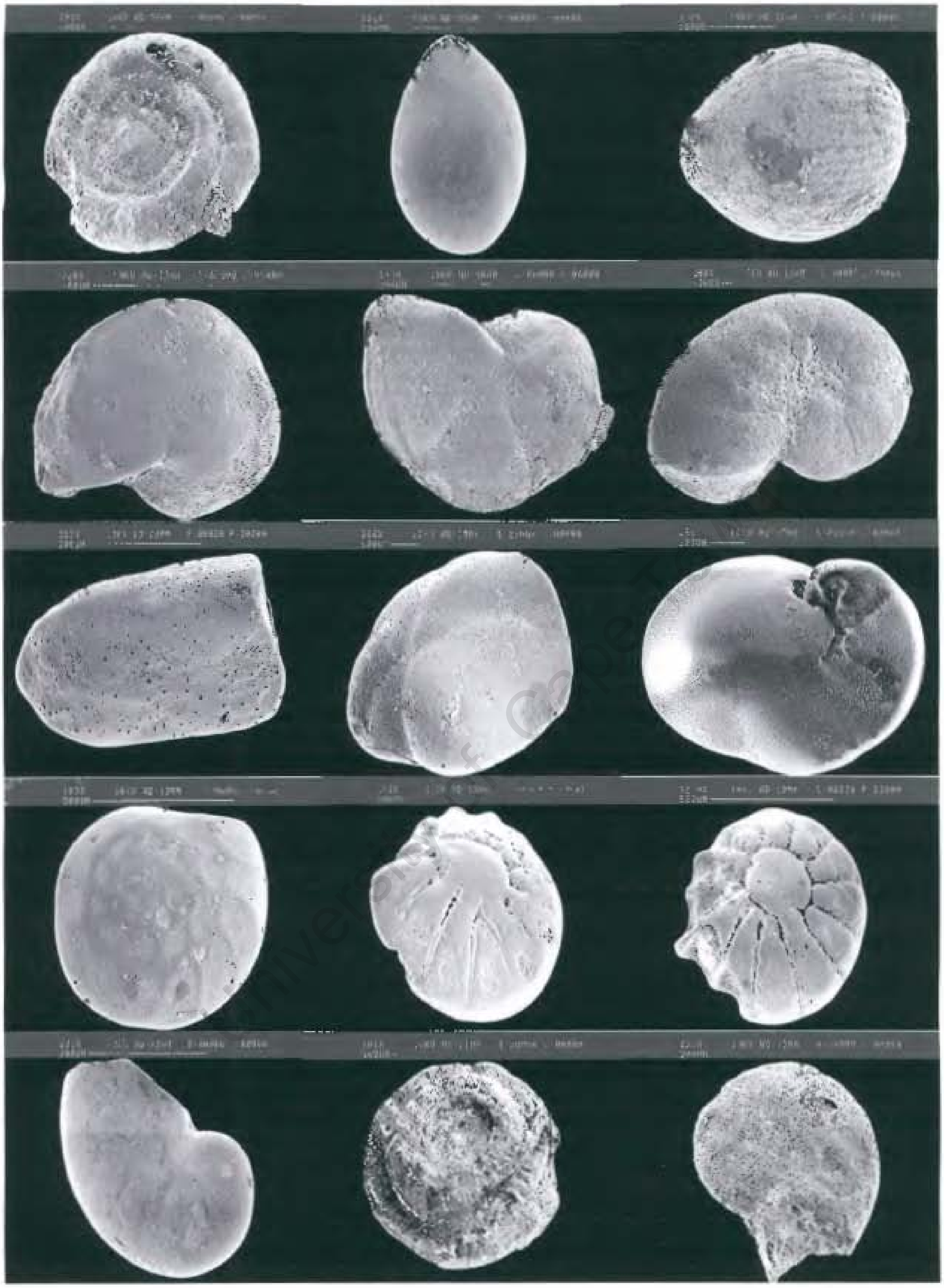


PLATE 15

Row 1a *Globorotalia inflata,* oblique-side view

Row 1b *Globorotalia inflata,* ventral view

Row 1c *Globorotalia inflata,* side view

Row 2a *Globorotalia inflata,* ventral view

Row 2b *Globigerinoides triloba,* ventral view

Row 2c *Globigerina sp.*, ventral view

Row 3a *Neogloboquadrina pachyderma*, dorsal view

Row 3b *Neogloboquadrina pachyderma*, dorsal view

Row 3c *Globoquadrina dutertrei*, oblique-dorsal view

Row 4a *Globigerinoides rubber,* apertural view

Row 4b *Globigerinoides rubber,* side view

Row 4c *Globigerinoides rubber,* side view

Row 5a *Globigerinoides rubber,* side view

Row 5b *Globigerinoides rubber,* side view

Row 5c *Globigerina bulloides* dorsal view

Row 6a juvenile *Neogloboquadrina pachyderma*, ventral view

Row 6b juvenile *Neogloboquadrina pachyderma*, ventral view

Row 6c juvenile *Neogloboquadrina pachyderma*, ventral view

PLATE 15 PLANKTIC FORAMINIFERA

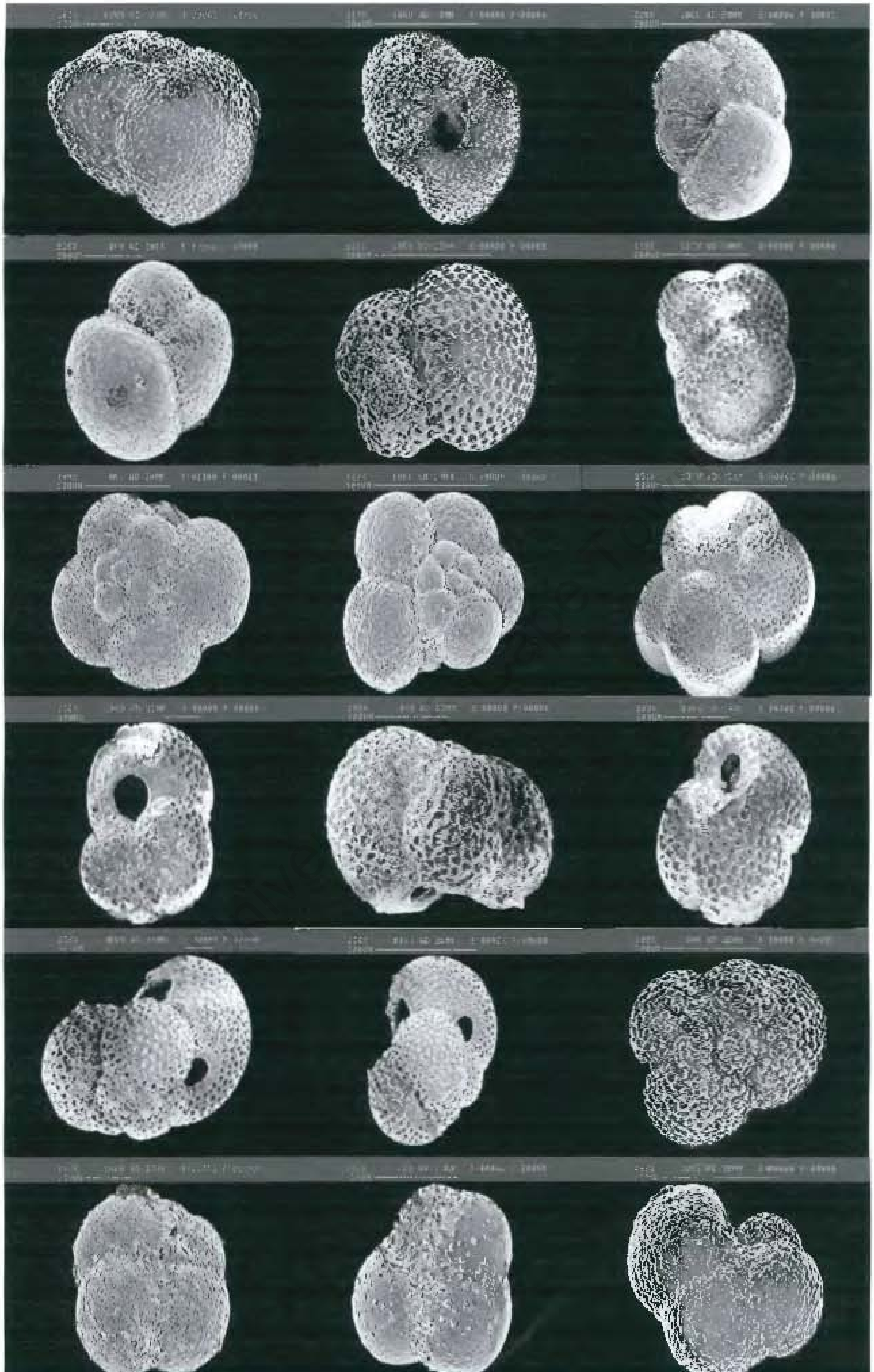


PLATE 16

Ostracods of the Knysna Estuary.

PLATE 16 OSTRACODS OF THE KNYSNA ESTUARY

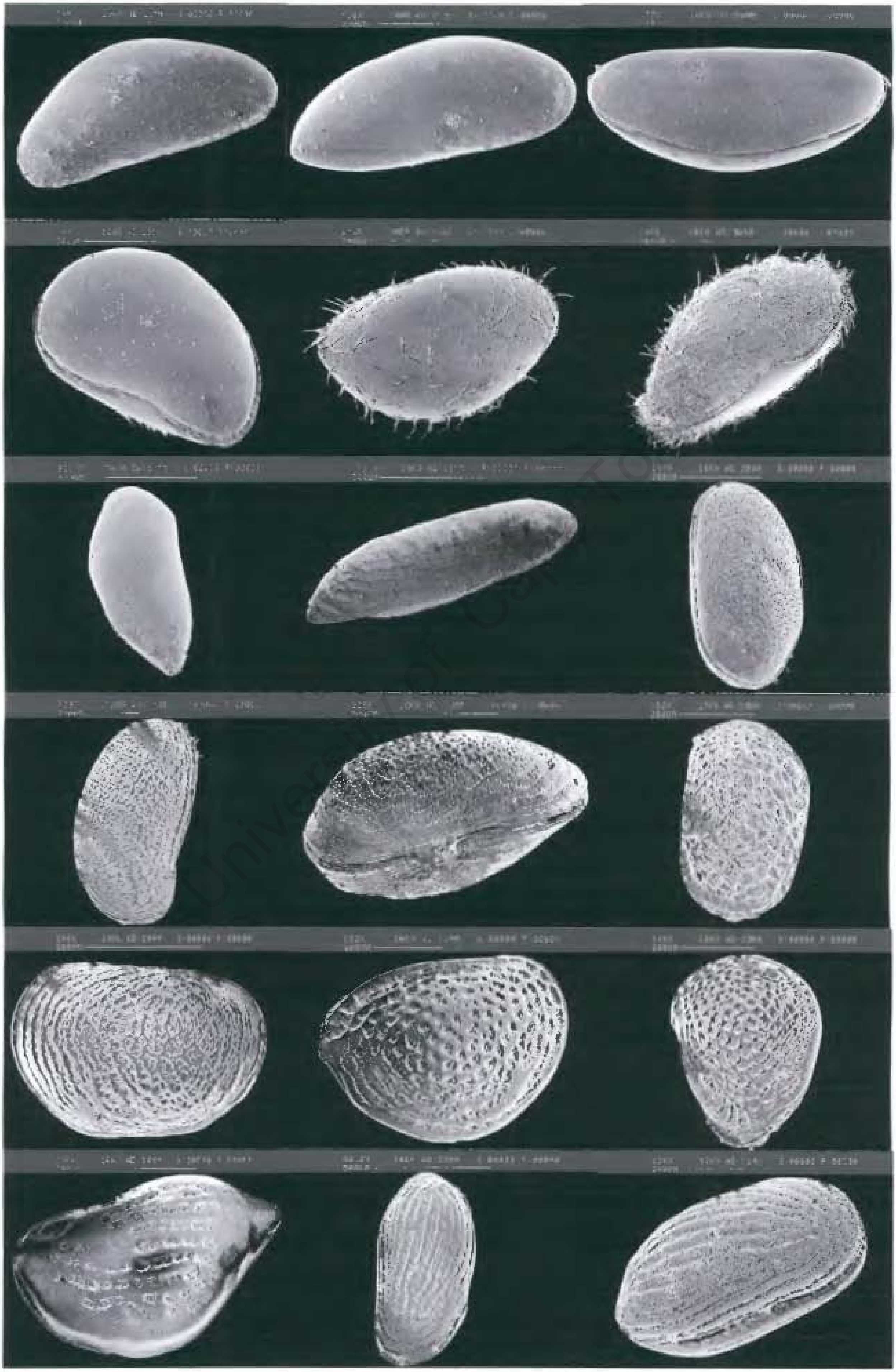


PLATE 17

Row 1and 2 Ostracods of the Knysna Estuary

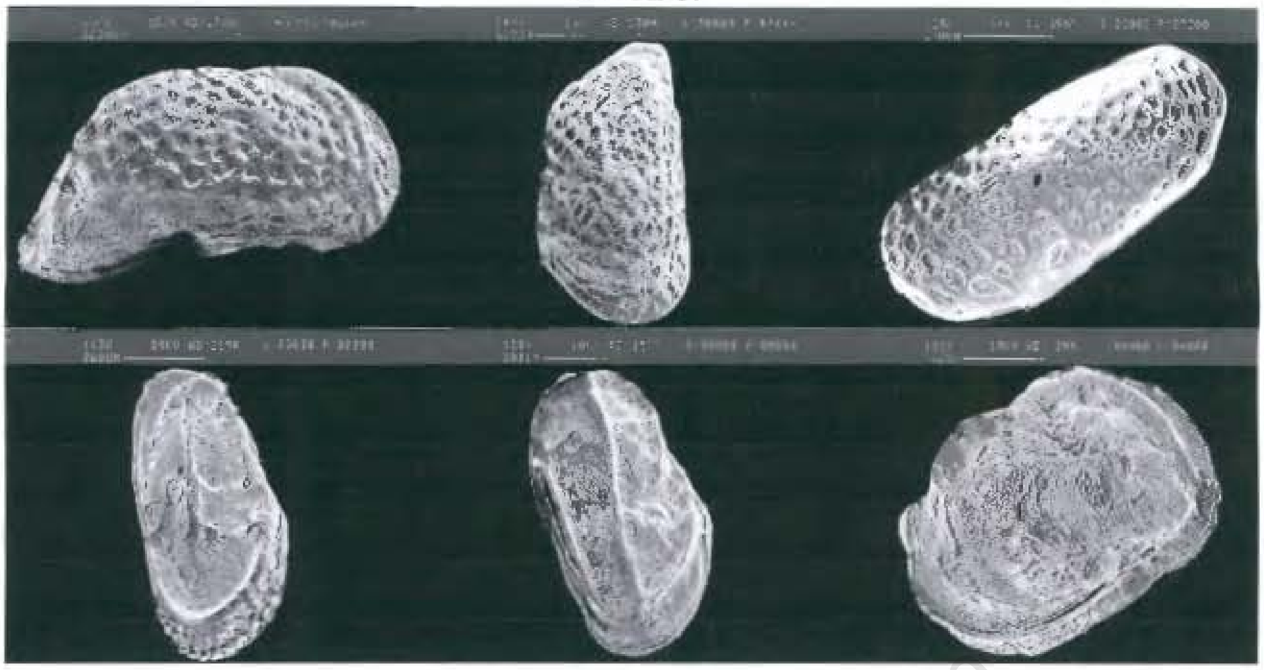
Row 3 and 4 Gastropods in sediments near the mouth of the Knysna Estuary

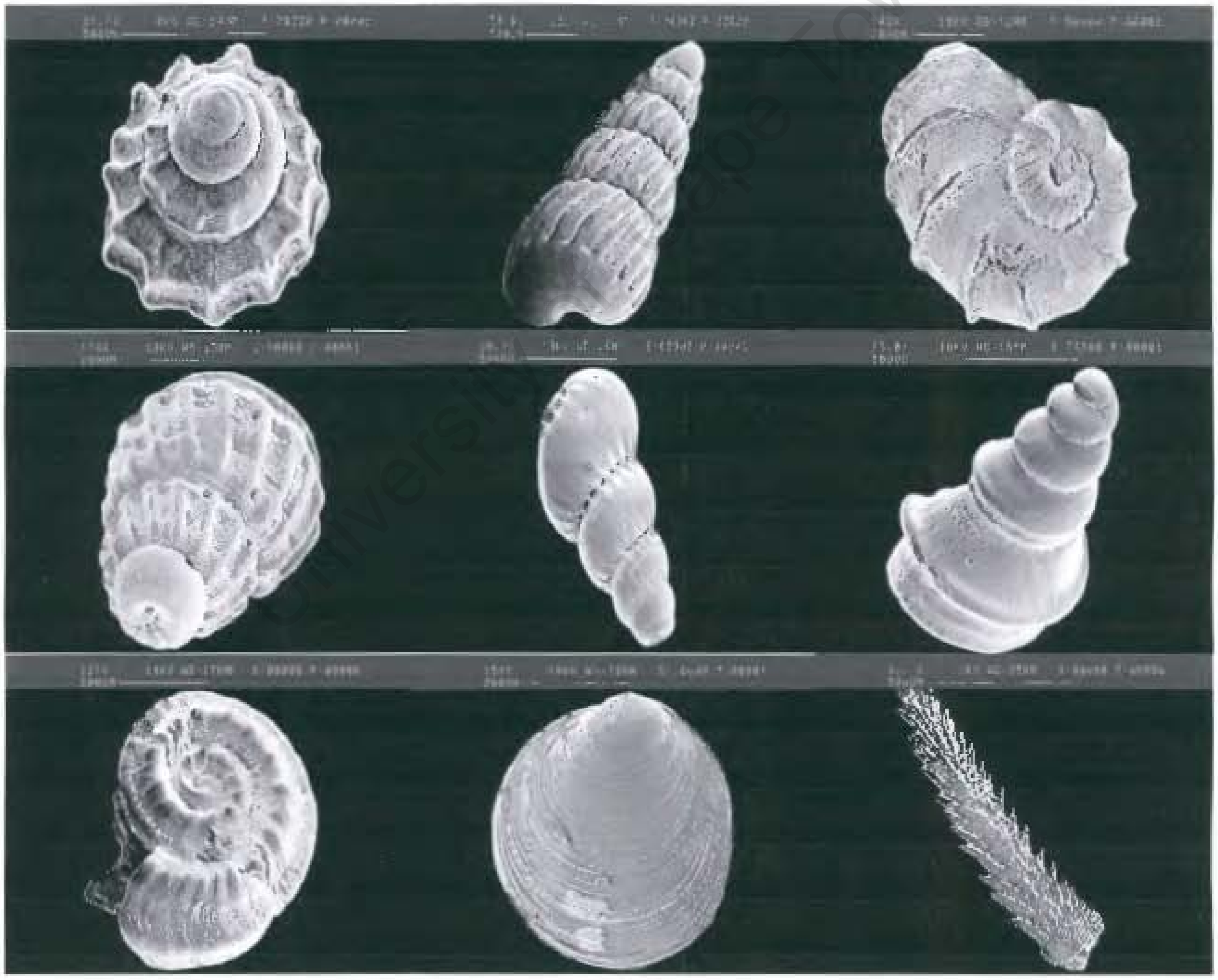
Row 5a Serpulid worm tube

Row 5b Bivalve shell

Row 5c Glass sponge spicule

PLATE 17





APPENDIX 6

Foraminifera Species of Knysna Lagoon

Recorded according to list of species in chapter 4.3

1) Miliammina fusca (Brady, 1870)

Quinqueloculina fusca H.B. Brady, in G.S. Brady & Robertson, 1870: 286, pl.11, fig.2a-c, 3a-b.

Original reference: G.S. Brady & D. Robertson (1870) The Ostracoda and foraminifera of tidal rivers, with an analysis and descriptions of the foraminifera by Henry B. Brady. Annals and Magazine of Natural History, 4th. Series, **6**: 273-309.

2) Trochammina inflata (Montagu, 1808)

Nautilus inflatus Montagu, 1808: 81, pl.18, fig.3.

Original reference: G. Montagu (1808) Testacea Britannica: Supplement. S. Woolmer, Exeter: 1-183.

3) Haplophragmoides wilberti Andersen, 1953

Haplophragmoides wilberti Andersen, 1953: 21, pl.4, fig.7a-b.

Original reference: H.V. Andersen (1953) Two new species of Haplophragmoides from the Louisiana coast. Contributions from the Cushman Foundation for Foraminiferal Research **4**: 21-22.

4) Haplophragmoides canariensis (D'Orbigny, 1839)

Nonionina canariensis D'Orbigny, 1839: 128, pl.2, fig.33-34.

Original reference: A.D. D'Orbigny (1839) Foraminifères. In: P. Barker-Webb & S. Berthelot, Histoire Naturelle des Iles Canaries **2**(2) Zoologie. Béthune, Paris: 119-146.

5) Ammonia parkinsoniana (D'Orbigny, 1839)

Rosalina parkinsoniana D'Orbigny, 1839: 99, pl.4, fig.25-27.

Rosalina catesbyana D'Orbigny, 1839: 99, pl.4, fig.22-24.

Original reference: A.D. D'Orbigny (1839) Foraminifères. In: R. de la Sagra, Histoire Physique, Politique et Naturelle de l'Ile de Cuba. A.Bertrand, Paris: 1-224.

6) Ammonia japonica (Hada, 1931)

Rotalia japonica Hada, 1931: 137, text-fig.93a-c.

Original reference: Y. Hada (1931) Notes on the Recent foraminifera from Mutsu Bay. Report of the Biological Survey of Mutsu Bay, Part 19. Scientific Reports of the Tohoku Imperial University, Sendai, 4th Series (Biology) **6**: 45-148.

7) Elphidium articulatum (D'Orbigny, 1839)

Polystomella articulatum D'Orbigny, 1839: 30, pl.3, fig.9-10.

Original reference: A.D. D'Orbigny (1839) Voyage dans l'Amérique Méridionale - Foraminifères. Pitois-Levrault et Cie., Paris, and V. Levrault, Strasbourg **5**: 1-86.

8) Elphidium advenum (Cushman, 1922)

Polystomella advena Cushman, 1922: 56, pl.9, fig.11-12.

Original reference: J.A. Cushman (1922) Shallow-water foraminifera of the Tortugas region. Carnegie Institute, Washington, Publication No. **311** (Department of Marine Biology, Paper No.17): 1-85.

9) Elphidium cf. alvarezianum (D'Orbigny, 1839)

see Polystomella alvareziana D'Orbigny, 1839: 31, pl.3, fig.11-12.

Original reference: A.D. D'Orbigny (1839) Voyage dans l'Amérique Méridionale - Foraminifères. Pitois-Levrault et Cie., Paris, and V. Levrault, Strasbourg **5**: 1-86.

10) Elphidium crispum (Linné, 1758) s.l.

Nautilus crispus Linné, 1758: 709 (figured by Plancus, 1739: pl.1, fig.2d-f).

Original reference: C. von Linné, 1758: Systema Naturae per Regna Tria Naturae, Secundum Classes, Ordines Genera, Species, cum Characteribus, Differentiis, Synonymis, Locis. L. Salvius, Stockholm, Edition 10, **1**: 1-823.

11) Elphidium macellum (Fichtel & Moll, 1798) s.l.

Nautilus macellus Fichtel & Moll, 1798: 66, var.ß, pl.10, fig.h-k.

Original reference: L. von Fichtel & J.P.C. von Moll (1798) Testacea Microscopica, Aliaque Minuta ex Generibus Argonata et Nautilus, ad Naturam Delineata et Descripta. Camesina, Wien: 1-123.

12) Elphidium gunteri Cole, 1931

Elphidium gunteri Cole, 1931: 34, pl.4, fig.9-10.

Original reference: W.S. Cole (1931) The Pliocene and Pleistocene foraminifera of Florida. Florida State Geological Survey, Bulletin **6**: 1-79.

13) Globigerina bulloides D'Orbigny, 1826

Globigerina bulloides D'Orbigny, 1826: 277, modéles no. 17 (1ère livraison) and no.76 (4ème livraison).

Original reference: A.D. D'Orbigny (1826) Tableau méthodique de la classe des céphalopodes. Annales des Sciences Naturelles, Paris, Séries 1, **7**: 245-314.

14) Globigerina quinqueloba Natland, 1938.

Globigerina quinqueloba Natland, 1938: 149, pl.6, fig.7.

Original reference: M.L. Natland, (1938) New species of foraminifera from off the west coast of North America and from the later Tertiary of the Los Angeles Basin. University of California, Scripps Institute, Oceanography Bulletin, Technical Series **4**: 137-164.

15) Globigerinoides ruber (D'Orbigny, 1839)

Globigerina rubra D'Orbigny, 1839: 82, pl.4, fig.12-14.

Original reference: same as no. 5 (Ile de Cuba ref.).

16) Globigerinella aequilateralis (Brady, 1879)

Globigerina aequilateralis Brady, 1879: 285.

Globigerina aequilateralis Brady, 1884: 605, pl.80, fig.18-21.

Original references: H.B. Brady (1879) Notes on some of the reticularian Rhizopoda of the "Challenger" Expedition. Quarterly Journal of Microscopical Science, London, New Series **19**: 20-63, 261-299.

H.B. Brady (1884) Report on the foraminifera dredged by H.M.S. "Challenger" during the years 1873-1876. Reports of the Scientific Results of the Voyage of H.M.S. "Challenger" **9** (Zoology): 1-814 (2 volumes).

17) Globorotalia inflata (D'Orbigny, 1839)

Globigerina inflata D'Orbigny, in Barker-Webb & Berthelot, 1839: 134, pl.2, fig.7-9.

Original reference: same as no. 4 (canary island ref.)

18) Globoquadrina dutertrei (D'Orbigny, 1839)

Globigerina dutertrei D'Orbigny, 1839: 84, pl.4, fig.19-21.

Original reference: same as no. 5 (Ile de Cuba ref.).

19) Neogloboquadrina pachyderma (Ehrenberg, 1861)

Aristerospira pachyderma Ehrenberg, 1861: 303.

Aristerospira pachyderma Ehrenberg, 1873: 386, pl.1, fig.4.

Original reference: C.G. Ehrenberg (1861) Uber die tiefgrund-verhältnisse des oceans am eingange des Davisstrasse und bei Island. Königliche Preussische Akademie der Wissenschaften, Berlin, Monatsbericht: 275-315.

C.G. Ehrenberg (1873) Mikrogeologische studien über das kleinste leben der meeres - tiefgründe aller zonen und dessen geologischen einfluss. Königliche Preussische Akademie der Wissenschaften, Berlin, Abhandlungen (for 1872): 131-397.

20) Haynesina germanica (Ehrenberg, 1840)

Nonionina germanica Ehrenberg, 1840: 23.

Nonionina germanica Ehrenberg, 1841: pl.2, fig.1a-g.

Original reference: C.G. Ehrenberg (1840) Ein weitere erläuterung des organismus mehrerer in Berlin lebend beobachteter polythalamien der Nordsee. Königliche Preussische Akademie der Wissenschaften, Berlin, Berichte: 18-23.

C.G. Ehrenberg (1841) Uber noch jetzt zahlreich lebende thierarten der kreidebildung und den organismus der polythalamien. Königliche Preussische Akademie der Wissenschaften, Berlin, Phys.-Math. Klasse II, Abhandlungen (for 1839): 81-174.

21) Rotalia gaimardii (Barker, 1960)

Streblus gaimardii Barker, 1960: 218, pl.106, fig.9a-c.

Original reference: R.W. Barker (1960) Taxonomic notes on the species figured by H.B. Brady in his report on the foraminifera dredged by HMS Challenger during the years 1873-1876. Society of Economic Paleontologists and Mineralogists, Special Publication **9**: 1-238.

22) Triloculina "oblonga" -informal species

23) Quinqueloculina dunkerquiana - see also no. 63 below.

24) Chrysalidinella dimorpha (Brady, 1884)

Chrysalidina dimorpha Brady, 1884: 54, pl.46, fig.20, 21a,b.

Original reference: H.B. Brady (1881) Notes on some of the reticularian Rhizopoda of the Challenger Expedition Part 3, 1- classification; 2- further notes on new species; 3- note on Biloculina mud. Quarterly Journal of Microscopical Science, new series **21**: 31-71.

25) Cassidulina laevigata D'Orbigny, 1826

Cassidulina laevigata D'Orbigny, 1826: 282, pl.15, fig.4-5.

Original reference: A.D. D'Orbigny (1826) Tableau méthodique de la classe des Céphalopodes. Annales des Sciences Naturelles, Paris, Series 1, **7**: 245-314.

26) Nubecularia lucifuga Defrance, 1825

Nubecularia lucifuga Defrance, 1825: 210.

Original reference: M.J.L. Defrance (1825) Dictionnaire des Sciences Naturelles. F.G. Levrault, Paris **35**: 1-534.

27) Pararotalia nipponica (Asano, 1936)

Rotalia nipponica Asano, 1936: 614, pl.31, fig.2a-c.

Original reference: K. Asano, (1936) Fossil foraminifera from Muraoka-mura, Kamakura gôri, Kanagawa Prefecture. Journal of the Geological Society of Japan **43** (515): 603-615.

28) Cibicides refulgens De Montfort, 1808

Cibicides refulgens De Montfort, 1808: 122, text-fig.

Original reference: D. de Montfort (1808) Conchyliologie Systématique et Classification Méthodique des Coquilles **1**: 1-409.

29) Cibicidoides pseudoungerianus (Cushman, 1922)

Truncatulinoides pseudoungeriana Cushman, 1922: 97, pl.20, fig.9.

Original reference: J.A. Cushman (1922) The Byram Calcareous Marl of Mississippi and its foraminifera. United States Geological Survey, Professional Paper **129-E**: 79-122.

30) Poroeponides lateralis (Terquem, 1878)

Rosalina lateralis Terquem, 1878: 25, pl.2, fig.11a-c.

Original reference: O. Terquem (1878) Les foraminifères et les entomostracés ostracodes du Pliocène supérieur de l'Ile de Rhodes. Mémoire de la Société Géologique de France, Paris, Séries 3, **1**(3): 1-135.

31) Lobatula lobatula (Walker & Jacob, 1798)

Nautilus lobatulus Walker & Jacob, in Kanmacher, 1798: 642, pl.14, fig.36.

Original reference: G. Walker & E. Jacob (1798) In: Essays on the Microscope, etc. by G. Adams. Second Edition, with Considerable Additions and Improvements, by F. Kanmacher. Dillon & Keating, London: 1-712.

32) Planorbulina mediterranensis D'Orbigny, 1826

Planorbulina mediterranensis D'Orbigny, 1826: 280.

Original reference: A.D. D'Orbigny (1826) Tableau Méthodique de la Classe des Céphalopodes. Annales des Sciences Naturelles, Paris, Séries 1, **7**: 245-314.

33) Acervulina inhaerens Schultze, 1854

Acervulina inhaerens Schultze, 1854: 68, pl.6, fig.12.

Original reference: M.S. Schultze (1854) Uber den Organismus de Polythalamien (Foraminiferen), nebst Bemerkungen über die Rhizopoden im Allgemeinen. Wilhelm Engelmann, Leipzig: 1-68.

34) Glabratella "australensis (Heron-Allen & Earland, 1932)"

non Discorbina pileolus Brady, 1884: 469, pl.89, fig.2-4. (non Valvulina pileolus D'Orbigny).

Pileolina ?australensis Moura, 1965: 48, pl.6, fig.3 (non Heron-Allen & Earland).

Glabratella australensis McMillan, 1987: 363, pl.14, fig.14-18; pl.15, fig.1-2 (non Heron-Allen & Earland).

This species is unique to southern Africa. It is quite unlike Glabratella australensis, described from around Australia. Also unlike Glabratella pileolus, described from around South America. Species needs a new name.

Original reference: A.R. Moura (1965) Foraminíferos da Ilha da Inhaca (Moçambique). Revista dos Estudos Gerais Universitários de Moçambique, Maputo, Série 2, **2**: 1-74.
Extra reference: I.K. McMillan (1987) Late Quaternary foraminifera from the Southern Part of Offshore South West Africa/Namibia. Unpublished Ph.D. thesis, University College of Wales, Aberystwyth: 1-565.

35) Rosalina bradyi (Cushman, 1915)

Discorbis globularis (D'Orbigny) var. bradyi Cushman, 1915: 12, pl.8, fig.1a-c.

Original reference: J.A. Cushman (1915) A monograph of the foraminifera of the North Pacific Ocean, Part 5: Rotaliidae. United States National Museum, Bulletin **71**: 1-83.

36) *Rosalina williamsoni* (Chapman & Parr, 1932)

Rotalina nitida Williamson, 1858: 54, pl.4, fig.106-108 (non *Rotalina nitida* Reuss, 1841).

Discorbis williamsoni Chapman & Parr (m.s.): Parr, 1932: 226, pl.21, fig.25.

Original reference: W.J. Parr (1932) Victorian and South Australian shallow-water foraminifera, parts I and II. *Proceedings of the Royal Society of Victoria, new series*, **44**: 1-14, 218-234.

37) *Rosalina* cf. *globularis* D'Orbigny, 1826

see *Rosalina globularis* D'Orbigny, 1826: 271, pl.13, fig.1-4.

Original reference: D'Orbigny's "Tableau Méthodique" reference, 1826.

38) *Gavelinopsis praegeri* (Heron-Allen & Earland, 1913)

Discorbina praegeri Heron-Allen & Earland, 1913: 122, pl.10, fig.8-10.

Original reference: E. Heron-Allen & A. Earland (1913) The foraminifera of the Clare Island district, Co. Mayo, Ireland. Clare Island Survey, Part 64: foraminifera. *Proceedings of the Royal Irish Academy* **31**(64): 1-188.

39) *Lagena semilineata* Wright, 1886, var.

see *Lagena semilineata* Wright, 1886: 320, pl.26, fig.7.

Original reference: J. Wright (1886) Foraminifera of the Belfast Naturalists' Field Club's cruise off Belfast Lough, in the steam-tug "Protector", June 1885; also foraminifera found by Dr. Malcomson, at Rockport, Belfast Lough. *Proceedings of the Belfast Naturalists' Field Club, for 1885-6 (Appendix)*: 317-326.

40) *Lagena striata* (D'Orbigny, 1939)

Oolina striata D'Orbigny, 1839: 21, pl.5, fig.12.

Original reference: D'Orbigny, 1839, "Voyage dans l'Amérique Méridionale" ref.

41) *Lagena laevis* (Montagu, 1803)

Vermiculum laeve Montagu, 1803: 524, pl.1, fig.9.

Original reference: Montagu's "Testacea Britannica" ref. -see no.69.

42) *Lagena* cf. *lyellii* (Seguenza, 1862)

see *Amphorina lyellii* Seguenza, 1862: 52, pl.1, fig.40.

Original reference: G. Seguenza (1862) *Die terreni Terziarii del distretto di Messina, Parte II: descrizione dei foraminiferi monotalamici delle marne Mioceniche del distretto di Messina*. T. Capra, Messina: 1-84.

43) *Oolina melo* D'Orbigny, 1839

Oolina melo D'Orbigny, 1839: 20, pl.5, fig.9.

Original reference: D'Orbigny's "Amérique Méridionale" ref. again.

44) *Oolina hexagona* (Williamson, 1848)

Entosolenia squamosa (Montagu) var.γ *hexagona* Williamson, 1848: 20, pl.2, fig.23.

Original reference: W.C. Williamson (1848) On the Recent British species of the genus *Lagena*. *Annals and Magazine of Natural History*, Series 2, **1**: 1-20.

45) *Oolina* sp.A McMillan, 1887

Oolina sp.A McMillan, 1887: 220, pl.6, fig.13-14.

Original reference: McMillan, 1987 Ph.D. thesis.

46) *Oolina squamosa* (Montagu, 1803)

Vermiculum squamosa Montagu, 1803: 526, pl.14, fig.2

Original reference: Montagu's "Testacea Britannica" - see 41 and 69.

47) *Cyclogyra orbicula* - take this as informal species.

48) *Bulimina marginata* D'Orbigny, 1826

Bulimina marginata D'Orbigny, 1826: 269, pl.12, fig.10-12.

Original reference: A.D. D'Orbigny (1826) Tableau méthodique de la classe des Céphalopodes. *Annales des Sciences Naturelles, Paris, Series* 1, **7**: 245-314.

49) *Bulimina elongata* D'Orbigny, 1846

Bulimina elongata D'Orbigny, 1846: 187, pl.11, fig.19-20.

Original reference: D'Orbigny, 1846, Tertiary of Vienne (Autriche), again.

50) Bulimina "orangensis" McMillan, 1987

Bulimina "orangensis" McMillan, 1987: 240, pl.7, fig.17-20.
Bulimina cf. alazanensis Martin, 1981: 40, pl.4, fig.3-4 (non Cushman)

Original references: R.A. Martin (1981) Benthic foraminifera from the Orange-Luderitz shelf, southern African continental margin. Joint Geological Survey of South Africa/University of Cape Town, Marine Geoscience Group, Bulletin **11**: 1-75.

I.K. McMillan (1987) Late Quaternary foraminifera from the southern part of offshore South West Africa/Namibia. Unpublished Ph.D. thesis, University College of Wales, Aberystwyth: 1-565.

51) Brizalina striatula (Cushman, 1922)

Bolivina striatula Cushman, 1922: 27, pl.3, fig.10.

Original reference: J.A. Cushman (1922) Shallow water foraminifera of the Tortugas region, Carnegie Inst. No.311 - see ref. for no.8, Elphidium advenum.

52) Brizalina pseudopunctata (Höglund, 1947)

Bolivina pseudopunctata Höglund, 1947: 273, pl.24, fig.5a-b.

Original reference: H. Höglund (1947) Foraminifera in the Gullmar Fjord and the Skagerak. Zoologiska Bidrag från Uppsala **26**: 1-328.

53) Siphonaperta "martinae" McMillan, 1987

Quinqueloculina agglutinans (non D'Orbigny) Martin, 1974: 85.
Sigmoilopsis sp. McMillan, 1974: 37, pl.2, fig.7a-c.
Quinqueloculina agglutinans (non D'Orbigny) Martin, 1981: 25, pl.2, fig.8.
Sigmoilopsis schlumbergeri (non Silvestri) Martin, 1981: 27, pl.2, fig.13.
Siphonaperta "martinae" McMillan, 1987:
Siphonaperta sp. McMillan, 1990: 139, fig.7B-C.
Original references:
R.A. Martin (1974) Benthonic foraminifera from the western coast of southern Africa. Joint Geological Survey of South Africa/University of Cape Town Marine Geoscience Unit, Technical Report **6**: 83-87.

R.A. Martin (1981) Benthic foraminifera from the Orange-Luderitz shelf, southern African continental margin. Joint Geological Survey of South Africa/University of Cape Town Marine Geoscience Unit, Bulletin **11**: 1-75.

I.K. McMillan (1987) Ph.D. thesis.
I.K. McMillan (1990) Foraminifera from the Late Pleistocene (Latest Eemian to earliest Weichselian) shelly sands of Cape Town city centre, South Africa. Annals of the South African Museum **99**: 121-186.

Another species that needs its taxonomy resolved in a proper publication.

54) Textularia conica D'Orbigny, 1839

Textularia conica D'Orbigny, 1839: 143, pl.1, fig.19-20.

Original reference: D'Orbigny, 1839: Ile de Cuba again.

55) Gaudryina rudis Wright, 1900

Gaudryina rudis Wright, 1900: 53.

Original reference: J. Wright (1900) The foraminifera of Dogs Bay, Connemara. Irish Naturalist **9**: 51-55.

56) Triloculina "oblonga" - informal species

57) Triloculina trigonula (Lamarck, 1804)

Miliolites trigonula Lamarck, 1804: 351, pl.17, fig.4a-c.

Original reference: J.B.P.A. de M. De Lamarck (1804) Suite des mémoires sur les fossiles des environs de Paris (Explication des planches rélatives aux coquilles fossiles des environs de Paris). Annales du Museum National d'Histoire Naturelle, Paris **5** (for 1804): 179-188, 237-245, 349-357.

58) Triloculina tricarinata D'Orbigny, 1826

Triloculina tricarinata D'Orbigny, 1826: 299, modèles, no.7.

Original reference: same as Globigerina bulloides, no.13.

59) Triloculina terquemiana (Brady, 1884)

Miliolina terquemiana Brady, 1884: 166, pl.114, fig.1.

Original reference: Brady, 1884, Challenger Report.

60) Triloculina bertheliniana (Brady, 1884)

Miliolina bertheliniana Brady, 1884: 166, pl.114, fig.2a-b.

Original reference: Brady, 1884, Challenger Report again.

61) Triloculina fichteliana D'Orbigny, 1839

Triloculina fichteliana D'Orbigny, 1839: 171, pl.9, fig.8-10.

Original reference: D'Orbigny, Ile de Cuba reference.

62) Quinqueloculina cf. vulgaris D'Orbigny, 1826

see Quinqueloculina vulgaris D'Orbigny, 1826: 302, modèles no.33.

Original reference: same as Globigerina bulloides, see no.13.

63) Quinqueloculina dunkerquiana (Heron-Allen & Earland, 1930)

Miliolina dunkerquiana Heron-Allen & Earland, 1930: 56, pl.12, fig.9-11.

Original reference: E. Heron-Allen & A. Earland (1930) The foraminifera of the Plymouth district. Journal of the Royal Microscopical Society, London, Series 3, **50**: 46-84, 161-199.

64) Quinqueloculina seminulum (Linné, 1758)

Serpula seminulum Linné, 1758: 1264.

Original reference see Elphidium crispum, same reference.

65) Quinqueloculina contorta D'Orbigny, 1846

Quinqueloculina contorta D'Orbigny, 1846: 298, pl.20, fig.4-6.

Original reference: A.D. D'Orbigny (1846) Foraminifères Fossiles du Bassin Tertiaire de Vienne (Autriche). Gide et Cie., Paris: 1-312.

66) Quinqueloculina lata Terquem, 1876

Quinqueloculina lata Terquem, 1876: 82, pl.2, fig. 8a-c.

Original reference: O. Terquem (1876) Essai sur le Classement des Animaux qui Vivent sur le Plage et dans les Environs de Dunkerque: Deuxième Fascicule. O. Terquem, Paris: 55-100 (See also: O Terquem (1877) Mémoires de la Société Dunkerquoise pour Encouragement des Sciences, des Lettres et des Arts **20**: 146-191).

67) Quinqueloculina cf. curta Cushman, 1921

see Quinqueloculina curta Cushman, 1921: 426, pl.100, fig.1-2.

Original reference: J.A. Cushman (1921) Foraminifera of the Philippine and adjacent seas. United States National Museum, Bulletin 100, **4**: 1-608.

68) Spiroloculina communis Cushman & Todd, 1944

Spiroloculina communis Cushman & Todd, 1944: 63, pl.9, fig.4-5, 7-8.

Original reference: J.A. Cushman & R. Todd (1944) The genus Spiroloculina and its species. Cushman Laboratory for Foraminiferal Research, Special Publication **11**: 1-82.

69) Miliolinella subrotunda (Montagu, 1803)

Serpula subrotunda dorso elevato Walker & Boys, 1784: 2, pl.1, fig.4.
Vermiculum subrotundum Montagu, 1803: 521.

Original references: G. Walker & G. Boys (1784) Testacea minuta rariora nuperrime detecta in arena littoris sandvicensis (A collection of the minute and rare shells lately discovered in the sand of the sea-shore near Sandwich.) G. Walker, London: 1-25.

G. Montagu (1803) Testacea Britannica, or Natural History of British Shells, marine, land and freshwater. J.S. Hollis, Romsey: 1-606 (3 volumes).

70) Miliolinella circularis (Bornemann, 1855)

Triloculina circularis Bornemann, 1855: 349, pl.19, fig.4.

Original reference: J.G. Bornemann (1855) Die mikroskopische fauna des Septarienthones von Hermsdorf bei Berlin. Zeitschrift der Deutschen Geologische Gesellschaft, Berlin **7**: 307-371.

71) Challengerella bradyi Billman, Hottinger & Oesterle, 1980

Challengerella bradyi Billman, Hottinger & Oesterle, 1980: 91, pl.12, fig.1-14; pl.13, fig.1-7, text-fig.17.

Original reference: H. Billman, L. Hottinger, & H. Oesterle (1980) Neogene to Recent rotaliid foraminifera from the Indopacific Ocean: their canal system, their classification and their stratigraphic use. Schweizerische Paläontologische Abhandlungen **101**: 71-113.

72) Hyalinea balthica (Schröter, 1783)

Nautilus balthicus Schröter, 1783: 20, pl.1, fig.2.

Original reference: J.S. Schröter (1783) Einleitung in die Conchylienkenntniss nach Linné, **1**. J.J. Gebauer, Halle: 1-860.

73) Notorotalia clathrata (Brady, 1884)

Rotalia clathrata Brady, 1884: 709, pl.107, fig.8a-c.

Original reference: H.B. Brady's 1884 Challenger report again.

74) Nonion boueanus (D'Orbigny, 1846)

Nonionina boueana D'Orbigny, 1846: 108, pl.5, fig.11,12.

Original reference: same reference as Quinqueloculina contorta: forams of Tertiary of Vienne (Autriche).

75) Ehrenbergina cf. healyi Finlay, 1947

see Ehrenbergina healyi Finlay, 1947: 284, pl.7, fig.106-115.

Original reference: H.J. Finlay (1947) New Zealand foraminifera: key species in stratigraphy 5. New Zealand Journal of Science and Technology, Series B, **28**: 259-292.

76) Cancris cf. auriculus (Fichtel & Moll, 1798)

see Nautilus auricula var.α and var.β Fichtel & Moll, 1798: 108, pl.20, fig.a-f.

Original reference: same as for Elphidium macellum.
