Extant benthic Foraminifera from two bays along the SW coast of South Africa, with a comment about their use as indicators of pollution.

By

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This thesis is dedicated to my family.

Seraj and children Rafeeq, Muneeb and Imra and

my mother Gafsa and late father, Achmat Rashied Domingo

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RI – Robben Islands; CRI - Control sites Robben Island; PRI – Pipeline Sites Robben Island

Extant benthic Foraminifera from two bays along the South West coast of South Africa, with a comment about their use as indicators of pollution.

Abstract

Studies of foraminifera in South Africa have largely focused on their use in geology, and work on extant taxa is missing. This project goes some way to redressing the imbalance in emphasis and it is aimed at describing the benthic foraminifera from two bays along the SW coast of South Africa and determining the environmental factors that might be associated with structuring communities: an attempt is made to assess whether foraminifera can be used as indicators in the environmental assessment in the region.

Six sediment cores were collected from a number of control and polluted sites around Robben Island (Table Bay) and in St Helena Bay, and all living foraminifera in the upper 5 cm were identified and counted. Information on the size structure, carbon and nitrogen content and trace metal concentrations of the sediments were also collected, as was information on the size structure of the communities, and the trace-metal content of, and abnormalities to, tests. Relationships between variables were investigated using a suite of univariate and multivariate, parametric and non-parametric statistical methods.

Sediments were coarser around Robben Island than in St Helena Bay, which reflects the more sheltered aspect of the latter as well as the greater input of organic contaminants, and is supported by the higher levels of nitrogen and greater concentrations of trace metals in the latter than former. The sediment environment at control and pipeline sites around Robben Island did not differ significantly from each other, but in St Helena Bay, the control sites had a significantly smaller mean grain than the pipeline sites. The percentage nitrogen in St Helena Bay samples was higher than that of Robben Island, which may be a reflection of higher production and increased eutrophication within the area. The two locations showed obvious differences in the condition of the sediments: those at Robben Island did not display signs of sediment pollution, whereas in St Helena Bay, most trace metals were high and some higher than SA SQG's and ERL levels.

A total of 38 morpho-species of foraminifera were identified from 120 samples and 20 stations at both sites. The number of species is much the same as identified in other studies of nearshore and marginal marine environments, though studies in the deep-sea have yielded a higher species richness. Communities around St Helena Bay were of a lower diversity but a higher abundance than Robben Island, previously identified as an indication of a polluted environment. Assemblages of Robben Island were dominated by *Elphidium articulatum* (not *Ammonia parkinsoniana*): larger numbers of miliolids and fewer bolivinids were observed by comparison with St Helena Bay. The absence of miliolids is often used as an indication that an environment may be polluted as they generally do not display a wide tolerance range. A dominance of bolivinids, and opportunistic taxa (like *Elphidium* and *Ammonia)* is more indicative of a polluted environment.

The live and dead assemblages were characterized by the same species, an indication that these areas are not depositional environments. The abundance of specimens in each species accounted for the low correlations between dead and live assemblages, indicating an accumulation of dead tests on the seafloor. The differences were more marked in St Helena Bay than Robben Island, reflecting the differences in the currents and residence time of the two bays.

There was a high abundance of small foraminifera in both locations despite the generally large grain size. The small foraminifera may be indicative of pollution, but may also reflect the cold temperate waters present year-round, which generally support smaller foraminifera.

The results of the multivariate analyses suggest that most of the variation in the composition of the samples was of an intra-sample nature, illustrating large scale patchiness in foraminiferal distribution. There were, however, definite differences between communities around Robben Island and in St Helena Bay, and least variation was found between the control and pipeline sites, and between the stations of each site. When the trace metal concentrations and the percentage nitrogen increased, the richness, diversity and abundance of foraminifera tended to decrease. Sediment grain size positively affected abundance but negatively affected diversity and richness. In both areas mean grain size did not, however, appear to play a very large role in influencing diversity. Cadmium, copper, chromium, the percentage nitrogen and the mean grain size were identified as the most important variables influencing the community structure by the BIOENV BEST routine in PRIMER. The trace metals and percentage nitrogen only had negative

effects on the diversity and abundance as well as on the abundance of the dominant genera, whereas the mean grain size had variable effects.

Few foraminifera displayed morphological abnormalities and there was no clear correlation between the trace metal concentrations of the sediments and tests. Because foraminifera in a nearshore environment are exposed to wave action and stronger tides than those in deeper environments, it would be difficult in this case to use morphological abnormalities as indicative of pollution. The trace metal content of the tests of foraminifera is difficult to interpret as no baseline has been established against which the present values could be compared.

Although foraminifera have been used elsewhere to identify polluted environments, they display a few drawbacks as a monitoring tool. Examination of field collected samples is time-consuming, given that one needs a large number of replicates to ensure statistical rigour. These replicates are essential because foraminifera display large-scale variability and patchiness even between cores at the same station, so differences may merely be a result of micro-scale variability within the benthos and not as a result of pollutants. Identification of foraminifera is often difficult using light microscopy because of their size. However, once an assemblage is identified as a possible bio – indicator, these organisms could be a useful adjunct to other analyses.

The use of foraminifera as bio-indicators is still being explored to a large degree globally and is totally new in South Africa. Many of the findings of this study were similar to those of other studies but differed in that morphological abnormalities did not appear to be a reliable method of identifying polluted environments and the foraminifera did not appear to take up the trace metals from the sediments in as high concentrations as expected. This study would, therefore, contribute largely towards a better understanding of the ecology of foraminifera and how they react towards environmental conditions which would not only be useful in a South African setting but also globally.

Key Words: Foraminifera, trace metals, sediment grain size, percentage nitrogen, percentage carbon, taphonomy, morphological abnormalities, elemental analysis, South Africa, St Helena Bay, Robben Island.

Chapter 1
General Introduction

1.1 The South African Marine Environment

South Africa is bathed by a cold, north-flowing current (the Benguela Current) on the west coast and a warmer, southward flowing current on the east and south coasts (the Agulhas Current), these currents provide very different conditions and therefore support different marine organisms (Branch & Branch, 1995).

The surface waters of the Agulhas Current are nutrient poor, and most east coast areas are considered less productive than west coast areas at the same latitude (Bailey & Rogers, 1997). The origin of water in the Benguela Current is from South Atlantic Central Water, with a small contribution from the Agulhas Current (Nelson & Hutchings, 1983). Surface currents in the Benguela are primarily wind-driven, and although the net movement of water is equatorward there is evidence that subsurface waters move southward over the shelf and poleward west of the shelf break (Shannon, 1986). The coldest waters in the Benguela are found close inshore due to upwelling (Van Ieperen, 1971).

On the west coast, the outer-shelf sediments are dominated by Holocene planktonic foraminiferal ooze, the middle shelf sediments consist of glauconitic sands, and the inner shelf comprises of terrigenous muds and sands, which are organic-rich (Bailey & Rogers, 1997). The Benguela ecosystem has been exploited for many centuries with little understanding of the oceanographic processes, however when the South African demersal fishing industry developed at the beginning of the twentieth century, studies of the system were started by Dr J. D. F. Gilchrist (1895/1896) (Shannon & Pillar, 1986).

The west coast of South Africa is characterised by being an upwelling area, from Cape Point (34° 21' 24" S; 18° 29' 51" E) in South Africa to Cape Frio (18° 26' 60" S; 12° 1' 0" E) in the north of Namibia (Nelson & Hutchings, 1983). Two outcrops on the west coast at Cape Peninsula and Cape Columbine have canyons, which alter the velocity of the Benguela flow as well as enhancing upwelling (Nelson & Hutchings, 1983). These are areas of intense upwelling, high nutrient recycling and high primary production (Nelson & Hutchings, 1983). The water off Cape Town may be influenced by tongues of the Agulhas Current, but is mainly influenced by the Benguela Current (Van Ieperen, 1971). Two shallow regions near St Helena Bay and Walvis

Bay (Namibia), have less equatorward windstress and have been reported as being ecologically important within the system (Shannon, 1986).

Upwelling is caused by the prevailing south-easterly winds (mainly in summer) that blow parallel to the coast and the Coriolis Effect, which effectively pushes surface water off-shore and causes subsurface waters to well up (Hart & Currie, 1960). These nutrient rich bottom waters are what sustain high phytoplankton biomass and support an abundance of marine life, including a large-scale commercial fisheries (Van Ieperen, 1971). One of the consequences of the nutrient-rich water is phytoplankton blooms, which may on occasion be toxic and lead to large scale mortalities within the system (Hart & Currie, 1960).

Mixing and advection in the top 20 m of the water column assist in preventing upwelled water from sinking, and keeps nutrient-rich upwelled water in the euphotic zone for prolonged periods of time (Brink, 1987). Although the upwelling season is mostly in summer in South Africa, in winter, when westerly winds tend to dominate, winter storms and reduced insolation can result in a deep, well-mixed surface layer (Shannon & Pillar, 1986). The phytoplankton biomass and hence primary production is found to be higher but more variable in summer than in winter, as a result of upwelling and the response of phytoplankton to the increase in nutrients in surface layers (Shannon & Pillar, 1986).

Coastal waters in eastern boundary currents, such as the Benguela, are also thought to support high productivity due to the settling of particulate carbon and nutrients in the sediment, which is generally higher on the leeward side of upwelling centres (Bailey, 1987). The nutrient content of the St Helena Bay region was found to exceed that of other upwelling source water by 100 percent (Bailey, 1987). It was found that there is a northward reduction in the seasonality of upwelling, which was reflected in an increase in the reducing nature of the organic-rich sediments found between St Helena Bay and Walvis Bay (Bailey & Rogers, 1997).

Net plankton productivity in the Benguela Current appears to be controlled by nitrate concentration and regenerated nitrogen (Shannon & Pillar, 1986). Although nutrient cyling can be important in the system, it appears to be of more importance in the northern Benguela and off the shelf at St Helena Bay than off the Cape Peninsula (Shannon, 1986). Following a bloom, productivity drops due to nutrient-depletion and self-shading in surface waters as well as losses as a result of zooplankton grazing, death and sinking (Branch *et al.,* 1987). Mass mortality of

phytoplankton after a bloom and sinking provides detritus and increased food availability to benthic organisms causing them to increase in abundance.

In a review on the impacts of human activities in the Benguela region, Griffiths *et al.* (2004) have described the present as post-industrial and have found that although there is improved resource management and stabilisation of catches, there appears to be an increasing impact on the system which is non-fishery related.

1.2 Marine pollution and sediment chemistry

The coastal marine environment is constantly subjected to disturbance and changes as a result of storms and strong winds, as well as the structure of the coastline. Disturbance in a coastal environment is an important factor contributing to community structure and spatial heterogeneity (Guichard & Steenweg, 2008). However, an increase in anthropogenic disturbance is placing large-scale stress on near shore environments. More than half of the world's population now lives within 200 km of the coast and that number is still increasing (De Souza *et al*., 2003 in Gao *et al*., 2008). With increasing urbanisation and settlement on the coast, more domestic waste is being generated and as a result more outfalls have been built. In South Africa, two coastal cities, Cape Town and Port Elizabeth grew by 22 % and 24 % respectively in the 1990s (UNEP, 2003). Increased urbanisation has led to increased industrial effluent, stormwater run-off, sewerage, wind-blown litter, suspended sediments and agro-chemicals entering the sea (UNEP, 2003).

The ocean has for centuries been regarded as vast enough to accommodate waste without major changes and to have the ability to dilute toxic waste or carry it away from the coastline with its currents (O' Neill, 1993). However, it is becoming increasingly apparent that the increase in the rate of pollutant input is having an effect on coastal areas. Pollutants may be regarded as any introduced substance which may harm a resource, and includes substances that are usually present in the environment but have exceeded natural levels due to anthropogenic input (O'Neill, 1993).

Excessive nutrient loading can accelerate the eutrophication process and cause an imbalance in the products of this process. Eutrophication is the production of organic matter that forms the basis of the food web and is a natural process in many aquatic systems (Livingston, 2001). Nitrogen and phosphorous are regarded as limiting elements in biological production;

human activity has increased global nitrogen fluxes and has been found to cause a significant rise in the primary productivity of the coastal zone (Libes, 1992). An increase in the concentration of these otherwise limiting nutrients causes an increase in the growth of coastal phytoplankton, which causes an increase in the levels of organic carbon that in turn can be deposited on the sea floor (Mojtahid *et al*., 2009). This increase in the supply of organic material to sediments leads to an increase in the abundance of detritus-dependent benthic organisms, which rapidly remove oxygen and eventually produce hypoxic/anoxic sediments. This anoxia usually results in the decrease in the diversity of benthic organisms (Mojtahid *et al.,* 2009), as well as mortality of benthic organisms.

Increased anthropogenic inputs have been found to affect the trace metal content of the marine environment. Trace metals are present in marine sediments in the form of biogenic detritus (concentrated in the marine organism), clay minerals (in crystal lattice) and hydrogenous precipitates (polymetallic oxyhydroxides) (Libes, 1992). Essential trace elements are necessary for the growth of phytoplankton and for the catalysis of biological reactions (Libes, 1992). In an environment where organic carbon loading is very high, trace metals bind with sulphides and will only remobilize when resuspended during storms or dredging (Monteiro *et al.*, 1999). Disturbance remobilizes the contaminants and can cause localized effects and eventually form precipitates of hydroxides which return the metals to the sediments (Henry *et al*., 1989).

Organic materials form organometal complexes when binding to trace metals and these are regarded as hazardous to aquatic life when they occur in very high concentrations (Abel, 1996). Organisms tend to accumulate these metals within their body tissues which could be a toxic hazard to the organism itself and to organisms higher up in the food web due to bioaccumulation (Abel, 1996). Toxic heavy metals that appear to be most affected by human activity are As, Cd, Cu, Cr, Hg, Pb, Ni, Sb, Se, V and Zn, which have high enrichment factors (degree to which a metal is concentrated in the organism) and slow clearance rates (rate of degradation or excretion by the organism) (Libes, 1992).

It is apparent that anthropogenic inputs in the marine environment affect production by disturbing the balance of carbon, nitrogen, oxygen and trace metals which in turn determines the types of organisms present. It is therefore necessary to monitor the concentrations of these substances, in any area which could possibly be affected, on a regular basis in order to determine their possible effects.

1.3 Marine pollution in South Africa

About 67 ocean outfalls are located along the South African coast and these discharge approximately 1.3 million m^3/ day of sewage and industrial effluent into the sea (National State of the Environment Report – South Africa, 2008). Most of these discharge into deeper waters, but 27 of the older pipelines discharge above the high water mark, 23 of these being in the Western Cape (National State of the Environment Report – South Africa, 2008). All municipal waste water discharges to the offshore marine environment receive preliminary treatment with coarse and fine screens (Taljaard *et al.,* 2006). However, wastewater outlets from industries are solely controlled by the industry and there is no means of controlling the quality of the wastewater during the discharge process (Taljaard *et al.,* 2006). In an attempt to control the discharge process to the marine environment, the Department of Water Affairs and Forestry drew up an operational policy for the disposal of land-derived water containing waste with guidelines for both industries and municipalities (Taljaard *et al.,* 2006).

The Council for Scientific and Industrial Research (CSIR) as well as the Department of Environmental Affairs (Oceans and Coasts) (formerly Sea Fisheries Research Institute and Marine and Coastal Management), have been responsible for many marine-monitoring programs in South Africa. In South Africa, offshore marine outfalls are monitored at their point of discharge and in the environment they impact, whereas wastewater discharges into the surf zone and estuaries are only monitored at their source, and environmental monitoring is normally non-existent (Taljaard *et al.,* 2006). The CSIR in Durban has been conducting annual surveys on both domestic and industrial outfalls along the east coast of South Africa, and the surveys include chemical analysis of water and sediments, physical factors and biological studies of both meiofauna and macrofauna providing a complete study of the effects of the outfalls on the concentration of chemicals in sediments as well as the effects on marine organisms.

Most surveys on the west coast of South Africa have not included the shallow areas where outfalls occur. The CSIR in Stellenbosch has however conducted research on the Hout Bay, Camps Bay and Green Point sewage outfalls in 1999 and again in 2003. These surveys examined a variety of physical and chemical factors but excluded a biological component. The outfalls from the fish factories in St Helena Bay and Saldanha Bay have been monitored from time to time by the CSIR, however, these assessments and reports are not available for public perusal.

Few published biological assessments have been done in polluted environments in South Africa. Biological assessments that have been conducted mostly examine macrofauna. Globally, macrobenthic invertebrates are better understood and documented than those of smaller invertebrates and protozoans in terms of their life histories, responses to natural and anthropogenic conditions and changes, and trophic strategies (Burd *et al*., 2008). In addition, many commercially important invertebrate species live within the sediments (e.g., clams) or on the surface of the sediments or hard substrata (e.g., crabs) (Burd *et al*., 2008). The benthic environment, where most pollutants settle is inhabited by a vast number and variety of meiofauna, and these meiofauna react quickly to changes in their environment and can provide a good indication of the conditions therein. Examination of these sediments for meiofauna is labour intensive and time consuming and the need for easy biological assessment of these sediments is required.

1.4 Foraminifera

Foraminifera belong to the Kingdom Protista and are currently recognised as their own phylum Foraminifera, though they were previously classified as order Foraminiferida Eichwald, 1830 within the phylum Protozoa (Loeblich & Tappan, 1987). These unicellular organisms are characterised by the presence of a test, which surrounds the cytoplasm (Loeblich & Tappan, 1987). Their tests can be composed of chitin, silica or calcium carbonate, or they may be agglutinated, using detrital material to form a test (Cushman, 1959). The walls of some calcareous types are perforated for the extension of pseudopodia while others are smooth and imperforate (Albani *et al*., 2001). The nature of the test is often indicative of the environment in which the organism is found. For example, agglutinated species sometimes indicate an area where little or no carbonate is available, where salinities are low, or where the water is very cold (Scott *et al*., 2001). The formation of foraminiferal tests differ from that of other testate protists, like the phylum Rhizopoda or Pyrrophyta, in that it is constructed by incremental additions of the chambers, each new chamber covers the old external aperture, ensuring the continuity of the cytoplasm and contact with the external environment (Loeblich & Tappan, 1987).

Foraminifera are also characterized by an alternation of generations, that is, an alternation of an asexual and sexual reproductive mode, although it appears that the asexual mode normally outnumbers the sexual mode (Boltovskoy & Wright, 1976; Gooday, 1992). The morphology of

the different generations differ in that those produced sexually have a small first chamber and a large test (microspheric form) and the asexual form is characterised by a large first chamber and a small test (megalospheric form) (Scott *et al.*, 2001). When there is a dominance of sexual forms in some environments it is thought to be a response to harsher conditions (Boltovskoy & Wright, 1976).

In addition to being planktonic, foraminifera can form part of the meiofauna (63 μm – 100 μm) and are generally small in size, although large Tertiary (up to 5 cm) and Cretaceous (up to 10 cm) species have been reported (Boltovskoy & Wright, 1976). In temperate areas, such as the west coast of South Africa, a high abundance of small foraminifera are encountered (< 250 μm), with very few foraminifera being larger than 500 μm (Personal Observation).

Foraminifera are primarily marine and hypersaline organisms, although some freshwater forms have been reported (Phleger, 1973). Species in hypersaline environments exhibit less morphological variety than those encountered in a normal marine (35 ‰) environment (Murray, 1991). Foraminifera are ubiquitous in their distribution and will be found in all marine habitats from the plankton (Cifelli & Smith, 1970; Bé *et al*., 1971; Cifelli, 1982; Morard, *et al*., 2009) to the benthos where they may be living attached to hard substrates or algae (Hedley *et al*., 1967; Atkinson, 1969, Boltovskoy & Wright, 1976; Toefy *et a*l, 2005) as well as in soft sediments (Murray, 1991).

Most foraminifera are fairly specific in their depth ranges, being either neritic or oceanic (Murray, 1991). They also occupy specific temperature ranges, generally being cold, temperate or tropical in habitat (Halfar & Ingle, 2003). Foraminiferal distribution has been found to be influenced by a number of abiotic factors, such as salinity and pH, as well as varying with the organic matter content and grain size of the sediment (Duleba & Debenay, 2003). Some authors have found that fine, silty sand yields a high abundance of species and individuals while coarse sand or clay supports lower numbers, and this is thought to be a result of the higher organic matter and therefore more food in finer sediments (Samir & El- Din, 2001). However, other authors have found that coarse sediments provide more favourable habitats for benthic foraminifera, especially those which attach to the substrate (du Châtelet *et al*., 2009). Benthic species composition has been linked to sediment grain size in many studies, however, this factor has been found to be of variable importance in determining individual species abundance patterns and hence in determining the distribution of benthic assemblages (Bremner *et al.,* 2006).

1.5 Foraminiferal pollution studies

Their characteristic test generally preserves well in sediments and this has made foraminifera useful for mapping paleontological records and environmental changes. Foraminifera are useful because they provide an extensive geological record which dates from the Cambrian to the Recent (Buzas & Culver, 1991). The fact that extinct foraminifera have specific geological distribution ranges makes them suitable for aging sediments and therefore they can be of use to mining and geological explorations (Cushman, 1959). When foraminifera die, their tests accumulate on the sea floor and can provide a record of environmental conditions in both the ocean and the sediment at the time of their death (Phleger, 1973). This characteristic can provide "*a priori*" information of assemblages, in environmental studies where no baseline data are available (Yanko *et al.*, 1994).

Globally, foraminiferal studies have concentrated on fossilized material (Boltovskoy & Wright, 1976), although ecological studies have increased since the 1950s (Murray, 1991). With an increase in the number of ecological studies, authors have also realised their potential use in determining anthropogenic effects on the environment. Studies related to their use as indicators of anthropogenic effects were started in the late 1950s and early 1960s by Zalesny (1959), Resig (1960) and Watkins (1961).

Benthic foraminifera are useful as indicators of pollution because they live in, and on, sediments; they can be abundant even in small sample volumes and many species have very specific ecological requirements (Yanko *et al.*, 1994). Foraminifera generally have short life-cycles (one month to a year) and therefore they respond quickly to their environment, which makes them useful as bio-indicators of short-term and long-term changes in the marine environment on both local and global scales (Frontalini *et al*., 2009). Yanko *et al.* (1994) used foraminifers to study the effects of various pollution sources in the Mediterranean Sea along the coast of Israel. These included domestic sewerage, a coal-fired power station and heavy metal contamination. The results of their study showed that foraminifera were sensitive *in situ* monitors of coastal pollution. Sites with domestic sewage displayed high population densities and diversity of large foraminifera which were mostly agglutinated, while those exposed to coal pollution had the lowest population densities and diversity, and the sites where heavy metal contamination took place had foraminifera with smaller tests and these tests displayed abnormal

morphology (Yanko *et al*., 1994). Culver & Buzas (1995) studied the anthropogenic effects as well as the effects of global warming on shallow marine benthic foraminifera in geological history around North and Central America. The authors concluded that while foraminifera are widespread and exhibit rapid dispersal, rare and geographically restricted foraminifera are most at risk due to coastal development. The loss of habitat during geological time was attributed by these authors as the major cause of foraminiferal extinction.

Foraminifera have been found to be sensitive to a variety of chemicals being pumped into the sea. Lead has been found to affect shell composition in foraminifera as well as molluscs and other shelled invertebrates; shells were found to contain higher lead concentrations but lower calcium concentrations (Almeida *et al.* 1998). Tri-*n*-Butyltin (TBT) mesocosm experiments showed that foraminifera display greater tolerance to low levels of TBT than other taxa (nematodes, ostracods and small molluscs), but at high levels (2.00 nmol) they decreased in abundance but did not show any significant decrease in diversity (Gustafsson *et al.,* 2000). In sites with methane cold-seeps, the species composition of foraminifera were very similar to those of organic rich environments, and they appeared to be attracted to the extra food and had a high range of oxygen and carbon values in their shells (Rathburn *et al.*, 2000).

Very high trace metal concentrations have only negative impacts, unlike the varying impacts of high organic carbon. It has been observed that as the trace metal concentration of sediments increases and other chemicals are discharged, populations of foraminifera may decrease to such an extent that some areas may become completely devoid of living specimens (Scott *et al*., 2001; Ferraro *et al*., 2006; Frontalini *et al*., 2009).

Foraminifera are also sensitive to oxygen concentrations as well as to the levels of dissolved organic matter. Moodley *et al.* (1998) found fewer soft-shelled and more hard-shelled foraminifera in anoxic environments, and these authors concluded that some foraminifera can be facultative anaerobes. In dysoxic and anoxic environments, some foraminifera have been found to sequester chloroplasts from algae, which is thought to allow the host to be provided with oxygen (Bernhard & Bowser, 1999). Other studies of anoxic and hypoxic environments, generally found lower diversity and abundance and the strong dominance of certain species many of them deep infaunal species (Gustaffson & Nordberg, 2000; den Dulk *et al.,* 2000; Fernandez-Leborans & Herrero, 2000; Alve, 2003).

Typical anaerobic environments exhibit low foraminiferal species diversity, high dominance and large standing stocks of those taxa tolerant to this stress (Frontalini *et al*., 2009). The effect of organic matter on the diversity of foraminifera appears to be complex, as some authors report a decrease in abundance and diversity with increasing organic matter (Schafer *et al.,* 1995), while others report an increase in abundance and diversity (du Châtelet *et al*., 2009): some authors have reported no correlation (Alve, 1991). Anthropogenically sourced organic matter appears from most studies to produce above-background foraminiferal population densities (Bernhard, 1986; Yanko *et al.,* 1994; Scott *et al.*, 2001). Mojtahid *et al*. (2009) are of the opinion that when organic matter is high and oxygen levels are still tolerable, a number of opportunistic species will dominate, these being both epifaunal and mobile infaunal species.

Many authors have shown that foraminifera exposed to environmental stress may display large-scale malformations of the test (Toler & Hallock, 1998; Stouff *et al.,* 1999). However, Geslin *et al.* (2002) found a higher percentage of abnormal tests in non-polluted than polluted environments and cautioned against the use of using abnormal morphology as a pollution indicator. Test deformations and stunted growth have been primarily reported in areas contaminated by high trace metal concentrations, domestic sewage and various chemicals including liquid hydrocarbons (Culver & Buzas, 1995; Frontalini *et al*., 2009). Test deformations can range from changes in chamber shape or growth patterns; double apertures, wrong coiling, Siamese twins, high spires or poor development (Yanko *et al.,* 1994; Frontalini *et al*., 2009). Siamese twins are thought to arise from early fusion of juveniles or attachment of juveniles to the parental test after schizogony (Stouff *et al.,* 1999). Samir & El-Din (2001) suggest that trace metals affect the calcium uptake of foraminifera which weakens tests leading to test deformation. More recently the possibility of using the trace element content of foraminiferal tests as tracers of environmental quality has also been explored (Samir & El-Din, 2001; Frontalini *et al*., 2009).

When environmental conditions are measured and species are identified as being commonly found in those conditions, it can be concluded that the presence of these species or groups of species are indicative of certain environmental conditions. These species are often then used to identify biofacies, that is, species which commonly occur together in certain environmental conditions (Pielou, 1979). By identifying, describing and documenting these biofacies, one can immediately tell if an environment is polluted by the presence of that

assemblage or species. Opportunists are species that are most resistant to pollutants, and tend to dominate assemblages in polluted environments (Culver & Buzas, 1995). Foraminiferal species which tend to dominate stressed environments are often elongated, flattened and small. This may be due to sexual maturity being reached earlier, or due to dwarfism in adverse conditions (Bernhard, 1986). *Ammonia tepida* and species of *Bolivina* have been widely reported as indicative of environmental stress and have been found to have a wide tolerance range of chemical, thermal and oxygen conditions (Frontalini *et al*., 2009). Agglutinated foraminifera have also been cited as an important indicator of pollution in cold water sites, as it is thought that the ability of foraminifera to take up calcium for test formation is affected by pollutants, leading to fewer calcareous forms (Yanko *et al*., 1994). Although differences in foraminiferal assemblages in polluted environments have been widely reported, Gooday & Lambshead (1989) cautioned against the use of foraminifera without taking patchiness into account, as spatial heterogeneity may be due to patchiness in foraminiferal distribution and not to differences in environmental conditions. Patchiness occurs as a result of clumping and biological interactions like competition and reproduction which would affect the distribution of foraminifera in the micro-environment (Murray *et al*., 1991). Scott *et al.* (2001), however, are of the opinion that the more polluted an environment, the less the spatial variability as opportunists would tend to take over and the less complex and patchy the assemblage would become.

1.6 Foraminiferal studies in South Africa

Studies of foraminifera in South Africa have been mostly of a palaeontological nature, and have been conducted as a result of geological surveys and mineralogical exploration (Appendix 1.1). The earliest of these studies were undertaken by Chapman (1904, 1907, 1916, 1923, 1924, and 1930) who provided lists and some illustrations of species found. After this period studies on foraminifera stopped until the 1950s (Biesiot, 1957; Parr, 1958; Albani, 1965; Lambert & Scheibnerova, 1974). The Joint Geological Survey and the University of Cape Town Marine Geoscience Unit conducted a number of geological surveys on the RV *Thomas B. Davie* in the 1970s and 1980s, which reported some foraminifera on the west coast of South Africa(Martin, 1974; Salmon, 1979a, 1979b, 1981). During mineralogical studies conducted by the then De Beers Marine (PTY) Ltd, a number of papers on foraminfera were published

(McMillan, 1987, 1990, 1993; Dale & McMillan, 1998). More recently a study on extant foraminifera was conducted by Toefy *et al.* (2003).

Many of the above studies provided only lists of foraminifera and information on their distribution but did not attempt to relate distribution to any environmental factors. McMillan (1990) and Toefy *et al*. (2005) provided taxonomic descriptions of some foraminifera sampled around South Africa. Toefy *et al.* (2003) have conducted the only ecological study on extant foraminifera around South Africa which related the community structure to the level of exposure in an intertidal environment and to their algal habitat. Foraminifera were found to be more abundant on exposed than on sheltered rocky shores. Foraminifera studied have been mostly off-shore and from deep sea environments. Studies of foraminifera in coastal environments and as potential environmental indicators have been neglected.

1.7 Study Site - St Helena Bay

St Helena Bay is situated on the west coast of South Africa (32º 40' S; 17º 58' E) approximately 160 km north of the Cape Peninsula (Fig. 1.1). Just south of St Helena Bay is a major upwelling centre at Cape Columbine, and nutrients are transported off-shore near St Helena Bay via a cyclonic gyre (Walker & Pitcher, 1991). The southern Benguela upwelling system appears to exert considerable control on the biogeochemical characteristics of St Helena Bay (Monteiro & Roychoudhury, 2005). The nutrient-rich waters off Cape Columbine support a large pelagic fishery, and the close proximity of St Helena Bay to both the fishing grounds and the city of Cape Town led to the establishment of fish processing plants in the 1940s (Shannon, *et al.,* 1983). St Helena Bay is a semi-closed system, an anti-cyclonic gyre within the bay (Fig. 1.1) has been found to trap water for up to 25 days compared to a retention time of 3 – 5 days outside the bay (Walker & Pitcher, 1991). Particulate matter deposited in St Helena Bay, therefore, tends to settle in the area. Sediments in the bay are primarily brought in either as atmospheric input or carried by the Berg River or even from the Orange River (Monteiro & Roychoudhury, 2005). The Berg River and its tributaries flow through areas dominated by agriculture, wineries, canneries and textile mills (Monteiro & Roychoudhury, 2005).

Historically, two types of effluent were released by the fish processing plants. The first type was produced during off-loading, where the hold of the ship was flooded with sea water to float off the cargo and the water was then pumped directly into the sea. This is known as the wet

system of off-loading (Newman & Pollock, 1973). Secondly "blood water" from factory effluent was pumped into the sea and this contained all the biological material from processing, including guts, scales and bones (Newman & Pollock, 1973). Large amounts of organic matter were released into the bay, especially when off-loading large amounts of catch after long periods at sea (Newman & Pollock, 1973).

An accumulation of organic matter in St Helena Bay was thought to result in the high mortality of rock lobster (*Jasus lalandii)* and other inshore animals in 1972 (Newman & Pollock, 1973). As a result, the system of wet off-loading was replaced by dry off-loading (vacuum removal of fish from boats) in 1974/75. A small amount of water is still used in this method (Shannon *et al*., 1983).

In the 1950s, the Sea Fisheries Research Institute (SFRI) started a programme of research called the Pilchard Research Programme in St Helena Bay and this focussed on the physical and chemical properties of water, seasonal trends and annual anomalies of water in the upper 50 m (Clowes, 1954; Buys, 1957). These data were used to establish an environmental baseline for management purposes. Unfortunately, the research did not include the region in the bay where the fish factories and harbour are found. Studies in this region have continued, and are still being done at present (Bailey, 1983; Shannon *et al*., 1983; Bailey & Chapman, 1985; Walker & Pitcher, 1991; Guastella, 1992), although they are still only conducted in deeper coastal waters (≥ 30 m depth), which are accessible to ship-based research. Moldan (1983) examined the effects of a fish factory on benthic macrofauna in St Helena Bay but this study was presented in the form of a short note and no details of organisms were given. No study has examined the benthic meiofauna and more particularly foraminifera, in conjunction with chemical properties of the sediment.

The factory where the outfall was studied processes pilchard, anchovy and lobster into canned fish, fishmeal, fish oil, and processed and live lobster. It processes approximately 150 000 tons of fish per year and processing takes place for most of the year, when fish is available: usually no production takes place for about 3 weeks in January, and during winter the processing is slow as fish is scarce (Fish factory manager, pers. comm.). The factory pumps sea-water in, for the processing of fish and waste water is pumped out into the surf zone approximately 30 m off shore (Fish factory manager, pers. comm.). The estimated flow from the fish factory is 18 000 m^3 / day (DWAF, 2004).

1.8 Study Site - Robben Island

Robben Island (33º 48' S, 18º 22' E) is situated about 12 km from Cape Town in Table Bay (Fig. 1.2). The deepest point of the bay is 27 m and the substrate is comprised mostly of sand with a few rocky patches (Van Ieperen, 1971). The bay is open to the sea from the S.E. to the N.W. and tidal currents are weak (average of 20 cm/ sec), and are weakest in winter (Van Ieperen, 1971). Because of the high wind velocities and the shallowness of the bay, surface currents are thought to be wind-driven (Van Ieperen, 1971). Winds are S.S.E. for most of the year and in winter mostly northerly, however wind direction can vary greatly (Jury & Bain, 1989). Water enters the bay between Robben Island and Green Point, while in the bay water movement is mostly northward. The bathymetry around Robben Island is shallow and shows a high percentage of negligible current velocities, varying with wind speeds (Van Ieperen, 1971). There is some evidence of localised upwelling within Table Bay during summer, which is caused by the prevailing winds and this causes sea temperatures to be highly variable (Jury & Bain, 1989). The movement of upwelled water appears to be concentrated in a cool band 3 km offshore, related to the southerly wind wake of Table Mountain, which suppresses offshore transport and upwelling along a N-S line across Robben Island (Jury & Bain, 1989). The residence time of water varies from 15 to 190 hours, therefore, the flushing potential is variable (Van Ieperen, 1971). The path of pollutants will be a function of local wind direction and strength and when upwelling ceases in winter, water may become stagnant (< 5 cm/sec) (Van Ieperen, 1971). The area has some of the highest wave energy along the South African coastline, driven by the south-westerly swells. Wind and waves appear to be the most important agents in moving substances, while the tidal currents, which are highly variable and sometimes even negligible, are of lesser importance (Jury & Bain, 1989).

Robben Island has been historically isolated for over 400 yrs, being the site of a hospital for lepers and the mentally ill in the 1800s, a defence training camp in the Second World War, and a maximum security prison (for political prisoners) and is famous as it held former president Nelson Mandela for eighteen years (www.RobbenIsland.org.). The island was opened as a museum in 1997, after South Africa was established as a democracy in 1994, and as a result of its significant history it has become a major tourist attraction. Thousands of tourists visit the island each year which has placed increased pressure on its sewerage system.

A marine outfall to the sea was built in an attempt to alleviate this problem in 2002. The pipeline is approximately 400 m long and is situated on the eastern side of the island. The Robben Island pipeline discharges 550 m^3 / day at a depth of 8 m (DWAF, 2004).

The pipeline was designed to yield a 50 x dilution in accordance with the beneficial use and health requirements for this area (WAMTechnology & Rossouw, 1999). The design was based on standard jet dilution principles using historical environmental data (WAMTechnology & Rossouw, 1999). Two dye tests were conducted on the Robben Island pipeline in 2001 to test the dilution effects of the pipeline (Ove Arup Consulting Engineers, 2001). The results of both studies indicated that the direction of the plume differed according to the wind direction. The plume moved north easterly when the wind was south-westerly, and northwards along the coast with a slight onshore component when the wind was south-easterly (Ove Arup Consulting Engineers, 2001). In the first experiment a dilution of 50 x was achieved at 1200 m and in the second at 375 m from the diffuser (Ove Arup Consulting Engineers, 2001).

The building of the Robben Island marine outfall was completed in 2002 and began discharging in April of the same year. IOI-SA conducted a baseline study in 2001 and a subsequent study in 2002/2003 – after the pipeline had become operational (Prochazka, 2001; Prochazka, 2003). However, there is still some concern by the management of the island about the current sewerage system and the need for an upgrade (Cape Argus, Nov. 13 2004).

1.9 Aim of the study

The aim of this study was to

a. Examine environmental conditions in sediments, including sediment grain size analysis, trace metals and nitrogen and carbon concentrations.
b. Determine the foraminiferal assemblages present in these sediments and the factors that influence their distribution.

To this end two marine outfalls were studied, a fish factory outfall at St Helena Bay and a sewage outfall at Robben Island off Cape Town both situated on the west coast of South Africa. Samples collected were examined for the following:

1. Sediment grain size structure
2. Chemical analysis of the sediments for Carbon and Nitrogen content

3. Trace metal content of the sediments
4. Community structure of foraminiferal assemblages
5. Size structure and abundance of foraminifera
6. Trace metal content of the shells of some randomly selected foraminifera
7. Morphological abnormalities of foraminifera

The thesis has been divided into the following chapters:

Chapter 1: General Introduction (this chapter)

Chapter 2: An examination of the sediment structure and chemistry in two embayments along the south west coast of South Africa.

This chapter examines the sediments around the Robben Island outfall and the fish factory outfall of St Helena Bay. To this end, sediment grain size analysis was conducted, percentage carbon and percentage nitrogen and trace metal concentrations within the sediments were measured. Results of these measurements were reported and analysed and any correlations between the factors were discussed.

Chapter 3: The assemblage structure of foraminifera in two embayments along the south west coast of South Africa.

Chapter 4 examines the foraminiferal assemblage structure around the Robben Island pipeline and the fish factory outfall in St Helena Bay. Species richness, diversity and abundance of live foraminifera are examined per core, station, site and locality to determine patterns in distribution. Species and genera most important in determining this assemblage structure are also examined.

Chapter 4: A study linking foraminiferal communities to their environment in two embayments along the south west coast of South Africa.

Chapter 5 examines the influence of grain size, percentage carbon, percentage nitrogen and trace metals of the sediments on the foraminiferal assemblages of the two study sites. This chapter also attempts to identify foraminiferal taxa which could be used as proxies.

Chapter 5: General Conclusions

This chapter summarises the findings of the study, examines the use of foraminifera as proxies and examines the state of pollution studies in South Africa.

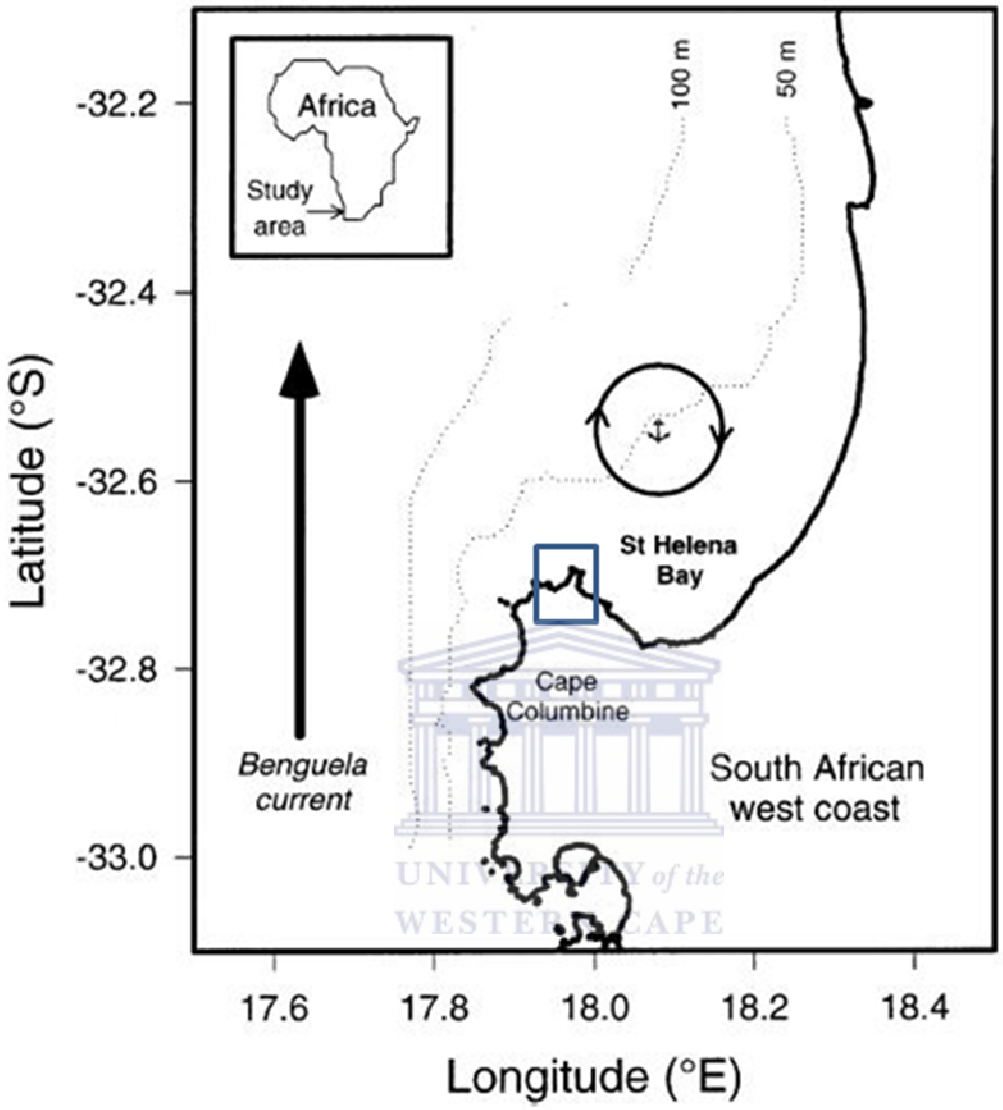


Figure 1.1: Map illustrating the position of St Helena Bay and the sampling area. The direction of the Benguela current relative to the bay and the anticylonic gyre are also illustrated (adapted from Touratier *et al*., 2003).

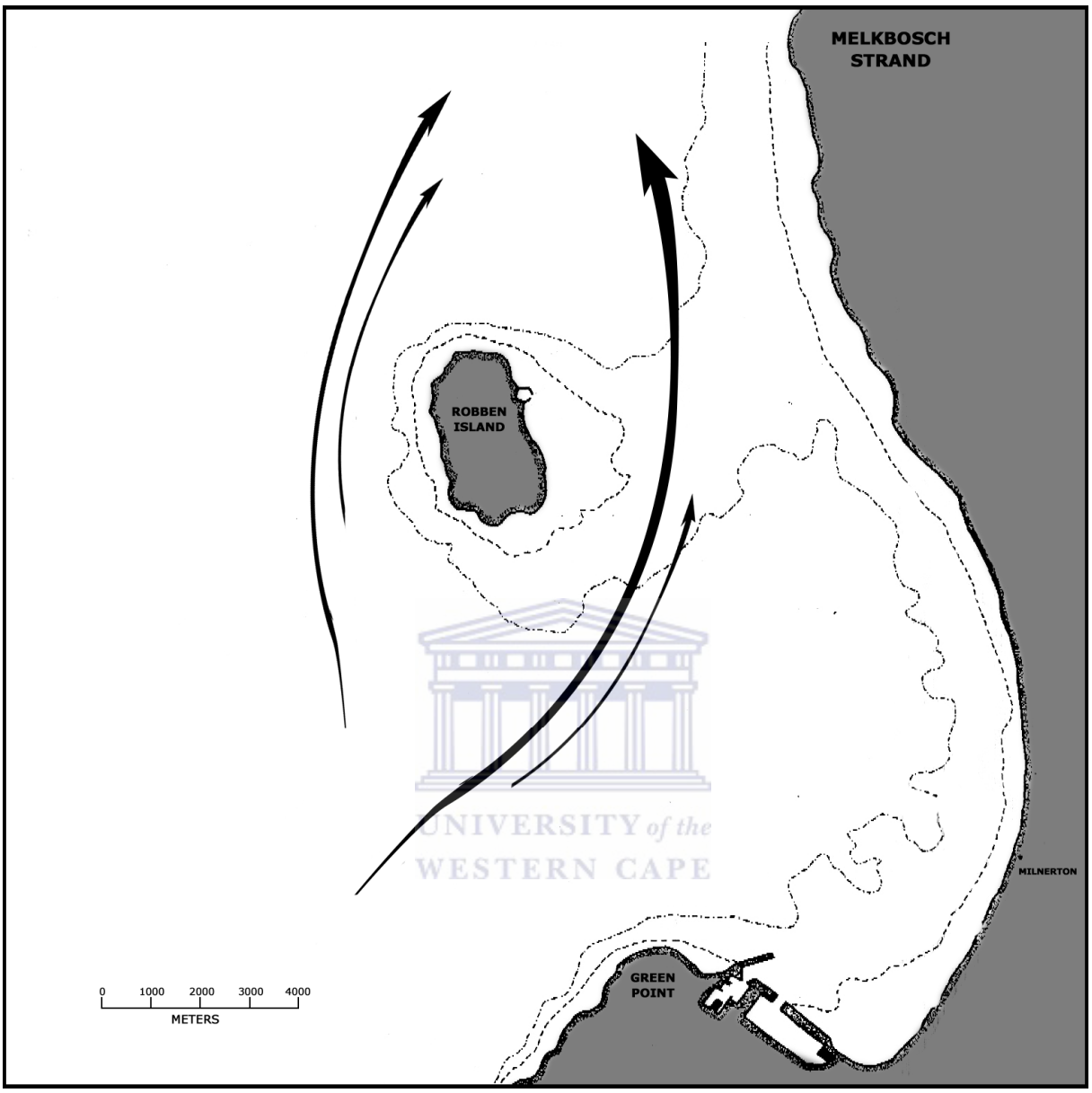


Figure 1.2: Map of Table Bay showing the position of Robben Island and the currents in the bay (adapted from Van Ieperen, 1971).

Chapter 2

An examination of the structure and chemistry of sediments in two study areas along the south west coast of South Africa

Abstract

The sediments around the Robben Island sewage pipeline and a fish factory pipeline in St Helena Bay were examined for sediment size structure, percentage total carbon and nitrogen and the trace metals Cd, Cu, Cr, Pb, Fe and Zn. Twelve stations were examined in St Helena Bay and eight at Robben Island: six cores per station were collected where possible. The mean sediment grain size from samples in both study areas was > 125 μm and little mud was present. The percentage total carbon was significantly higher at the Robben Island (7.17 %) stations compared to those of St Helena Bay (3.78 %) and samples from the control sites were significantly higher than those from the pipeline sites in both study areas in terms of the percentage total carbon, although some pipeline stations showed higher percentages (station SHD in St Helena Bay). The percentage nitrogen in the sediments was significantly higher at St Helena Bay (0.168 %) than Robben Island (0.1 %), especially at the pipeline sites, which could be a result of the loading from the fish factory. The percentage nitrogen was used as a proxy for the percentage organic carbon using data from a previous study in St Helena Bay. Except for the Pb concentrations in the sediments, all other measured trace metal concentrations were significantly higher in the St Helena Bay samples than the Robben Island samples. The trace metal concentrations were lower than accepted ERL (Effects Range Low) levels in both study areas. In St Helena Bay, Station SHD (pipeline site) had a concentration higher than ERL for Cd and Cu. No guidelines for acceptable Fe concentrations in sediments exist, however, the concentrations in the sample sediments from St Helena Bay (maximum 6000 μg / g) were more than double those from Robben Island (maximum 2800 μg / g). The samples from the pipeline sites in St Helena Bay had significantly higher trace metal concentrations than those of the control sites (except for Cr concentration), but no significant difference was found between the control and pipeline samples at

Robben Island. Most environmental variables were correlated with each other. Positive correlations occurred between all the trace metal concentrations and each other and the percentage nitrogen. The mean grain size had both positive (Cd, Cr, Cu, Fe, Zn & % N) and negative correlations (Pb) with the trace metal concentrations, but only the correlations with Cd, Cr, Zn and % N were significant. Samples from both sites displayed little evidence of organic or trace metal enrichment, although, St Helena Bay had higher trace metal and percentage nitrogen concentrations in the sediments than those from Robben Island. The reasons may be the length of time which the area has being exposed to pollutants, as well as the hydrodynamics of the bay which favour the retention of water along with any substances introduced into the bay.

2.1 Introduction

The sedimentary benthic marine habitat is shaped by a large number of environmental factors, the characteristics of the sediment itself being one of the most important factors. The shape and compositions of sediment grains provides the micro-habitat for small infaunal organisms (Fricke & Flemming, 1983). Coarse sediments are found in areas where currents are strong, whereas fine sediments are found in slow-moving currents which allow the settlement of fine particles (Castro & Huber, 2008). Coarse sediments generally have larger interstitial spaces, are more oxygenated and provide more micro-habitats for infaunal benthic organisms whereas muddy sediments have fewer interstitial spaces and are less oxygenated, but normally have a higher organic matter content (Fricke & Flemming, 1983). The ability of the sediment to trap organic matter is an important factor determining the ability of the environment to sustain organisms (Fricke & Flemming, 1983). The permeability of sediments also plays a large role in the adsorption or precipitation of trace metals out of porewater as sulphides, carbonates, phosphate phases or solid hydroxides, as more permeable sandy sediments allow transport through the interstitial space (Huettel *et al*., 1998). Sediments act as sinks and accumulate contaminants that are introduced into an aquatic system as a result of effluents or runoff from a variety of natural and anthropogenic activities (Mucha *et al*., 2003). Many contaminants are rapidly adsorbed to suspended sediments and organic matter and in this way are scavenged from the water column through flocculation, coagulation and sedimentation (Newman & Watling, 2007).

Organic matter in the oceans is produced as a result of primary production and additionally, the benthic environment receives input from sinking detritus (Fricke & Flemming, 1983). Bacteria are largely responsible for the breakdown of energy– rich organic compounds to carbon dioxide, water and ammonia (Clark, 1993). If the addition of organic material is greater than the rate at which bacteria can break down the material, accumulation may result and can lead to deoxygenation of environments (Clark, 1993). Nitrogen and phosphorous are regarded as limiting elements for biological production in aquatic systems (Smith *et al*., 2006). When organic matter input increases, the amount of nitrogen recycled by benthic organisms increases, which results in higher phytoplankton production when it is returned to the surface waters, and this in turn leads to an increase in organic carbon (Mojtahid *et al.,* 2009). Nutrient enrichment, besides

causing an increase in biological activity, has also been found to change the biotic community structure in marine ecosystems (Smith *et al.,* 2006). While eutrophication is a natural process in many aquatic systems, an unnatural increase in limiting nutrients like nitrogen and phosphorous can cause a significant increase in organic carbon deposited on the seafloor (Mojtahid *et al*., 2009). Humans using water to dispose of waste have been found to increase the load of nitrogen and phosphorous in the world's rivers, lakes and oceans (Smith *et al*., 2006). Nitrogen pollution is regarded as one of the greatest consequences of anthropogenic global change on the coastal oceans, and has been found to be highest near areas of intense agricultural activity and urban development, and is the leading cause of the increase in eutrophication observed in coastal systems (Howarth & Marino, 2006).

Trace metals are normally present in marine sediments and are necessary for the growth of phytoplankton and the catalysis of biological reactions (Libes, 1992). The natural occurrence of trace metals sometimes complicates assessments as a high trace metal concentration may not necessarily be as a result of anthropogenic enrichment (Mucha *et al*., 2003). Trace metals, halogenated hydrocarbons, DDT and PCB's are not bio-degradable and can become a permanent addition to the environment and may accumulate in body tissues and bio-magnify up the food web (Abel, 1996). The toxicity of trace metals depends on the form in which they are present in the environment. Metals can form complexes with organic compounds or inorganic molecules; complexes with organic compounds tend to be more toxic to organisms than those with inorganic molecules (Clark, 1993). Toxic heavy metals that are most affected by human activity are those with high enrichment factors and slow clearance rates such as Cd, Cu, Cr, Pb, Zn and Hg (Libes, 1992). Abnormally high trace metal concentrations in sediments have been found to have negative effects on the diversity of organisms and some areas have even been reported that are devoid of any benthic organisms (Scott *et al*., 2001; Ferraro *et al*., 2006).

While trace metals are important in the normal functioning of the marine benthos, excess amounts of any of these substances can lead to a highly polluted environment. Pollution is defined here as occuring when a substance or material is added to an environment above the natural level and causes harm to the system (O' Neill, 1993). Pollutants reach the sea via various sources, for example, point sources, river run-off, shipping, offshore dumping and atmospheric inputs. Globally, the greatest volume of discharge is composed of organic material (Clark, 1993).

The aim of this chapter is to examine the structure and chemistry of the sediments at two study areas on the west coast of South Africa, namely, St Helena Bay and Robben Island in order to understand the abiotic environment of the foraminifera studied in chapters 3 and 4. These sites were identified as being potentially polluted as they are both exposed to discharge from pipelines.

2.2 Materials and Methods

2.2.1 Field Sampling

Sampling in St Helena Bay took place during September 2003. Nine sites were randomly selected around the pipeline within a 150 m radius of the outfall (Fig. 2.1). Three control sites were selected ((SPA) 3.6 km, (SPB) 1.5 km and (SPC) 0.9 km away from the pipeline with similar depths to stations around the pipeline (Fig. 2.1). The approximate depth of all sampling sites was 4 m. Sites were chosen of similar depth in order to eliminate depth as a potential variable as depth has been shown to determine differences in abundance, diversity and community structure within the marine environment (Sajan *et al*., 2010).

Sampling at Robben Island took place during February 2004. Eight sites were randomly selected, five within a 225 m radius around the opening of the outfall and three control sites (Fig. 2.2). Two of the control sites were on the western side of the harbour 190 m and 300 m from the pipeline and one on the same side as the pipeline but 190 m away. These sites were chosen as they are situated away from the direction of the outfall plume (Fig. 2.2). Again, an attempt was made to choose sites of similar depth in order to eliminate depth as a potential variable, although this was not always possible as depth varies greatly within the area.

In both areas, sampling was conducted by SCUBA using modified *Hagge corers* (Fleeger *et al*., 1988). Each corer was 30 cm in length and 3.57 cm in internal diameter (10 cm^2 area). Six cores were obtained at each site, because foraminifera (like most meiofauna) are known to be patchily distributed and many replicates are required to provide an overall picture of distribution in the area (Harrad *et al*., 2008). Samples were kept on ice on the boat and transferred to the freezer on return to the laboratory.

2.2.2 Laboratory Analysis

Only the top 5 cm of each sediment core was examined. Sub-samples of the core were used for the determination sediment grain size structure, percentage carbon and nitrogen and trace metal concentration.

2.2.2.1 Sediment Size Structure

Sediments were dried at 60 º C in an oven for 24 hours and each sample was size-fractionated using sieves with mesh sizes of 500 µm, 250 µm, 125 µm and 63 µm. In order to determine the sediment size structure, the dry sediment weight in each grain size class was determined using an analytical balance.

The sediment grain size was converted from µm to phi units using the formula:

Phi units (ø) = $-\log_2 D$, where D = grain diameter in mm (Pfannkuch & Paulson, 2010)

Therefore, < 63 µm = 5 Phi, 63 µm = 4 Phi, 125 µm = 3 Phi, 250 µm = 2 Phi and 500 µm = 1 Phi. The mean grain size was calculated using the following formula:

Mean sediment grain size = $(ø_{16} + ø_{50} + ø_{84})/ 3$ (Pfannkuch & Paulson, 2010).

2.2.2.2 Percentage Total Carbon and Percentage Total Nitrogen

Approximately 5 g of sediment from each station was kept frozen to determine the percentage of total carbon and the percentage of total nitrogen. Subsamples from each station were combined, dried and homogenised to produce one sample for each station. The percentage total carbon and the percentage nitrogen of the 12 stations were determined using a Eurovector EA CHN Analyser. Combustion of samples in the presence of oxygen was used to determine the Wt % of total carbon and nitrogen. Detection limits for the Analyzer were 0.1 Wt %. Calibration was performed using certified Eurovector standards, accepting a margin of error of 0.05 % for the percentage total carbon and 0.02 % for the percentage nitrogen. Samples were not acid-digested, therefore, the percentage organic carbon concentrations were not determined.

Because the percentage organic carbon measurements were not measured, data on the percentage total carbon, total nitrogen and percentage organic carbon concentrations from Monteiro & Roychoudhury (2005) were analysed for correlations between the percentage nitrogen and the percentage organic carbon (Fig. 2.3 (a) to (c)). This was conducted to determine

whether the percentage nitrogen concentrations could be used as a proxy for the percentage organic carbon concentrations in St Helena Bay. The correlation between the percentage nitrogen and the percentage organic carbon using data from Monteiro & Rochoudhury (2005) had a highly significant r-value of 0.918 and p-value of < 0.0001. From this, one could conclude that the percentage nitrogen concentration could be used as a proxy for percentage organic carbon concentration in the sediments. The percentage total carbon was also significantly correlated with the percentage organic carbon (R = 0.675) and the percentage nitrogen (R = 0.747).

Unfortunately, no data for the percentage nitrogen and percentage organic carbon could be found for Robben Island, but it is assumed that relationships established in the one site would hold good, in this regard, for the other.

While the correlation between the two elements is significant, Kähler and Koeve (2001) caution against using particular ratios for organic carbon and nitrogen. This is because, especially during phytoplankton blooms, these elements may be decoupled due to overconsumption of either one at different stages of the bloom. Ratios may also vary as a result of depth, biogeography and latitudes, therefore it would be preferable to have both measurements. However, as a result of an error in the analysis of samples for this study, it is assumed that there would be a strong relationship between the two elements as previously reported.

2.2.2.3 Trace Metals

Subsamples of sediments from each core were dried and ground to homogeneity. Approximately 2 g of sediments were digested using an acid mixture of 4 HCl:1 HNO_3 following Morton & Roberts (1999). A 4:1 ratio was used as it was regarded as a better method for the digestion of sludges and sediments that are thought to contain high trace metal concentrations. Sediments were digested at temperatures of 110 ºC on a Gerhardt digestion block for three hours (Morton & Roberts, 1999). The supernatant was then filtered off and diluted to 100 ml with distilled water. A UNICAM SOLAAR M-SERIES Atomic Absorption Spectrometer was used to determine trace metal concentrations of the sediments. Readings were then taken of Cu, Zn, Pb, Fe, Cd and Cr.

2.2.3 Statistical Analyses

2.2.3.1 Sediment grain size structure

In order to determine whether there were any significant differences within each study area as well as between the control and pipeline sites in terms of their mean grain size, STATISTICA v. 9 (Statsoft) was used to conduct a one-way ANOVA. One-way ANOVA was used in this study as there were unequal sample numbers within each group. STATISTICA was used for the statistical analyses, data management and graphics throughout the study. The Tukey Honest Significant Difference Test was used as a post-hoc comparison of means (or multiple comparison test) to determine the significant differences between the means of multiple groups (Zar, 1999). The Tukey HSD is generally regarded as more conservative than the Fisher LSD test but less conservative than Scheffe's Test (Zar, 1999).

In all statistical analyses, a confidence limit of 95 % or p = 0.05 was used; this was adjusted for multiple testing using the Bonferroni correction (a posteriori) (Hochberg, 1988). This decreases the risk of making Type-I statistical errors and p-values lower than the Bonferroni value were then accepted as being significant. The bonferroni adjusted p-value was calculated as the number of variables divided by the significant p – value of 0.05 (Hochberg, 1988).

In order to examine the similarity in the sediment structure of the different stations, a dendogram representing the cluster analysis of the sediment structure of all samples was produced using PRIMER (Plymouth Routines in Multivariate Ecological Research) version 6. PRIMER is a software package that consists of a wide range of univariate, graphical and multivariate routines for analysing community ecology (Clarke & Gorley, 2006).

Dendograms representing the cluster analysis of samples were produced to visualise groupings of samples which were most similar to each other, samples within a group are generally regarded as more similar than those from different groups (Clarke & Warwick, 2001). Groupings were often determined arbitrarily as no particular cut-off for a 'good' similarity or distance linkage is provided. Data were log x + 1 transformed and normalised and Euclidean distance was used to produce a similarity matrix. Transformation of environmental data is used to justify using Euclidean distance as a dissimilarity measure on normalised data (Clarke & Gorley, 2006). Euclidean distance is regarded as an appropriate measure for environmental data (Clarke & Gorley, 2006).

2.2.3.2 Percentage Total Carbon and Percentage Nitrogen

To determine whether there were any significant differences between the pipeline and the control sites and between the two study areas, occurred in the percentage total carbon and the percentage Nitrogen, a one-way ANOVA was used. The Tukey Honest Significant Difference post-hoc comparison of means was used to obtain a significant value.

2.2.3.3 Trace Metal Content of Sediments

In order to determine whether there were significant differences between the control sites and the pipeline sites of each study area as well as for differences between the two study areas, a one-way ANOVA was conducted. The Tukey HSD post-hoc comparison of means was performed, and a Bonferroni adjusted p-value was used to determine significant values.

2.2.3.4 Summary of environmental variables

In order to determine the relationship between the measured environmental variables, non-parametric Spearman Rank Order correlations were performed in STATISTICA. Non-parametric correlations were used as the data set was not normally distributed (Zar, 1999) and a Bonferroni p-value was calculated.

An MDS (multi-dimensional scaling) ordination of all environmental variables of the each study area as well as the control and pipeline sites was produced in PRIMER. MDS ordinations were used to plot samples so that their relative distances are in the same rank order as their relative dissimilarities, this allows for visualisation of the samples (Clarke & Gorley, 2006). Samples that are similar to each other are close together whilst dissimilar samples are further apart. The stress level indicates how well the relationships are represented in two-dimension: the lower the stress level the better the relationship, little confidence can be placed on ordination plots where the stress level is > 0.2 (Clarke & Gorley, 2006).The data were first log x + 1 transformed and normalised and Euclidean distance was used (Clarke & Gorley, 2006).

In order to determine whether there were significant differences in the multivariate state of control and pipeline sites at both study areas, an ANOSIM (Analysis of Similarity) was used. ANOSIM is used to test the null hypothesis that there were no significant differences between the two sets of samples which were set *a priori* (Clarke & Gorley, 2006). In order to determine

the percentage similarity within the control and pipeline sites, as well as the environmental variables most responsible for determining the average percentage dissimilarity between the sites and study areas, a SIMPER (Similarity Percentage) was conducted. This provides an indication of which environmental factors would be most important in structuring the general environment in the study area.

2.3 Results

2.3.1 Sediment Size Structure

The mean sediment grain size varied across the stations (Fig. 2.4; Appendix 2.1), and most samples from the sites in St Helena Bay had a smaller mean grain size (1 – 3 Phi; 125 μm – 500 μm) than those from Robben Island (all less than 2 Phi; > 250 μm). The results of a one–way ANOVA between the mean grain sizes of all stations from Robben Island showed no significant differences between the control sites (RIF, RIG and RIH) (Table 2.1). RIA and RIC had the largest mean grain sizes, with RIA being significantly larger than most other sites; RIC was only significantly larger than RID and RIH.

In St Helena Bay the mean grain sizes of all the sampled stations showed no significant differences within the control sites (Table 2.2). However there were some significant differences between SHD and some of the other pipeline sites, and SHF with the control stations and SHA. The samples from the control sites (2.44 ± 0.35 Phi) in St Helena Bay had a lower mean grain size (overall) than those from the pipeline sites (1.84 ± 0.7 Phi), and these differences were significant ($F(1, 68) = 11.93$; $p < 0.001$) (Table 2.3). Samples from the control sites (0.84 ± 0.18 Phi) of Robben Island had a larger mean grain size than the pipeline sites (1.17 ± 0.48 Phi) although these differences were not significant (Table 2.3). The mean grain size of the samples from the control and pipeline sites of Robben Island was significantly larger than those in St Helena Bay.

The sediment size structure and the percentage contribution of each sediment size class varied greatly between the St Helena Bay stations (Fig 2.5). Stations SPA, SPB and SPC (the control sites), as well as SHA and SHI were dominated by a grain size of 3 Phi. Most other stations were otherwise dominated by the 1 phi grain size. Mud (5 Phi) formed less than 2 % of the total sediments at most stations except for SHC and SPA which had > 15 % mud. All

stations in Robben Island were dominated by the 1 Phi mean grain size and mud formed less than 2 % of the total sediments at each station.

In a cluster analysis of the sediment size structure of all samples, Robben Island samples grouped separately from those of St Helena Bay although some overlap between the sites did occur (Fig 2.6). In the St Helena Bay samples, the control and pipeline sites grouped separately, and although some grouping was evident in Robben Island samples, the distance between groupings was very small. Samples from all the stations in Robben Island were found to group together, although there was no apparent structure within groups, suggesting large scale variation of sediment size at a micro level.

2.3.2 Percentage total carbon and Percentage Nitrogen

The percentage total carbon at each of the stations varied between 1 % and 10 % (Table 2.4). The percentage total carbon in the samples from Robben Island was higher than observed in St Helena Bay (Table 2. 4). For St Helena Bay the percentage carbon at site SHD was the highest (7 %), while RIH was highest (10.3 %) around Robben Island. The mean percentage carbon from the St Helena Bay samples (3.78 %) was significantly lower than that from Robben Island (7.17 %) ($F (1, 111) = 125$; $p = 0.000\ 1$) (Table 2.5(a)). The control sites at both study areas had significantly higher percentage carbon than those of their corresponding pipeline sites (Table 2.5 (b)) ($F (1, 111 = 84.94$; $p < 0.05$).

The percentage nitrogen varied from 0.02 % to 0.8 % in all samples (Table 2. 4). Station SHD from St Helena Bay was much higher in this regard than the rest of the stations. The mean percentage nitrogen of Robben Island samples (0.1 %) was significantly lower than the mean percentage nitrogen of the St Helena Bay samples (0.17 %) ($F (1, 111) = 5.69$; $p = 0.000\ 1$) (Table 2.5 (a)). The percentage nitrogen in the samples from the pipeline sites of St Helena Bay (0.2 % ± 0.23%) was significantly higher than from the control sites around Robben Island (0.05 ± 0.02 %) ($p = 0.02$) and St Helena Bay (0.09 ± 0.015 %) ($p = 0.05$), but not from the pipeline sites at Robben Island ($F (1, 111) = 5.39$) (Table 2.5 (b)).

2.3.3. Trace Metals

The trace metal content of the sediments in the Robben Island samples were lower than both the maximum allowable ERL at all sites as well as the South African sediment quality guidelines (SA SQG) (Fig. 2.7). The mean metal concentration of samples from the control sites were lower than those from the pipeline sites (Table 2.6).

In the St Helena Bay samples, station SHD was higher than both the ERL and SA SQG for Cr and Cu concentrations, and station SHG was higher than both the ERL and SA SQG for Cu (Fig. 2.8). All other trace metal concentrations were lower than the ERL value.

Samples from the pipeline sites had higher trace metal concentrations in the sediments than the control sites, for both areas, with those from the pipeline sites in St Helena Bay being the highest (Fig. 2.9). Samples from the control and pipeline sites in St Helena Bay had concentrations higher than the SA SQG for Cd. Except for the Pb concentrations, samples from the Robben Island sites were significantly lower than those of St Helena Bay for all the other trace metals (Table 2.6 (b)). Table 2.6 (a) shows that the pipeline sites in St Helena Bay (PSH) were significantly higher than all other sites in all trace metals except Pb, where they were only significantly higher than the control sites in St Helena Bay (CSH) ($p < 0.05$). CSH was also significantly higher than all sites for Cd concentration and higher than CRI for Cr concentration. Although the pipeline sites of Robben Island (PRI) were generally higher than the control sites (CRI), these differences were not significant.

3.3.4 Summary of environmental variables

Non-parametric Spearman Rank Order correlations of all environmental variables revealed significant relationships between most of the measured environmental variables (Table 2. 7). The mean sediment grain size, however, appeared to have the fewest significant correlations with the other environmental variables, and it only correlated significantly with Cd and Cr .

An MDS of all environmental data for Robben Island and St Helena Bay (stress = 0.08) showed the Robben Island samples grouped separately from the St Helena Bay samples although some overlap did occur (Fig 2.10). An ANOSIM between control and pipeline sites of Robben Island showed a significant difference in environmental variables (Global R = 0.518, p = 0.001). Although an ANOSIM between the control and pipeline sites of St Helena Bay showed a significant difference in environmental variables, the r-value was low (Global R = 0.167, p = 0.05) which indicated that these differences were not very strong.

The MDS which separated the control and pipeline sites of the two study areas, revealed a large amount of overlap in these samples for both study areas (Fig 2.10). An ANOSIM between the environmental variables of Robben Island and St Helena Bay showed that these differences were significant (Global R = 0.404, p = 0.001).

The results of the SIMPER analysis (Table 2. 8) showed that the factors that were most responsible for the similarity within the Robben Island samples were the trace metals (except Cd) and the mean sediment grain size. By contrast, the percentage nitrogen and only some of the trace metals (Zn, Fe, Cu and Pb) were important in the samples from St Helena Bay. The trace metals and the mean sediment grain size were most responsible for the differences between the two study areas.

The trace metals and the mean grain size were most responsible for the similarity with the control sites of Robben Island, whereas the only the trace metals were most responsible for the similarity within the pipeline sites (Table 2.9). In the pipeline sites of St Helena Bay on the other hand, the percentage nitrogen was the largest contributor along with the mean grain size and a few of the trace metals (Cr, Fe and Cu). In the control site, the percentage nitrogen and the mean sediment grain size contributed very little and the most important contributor to the similarity within the group was the trace metals.

2.4 Discussion

2.4.1. Sediment Grain Size Structure

Although both study areas were dominated by sediments having a large mean grain size, those around Robben Island were of a significantly larger mean grain size than those of St Helena Bay. In both sites, mud was largely absent. Strong water movement tends to wash away fine material to leave coarse particles in sediments (Castro & Huber, 2008). Physical resuspension by heavy wave action can also maintain fine sediments in the water column resulting in coarser sediments dominating the top 2 cm vertically into the benthos (Wheatcroft & Butman, 1997). While both study sites were located near the surf zone (which could explain the dominance of large grains), the presence of coarser sediments in St Helena Bay may also be due to the presence of calcareous reefs in the vicinity (Monteiro & Roychoudhury, 2005). The dominance of Robben Island sediments by coarse grains and the absence of mud and fine sand is more an indication of a highly exposed area with strong wave action (Jury & Bain, 1989). Coarse

grains are normally well oxygenated and ideal for infauna but have been found to have less organic matter as a source of food than fine sand as a result of lower settlement rates in these environments (Samir & El- Din., 2001). Therefore, while having the potential microhabitats to support infauna, food supply may be a limiting factor. In areas with sandy grains, transport of interstitial water is influenced mainly by bottom current-sediment interactions, advection and dispersion (Jahnke *et al*., 2005). Sediment permeability, especially in sandy sediments, plays a large role in advective transport of metals and remineralization of NH_4^+ (Huettel *et al*., 1998).

2.4.2 Percentage total carbon and Percentage Nitrogen

Nitorgen in the marine environment stimulates phytoplankton production, which increases the amount of organic carbon in the system; when phytoplankton die, this organic carbon reaches the benthos as phytodetritus, which is broken down by the micro-oragnisms and bacteria in the benthos releasing nitrogen into the water column again (Cloern, 2001). Carbon and nitrogen cycling in the marine environment are thus closely linked.

The percentage total carbon in the samples from St Helena Bay was generally high; Monteiro & Roychoudhury (2005) observed much the same in their study from St Helena Bay and also found the concentrations to be higher than most other harbours globally. Bailey (1987) reported a percentage total carbon of 4 % and percentage nitrogen of 0.5 % in the top 5 cm of the sediment in St Helena Bay. This high percentage carbon may merely be a result of the hydrodynamics of the bay, i.e. sluggish flowing, semi-closed bay with a retention time of approximately 25 days as opposed to 2 -3 days outside the bay (Walker & Pitcher, 1991) rather than from high carbon loading from the fish factories. St Helena Bay is also downstream of an upwelling area and has enhanced primary productivity and high deposition of particulate organic matter which results in highly organic sediments (Bailey, 1987). In other areas with upwelling, such as in the Arabian Sea, marine sediment accumulates very rapidly, this material is rich in organic matter which is derived from pelagic primary production and also tends to be anaerobic (Murray *et al*., 2002). Carbon reaching the sediments can also be from a number of other sources like detritus, faecal matter and large zooplankton, in fact, Touratier *et al*. (2003) considered that only 8.4 % of carbon that reached sediments were found to be a result of primary production in St Helena Bay.

In St Helena Bay, the percentage total carbon from the control sites was significantly higher than the sites around the pipeline but station SHD was much higher than all other stations. Site SHD was the station with a high amount of biological material (fish scales and bones) in the top layer which may account for the presence of the high percentage carbon in the sediments. It has been suggested by Monteiro & Roychoudhury (2005) that organic carbon loading in St Helena Bay is of planktonic origin, and alternating upwelling and relaxation events that transport external blooms from poleward nearshore flow into the retention area. The data presented here tends to support this as no significant difference was found between the control and pipelines sites.

In a study of Table Bay, Monteiro (1997) concluded that the organic matter loading was of natural marine origin linked to the Benguela upwelling system, as well as input from the Salt and Diep Rivers driven by winter rains, and that land derived organic matter was a samller contribution. In addition to upwelling it is also thought that organic matter of marine origin is also advected into the bay during poleward movement of water between upwelling events (Monteiro, 1997).

The percentage nitrogen in the sediments of St Helena Bay was significantly higher than those around Robben Island, and the pipeline sites in both study areas were richer in nitrogen than those of the control sites. Station SHD once again displayed levels higher than all other stations in both study areas. An increase in the percentage nitrogen input into a system is said to increase eutrophication of a system by increasing the primary production (Cloern, 2001; Howarth & Marino, 2006). In a study in St Helena Bay, Touratier *et al.* (2003) found that regeneration of nutrients from the sediments was important in the pelagic productivity of the area and that nitrogen recycling did not only come from nitrates but also from ammonia, urea and other forms so that the area is not nitrogen limited as in most marine environments. Verardo & McIntyre (1994 in Twichell *et al*., 2002) found that areas with high carbon but low nitrogen result from more rapid loss of nitrogen than carbon because nitrogen-rich proteinaceous matter is more readily utilized by microbes than carbohydrate components. It does appear that the effluent from the fish factory has a localized effect displayed by the higher percentage nitrogen closest to the outlet.

2.4.3. Trace Metals

Trace metals occur naturally in the marine environment, and in order to assess whether trace metals have natural or enriched levels it is necessary to normalize the concentration against the regional background values (Herut & Sandler, 2006). Normalisation of trace metals against iron or aluminium in marine sediments is important as it effectively takes granulometry and organic matter content into account (Newman & Watling, 2007). Different trace metals have different affinities to sediments and their organic matter content. For example, anthropogenic Cd and Hg have a stronger affinity to organic matter than to clays (Herut & Sandler, 2006). No baseline data was available for the study areas and therefore, no normalisation of the trace metal data could be performed. As a consequence, it was not possible to determine if any of the sites were enriched (above background) and hence polluted.

With the exception of Pb, all other measured trace metals occurred at significantly higher concentrations in samples from St Helena Bay than Robben Island. No significant difference was found between the metal concentrations of the control and pipeline sites around Robben Island, but all the measured trace metals (except Cr) were significantly higher in the samples from the pipeline sites in St Helena Bay. Station SHD was higher than all the other stations and appears to be the point of deposition and accumulation in St Helena Bay because it was found to be higher in organic carbon, nitrogen and trace metals than all other sites. A high organic carbon input is thought to lead to the accumulation of trace metals, due to changes in the redox potential and accompanying eutrophication when sediments become anoxic (Monteiro *et al*., 1999). In retention zones associated with upwelling, as in St Helena Bay and Robben Island, complex biological, chemical and physical processes also control the trace metal variability and it has been suggested that the dominant source of trace metals in the benthos is from phytoplankton and newly upwelled water from the South Atlantic (Monteiro & Roychoudhury, 2005). Trace metal concentrations in sediments and suspended matter are also found to be several orders of magnitude higher than those in the dissolved phase and are likely to be found in areas where finer sediments (< 200 μm) accumulate (Monteiro, 1997). This may explain the higher trace metal concentrations of St Helena Bay (mean grain size < 250 μm) as opposed to Robben Island (> 250 μm). In this study there was a definite correlation between the sediment grain size and some of the trace metal concentrations (Cd, Cr and Zn).

Trace metals that are at levels higher than permissible ERL levels (below this level adverse biological effects are rarely observed) and ERM levels (levels between ERL and ERM or higher than ERM are where adverse biological effects are observed) are a cause for concern (Bjørgesæter & Gray, 2008). The metals considered toxic to most marine life are, in descending order of toxicity, mercury, cadmium, silver, nickel, selenium, lead, copper, chromium, arsenic and zinc (Islam and Tanaka, 2004). The levels of Cd, Cr, Cu and Zn were significantly higher in St Helena Bay samples than in Robben Island, suggesting potentially toxic trace metals. This is also supported by the fact that the higher trace metal concentrations were at the pipeline sites in St Helena Bay and that the area is impacted by the fish factory and possibly the other activities within the bay.

Monteiro & Roychoudhury (2005) reported values lower than the world average for trace metal concentrations with the lowest trace metal concentrations near the shore and the highest near the middle of the bay; sites corresponding with those of this study share similar concentrations of trace metals in the sediments. These concentrations of trace metals were much higher than those of Robben Island (this study), Table Bay (Cu), Saldanha Bay (Cu, Cd, Pb), but lower than the highest concentrations in Sidney, Kenya, Hong Kong, Dutch Wadden Sea, NW Mediterranean and Gulf of Thermaikos, Greece which were used in the comparison of Monteiro (1997).

Trace metal concentrations from samples around Robben Island were lower than those reported from Prochazka (2003). However, it has since been established that incorrect calculations were used by Prochazka (pers. comm.).

The biological uptake and the toxicity of trace metals depends on which free ions they combine with; for example with, chloride, carbonate, hydroxide or sulphide (Cherchi *et al*., 2009). When trace metals bind with sulphides, they form an insoluble species that concentrates the metals in the sediments (Monteiro & Scott, 2001). In an environment where the organic carbon loading is very high, trace metals remain within the system by binding with sulphides and will only remobilize when resuspended during storms or dredging (Monteiro *et al.*, 1999). The trace metal concentrations, in this study, were positively related with the percentage nitrogen.

Most studies that have reported a high anthropogenic input of organic matter have noted a high concentration of trace metals. However, trace metals may be partitioned between residual organic matter, terrigenous clays and sulphide complexes in St Helena Bay and Robben Island

(Monteiro & Roychoudhury, 2005). A large percentage of marine trace elements are also scavenged onto Fe-oxyhydroxides (especially Ni, Cd, As, Pb and Cu) or complexed with large aggregates or colloids, which is not necessarily organic carbon (Powell *et al*., 1996). Iron may, therefore, control the concentrations of other trace metals in the seawater and may exhibit non-conservative removal of Fe-oxyhydroxides and non-labile organic complexes (Powell *et al*., 1996). The concentration of Fe in St Helena Bay was almost double that of Robben Island and it is possible that Fe is controlling the concentrations of trace metals more so than the concentration of organic compounds.

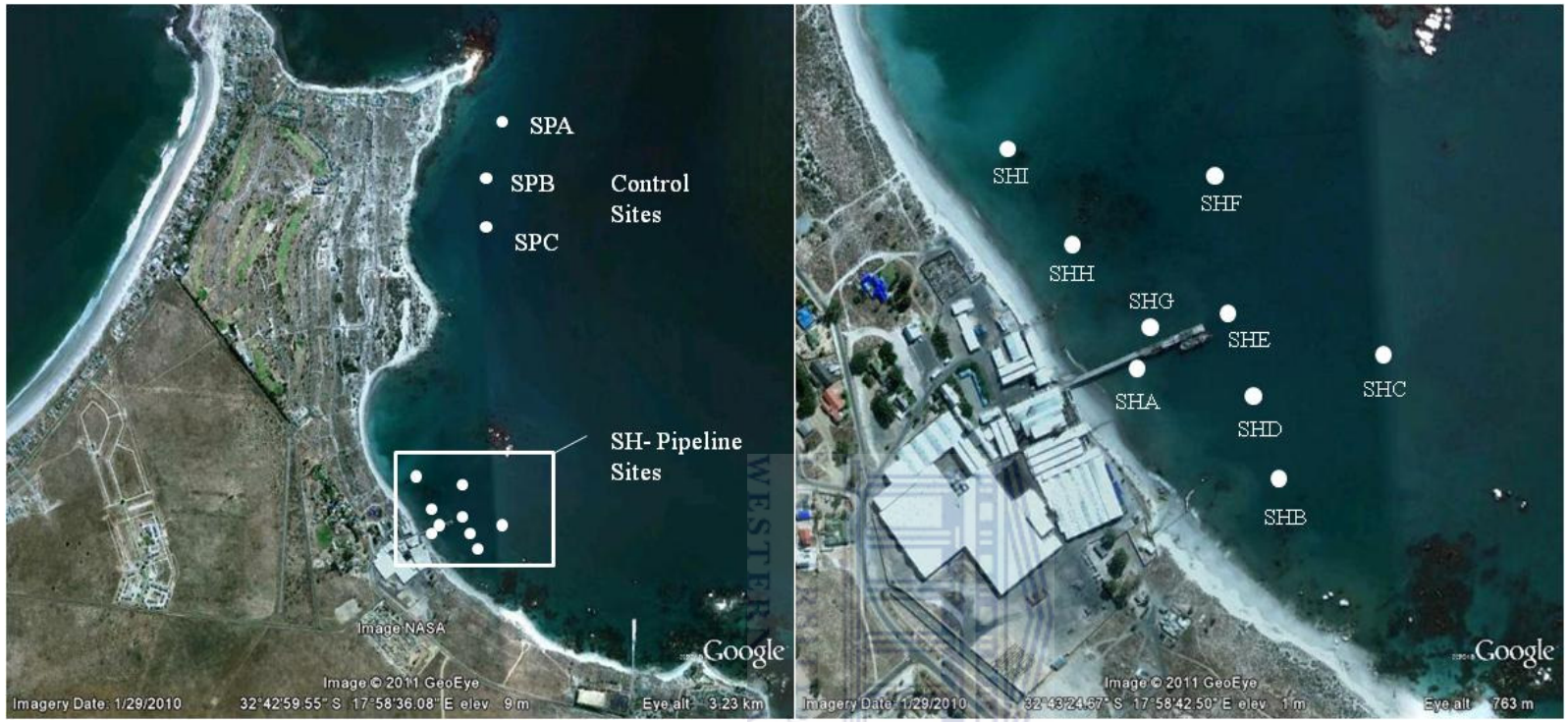
Therefore a semi-closed sheltered bay, not easily affected by storms, like St Helena Bay, will tend to trap and accumulate these trace metals as resuspension would not take place on a regular basis. The observed strong correlation between the trace metals suggests that their input is from a common source (Monteiro & Roychoudhury, 2005).

2.5 Conclusions

Spatial variability within the sediments of the benthos was extremely marked. Variability often occurs as a result of the fluctuations of food supply as a result of different settlement rates of phytodetritus, in addition, faunal tubes and burrows can influence spatial distribution of organic matter which is being transported by currents (Lavigne *et al*., 1997). There is also considerable variability in the supply of organic matter to the sediment as a result of spatial and temporal differences in the rates of primary production and zooplankton grazing, chemical and hydrographic regimes in the water column and environmental conditions (Gee *et al*., 1985).

The two study areas had obvious environmental differences. St Helena Bay has been exposed to effluent since 1945 with the opening of the fish factories whereas the sewage plant of Robben Island has only been discharging since 2002. The very obvious differences are in both the nitrogen and trace metals concentrations which were much higher in St Helena Bay samples than Robben Island. St Helena Bay thus should be constantly monitored. Besides the length of time that St Helena Bay has been exposed and the level of exposure, the two bays have very different hydrodynamics. Robben Island will experience fewer effects from anthropogenic inputs, as the strong winds and the turbulence within Table Bay allows very little settling. The wind direction is also highly variable and the plume from the sewage plant will change accordingly, therefore settlement of substances does not consistently occur in one particular area.

St Helena Bay appears to be more at risk than Robben Island because the bay is not as turbulent and is not exposed to high winds and therefore pollutants will more easily settle. The sewage pipeline of Robben Island does not appear to pose any risks to the area directly and provided that the input does not increase dramatically does not appear to be causing any changes in the levels of naturally occurring elements.



(a) (b)

Figure 2.1: Map of St Helena Bay illustrating the position of the sampling sites (a) as well as those around the pipeline (b). (SHA to SHI are the pipeline sites and the control sites are SPA to SPC) (http://maps.google.com).

Figure 2.2: Map of Robben Island illustrating the position of sampling sites around the pipeline (RIA to RIE) and the control sites (RIF to RIH) (http://maps.google.com).

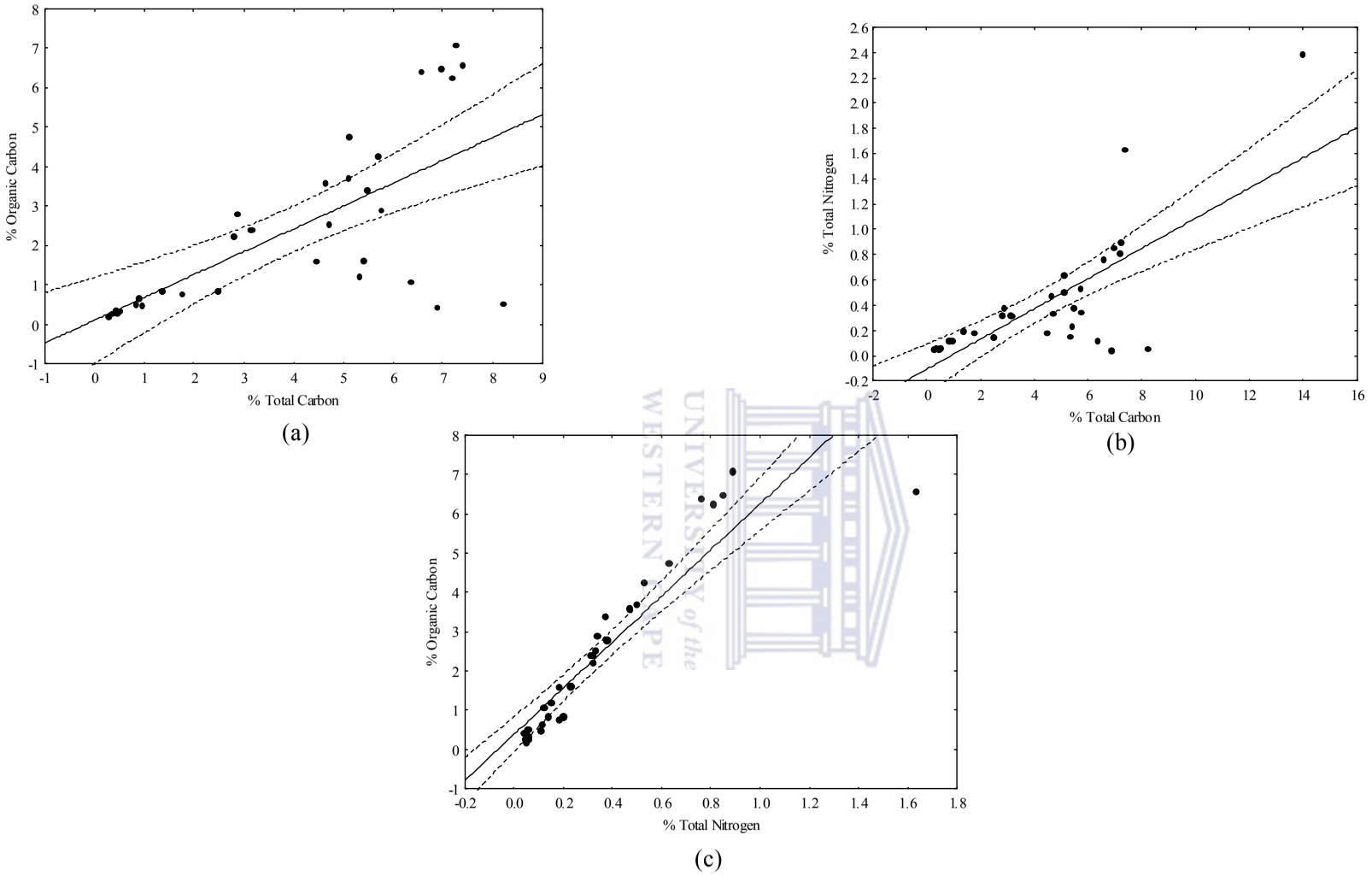


Figure 2.3 (a) to (c): Correlations of the percentage total carbon, percentage organic carbon and percentage total nitrogen using data collected from St Helena Bay by Monteiro & Roychoudhury (2005). Correlation co-efficients are (a) R = 0.675 (b) R = 0.747 (c) R = 0.919.

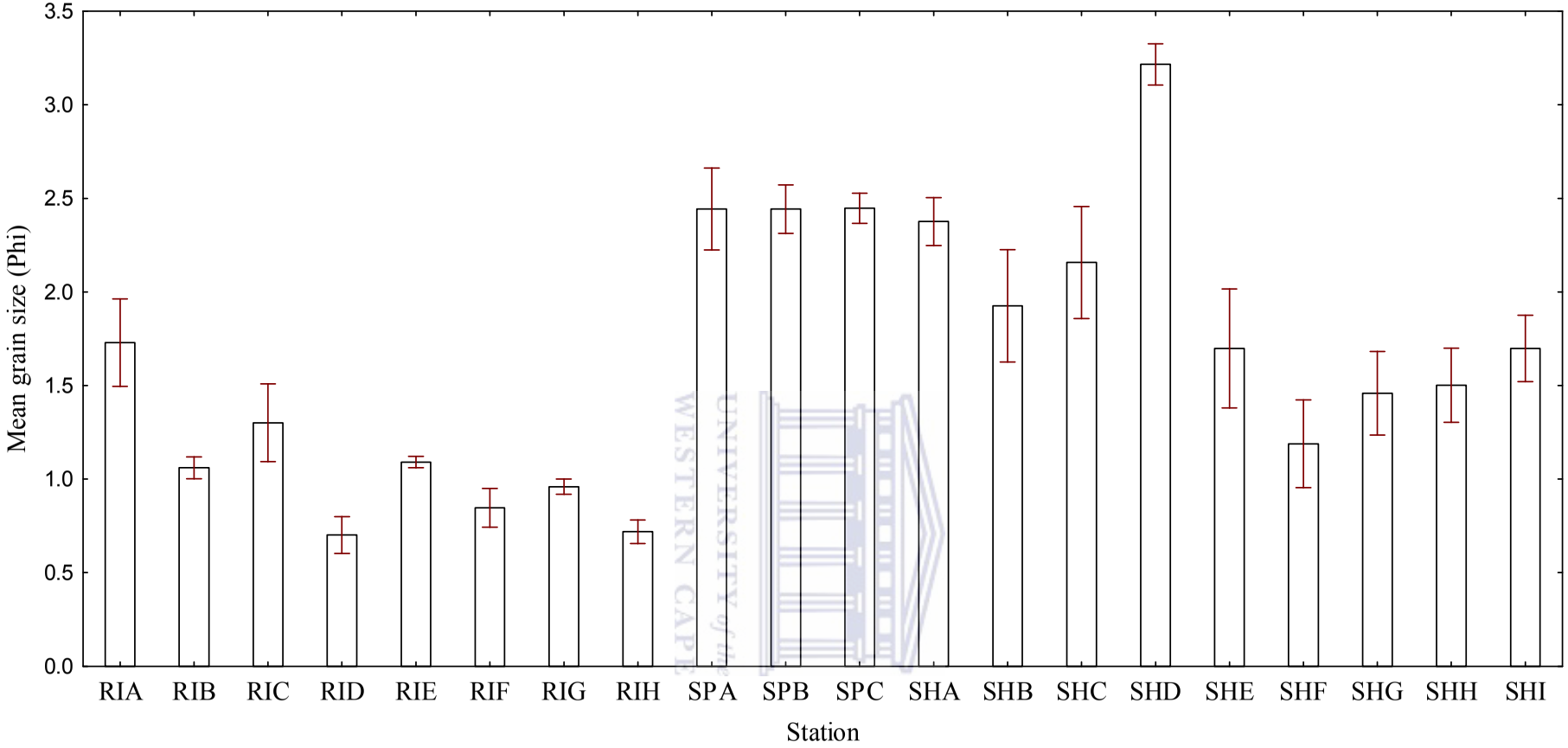


Figure 2.4: The mean grain size (Phi) and the standard error (n = 6) for each of the sampling stations at Robben Island, RIA to RIE are pipeline stations and RIF to RIH are control stations, and St Helena Bay, SPA to SPC are control stations and SHA to SHI are pipeline stations. Refer to Fig. 2.1 and Fig. 2.2 for the location of each station.

Table 2.1: The following are the results of a one-Way ANOVA performed on the mean sediment grain size (Phi) of all cores for each site in Robben Island. For a post-hoc comparison of means, the Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance. F (7, 39) = 7.16. Significance at $p < 0.05$* after the Bonferroni adjustment.

	RIA	RIB	RIC	RID	RIE	RIF	RIG	RIH
Mean Grain Size	1.73	1.06	1.30	0.70	1.09	0.85	0.96	0.72
RIA								
RIB	0.01							
RIC	0.27	0.87						
RID	0.00*	0.49	0.03					
RIE	0.02	1.00	0.93	0.38				
RIF	0.00*	0.94	0.26	0.99	0.89			
RIG	0.00*	1.00	0.55	0.83	1.00	1.00		
RIH	0.00*	0.55	0.04	1.00	0.44	1.00	0.88	

Table 2.2: Results of the one-way ANOVA performed on the mean sediment grain size (Phi) of all cores of St Helen Bay. Levene's test for homogeneity of variances did not show a significant result ($p = 0.11$). For a post- hoc comparison of means, the Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance. $F(11, 58) = 8.92$. Significance at $p < 0.05$ * and in bold type.

	SPA	SPB	SPC	SHA	SHB	SHC	SHD	SHE	SHF	SHG	SHH	SHI
MEAN GRAIN SIZE	2.44	2.44	2.45	2.38	1.93	2.16	3.22	1.38	1.12	1.48	1.55	1.81
SPA												
SPB	1.00											
SPC	1.00	1.00										
SHA	1.00	1.00	1.00									
SHB	0.80	0.80	0.79	0.92								
SHC	1.00	1.00	1.00	1.00	1.00							
SHD	0.35	0.35	0.36	0.23	0.00	0.04						
SHE	0.01	0.01	0.01	0.02	0.70	0.19	0.00*					
SHF	0.00*	0.00*	0.00*	0.00*	0.14	0.01	0.00*	1.00				
SHG	0.03	0.03	0.03	0.07	0.90	0.39	0.00*	1.00	0.98			
SHH	0.07	0.07	0.06	0.12	0.97	0.56	0.00*	1.00	0.93	1.00		
SHI	0.50	0.50	0.49	0.68	1.00	0.99	0.00*	0.93	0.34	0.99	1.00	

Table 2.3: Results of the one-way ANOVA performed on the mean sediment grain size (Phi) of all cores for each of the sampling sites. The Tukey Honest Significant Difference (HSD) Test post-hoc comparison was performed to obtain a statistical significance. $F(1, 111) = 31.89$. Significant at $p < 0.05$ * after the Bonferroni adjustment. Pipeline Robben Island (PRI), Control Robben Island (CRI), Control St Helena Bay (CSH) and Pipeline St Helena Bay (PSH).

	PRI	CRI	CSH	PSH
	1.17	0.84	2.44	1.86
CRI	0.22			
CSH	0.000 1*	0.000 1*		
PSH	0.000 1*	0.000 1*	0.002*	

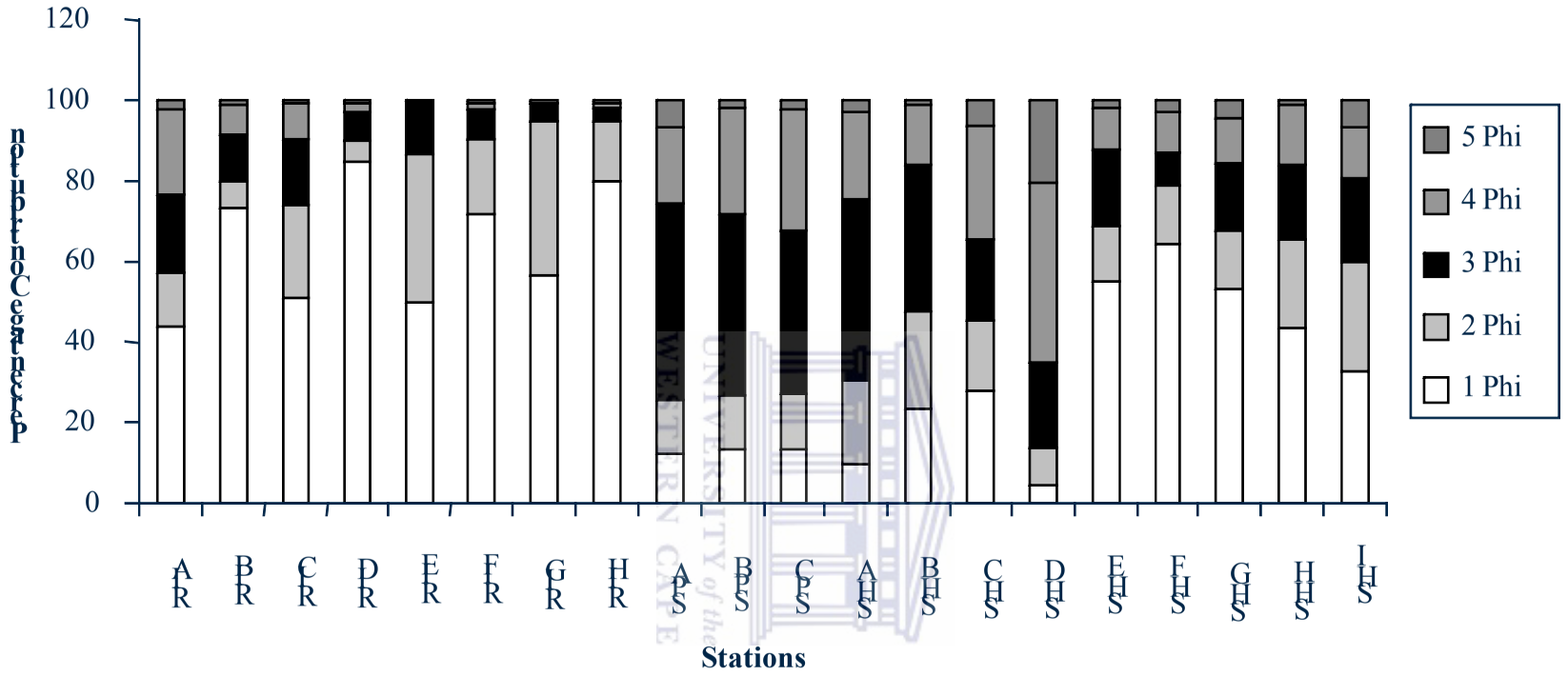


Figure 2.5: The mean percentage contribution of each sediment size class of the total sediment weight for each of the stations sampled in Robben Island and St Helena Bay.

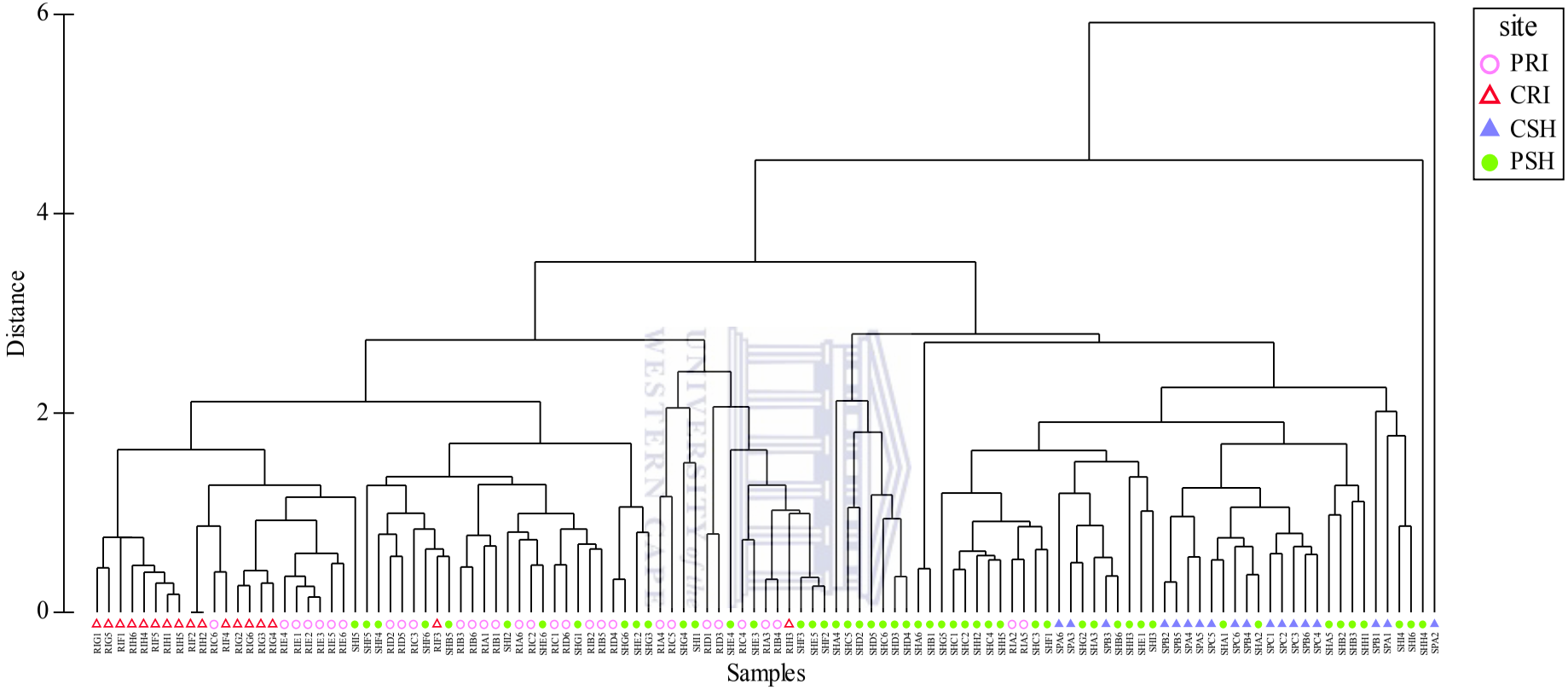


Figure 2.6: Dendogram representing the cluster analysis of the sediment structure of each sample in Robben Island and St Helena Bay. These data were log x + 1 transformed and Euclidean distance was used in the analysis. (PRI is the pipeline stations at Robben Island, CRI is the control stations at Robben Island, CSH is the control stations of St Helena Bay and PSH refers to the pipeline stations of St Helena Bay. Each of the samples is labelled according to the station and the core number. Refer to Figs. 2.1 and 2.2 for the location of each station.

Table 2.4: Results of the percentage total Carbon and the percentage total Nitrogen measured samples collected from around Robben Island (RIA to RIH) and St Helena Bay (SPA to SHI), as well as that for the various sites and a mean for the two study areas.

Station	Site	% total N	% total C
RIA	Pipeline	0.16	4.97
RIB	Pipeline	0.14	5.89
RIC	Pipeline	0.22	6.75
RID	Pipeline	0.09	7.78
RIE	Pipeline	0.04	5.22
RIF	Control	0.08	9.48
RIG	Control	0.02	7.34
RIH	Control	0.05	10.30
SPA	Control	0.08	4.77
SPB	Control	0.09	4.44
SPC	Control	0.11	4.33
SHA	Pipeline	0.07	3.71
SHB	Pipeline	0.17	4.29
SHC	Pipeline	0.14	3.02
SHD	Pipeline	0.80	7.52
SHE	Pipeline	0.1	2.92
SHF	Pipeline	0.13	2.67
SHG	Pipeline	0.24	4.15
SHH	Pipeline	0.08	1.51
SHI	Pipeline	0.08	2.00
Mean RI		0.1	7.17
Mean SH		0.17	3.78
Control RI		0.05	9.01
Pipeline RI		0.13	6.12
Control SH		0.09	4.51
Pipeline SH		0.2	3.51

Table 2.5: The following represents the one-way ANOVA performed on the total % Nitrogen and % Carbon between the study areass (a) and the sites (b). RI refers to Robben Island and SHB to St Helena Bay; PRI is the pipeline stations at Robben Island, CRI is the control stations at Robben Island, CSH is the control stations of St Helena Bay and PSH refers to the pipeline stations of St Helena Bay. The Tukey Honest Significant Difference post-hoc comparison of means was performed to obtain a significant value ($p < 0.05$) * after the Bonferroni adjustment. F (1, 111).

(a)

study area	% N	RI	% C	RI
F	5.69		125	
	Mean	p	Mean	P
RI	0.100		7.168	
SHB	0.168	0.000*	3.782	0.000*

(b)

Site	%N Mean	PRI p	CRI p	CSH p	% C Mean	PRI p	CRI p	CSH p
F	5.39				84.99			
PRI	0.130				6.122			
CRI	0.048	0.25			9.014	0.000*		
CSH	0.093	0.83	0.79		4.513	0.000*	0.000*	
PSH	0.195	0.22	0.002*	0.05	3.518	0.000*	0.000*	0.029

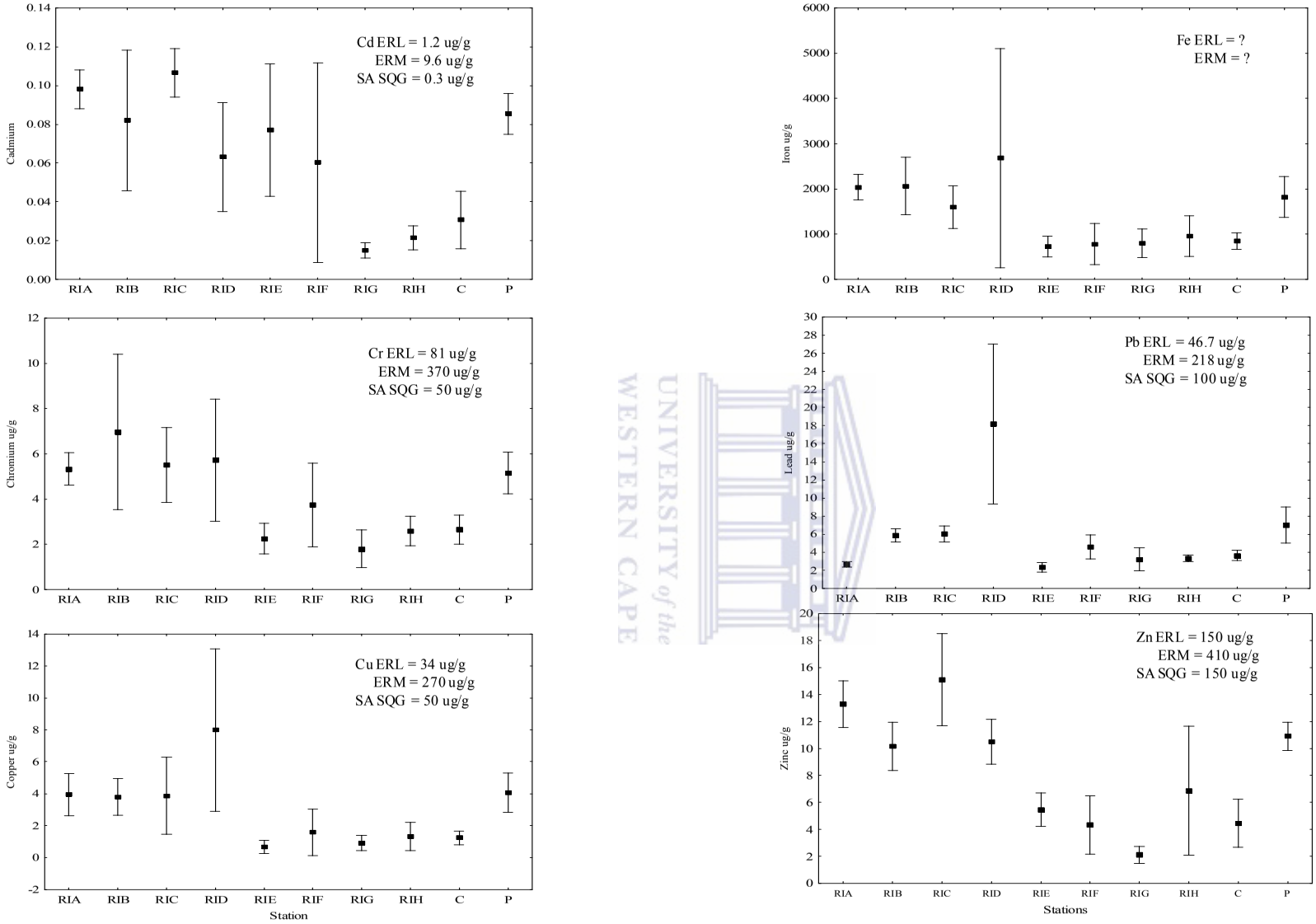


Figure 2.7: Graphs illustrating the means and standard errors of the trace metal concentration in the sediments at the Robben Island stations as well as the mean for the control (C) and pipeline (P) sites.

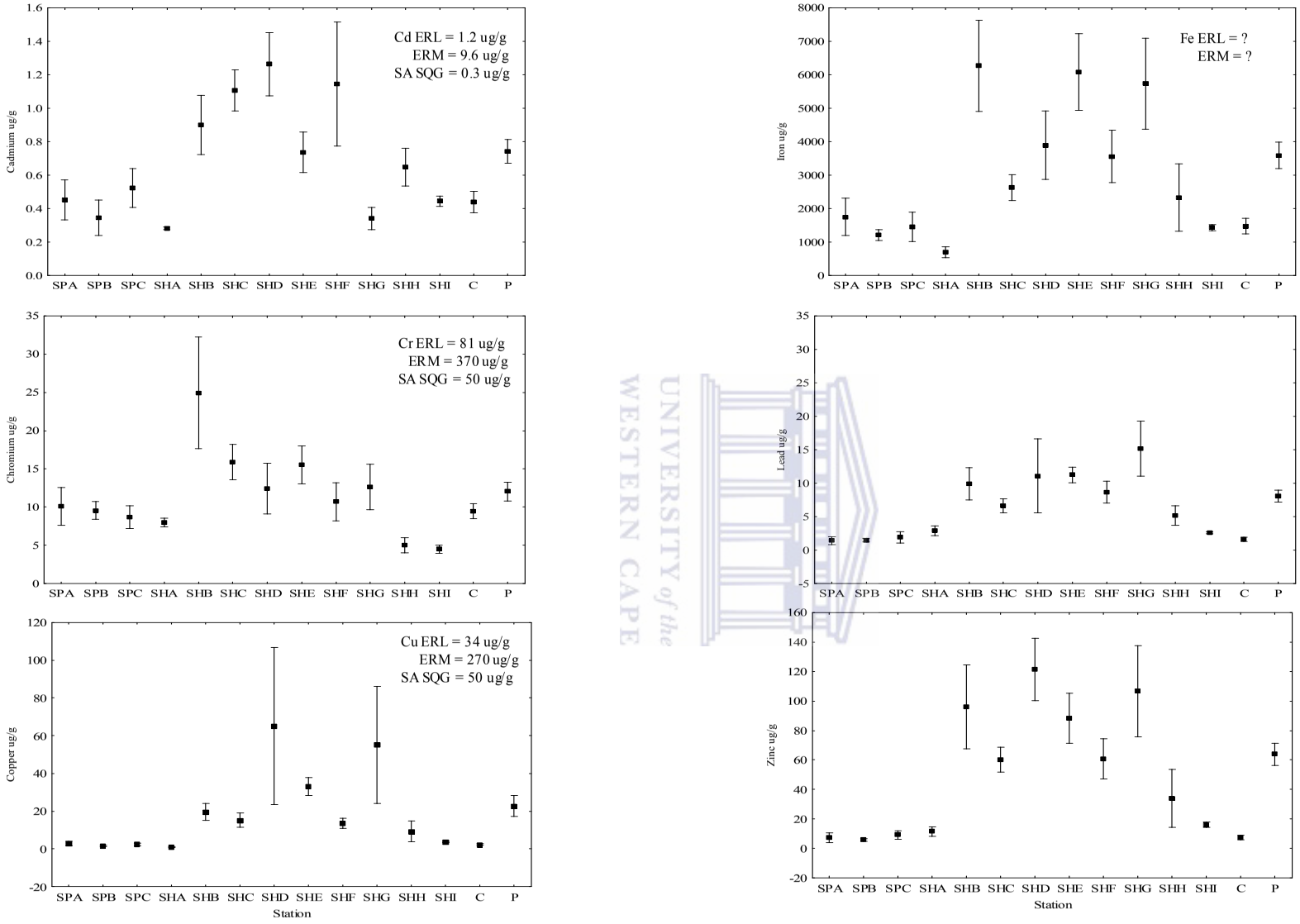


Figure 2.8: Graphs illustrating the means and standard errors of the trace metal concentration in the sediments at the sites sampled St Helena Bay as well as the mean for the control (C) and pipeline (P) sites.

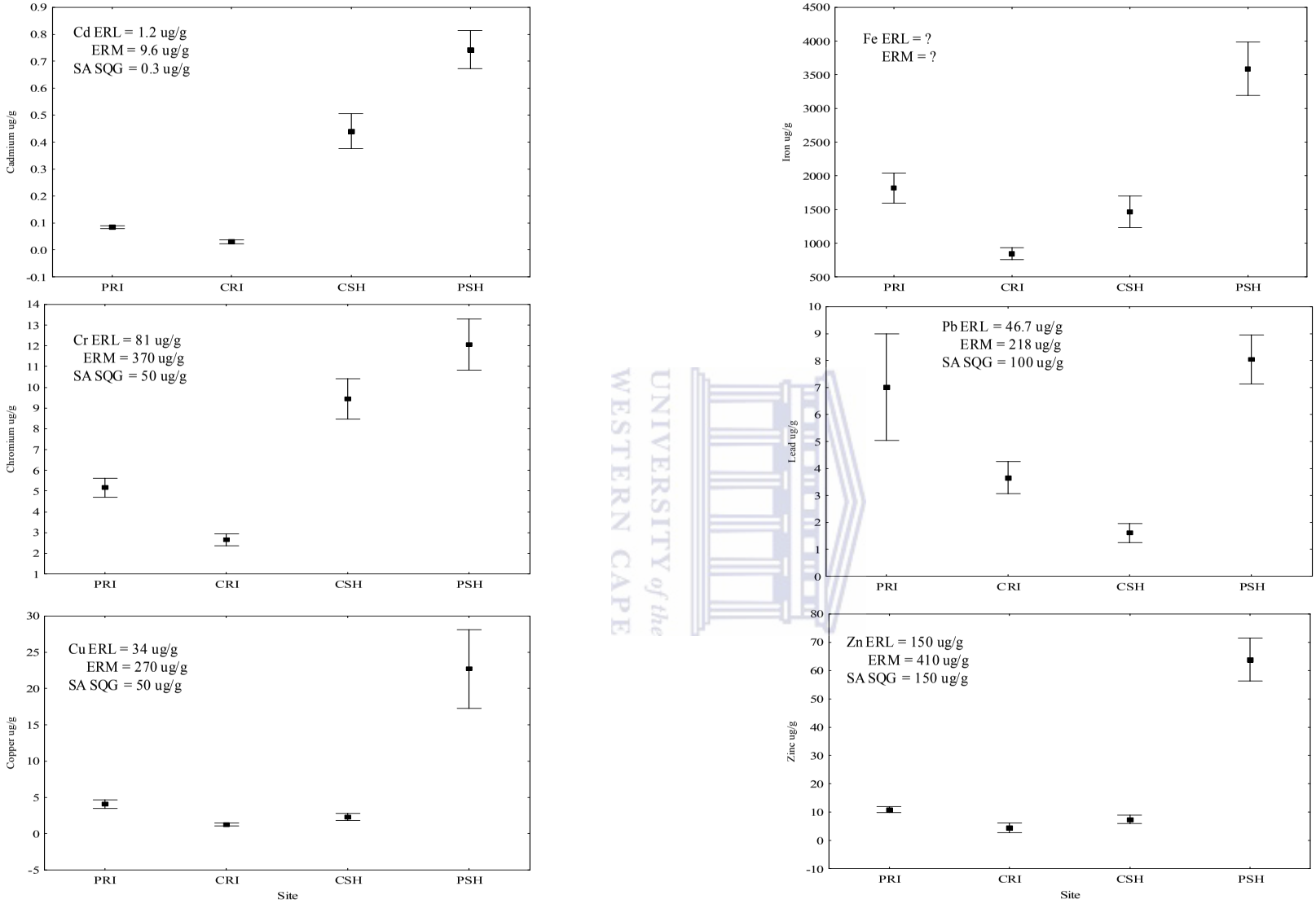


Figure 2.9: Graphs illustrating the means and standard errors of the trace metal concentration in the sediments at Robben Island (PRI and CRI) and St Helena Bay (CSH and PSH), P = pipeline sites and C = control sites.

Table 2.6: The following tables represent the ANOVA performed on the trace metal concentrations in the sediments between the sites (a) and the study areas (b). The Tukey Honest Significant Difference post-hoc comparison of means was performed to obtain a significant value ($p < 0.05$) *, F (1, 111).

(a)

Site	**Cd**	**PRI**	**CRI**	**CSH**	**Cr**	**PRI**	**CRI**	**CSH**	**Cu**	**PRI**	**CRI**	**CSH**
F	7.47				13.7				5.66			
	Means	**p**	**p**	**p**	**Means**	**p**	**p**	**p**	**Means**	**p**	**p**	**p**
PRI	0.085				5.157				4.059			
CRI	0.031	0.955			2.651	0.541			1.248	0.984		
CSH	0.440	0.005*	0.004*		9.438	0.098	0.008*		2.296	0.996	0.999	
PSH	0.743	0.000*	0.000*	0.011*	12.054	0.000*	0.000*	0.415	22.698	0.012*	0.019*	0.024*

Site	**Fe**	**PRI**	**CRI**	**CSH**	**Pb**	**PRI**	**CRI**	**CSH**	**Zn**	**PRI**	**CRI**	**CSH**
F	11.43				4.52				22.44			
	Means	**p**	**p**	**p**	**Means**	**p**	**p**	**p**	**Means**	**p**	**p**	**p**
PRI	1819.7				7.015				10.895			
CRI	847.0	0.382			3.658	0.405			4.446	0.936		
CSH	1470.2	0.936	0.793		1.607	0.056	0.827		7.405	0.988	0.995	
PSH	3586.5	0.001*	0.000*	0.0018	8.053	0.921	0.127	0.007*	63.910	0.000*	0.000*	0.000*

(b)

study	**Cd**	**RI**	**Cr**	**RI**	**Cu**	**RI**	**Fe**	**RI**	**Pb**	**RI**	**Zn**	**RI**
F	75.38		36.248		8.065		14.854		0.005		27.266	
	Means	**p**	**Means**	**p**	**Means**	**p**	**Means**	**p**	**Means**	**p**	**Means**	**p**
RI	0.0656		4.251		3.042		1467.9		5.8		8.563	
SHB	0.66247	0.000*	11.362	0.000*	17.297	0.005*	3026.3	0.000*	6.346	0.699	48.953	0.000*

Table 2.7: Results of the Non-parametric, Spearman Rank Order Correlations between all environmental variables measured showing R Values. Significant R-values are at $p < 0.05$ after the Bonferroni adjustment.

	Cd	**Cr**	**Cu**	**Fe**	**Pb**	**Zn**	**% N**
Cd							
Cr	0.740*						
Cu	0.625*	0.677*					
Fe	0.595*	0.749*	0.896*				
Pb	0.332	0.509*	0.717*	0.716*			
Zn	0.730*	0.702*	0.881*	0.848*	0.679*		
% N	0.414*	0.554*	0.653*	0.663*	0.434*	0.592*	
Mean grain size	0.552*	0.470*	0.115	0.156	-0.209	0.259	0.240

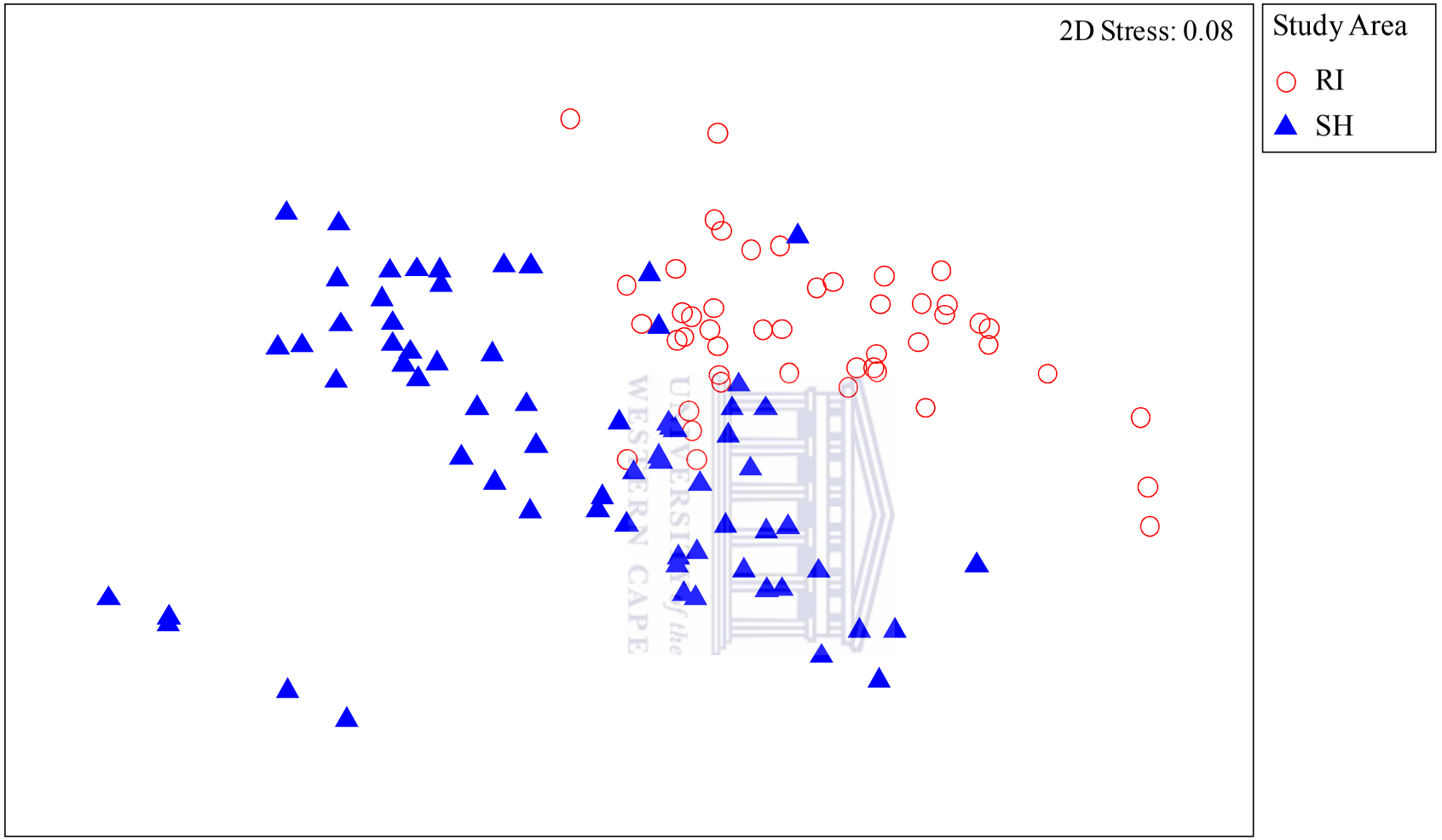


Figure 2.10: MDS ordination of the two study areas sampled using all environmental data. The data were log x+1 transformed and normalised. Euclidean distance was used to plot the samples. RI refers to Robben Island and SH to St Helena Bay.

Table 2.8: SIMPER (Similarity Percentage) of the two study areas using all environmental variables. A resemblance matrix using Euclidean distance was used in the analysis. Table (a) represents the average similarity between the four groups. The values in bold represent the environmental variables which contribute most to the similarity within each group. Table (b) represents the average dissimilarity between the two study areas and the environmental factors most responsible for the dissimilarity between the two study areas.

(a)

Site	RI	SH
Average squared distance	3.91	7.47
Environmental factor	% contribution	% contribution
Cd	4.83	5.51
% N	7.1	**19.03**
Mean Grain size	**10.56**	9.83
Zn	**13.13**	**12.36**
Fe	**14.03**	**15.22**
Cr	**15.42**	8.63
Cu	**16.99**	**13.1**
Pb	**17.93**	**16.33**

(b)

Groups RI & SH	
Average squared distance	19.52
Environmental Variable	% Contribution
Cd	17.35
Mean Grain size	14.22
Cr	14.22
Zn	12.49
Cu	11.56
Fe	10.81
Pb	9.68

Table 2.9: SIMPER (Similarity Percentage) of the control and pipeline sites of both sites using all environmental variables. A resemblance matrix using Euclidean distance was used in the analysis. The following table represents the average similarity between the four groups. The values in bold represent the environmental variables which contribute most to the similarity within each group.

Site	**PRI**	**CRI**	**PSH**	**CSH**
Average squared distance	3.2	2.59	6.98	3.01
Environmental factor	**% contribution**	**% contribution**	**% contribution**	**% contribution**
Cd	1.84	4.8	4.22	**19.52**
Zn	5.61	**19.96**	8.84	**10.35**
% N	7.81	1.76	**25.96**	0.37
Cr	**13.7**	**17.61**	**11.13**	9.3
Fe	**13.71**	**11.46**	**17.03**	**15.4**
Mean Grain Size	**15.31**	4.64	**11.74**	4.16
Cu	**18.35**	**18.89**	**12.19**	**11.14**
Pb	**23.67**	**20.88**	8.89	**29.76**

Chapter 3

The assemblage structure of foraminifera in two study areas along the SW coast of South Africa

Abstract

Sediment samples from around the Robben Island sewage pipeline and a fish factory pipeline in St Helena Bay were examined for foraminifera. Twelve stations were sampled in St Helena Bay and eight in Robben Island, six cores per station were examined. The top 5 cm of sediments within each core were examined. Foraminifera were size-fractioned (63 µm, 125 µm, 250 µm and 500 µm) and counted. A total of 300 foraminifera per samples were picked, separated into live or dead and identified to species level.

A total of 38 morpho species in the live assemblages were identified from both study areas. Samples from Robben Island had a significantly higher species richness (34) than those from St Helena Bay (28). The mean species diversity of the samples from St Helena Bay (1.69 ± 0.06) was significantly lower than that of samples from around Robben Island (2.17 ± 0.04), although the abundance of foraminifera in samples from St Helena Bay (537 ± 109) was higher than that from Robben Island (236.3 ± 23.6). The species diversity was lowest at the pipeline stations in St Helena Bay and highest at the Robben Island control sites. Species accumulation curves reached an asymptote, indicating that the sampling effort was sufficient.

Samples from St Helena Bay were dominated by *Ammonia parkinsoniana, Elphidium articulatum* and bolivinids, while those from Robben Island contained lower numbers of *Ammonia parkinsoniana* and a dominance of *Elphidium articulatum* and miliolids. The dominance of bolivinids and *Ammonia,* and the rarity of miliolids in St Helena Bay samples may be a result of organic matter accumulation and sedimentation due to the high retention time within the bay.

The structure of assemblages from St Helena Bay was different to that of Robben Island, although variability within the cores of each station was

very high, attesting to small scale variability/patchiness within the benthic environment. Samples from both study areas had a dominance of small foraminifera which may be a result of the cold temperate waters.

A significant relationship was found between the generic data and the species data of the live assemblages. This was conducted to determine whether generic data could be used as a proxy for species, in a study of this type, and whether they would provide sufficient information for interpretation, a relate statistic was performed.

The dead assemblages were examined separately to give an indication of the effect of taphonomic processes (such as transport and test dissolution). Although significant correlations were found between the dead and live assemblages were found, the correlation co-efficients were all low. The correlation between the live and dead assemblages in St Helena Bay samples (0.388) were lower than those in samples from around Robben Island (0.551) which indicates greater accumulation of dead tests, which could be an indication of a depositional environment. The rate of deposition within St Helena Bay could increase the risk of accumulation of pollutants.

3.1 Introduction

Communities in the marine benthic environment often show a hump-shaped relationship between diversity and depth. Shallow areas are typically less diverse due to the dominance of opportunistic species which are adapted to the fluctuating environment, while mid-depth waters are often more diverse due to greater stability, and very deep water shows another decrease due to less habitat variability (Flint & Holland, 1980). The factors that appear to govern the depth distribution of taxa in the marine environment are light transparency, a decrease in temperature and hydrodynamic energy (Cleary *et al*., 2005 in Samaai *et al*., 2010). The soft sediments of shallow water environments have been found to be dominated by polychaetes, while deposit feeding mollusks and crustaceans dominate the mid-depths and no particular dominance is found in the deep waters (Flint & Holland, 1980). Sponges off the east coast of South Africa appear to follow this trend of decreasing diversity with depth (Samaai *et al*., 2010).

Latitudinal gradients of species richness in the marine environment appear to follow the same pattern as those of the terrestrial environment, that is, a decrease in species richness with an increase in latitude (Hillebrand, 2004). These gradients are thought to be a result of seasonal variability and the greater range of environmental conditions experienced at higher latitudes (Samaai *et al*., 2010). Weak gradients have been found in aquatic macrophytes, sediment infauna and unicellular eukaryotes; the weak gradient in unicellular eukaryotes like diatoms and other protists have been thought to be a result of their low body mass (Hillebrand, 2004). In a comparative study of benthic nematodes, polychaetes and molluscs across latitudinal gradients, no clear trends or changes in the species diversity were identified with latitude (Gobin & Warwick, 2006). Benthic diversity has also been found to be negatively affected by the increase in the input of phytodetritus, although, these effects have been found to vary with habitat, depth and study area and often short-term due to the rapid utilization by benthic organism (Quijón *et al*., 2008).

To date, approximately ~2140 extant benthic foraminiferal species have been formally described, 701 from marginal marine environments, 989 from the shelf and 831 from the deep sea (Murray, 2007). Only 33 % of these have been found to be in large abundance (> 10 %) while 67 % are of minor abundance, most being rare and endemic

and few being cosmopolitan (Murray, 2007). Studies in most areas have reported a low species richness of between 20 and 80 species, with the greatest numbers being identified in lagoon areas (180 – 340) and on the European coast, although these numbers may be a reflection of the number of studies conducted there rather than an indication of a species rich environment (Murray, 2007).

In the deep-sea, comparisons between foraminifera and metazoan meiofauna (nematodes and harpaticoid copepods) have shown that foraminifera did not exceed these taxa in abundance but sometimes did exceed them in biomass (Bernhard *et al*., 2008). The density and biomass of foraminifera also did not consistently vary with depth (Bernhard *et al*., 2008).

Foraminiferal tests remain in the sediments after death, and can provide an idea of environmental conditions (Yanko *et al*., 1999; Scott *et al*., 2001; du Châtelet *et al*., 2004). In ecological studies, live foraminifera are examined as they can provide an indication of the present environmental conditions, and dead assemblages are studied to provide an indication of post-mortem processes (Murray, 1991). The study of dead assemblages in ecological studies can assist in the interpretation of taphonomic changes like the transport of tests and test dissolution (Murray & Pudsey, 2004). Differences between live and dead assemblages in an area could be indicative of depositional sinks (Alve & Murray, 1997).

Foraminifera have short life-cycles and respond quickly to changes in the environment, both positively and negatively, and they are therefore useful bio-indicators. Most environmental studies involving taxa have concentrated on identifying biofacies or proxies, that is, species or assemblages that can be used to identify a particular set of environmental conditions (Pielou, 1979; Murray, 2001). Opportunistic taxa could be identified as proxies as these species would tend to dominate environments which have become harmful to those with a limited tolerance range (Culver & Buzas, 1995). Taxa that have typically been reported in these studies have been species of the genera *Bolivina* (which are small foraminifera) and *Ammonia*, as both taxa appear to have a wide tolerance to a range of environmental factors (Frontalini *et al.,* 2009). Although genera and species have been identified as bio-indicators in previous studies, Murray (2001) is of the opinion that studies should identify assemblages rather than species as proxies.

In any study of foraminiferal assemblages, it is important to take patchiness of distribution into account (Gooday & Lambshead, 1989), as foraminifera are meiofauna and respond to changes in the micro-environment as found in other benthic fauna (Flint & Holland, 1980; Murray, 1991). Clumping of foraminifera often occurs when opportunistic species reproduce quickly in response to an increase in the food source and increase their numbers (Murray, 2001).

The aim of this chapter is to describe foraminiferal communities (live and dead) and their size structure at two study areas on the west coast of South Africa, namely, St Helena Bay and Robben Island. These assemblages will be compared to those of other studies glaobally. The assemblages were also examined at generic level, to determine whether genera could be used as proxies for species. The influence of taphonomic processes on the communities will also be examined.

3.2 Materials and Methods

3.2.1 Field Sampling

Please refer to Chapter 2 for a full description of the field methods employed (Fig. 2.3 and 2.4). Essentially, twelve stations were sampled in St Helena Bay, nine of these stations were randomly selected within a 150 m radius of the fish factory outfall (pipeline sites) and three stations were selected as the control site (3.6 km, 1.5 km and 0.9 km from the pipeline). Around Robben Island, a total of eight stations were selected, five of them within a 225 m radius of the outfall (pipeline sites) and three between 190 m and 300 m from the pipeline (control sites). SCUBA divers used hand-held *Hagge corers* (Fleeger *et al*., 1988) to obtain sediment samples. Each core was 30 cm long and had a diameter of 3.57 cm. Where possible, 6 cores per station were collected. Samples were kept on ice in the field and frozen on return to the laboratory.

3.2.2 Laboratory Analyses

3.2.2.1 Foraminiferal assemblages

Subsamples from the top 5cm of the sediment core were preserved in 70 % ethanol with Rose Bengal stain. Rose Bengal was used to stain foraminifera because this stain gives an indication of which foraminifera were alive at the time of collection as it

stains protoplasm pink (Murray, 1991). Sediments from each core were size fractioned using mesh sizes 63 µm, 125 µm, 250 µm and 500 µm. Carbon Tetrachloride was used to separate foraminifera from the sediments (Murray, 1991). Each size fraction was examined for foraminifera using a stereoscopic dissecting microscope at 80 x magnification. Specimens were placed in water for examination as this assists in the recognition of stained tests (Berkeley *et al*., 2008). Live and dead foraminifera per size fraction were counted separately.

Where possible, 300 foraminifera per sample were picked and mounted onto a slide for the identification of species; these were also separated into live and dead specimens. It was difficult to determine the exact numbers of species in all instances, as bolivinids, for example, are difficult to consistently identify under normal light microscopy. The bolivinids were therefore grouped into elongated bolivinids and perforated bolivinids. That said, some species of bolivinids could be consistently identified, for example, *Bolivina pseudoplicata*, *Brizalina pseudopuncata, Bulimina elongata* and *Bulimina elegantissima.*

3.2.3 Statistical Analyses

3.2.3.1 Live Foraminiferal Community Structure

Thirty-eight species were used in the analyses. The bolivinid species and specimens of foraminifera from the genera *Fissurina*, *Oolina* and *Lagena* were similarly hard to separate and were grouped as genera rather than identified into species.

Dominant species were determined for each station as well as for the control and pipeline sites. The diversity indices, namely, species richness (S), evenness (J') and species diversity (H') were determined using PRIMER software. These diversity indices have commonly been used to assess the impact of disturbance on the marine environment. Other estimators of species richness were also considered using the *EstimateS* 8.2.0 program (Colwell, 2009). These were only conducted on the live assemblages as the nature of this study is ecological. The estimators ICE (incidence-based coverage estimator), Chao 2 and Jackknife 2 were chosen as they are regarded as more robust when assemblages are prone to patchy spatial distributions and additionally they are relatively insensitive to sample size (Lambshead *et al*., 2003). Chao 2 is non-

parametric and based on the number of species with one and two individuals per species, this estimator was found to overestimate species and a very large sample size is required before it was found to be a reliable estimator (Gray, 2000).

In order to determine whether the sampling effort was sufficient to determine diversity, species accumulation curves were plotted of the observed species richness against the sample number for each study area and for the pooled data using Colwell's *EstimateS* 8.2.0 program. The program calculates species accumulation curves for randomized samples without replacement (Colwell, 2009). Models were fitted to the observed data using non-linear regression in the program CurveExpert 1.4 which provided the best fit to the data as the sigmoidal MMF Model with the equation y=(a*b+c*x^d)/(b+x^d). The shape of the rarefraction curve depends on the relative abundance of sampled species and the fitted model provides a prediction of the increase in richness with additional sampling effort (Colwell & Coddington, 1994).

In order to visualize the similarity of the assemblages between all samples, a similarity matrix of all samples was constructed using the Bray-Curtis Similarity Index on fourth root transformed data with group average linkage, and a cluster analysis was performed on this to construct a dendrogram. Fourth-root transformation reduces the distortion of similarities calculated between samples by rare or dominant species (Clarke & Gorley, 2006). The Bray-Curtis Similarity Index was used for biological data as it appears to follow natural biological axioms not found in other co-efficients (Clarke & Gorley, 2006). To plot the relationships between all stations of the control and pipeline sites, an MDS (Multi-dimensional Scaling) Ordination was performed on same similarity matrix.

To determine which species were most responsible for the similarity within and the dissimilarity between, each site, a SIMPER (Similarity Percentage) was performed on the assemblages of each study area separately and together. This SIMPER provided an idea of the species that may have been different between the two study areas. To determine the partition variation within the live species data between sites, stations and cores of each study area and for the pooled data, PERMANOVA was conducted on the fourth root transformed species data, it provided an indication of which of these groupings displayed

the most variation. This provided tool for the evaluation of micro- or macro-scale variation of the foraminifera from the samples.

In order to determine whether genera rather than species, would be sufficient to use in the evaluation of communities, species data were reduced to generic data. These data were fourth –root transformed and a similarity matrix was produced using the Bray-Curtis similarity index, group average linkage and cluster analysis provided a dendrogram. To determine the correlation between the generic and species data, their similarity matrices of the species data and the generic data were then subjected to a Relate statistic using PRIMER software. The non-parametric correlation coefficient (Rho) indicated whether these two matrices were significantly correlated.

To determine whether any significant differences in the abundance of specimens per genus occurred between the control and pipeline sites and each station of both St Helena Bay and Robben Island, one-way ANOVA's were used with a Bonferroni adjustment.

3.2.3.2 Size structure of live foraminiferal communities

Foraminifera separated into size classes were used for these analyses, no separation into species was done. One-way ANOVA was used to determine any differences between the abundance of foraminifera per size class between the control and the pipeline sites of both study areas. A post-hoc comparison of means was performed using the Tukey Honest Significant Difference Test.

A similarity matrix was constructed using fourth-root transformed data, the Bray-Curtis Similarity Index with group average linkage and a cluster analysis was performed to construct a dendrogram (Clarke & Gorley, 2006). An MDS Ordination was performed in on the similarity matrix of the live foraminifera in order to visualise the relationship between all stations of the control and pipeline sites.

3.2.3.3 Dead Foraminiferal Assemblages

Dominant species were determined for each station as well as for the control and pipeline sites. To illustrate the similarity between the dead assemblages of all samples, a similarity matrix was constructed using the Bray-Curtis Similarity Index on fourth root transformed data with group average linkage. A cluster analysis was performed on this to

construct a dendrogram. In order to plot the relationships between all stations of the control and pipeline sites, an MDS Ordination was performed on the assemblages from each sample. To determine which species were most responsible for the similarity within and the dissimilarity between each site, a SIMPER (Similarity Percentage) was performed on the assemblages of each study area separately and together. To provide an indication of whether there were similarities between live and dead assemblages of all samples, a RELATE statistic was conducted. Similarities or differences between the assemblages could give an indication of taphonomic processes.

ANOVA was used to determine any significant differences between the abundance of foraminifera between the control and the pipeline sites of both study areas. A post-hoc comparison of means was performed using the Tukey Honest Significant Difference Test.

A similarity matrix was constructed using fourth-root transformed data. The Bray-Curtis Similarity Index with group average linkage was utilized and a cluster analysis was performed to construct a dendrogram (Clarke & Gorley, 2006). An MDS Ordination was performed on the same data in order to visualise the relationship between all stations of the control and pipeline sites. A RELATE statistic was conducted between the abundance of live and dead foraminifera to establish the correlation between them.

3.3 Results

3.3.1 Live Foraminiferal Community Structure

Twenty eight morphospecies of foraminifera were identified from the samples collected from St Helena Bay and 34 from around Robben Island; 38 morphospecies were collected in total from the two study areas (Appendix 3.1; 3.2)). Most species were present in all samples and in all size classes. *Elphidium articulatum* was the most common species in Robben Island samples (Table 3.1) while *Ammonia parkinsoniana* was most abundant in the live assemblages of St Helena Bay samples (Table 3.2). Robben Island samples were also characterized by a high abundance of *Cibicides lobatulus, Quinqueloculina seminulum* and *Glabratella australensis.* With the exception of *C. lobatulus,* the other species did not form a major component of the assemblages in St Helena Bay. The bolivinids, which were also important in the assemblages of St Helena Bay, did not form a major component in Robben Island samples.

The species richness (S) of the live community was lowest at the pipeline sites in St Helena Bay, particularly at stations SHD, SHE and SHF (Table 3.3). The samples from the stations around Robben Island displayed a higher species richness than those of St Helena Bay samples, particularly the control site RIH. The species diversity (H') was highest in the Robben Island samples and in the control sites from St Helena Bay (Table 3.3). The species diversity was lowest at the St Helena Bay pipeline sites SHC and SHD, while it was highest at the Robben Island control sites (RIH). Evenness (J') did not differ much between sites and values were approaching unity, an indication that the numbers of individuals were almost evenly spread across the species (Table 3.3). The abundance of live foraminifera was highest around the control sites in St Helena Bay while all other sites were generally low with the lowest abundance at the pipeline sites of St Helena Bay (Table 3.3).

Species richness in the samples from the Robben Island sites (14 ± 0.5) was significantly higher than those of St Helena Bay (9 ± 0.5) ($p < 0.000\ 1$; $F\ (1, 113) = 33.87$). Similar differences were observed in the diversity (St Helena Bay – 1.69 ± 0.06; Robben Island – 2.17 ± 0.04; $p < 0.000\ 1$; $F\ (1, 113) = 36.92$). The abundance of foraminifera was significantly lower (St Helena Bay – 537 ± 109 / 10 cm^3; Robben Island – 236.3 ± 23.7/ 10 cm^3 ; $p = 0.02$; $F\ (1, 113) = 5.066$). When examining the control and pipeline sites of both study areas, the pipeline sites of St Helena Bay had a significantly lower species richness ($p = 0.0001$; $F\ (1, 66) = 46.53$) and diversity ($p = 0.001$; $F\ (1, 66) = 15.85$) than the control sites of St Helena Bay as well as all sites of Robben Island. However, the control sites of St Helena Bay had a significantly higher abundance ($p = 0.0001$; $F\ (3, 111) = 34.065$) of foraminifera than all other sites.

The species accumulation curves of St Helena Bay samples (Fig. 3.1 (a)), Robben Island samples (Fig. 3.1 (b)) and the pooled data (Fig. 3.1 (c)) reached an asymptote after 15 to 20 samples indicating that the sampling effort was sufficient to determine the richness of the sites. The fitted extrapolation curve, the sigmoidal MMF curve, provided an indication of the estimated richness in the sites and all three graphs fitted the model with a correlation co-efficient of 0.999 (Table 3.4). Table 3.5 compares the observed species richness with that estimated by the MMF model, which was slightly higher than the observed richness, except for the St Helena Bay samples where the estimate was

lower than the true species richness. The ICE and Chao 2 were the same as the observed total species richness for the St Helena Bay samples but not for the Robben Island samples. The Jackknife 2 calculation underestimated richness for the pooled data and the St Helena Bay samples but overestimated richness for the Robben Island samples.

The cluster analysis (Fig. 3.2) of the live assemblage per sample, for both study areas, showed high variability between the cores from the same station. Robben Island and St Helena Bay samples nevertheless grouped separately from each other with a similarity percentage below 40 %, indicating that there are differences in assemblage structure between the two study areas. In St Helena Bay, the pipeline sites and the control sites mostly grouped separately, although cores from SHA and SHB also grouped with those of the control sites. Robben Island samples however overlapped and there was no clear grouping of the control and pipeline sites. An MDS ordination of the two study areas (stress 0.17) showed much the same as the dendrogram (Fig. 3.3): there was a definite difference between the Robben Island and St Helena Bay assemblages. A large amount of overlap occurred between the control and pipeline sites of Robben Island but some separation was evident in St Helena Bay.

The results of the SIMPER analysis of the live assemblages of St Helena Bay samples revealed that *A. parkinsoniana, E. articulatum, Elphidium macellum, C. lobatulus* and *Pararotalia nipponica* were most responsible for the similarity within the control sites (69.84 %), all with similar percentage contributions of under 15 % (Table 3.6). In the pipeline sites, *A. parkinsoniana, Bulimina eleganitissima,* elongated bolivinids*, Rosalina globularis* and *Trochammina squamata* were the main species contributing to the similarity within the group (44.09 %). *A. parkinsoniana* dominated this assemblage with a percentage contribution of 34 %. The dissimilarity between the two groups (55.56 %) was mainly as a result of the differences in the contribution of *E. articulatum, P.nipponica* and *C. lobatulus* - all with just under 5 % contribution to the dissimilarity.

The similarity within the control sites (62.44 %) and the pipeline sites (60.14 %) of the live assemblages of Robben Island were a result of the contributions by *E. articulatum, R. globularis, C. lobatulus, Miliolinella subrotunda* and *Miliolinella seminulum* (Table 3.7). The average dissimilarity between the two groups was only

40.34 % caused by the differences in the contribution of *Glabratella australensis, P. nipponica,* Bolivinitidae and *Quinqueloculina isabellei.* Upon examination of the two study areas, St Helena Bay samples showed a similarity of 45 % as a result of *A. parkinsoniana, B. eleganitissima, e*longated bolivinids, *R. globularis* and *E. articulatum* (Table 3.8). Robben Island (60.61 % similarity) samples were characterised by *E. articulatum, C. lobatulus, R. globularis, Miliolinella subrotunda* and *Quinqueloculina seminulum.* The average dissimilarity between the two study areas was 68.7 % which was mainly a result of the differences in the average abundance of *A. parkinsoniana, M. subrotunda, Q. seminulum* and *E. articulatum.*

The nested PERMANOVA using site, stations and cores of St Helena Bay showed that 33.1 % of the variation within the data was due to the differences between the composition of the fauna of the control and pipeline sites, and the least variation occurred between stations within the two sites (16.85 %) (Table 3.9). The largest percentage of the variation occurred between the cores within the stations themselves (50 %). The nested PERMANOVA using site, stations and cores of Robben Island showed that only 8.9 % of the variation within the data was due to the differences between the composition of the fauna of the control and pipeline sites, and most variation occurred between all the stations within the two sites (31.03 %) and between samples within each station (60.05 %) (Table 3.10).

The nested PERMANOVA using all samples of the two study areas, sites, stations and samples showed that 33.1 % of the variation within the data was due to the differences between the two study areas, while the most variation was still between samples (35.41 %) (Table 3.11). In other words, there is a high degree of mesoscale variability in foraminiferal assemblage structure.

In summary, the SIMPER analyses showed clear differences in terms of the species of the live assemblages and their related contribution between the two study areas, while the dissimilarity between the control and pipeline sites of St Helena Bay was also more marked than that of Samples from around Robben Island, further evident in the cluster analysis and the MDS ordination. The PERMANOVA conducted showed large scale within station variation of foraminiferal community structure for both study areas while St Helena Bay samples shows clear differences between the control and pipeline sites

which were not evident in the community structure of Samples from around Robben Island. The two study areas were therefore obviously different in terms of community structure, which was also further supported by the ANOSIM, cluster analysis and MDS ordination.

The generic data was very similar to that of the species data, with the control and pipeline sites of Robben Island overlapping, but the St Helena Bay control sites grouped separately from the pipeline sites (Appendix 3.4). The Relate statistic between the species resemblance matrix and that of the generic data had a Rho value of 0.645 and a p – value of 0.001 which shows that the two data sets are significantly correlated and that generic data could possibly be used as a proxy for species.

The genera (of the live assemblages), that were most abundant in all the assemblages of St Helena Bay, were *Ammonia, Bolivina, Elphidium, Cibicides and Rosalina* (Fig. 3.4). All these genera were significantly more abundant at control sites than at pipeline sites, with the exception of *Rosalina* which was not significantly different (Table 3.12). An ANOVA of the five genera in each station revealed that generally SPA, SPB and SPC (control sites) had higher mean abundances of these genera than sites nearer the pipeline, no significant differences could be found with the genus *Rosalina* (Table 3.13). *Elphidium* and *Cibicides* appeared to have the most significant differences between the stations of the control site and those of the pipeline sites. The genera with the most abundance of specimens in samples from around Robben Island were *Bolivina, Elphidium, Cibicides, Quinqueloculina* and *Rosalina* (Fig. 3.5). *Bolivina, Quinqueloculina* and *Rosalina* were significantly more abundant at control sites than at pipeline sites (Table 3.14). An ANOVA of the five genera in each station revealed that generally *Rosalina and Quinqueloculina* were not significantly different between stations, however, RIE (pipeline station) consistently showed significant differences in terms of *Bolivina, Cibicides* and *Elphidium* (Table 3.15).

3.3.2 Size Structure of Foraminiferal Communities

Foraminiferal specimens in the 63 μm and 125 μm size classes dominated the live assemblages in both St Helena Bay and Robben Island samples (Table 3.16, Fig. 3.6, Appendix 3.5; Appendix 3.6). A larger percentage of small foraminifera dominated at the

pipeline sites than the control sites in both study areas. The abundance of live foraminifera at the pipeline sites were significantly lower than that of the control sites in the 63 µm, 125 µm and 250 µm size classes in the St Helena Bay samples. In the Robben Island samples, the abundance of the small foraminifera (63 µm and 125 µm size classes) was higher at the pipeline site but foraminifera lower in the 250 µm and 500 µm size classes; there was only a significant difference in the 500 µm size class.

A cluster analysis of the abundance of live foraminifera separated into their size classes revealed a high similarity between samples from around Robben Island and St Helena Bay samples, although the control sites of St Helena Bay did mostly group teogether (Fig. 3.7). The grouping or separation between sites or study areas was not clearly defined in the size structure of live foraminifera, revealing no particular patterns in study area, sites or stations. An MDS of the live assemblages showed that all samples from both study areas displayed a large degree of overlap (Fig. 3.8).

3.3.1 Dead Foraminiferal Community Structure

Elphidium articulatum was the most common species in the Robben Island (Table 3.17) and St Helena Bay samples (Table 3.18) in the dead assemblages. As for the cluster analysis and the MDS Ordination of the live assemblages, the dead assemblages also showed a separation between the St Helena Bay and Robben Island samples with a similarity of about 50 % (Fig. 3.9 and Fig. 3.10). The samples of the control and pipeline sites of both study areas did not separate from each other.

The Relate statistic for live and dead assemblages for all samples, St Helena Bay and Robben Island samples separately, show a significant relationship (Table 3.19). The correlation co-efficients (Rho) for all three tests were relatively low, an indication that there is a difference between the live and dead assemblages. The correlation co-efficient between the St Helena Bay live and dead assemblages are even lower than that of samples from around Robben Island, showing an even greater difference live and dead assemblages.

The SIMPER of both study areas (Table 3.20 and Table 3.21) also showed that the average dissimilarity between the control and pipeline sites was low (38.91 % and 37.17 %, respectively). The SIMPER between the two study areas showed an average

dissimilarity of 54.72 % (Table 3.22). The species most responsible for the differences in the community structure in both study areas reflect those of the live assemblages, namely the bolivinids, *A. parkinsoniana, M. subrotunda, M. seminulum* and *Q. isabellei.*

The dead assemblages were dominated by foraminifera in the 63 µm and 125 µm size classes, with the 250 µm and 500 µm contributing small amounts (Fig. 3.11). The size structure of the dead assemblages of the St Helena Bay samples only have significant differences between the control and pipeline sites in the 250 µm size class, while the Robben Island samples have significant differences in the 250 µm and 500 µm size classes (Table 3.23).

A cluster analysis of the abundance of dead foraminifera separated into their size classes revealed a high similarity between samples from around Robben Island and St Helena Bay samples (Fig. 3.12). No real grouping of or separation between sites or study areas occured, revealing overlap in the study areas, sites and stations. The MDS of the dead assemblages further displayed the levels of overlap (Fig. 3.13). This pattern follows that of the size structure of the live foraminifera. A RELATE statistic between the abundance of live and dead foraminifera of all samples, St Helena Bay and Robben Island samples, was significant, however, the correlation coefficients were very low (Table 3.24). These low co-efficients may reveal that some differences between the abundance of live and dead assemblages does occur.

Non-parametric Spearman rank order correlations between the mean size of foraminifera in the live and dead assemblages of St Helena Bay, Robben Island and all samples together were significant (Table 3.25). No significant differences were found in the mean size of live foraminifera between Robben Island and St Helena Bay (Table 3.26). However, there was a significant difference in the mean size of dead foraminifera, with Robben Island having a larger mean size of dead foraminifera.

3.4 Discussion

3.4.1 Community Structure

Thirty-eight species of foraminifera were identified. This species number may be higher but many species could not be consistently identified, especially those that were of small size. Previous studies have shown that using morphotypes, or even just separating

foraminifera based on their test shape, can be useful for ecological studies, as the shape of the foraminifers often determine where they would live (Bernhard, 1986). According to Debenay *et al.* (2001), commonly occurring species can explain the characteristics of an area just as well as using all species. Morphotypes are often considered to be equivalent to species for the purpose of biodiversity studies (Lambshead *et al.,* 2003).

Ammonia parkinsoniana was present in the largest abundance throughout the St Helena Bay samples in the live assemblages, but was absent or rare in Robben Island samples. The genus *Ammonia* has been reported as opportunistic and found in most types of environments, even those experiencing chemical stress (Seiglie, 1971; Alve, 1987; Yanko *et al.,* 1994; Scott *et al*., 2001; Ferraro *et al.*, 2006; Bergin *et al*., 2006).

E. articulatum and *E. advenum* were also present in large numbers in both St Helena Bay and Robben Island samples. *E. excavatum* has the ability to change from an epifaunal to an infaunal habitat and appears to be highly adaptable to food and environmental changes (Debenay *et al*., 2001). *Elphidium* feed mainly on diatoms; in an area with increased productivity, diatom abundance increases with an incremental increase in *Elphidium* (Thomas *et al*., 2004). When diatoms are not in large abundance, *Ammonia* tends to be present in higher abundance than *Elphidium* (Thomas *et al*., 2004).

C. lobatulus were also present in large numbers at the stations around the pipeline in St Helena Bay. This species is associated with hard surfaces and coarse sediments and does not live in sandy sediments (Murray, 2001). The area surrounding the study site at St Helena Bay is typically rocky with a large mean sediment size and represents an ideal habitat for this species.

Bolivinids were dominant in the samples around the pipeline in St Helena Bay. Bolivinids have an elongated, tapering shape: this genus is known to be infaunal, capable of living 6 – 8 cm below the surface, because of lower oxygen levels deeper in the sediments, and they are thought to be able to survive anoxic conditions better than other groups (Stott *et al.*, 1996). The miliolids which were rare or absent in St Helena Bay samples were very common in most samples around Robben Island. The miliolids are generally warmer water species which could explain their higher dominance in Robben Island samples (Murray, 1991), as some injection of warmer waters from the Agulhas Current does occur in the area.

Agglutinated foraminifera were absent in samples, this was also the case in Israel (Yanko *et al*., 1994) and was attributed to the warm water in the bays that were studied. The absence of live or dead agglutinated tests in samples could also be a result of the fact that these tests are very weakly held together by organic material and do not often last for very long after death (Murray, 1991), therefore, they deteriorate very quickly, unless examined immediately after careful collection, fixation and preservation. Calcareous species dominated assemblages, while hyalinated species were less abundant; this was also the case in a study in France (Debenay *et al*., 2001).

The species-accumulation curves for both sampling study areas reached asymptote and estimates of species richness were close to the observed species richness within the areas. This implies that the sampling effort was sufficient (Colwell & Coddington, 1994). The fact that asymptotes were reached and the curves did not differ appreciably from the fitted models indicates that all samples came from a relatively homogenous spatial habitat (Colwell & Coddington, 1994). Habitat variation or heterogeneity is regarded as a driver of functional composition and diversity and coastal areas which are non-degraded are known for a higher diversity as a result of this high habitat variation (Hewitt *et al*., 2008). Homogenous coastal areas which have lost previous habitat diversity due to development or dredging activities, display decreased diversity or a change in the taxa to more colonizing species (Airoldi *et al*., 2008). Variability within aquatic systems is thought to be a result of this heterogeneity and the tendency of patchiness within benthic organisms (Flint & Holland, 1980).

Some of the non-parametric estimators, particularly the Jackknife 2, under-estimated species richness and this is thought to be a result of small-scale patchiness in species composition which is evident in the samples of this study (Butler & Chazdon, 1998). Gray (2000) is of the opinion that one measurement of diversity is not sufficient or robust enough for different environments or taxa and that a suite of measurements should be used. However, the differences between the various estimators and the observed species richness were not very large, an indication that in this study, the use of the observed species richness would be sufficient.

Evenness in both study areas was high, therefore there was a lack of dominance by any particular species. This suggests that species have been environmentally filtered and

would share many traits (Hewitt *et al*., 2008). It also reflects the potential for the maintenance of ecosystem function even with the loss of individual species (Hewitt *et al*., 2008). Foraminiferal assemblages in both study areas were largely homogeneous at the mesoscale, and most species were present in all samples. The high evenness may also reflect the homogeneity of the habitat; high variation in habitat normally leads to higher diversity and lower evenness as more species are able to inhabit the area.

The species found were much less than the cumulative number reported from other studies around South Africa (Appendix 1.1). The studies which were reported on were from a wide variety of study sites from deep sea to coastal, most were geological studies and from different geological eras and some were on different coasts (east, south and west coasts which support different assemblages of most organisms). This species richness was also compared to some previous studies in coastal areas (Appendix 3.3 (a) and (b)). Most authors reported between 20 and 100 species of foraminifera, but the species richness varied between samples depending on the location of the sampling site. Authors also reported a high dominance of only three or four species with most species being rare in samples.

Murray (2007) reported that studies on the shelf areas of Africa reported only 28 benthic species, much lower than other shelf areas. He was of the opinion that this has something to do with the lack of studies in the area. Other authors investigating foraminiferal assemblages in shallow water environments have reported a varying number of species, depending on the location of samples; these varied from no live species in areas of strong contamination to about 100 species in non-polluted areas. In a study in Havstens Fjord, Sweden, the pattern in species richness appeared to be related to depth, where the shallowest areas had the lowest species richness due to a larger influence by seasonal fluctuations (Gustaffson & Nordberg, 2000). Buzas *et al.* (2007) reviewed the community structure of benthic foraminifera in the Gulf of Mexico, finding that shallow (S = 22) and deep environments (S = 12) were less species rich, whereas the mid-depths were the most species rich (S = 44-86). Deep-sea benthic foraminifera appear to display a decreasing diversity with increasing latitude in the North and South Atlantic and greater diversity in the South than the North (Culver & Buzas, 2000). These differences appear to be a result of differing phytodetritus supply and originated more

than 36 million years ago (Culver & Buzas, 2000). Latitudinal gradients have been found in shallow water foraminifera which have been attributed to its dispersal capabilities; other meiofauna, like nematodes, have not displayed these gradients and this is thought to be due to the group's lack of dispersal abilities (Culver & Buzas, 2000).

Patterns of distribution of foraminifera are dependent on a broad range of factors including depth, oxygen levels and organic matter flux (Murray, 2001). Ecological factors would determine the range of species, and the number of species could vary both spatially and temporally even in the same area. The number of species found in this study is not much different from what could be encountered in shallow water environments that are highly variable. Many authors reporting on the richness and diversity of foraminifera report a large percentage of rare species with only 4 or 5 species making up the largest abundance (refer to authors in Appendix 3.3 a). Authors that reported high species richness had conducted sampling of the same area over a period of time (eg. Gustfsson & Nordberg, 2000; Bernhard *et al*., 2001), sampled at a greater depth than that of this study (eg Yanko *et al.,* 1994; Romano *et al*., 2008) and/ or had conducted research on deep cores (Tsujimoto *et al*., 2006) which were more than just the top few centimeters of sediments, these studies sometimes did not distinguish between live and dead. Foraminiferal assemblages reported in most studies do not appear to be very diverse, with few species being common, this despite their potential to be transported easily in the marine environment.

The number of species reported in an area also appears to be dependent on the conditions that the area was subjected to at the time of sampling, for example, an increase in organic matter causes an increase in the type of species that could inhabit the area. Foraminifera, as in other meiofauna, respond to changes in the micro-environment spatially and temporally, therefore repeated sampling of the same area could yield different numbers and proportions of species.

In a study of marine nematodes in Saldanha Bay on the west coast of South Africa, Hendricks (unpublished) found between 5 and 36 species per sample but cumulatively there were 136 species; these nematodes varied with season as well as the level of disturbance within the bay. The degree of patchiness and variability in these nematodes appear to be of a larger scale than observed in foraminifera in this study. A temporal

study of foraminifera on the west coast might yield similar results for foraminifera as the area experiences seasonal variation in organic matter and phytodetritus input.

While some foraminiferal studies have used morphotypes and test shape in biodiversity studies Bernhard (1986), the use of genera, which are more easily identified than species in foraminifera, has been relatively unexplored. With the growing evidence that biological assessments at species level is very expensive as it requires large numbers of manpower, authors like Williams & Gaston (1994) proposed the use of higher taxon richness as surrogates for species richness. Balmford *et al.* (1996) examined higher taxon richness (genus and family) in woody plants as measures of species diversity. They concluded that in their study, information from higher taxon richness was comparable to that of species richness. Their concerns were the reduction of information on in-site variation and whether the trade-off between cost savings and the loss of specific information was worth it. Andersen (1995) tested this theory using Australian ant fauna, these ants are used extensively as bio-indicators in environmental assessment in Australia, their species taxonomy is poorly known but their genera are clearly defined. Andersen (1995) found that the species: genus relationship was only good when there were few habitat and biogeographic differences in an area and when a genus was represented by few species. He concluded that although, the relationship can work well on organisms which are difficult to identify (invertebrates and insects) there is some masking of detailed information.

While most authors conclude that the use of genera is sufficient, they also advise that caution should be used and each taxon and area should be assessed individually; Grelle (2002) in assessing mammal diversity in the Amazon and Central America, Prinzing *et al.* (2003) in the assessment of woddy plants in Kenya, Cardoso *et al*., (2004) assessing spiders in Portugal and Mazaris *et al*. (2008) in the assessment of birds, mammals, amphibian and reptiles in Greece. The species and generic data for all sites in this study were significantly related and it was evident that in this study, the use of generic data would be sufficient for use in an ecological or diversity study on foraminifera and identification of species would only really be necessary for pure taxonomic studies. Foraminifera are particularly difficult to identify at species level but the genera have been

clearly defined by Loeblich & Tappan (1987) and are widely use. The labour intensive factor could also be reduced in future studies on environmental assessment.

The variability in foraminiferal assemblages both between cores, stations and sites was found to be extremely high and it is very difficult to pinpoint clear patterns in the data. The large amount of variability occurs as a result of patchiness of distribution especially of meiofauna which occurs within the benthos. One of the reasons for patchiness is the variability in food source and organic matter input at the sediment-water interface (Lavigne *et al*., 1997). Some opportunistic foraminferal species can exist in very small numbers when unfavourable conditions occur but as soon as conditions improve, especially an increase in organic matter input, they reproduce rapidly in those micro-environments (Murray, 2001). Some species respond to changes in food levels faster than others and assemblage structure can change at a micro-level, a quick response may be favoured by the short life cycle, of small paralic species, that may be as short as one month (Morvan *et al*., 2006). Species were counted based on their size and whether they were live or dead at the time of sampling. Planktonic species found in the samples were excluded from the statistical analyses of community structure, as planktonic species are assumed to have no function within the benthic environment. More species were identified in the samples from Robben Island than in those from St Helena Bay samples, and there may be a variety of reasons for this. Robben Island is in the transitional zone for two biogeographic provinces on the west coast of South Africa, the Namaqua Province and the Agulhas Province (Bustamante & Branch, 1996). Transitional zones often have species which would be common to both regions, therefore Robben Island would have both warm and cold water species. St Helena Bay, on the other hand, is in the cold temperate province and would therefore not have species found in warmer temperate provinces (Bustamante & Branch, 1996).

3.4.2 Size Structure of Foraminiferal Communities

Live foraminifera were much more abundant around the control than the pipeline sites of both study areas and highest at St Helena Bay. In a previous study in Saldanha Bay on macrofauna around a fish factory it was also found that abundances tended to increase away from the pipeline as the toxic effects of the effluent are diluted and the increased

organic carbon loading can be taken advantage of by increasing reproduction of the organisms (Christie & Moldan, 1977). The ratio of live:dead foraminifera was much lower at the pipeline sites i.e. more dead than live tests, the small number of live tests attests to foraminiferal response to conditions when sampling took place.

The dominance of smaller foraminifera in samples within communities has been regarded as an indication of pollution (Yanko *et al.*, 1994; Samir *et al*., 2001) and anoxic environments (Bernhard, 1986). However, the area in which sampling took place is cold, temperate which is generally characterized by smaller organisms than warmer waters.

3.4.3 Dead Foraminiferal Assemblages

The separation of live and dead tests of foraminifera may lead to some errors even when using Rose Bengal stain. There is some evidence that preserved protoplasm can stain for at least three months after death especially in anoxic environments (Gustafsson & Nordberg, 2000). Despite this flaw, Rose Bengal is still the only practical way to distinguish between live and dead tests, and is said to lead to 96 % correct identification (Frontalini & Coccioni, 2008). No separation or grouping of the dead assemblages of samples from the same sites occurred, in contrast to the live assemblages where the two study areas and the control and pipeline sites separated. This attests to the fact that the live assemblages were responding to conditions within the area; this response was absent in the dead assemblages. The differences in the structure of the two assemblages allows for the conclusion that although some error in the separation of live and dead tests may have occurred, the margin of error is small and still reflects the differences between live and dead assemblages.

Although, the live and dead assemblages in both study areas were characterized by the same species, there were low correlations between the live and dead assemblages; this may be attributed to different numbers of individuals represented within each species. Dead assemblages provide a time-averaged faunal record of between 12 and 50 years depending on the rate of bioturbation in an area (Murray & Pudsey, 2004). Therefore the fact that dead and live assemblages are characterised by the same species only attests to changes in relative or absolute abundance of the species already present. Although, it is also known that taphonomic processes like calcareous test dissolution may affect the

number of species present in dead assemblages (Murray & Pudsey, 2004). Carbonate dissolution is complex and may be caused by corrosive bottom or sediment pore waters usually a result of metabolization of organic matter or bacterial decomposition (Murray & Alve, 1999).

The fact that no other species were found in the dead assemblages than those present in live assemblages shows that in both areas dead tests are not transported into the area from elsewhere and deposited there (Alve & Murray, 1997). The differences in the abundance of live and dead assemblages can therefore be attributed to deposition of dead tests over time. The abundance of foraminifera within each species of the dead assemblages was larger than the abundance in live assemblages and this was more marked in St Helena Bay samples than those from around Robben Island, providing some idea of the amount of accumulation that occurs there. The relationship between the overall abundance of live and dead foraminifera in both study areas were very low.

The mean size of foraminifera of the live and dead assemblages correlated for both study areas, possibly an indication there has been no significant changes over time that have affected the size and possibly rate of growth of the foraminifera present. Robben Island had a larger mean size of dead foraminifera than St Helena Bay, this may indicate suspension and transport of smaller foraminifera away from the area, leaving only the larger foraminifera in the sediment: similar to processes which determine mean sediment grain size.

3.5 Conclusion

The samples from Robben Island and St Helena Bay displayed different foraminiferal communities. The dominance of *Ammonia* and *Elphidium*, as well as *Bolivina* in the assemblages of St Helena Bay samples could point to an environment that is dominated by opportunistic species. Samples from around Robben Island does not have the same assemblage structure with *Elphidium* and *Miliolinella* dominating and a very low abundance of the *Bolivina*. Live and dead assemblages were dominated by the same species, but had a low correlation, showing no deposition from other environments. A higher abundance of dead tests in St Helena Bay samples is an indication of accumulation of dead tests, possibly a result of the long retention time of water within the bay. The

higher diversity and richness of the live assemblages in Robben Island than St Helena Bay samples may be a result of its more dynamic environment. Species accumulation curves reached asymptote and the estimated species richness from the extrapolated data did not differ much from the observed data, therefore, the sampling effort was sufficient and the diversity points to a relatively homogenous species richness at the mesoscale. However, there is large scale patchiness and variability at the microscale. The higher abundance of live foraminifera in St Helena Bay samples appears to be a result of higher settlement and accumulation rates as a result of its low energy environment; bed-load transport of Robben Island would carry fine sediments as well as foraminifera with it.

Table 3.1: The dominant species of foraminifera and their percentage of the total numbers, in samples collected from Robben Island.

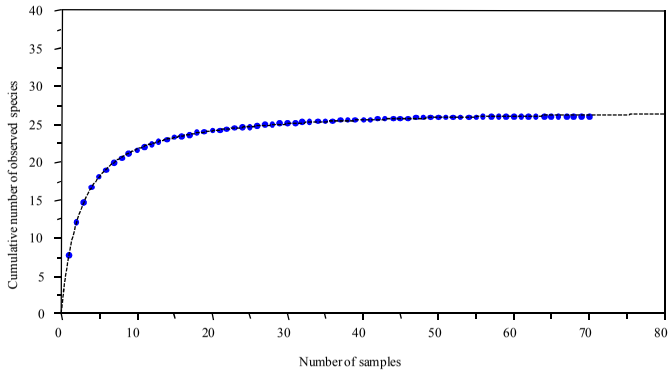
Site	Live	Percentage of the Total
RIA	*E. articulatum*	37 %
RIB	*E. articulatum*	36 %
RIC	*E. articulatum*	21 %
	C. lobatulus	20 %
RID	*E. articulatum*	23 %
RIE	*Q. seminulum*	20 %
RIF	*C. lobatulus*	27 %
RIG	*G. australensis*	15 %
RIH	*E. articulatum*	19 %
CONTROL	*E. articulatum*	16 %
	C. lobatulus	17 %
PIPELINE	*E. articulatum*	25 %
	C. lobatulus	14 %

Table 3.2: The dominant species of foraminifera in St Helena Bay samples, as a percentage of the total abundance.

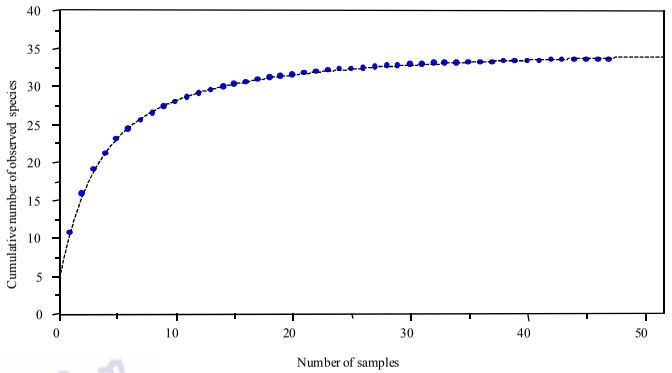
Site	Live	Percentage of the Total
SPA	*A. parkinsoniana*	21 %
SPB	*A. parkinsoniana*	36 %
SPC	*A. parkinsoniana*	25 %
SHA	*A. parkinsoniana*	20 %
SHB	*A. parkinsoniana*	36 %
SHC	*A. parkinsoniana*	20 %
SHD	*C. lobatulus*	40 %
SHE	*A. parkinsoniana*	29 %
SHF	*A. parkinsoniana*	33 %
SHG	*A. parkinsoniana*	46 %
SHH	*A. parkinsoniana*	40 %
SHI	*A. parkinsoniana*	33 %
CONTROL	*A. parkinsoniana*	29 %
PIPELINE	*A. parkinsoniana*	38 %

Table 3.3: Diversity indices of living foraminifera from Robben Island and St Helena Bay and the means of the control and pipeline sites. S- total species, J' – Pielou's evenness, H' – Shannon-Weiner Index of diversity and the abundance/10 cm^3 sediment.

STATION	SITE	STUDY	S	J'	H'	Abundance / 10
SPA	Control	St Helena Bay	15	0.78	1.86	1662
SPB	Control	St Helena Bay	15	0.69	2.17	1902
SPC	Control	St Helena Bay	15	0.79	1.92	1117
SHA	Pipeline	St Helena Bay	11	0.85	1.66	61
SHB	Pipeline	St Helena Bay	10	0.72	1.78	131
SHC	Pipeline	St Helena Bay	9	0.84	1.28	663
SHD	Pipeline	St Helena Bay	7	0.80	1.23	34
SHE	Pipeline	St Helena Bay	4	0.86	1.58	17
SHF	Pipeline	St Helena Bay	8	0.83	1.55	107
SHG	Pipeline	St Helena Bay	10	0.68	1.66	155
SHH	Pipeline	St Helena Bay	9	0.77	1.55	94
SHI	Pipeline	St Helena Bay	7	0.87	1.70	203
RIA	Pipeline	Robben Island	27	0.695	2.294	465
RIB	Pipeline	Robben Island	26	0.687	2.241	361
RIC	Pipeline	Robben Island	29	0.778	2.622	282
RID	Pipeline	Robben Island	25	0.757	2.439	164
RIE	Pipeline	Robben Island	19	0.804	2.368	49
RIF	Control	Robben Island	27	0.753	2.485	190
RIG	Control	Robben Island	28	0.749	2.498	129
RIH	Control	Robben Island	33	0.77	2.721	240
Mean control RI			16	0.84	2.31	186
Mean pipeline RI			14	0.80	2.08	264
Mean control SH			15	0.76	2.05	1560
Mean pipeline SH			8	0.80	1.58	167



(a)



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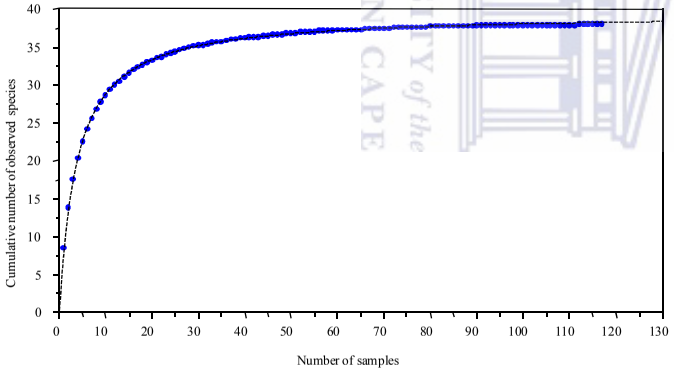

Figure 3.1: Species accumulation curves of live foraminifera for St Helena Bay (a), Robben Island (b) and all samples (c). The MMF Model y = (a*b+c*x^d)/(b+x^d) using Curve Expert is indicated by the dashed line, dots represent the observed data.

Table 3.4: Estimations of the species richness of the live foraminifera using an extrapolation of an MMF Model: y = (a*b+c*x^d)/(b+x^d) of a plot of species accumulation per sample.

Data	Sigmoidal Growth Model Parameters	r	Standard Error	Estimated Species Richness	Observed species richness
All Samples	a = 0.213 b = 3.843 c = 39.359 d = 1.014	0.999	0.106	39	38
St Helena Bay	a = 1.129 b = 2.904 c = 27.074 d = 1.047	0.999	0.065	27	28
Robben Island	a = 0.116 b = 2.507 c = 36.198 d = 0.941	0.999	0.165	36	34

Table 3.5: Non-parametric statistical estimators of species richness of the live assemblages from Colwell's EstimateS program compared with actual species richness and estimated species richness from the Curve Expert program.

	Observed species richness	**MMF Model**	**ICE**	**Chao 2**	**Jackknife 2**
All	38	39	38	38	37
St Helena Bay	28	27	28	28	26
Robben Island	34	36	36	36	37

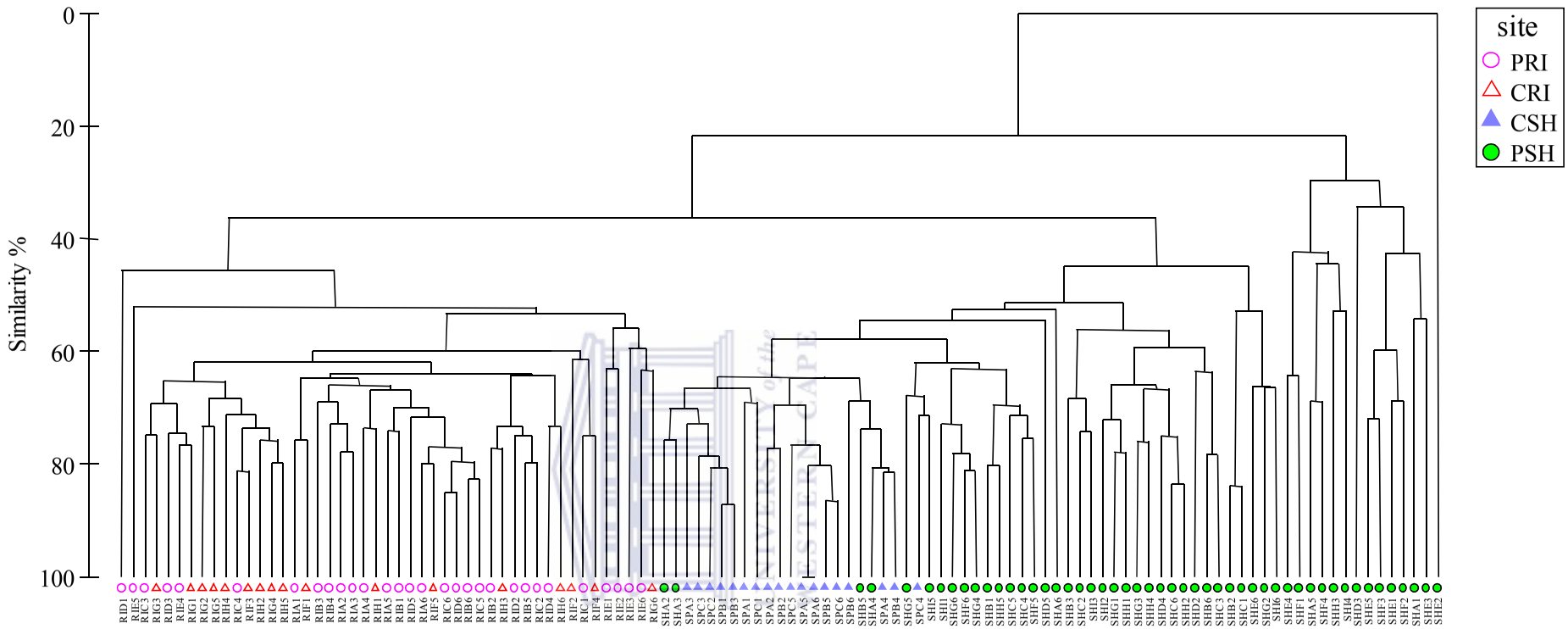

Figure 3.2: Dendrogram showing the similarity between samples, in terms of the structure of live foraminiferal assemblages across all study sites and samples (Bray-Curtis Index). Species data were root- root transformed and the dendrogram was produced using Group-Average Linkage. (PRI –Pipeline sites Robben Island, CRI – Control sites Robben Island, CSH – Control sites St Helena Bay and PSH – Pipeline sites St Helena Bay).

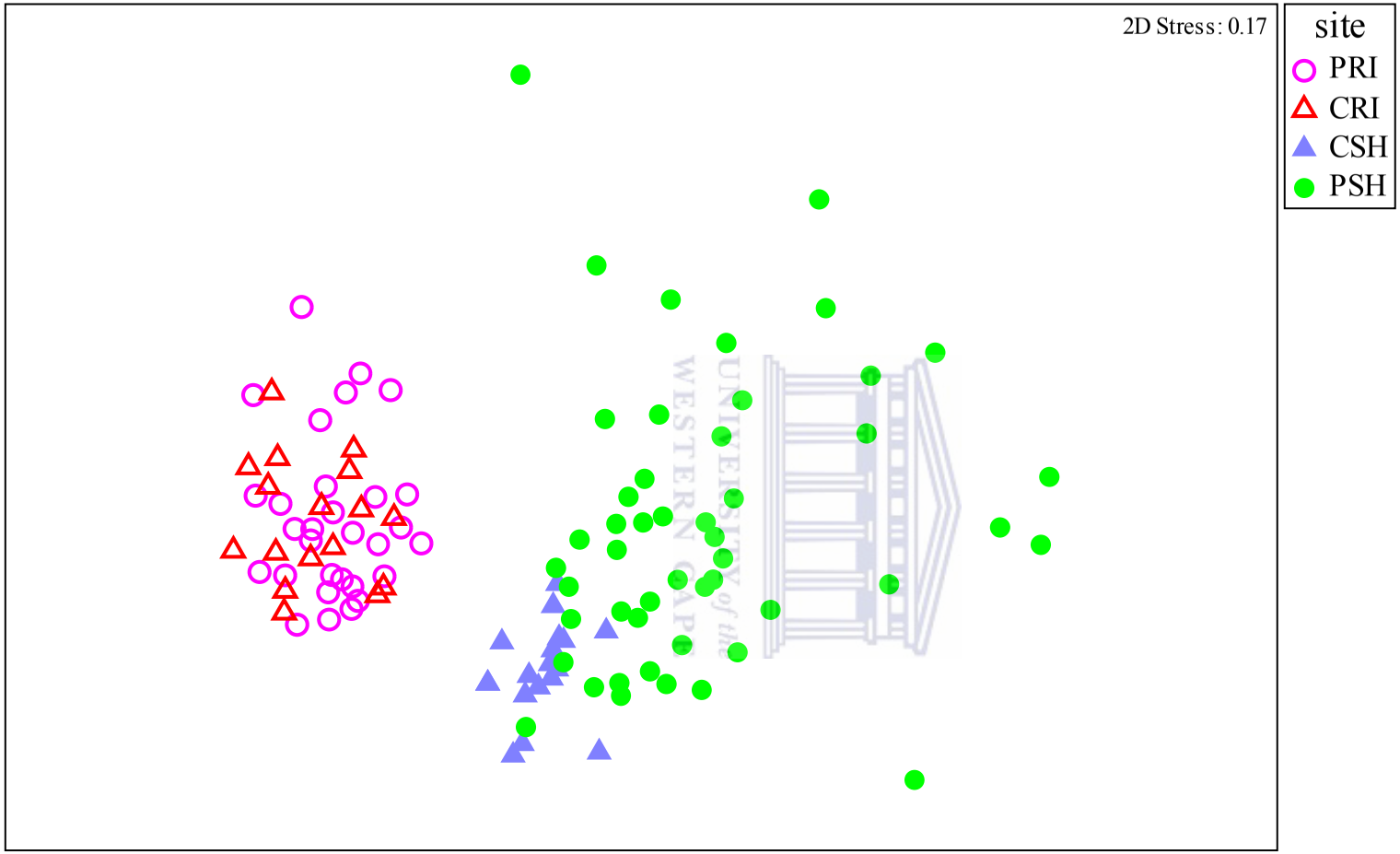

Figure 3.3: MDS Ordination of all live foraminiferal species. Species data were fourth root transformed and the MDS was produced using the Bray Curtis similarity index. (PRI –Pipeline sites Robben Island, CRI – Control sites Robben Island, CSH – Control sites St Helena Bay and PSH – Pipeline sites St Helena Bay).

Table 3.6: The SIMPER procedure in PRIMER between all species of the live assemblages in all samples of St Helena Bay performed on fourth root transformed data using the Bray-Curtis similarity matrix. The average similarity percentage of each of the two groups is in brackets and the species most responsible for determining community structure within each group is in bold (a). The average dissimilarity between the two groups is in brackets and the species most responsible for the dissimilarity is represented in (b).

(a)

Species	**% Contribution Control (69.84 %)**	**% Contribution Pipeline (44.09 %)**
A. parkinsoniana	**14.91**	**33.99**
E. articulatum	**10.24**	4.74
E. macellum	**10**	4.24
C. lobatulus	**9.37**	3.12
P. nipponica	**8.01**	< 1
B. elegantissima	6.23	**13.76**
Elongated bolivinids	6.67	**10.72**
R. globularis	6.85	**10.05**
T.squamata	< 1	**6.77**

(b)

Species	**Average dissimilarity (55.56 %)**	**% Contribution**
E. articulatum	4.51	8.12
P. nipponica	4.44	7.98
C. lobatulus	4.11	7.41
E. Advenum	3.94	7.1
E. Macellum	3.73	6.72
A. parkinsoniana	2.58	4.65
Perforated bolivinids	2.54	4.58
Elongated bolivinids	2.49	4.49

Table 3.7: The SIMPER between all live species in all Robben Island samples. The data were root-root transformed and the Bray-Curtis similarity matrix was used to produce the SIMPER. The average similarity percentage of each of the two groups is in brackets and the species most responsible for determining community structure within each group is in bold (a). The average dissimilarity between the two groups is in brackets and the species most responsible for the dissimilarity is represented in (b).

(a)

Species	**% Contribution Control (62.44 %)**	**% Contribution Pipeline (60.14 %)**
E. articulatum	8.9	3.05
R. globularis	6.47	2.2
C. lobatulus	5.96	5.33
M. subrotunda	2.44	2.05
Q. seminulum	2.43	2.33

(b)

Species	**Average dissimilarity (40.34 %)**	**% Contribution**
G. australensis	2.76	6.85
P. nipponica	1.99	4.93
Bolivinitidae	1.9	4.71
Q. isabellei	1.83	4.53
E. advenum	1.72	4.27
T. squamata	1.69	4.20
Q. dunkerquiana	1.65	4.10
T. trigonula	1.65	4.08
B. pseudoplicata	1.6	3.96
B. psedopunctata	1.57	3.90

Table 3.8: The SIMPER between all live species in the two study areas, performed on fourth root transformed data using the Bray-Curtis similarity matrix. The average similarity percentage of each of the two groups is in brackets and the species most responsible for determining community structure within each group is in bold (a). The average dissimilarity between the two groups is in brackets and the species most responsible for the dissimilarity is represented in (b).

(a)

SITE **Species**	**RI (60.61 %)** **% Contribution**	**Species**	**SH (45.04 %)** **% Contribution**
E. articulatum	14.67	*A. parkinsoniana*	27.75
C. lobatulus	13.66	*B. elegantissima*	12.11
R. globularis	11.31	Elongated Bolivinids	10.14
M. subrotunda	10.61	*R. globularis*	10.02
Q. seminulum	10.16	*E.articulatum*	6.8

(b)

Species	**RI** **Average**	**SH** **Average**	**Ave. diss. (68.7** **% Contribution**
A. parkisoniana	0.2	1.93	7.8
M. subrotunda	1.54	0.03	7.03
Q. seminulum	1.47	0.09	6.45
E.articulatum	2.01	1.01	5.96
C. lobatulus	1.85	0.81	5.71
B. elegantissima	0.36	1.16	4.36
R. globularis	1.57	1	3.87
Bolivinitidae	0.85	0	3.67
Q.isabellei	0.79	0	3.58
T. squamata	0.97	0.5	3.55

Table 3.9: Results of the PERMANOVA based on Bray-Curtis similarity of the live species data for St Helena Bay. Data were fourth root transformed. Each test was conducted using 998 random permutations.

	df	**SS**	**MS**	***F***	***p***	**% variation**
Site (Control vs Pipeline)	1	16821	16821	7.85	0.001	33.1
NESTED (Stations)	10	20 868	2086.8	1.65	0.003	16.85
Residual (cores)	57	72085	1264.6			50

Table 3.10: The PERMANOVA based on Bray-Curtis similarity of the live foraminiferal species from Robben Island samples. Data were fourth root transformed. Each test was conducted using 998 random permutations.

	df	**SS**	**MS**	**F**	**p**	**% Variation**
Site (Control vs Pipeline)	1	2007.8	2007.8	1.1869	0.266	8.9
Nested (Stations)	6	10 281	1713.5	2.5717	0.003	31.03
Residual (cores)	39	25 985	666.28			60.05

Table 3.11: The PERMANOVA based on Bray-Curtis similarity of the live foraminiferal species data from all samples from Robben Island
and St Helena Bay. Data were fourth root transformed. Each test was conducted using 998 random permutations.

Source	df	SS	MS	Pseudo-F	P (perm)	% Variation
study area (SH & RI)	1	53566	53566	6.0269	0.023	33.19
Nested (sites within study areas)	2	17915	8957.7	4.7194	0.002	18.58
Nested (stations within the sites within study area)	16	30008	1875.5	1.7504	0.001	12.82
Residual (samples)	95	101790	1071.5			35.41

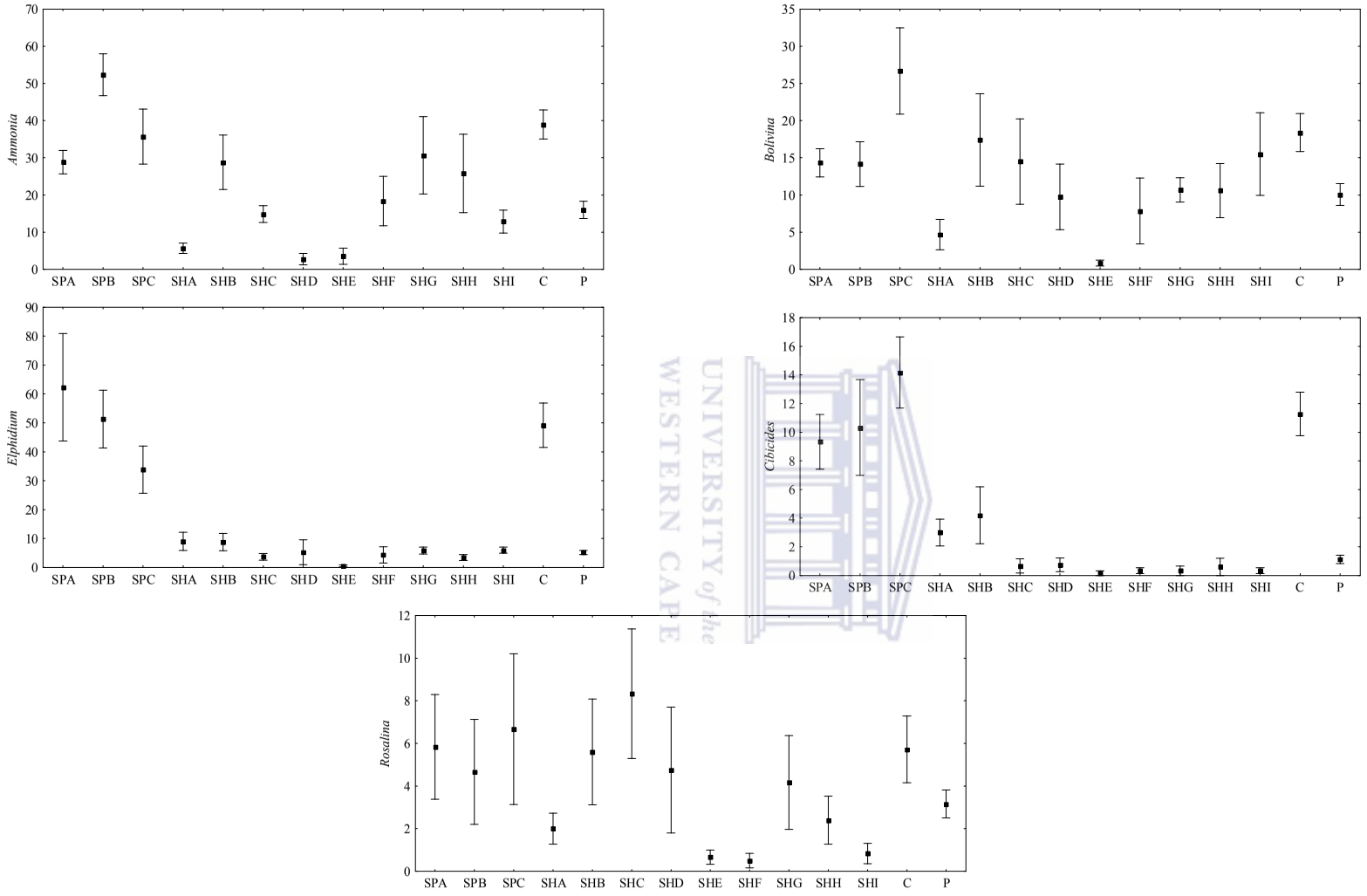

Figure 3.4: The mean and standard error for each of the five dominant genera for each station in St Helena Bay as well as the pooled results for the control (C) and pipeline (P) sites.

Table 3.12: The one-way ANOVA, of the abundance of the dominant genera at the control and pipeline sites of St Helena Bay, as well as the p values and the result of the post- hoc comparison of means using the Tukey Honest Significant Difference (HSD) Test. Significant p-values < 0.05* after the Bonferroni adjustment.

Genus		control	pipeline
Ammonia	**mean**	38.94	15.5
	F(df1,2)=1,68	27.09	
	p-level	0.000 1*	
Bolivina	**mean**	18.38	9.73
	F(df1,2)=1,68	9.18	
	p-level	0.003*	
Elphidium	**mean**	49.16	5.09
	F(df1,2)=1,68	91.5	
	p-level	0.000 1*	
Cibicides	**mean**	11.28	1.13
	F(df1,2)=1,68	100.6	
	p-level	0.000 1*	
Rosalina	**mean**	5.72	3.038
	F(df1,2)=1,68	3.63	
	p-level	0.06	

Table 3.13: The one-way ANOVA, of the abundance of the dominant genera in St Helena Bay, the result of the post- hoc comparison of means using the Tukey Honest Significant Difference (HSD) Test. Significant differences were only found between SPA, SPA & SPC (control sites) and all other sites, no significant differences were found between pipeline sites an were therefore not represented. *Rosalina* showed no significant differences and therefore the results were not represented. Significant p- values are < 0.05* after the Bonferroni adjustment.

Site	*Ammonia* Mean	SPA	SPB	SPC	*Bolivina* Mean	SPA	SPB	SPC	*Elphidium* Mean	SPA	SPB	SPC	*Cibicides* Mean	SPA	SPB	SPC
SPA	28.83				14.33				62.33				9.33			
SPB	52.33	0.17			14.17	1.00			51.33	0.99			10.33	1.00		
SPC	35.67	1.00	0.66		26.67	0.54	0.52		33.83	0.16	0.81		14.17	0.49	0.80	
SHA	5.67	0.19	0.00*	0.02	4.67	0.84	0.86	0.01	9.00	0.00*	0.00*	0.33	3.00	0.13	0.04	0.00*
SHB	27.33	1.00	0.12	1.00	15.00	1.00	1.00	0.63	8.00	0.00*	0.00*	0.27	3.67	0.26	0.09	0.00*
SHC	12.67	0.70	0.00*	0.20	17.67	1.00	1.00	0.89	6.00	0.00*	0.00*	0.18	0.50	0.01	0.00*	0.00*
SHD	1.25	0.13	0.00*	0.02	4.25	0.89	0.90	0.03	0.75	0.00*	0.00*	0.12	0.75	0.03*	0.01	0.00*
SHE	3.67	0.11	0.00*	0.01	0.83	0.40	0.42	0.00*	0.67	0.00*	0.00*	0.05	0.17	0.00*	0.00*	0.00*
SHF	19.67	0.99	0.01	0.71	8.83	1.00	1.00	0.08	4.83	0.00*	0.00*	0.14	0.33	0.00*	0.00*	0.00*
SHG	31.17	1.00	0.30	1.00	10.33	1.00	1.00	0.15	6.00	0.00*	0.00*	0.18	0.33	0.00*	0.00*	0.00*
SHH	22.67	1.00	0.03	0.90	14.33	1.00	1.00	0.54	4.17	0.00*	0.00*	0.12	0.67	0.01	0.00*	0.00*
SHI	10.67	0.54	0.00*	0.12	9.83	1.00	1.00	0.13	5.00	0.00*	0.00*	0.15	0.67	0.01	0.00*	0.00*

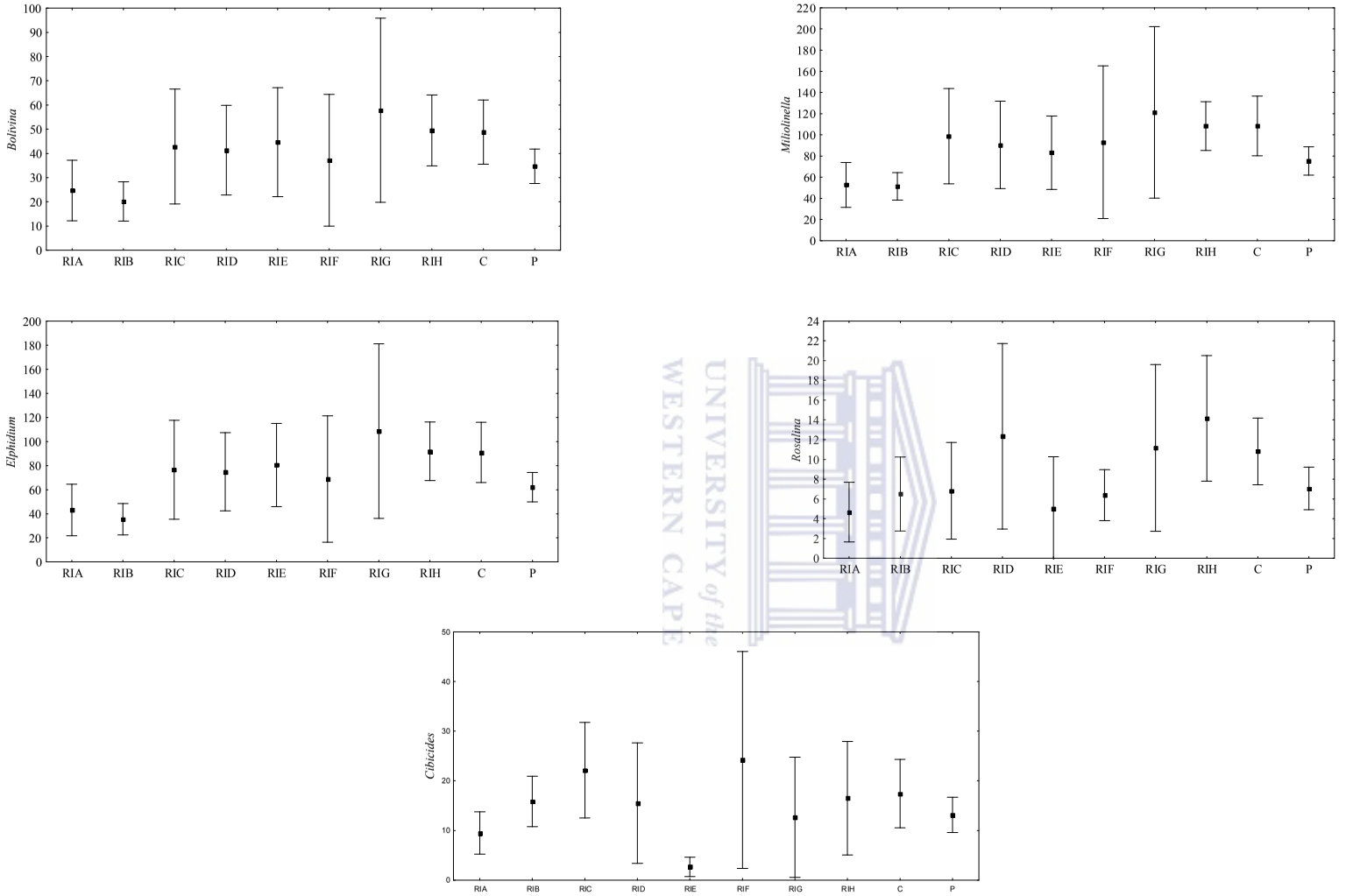

Figure 3.5: The mean and standard errors for each of the five dominant genera for Robben Island as well as the pooled results for the control (C) and pipeline (P) sites.

Table 3.14: The results of a one-way ANOVA, of the abundance of the dominant genera at the control and pipeline sites of Robben Island, as well as the p values and the result of the post- hoc comparison of means using the Tukey Honest Significant Difference (HSD) Test. No Significant p-values < 0.05 were found after the Bonferroni adjustment.

Genus		**control**	**pipeline**
Quinqueloculina	**mean**	25	17.3
	F(df1,45)	4.187	
	p-level	0.04	
Bolivina	**mean**	48.8	34.7
	F(df1,45)	4.57	
	p-level	0.03	
Elphidium	**mean**	24.56	18.88
	F(df1,45)	1.868	
	p-level	0.17	
Cibicides	**mean**	13.13	17.4
	F(df1,45)	1.63	
	p-level	0.202	
Rosalina	**mean**	7.06	10.82
	F(df1,45)	4.16	
	p-level	0.04	

Table 3.15: The one-way ANOVA, of the abundance of the dominant genera from Robben Island samples, only significant results from the post- hoc comparison of means using the Tukey Honest Significant Difference (HSD) Test were represented; significant p-values < 0.05 after the Bonferroni adjustment are highlighted*.

Bolivina

	RIE	RIH
RIC	0.03	
RIH	0.0006*	
RIG		0.016

Cibicides

	RIE
RIC	0.02
RIF	0.01

Elphidium

	RIE	RIB
RIA	0.02	
RIB	0.0005*	
RIC	0.03	
RIG		0.02

Table 3.16: The following are results of a one-way ANOVA between the control and pipeline sites of both study areas on the abundance of live foraminifera per size class. The post-hoc comparison of means using the Tukey Honest Significant Difference (HSD) Test is also represented. Significant p-values < 0.05 after the Bonferroni adjustment.

		Size class	**Control**	**Pipeline**	**p-value**	**F(df1,2)1,68**
St Helena Bay	LIVE	> 63 um	616.28	95.23	0.000 1*	17.6
		>125 um	800.50	58.87	0.000 1*	41.37
		>250 um	141.67	11.63	0.000 1*	41.06
		>500 um	1.50	0.81	0.049	4.01
Robben Island	LIVE	> 63 um	48.7	96.33	0.1	2.85
		>125 um	98.43	151.6	0.26	1.27
		>250 um	27.14	16.43	0.04	4.16
		>500 um	1	0.13	0.0003*	15.76

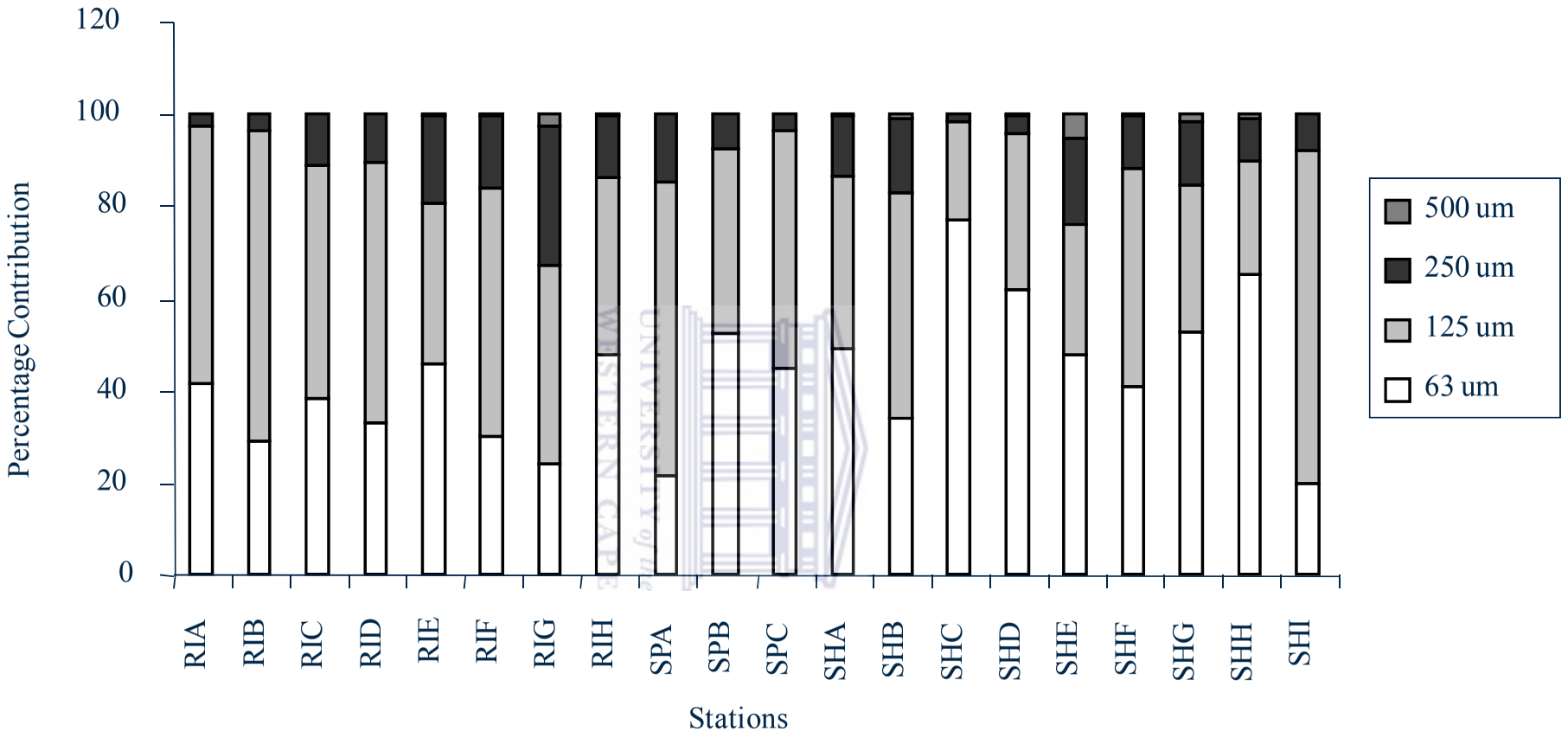

Figure 3.6: Graph depicting the percentage contribution of the abundance of each live foraminiferal size class for each of the stations in St Helena Bay and Robben Island. The mean data of the foraminiferal size classes for each of the samples per station were used.

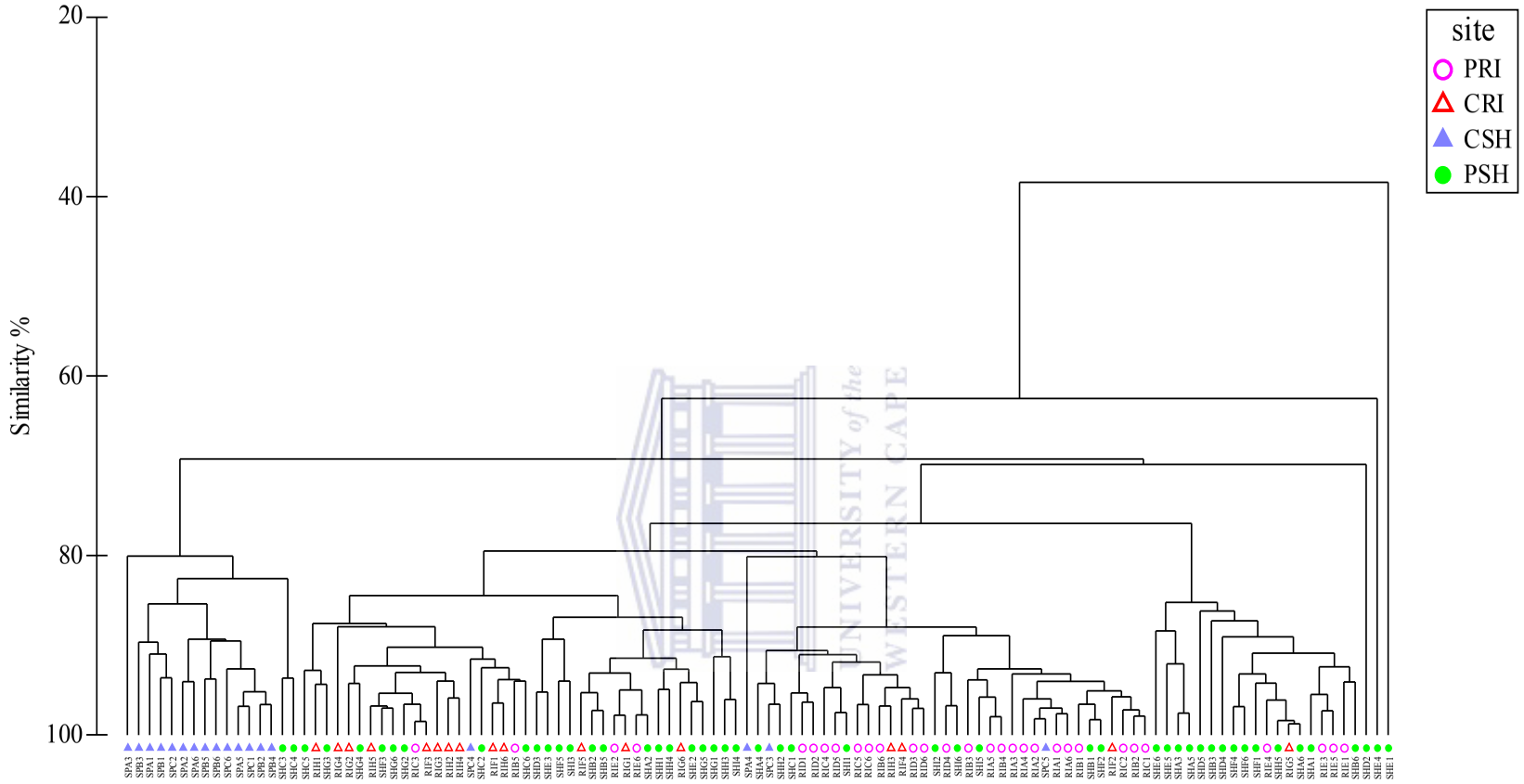

Figure 3.7: Dendrogram of the Bray-Curtis similarity index between all sites using the abundance of live foraminifera divided into the size classes. Data were root-root transformed and the cluster analysis used Group-Average linkage. PRI –Pipeline sites Robben Island, CRI – Control sites Robben Island, CSH – Control sites St Helena Bay and PSH – Pipeline sites St Helena Bay.

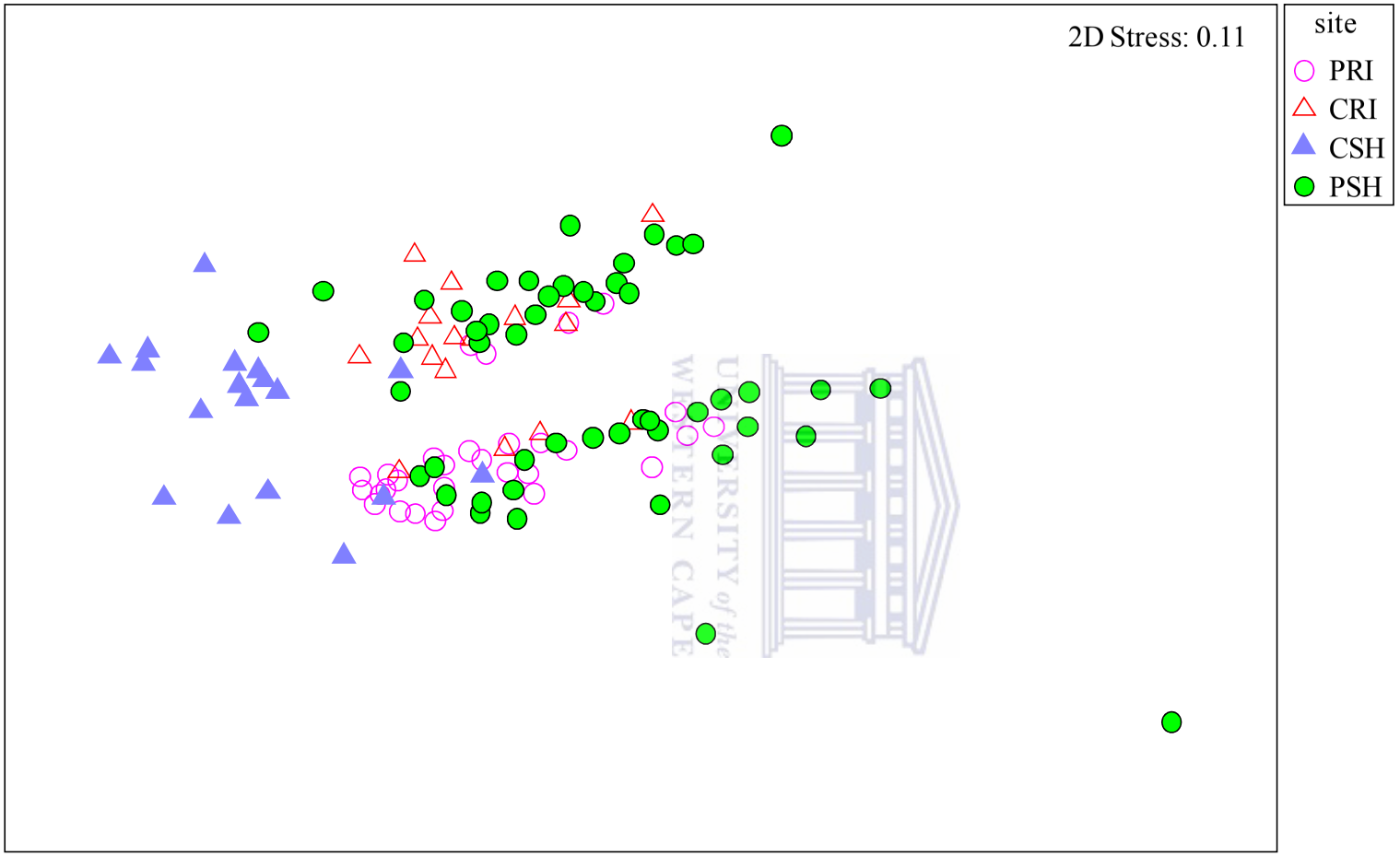

Figure 3.8: MDS Ordination of the total abundance of live foraminifera of polluted and control sites in Robben Island and St Helena Bay using Bray Curtis similarity and fourth root transformation. (PRI –Pipeline sites Robben Island, CRI – Control sites Robben Island, CSH – Control sites St Helena Bay and PSH – Pipeline sites St Helena Bay).

Table 3.17: The dominant species of foraminifera in the dead assemblages and their percentage of the total numbers, in samples collected from Robben Island.

Site	Dead	Percentage of the total
RIA	*E. articulatum*	27 %
RIB	*E. articulatum*	27 %
RIC	*E. articulatum*	22 %
RID	*E. articulatum*	34 %
RIE	*M. subrotunda*	26 %
RIF	*E. articulatum*	17 %
RIG	*G. australensis*	20 %
RIH	*E. articulatum*	18 %
CONTROL	*E. articulatum*	17 %
PIPELINE	*E. articulatum*	25 %

Table 3.18: The dominant species of foraminifera from the dead assemblages and their percentage of the total numbers, in samples collected from St Helena Bay.

Site	Dead	Percentage of the total
SPA	*E. articulatum*	36 %
SPB	*E. articulatum*	40 %
SPC	*E. articulatum*	21 %
SHA	*E. articulatum*	31 %
SHB	*E. articulatum*	20 %
SHC	Elongated bolivinids	26 %
	E. articulatum	21 %
SHD	Elongated bolivinids	19 %
SHE	*A. parkinsoniana*	32 %
SHF	Elongated Bolivinids	25 %
SHG	*E. articulatum*	28 %
SHH	*B. elegantissima*	18 %
SHI	*E. articulatum*	30 %
CONTROL	*E. articulatum*	32 %
PIPELINE	*E. articulatum*	21 %

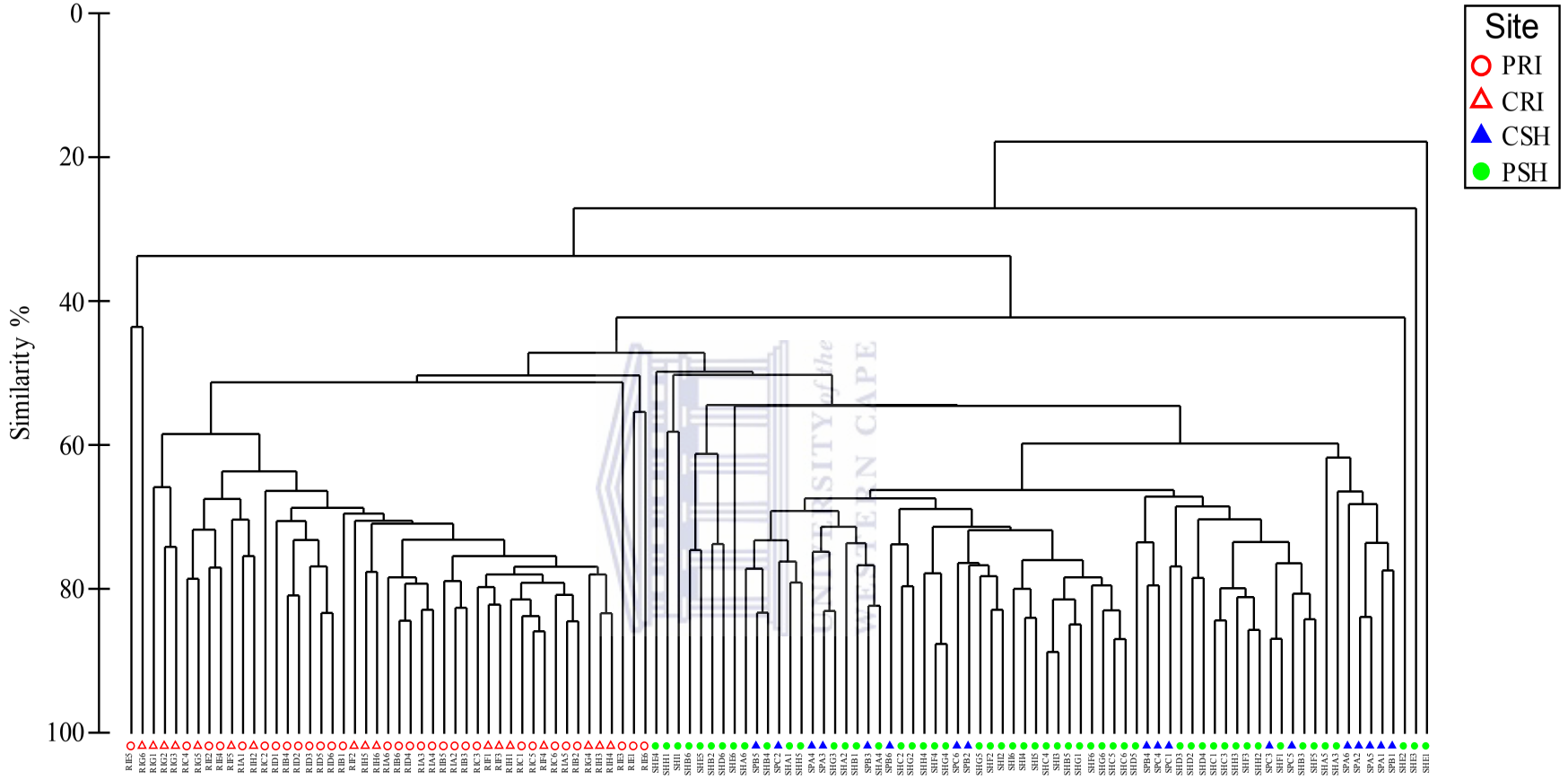

Figure 3.9: Dendrogram of the dead foraminiferal assemblages of each sample from each site in St Helena Bay and Robben Island. Species data were fourth root transformed and the dendrogram was produced using the Bray-Curtis Similarity Index with Group-Average Linkage. (PRI –Pipeline sites Robben Island, CRI – Control sites Robben Island, CSH – Control sites St Helena Bay and PSH – Pipeline sites St Helena Bay).

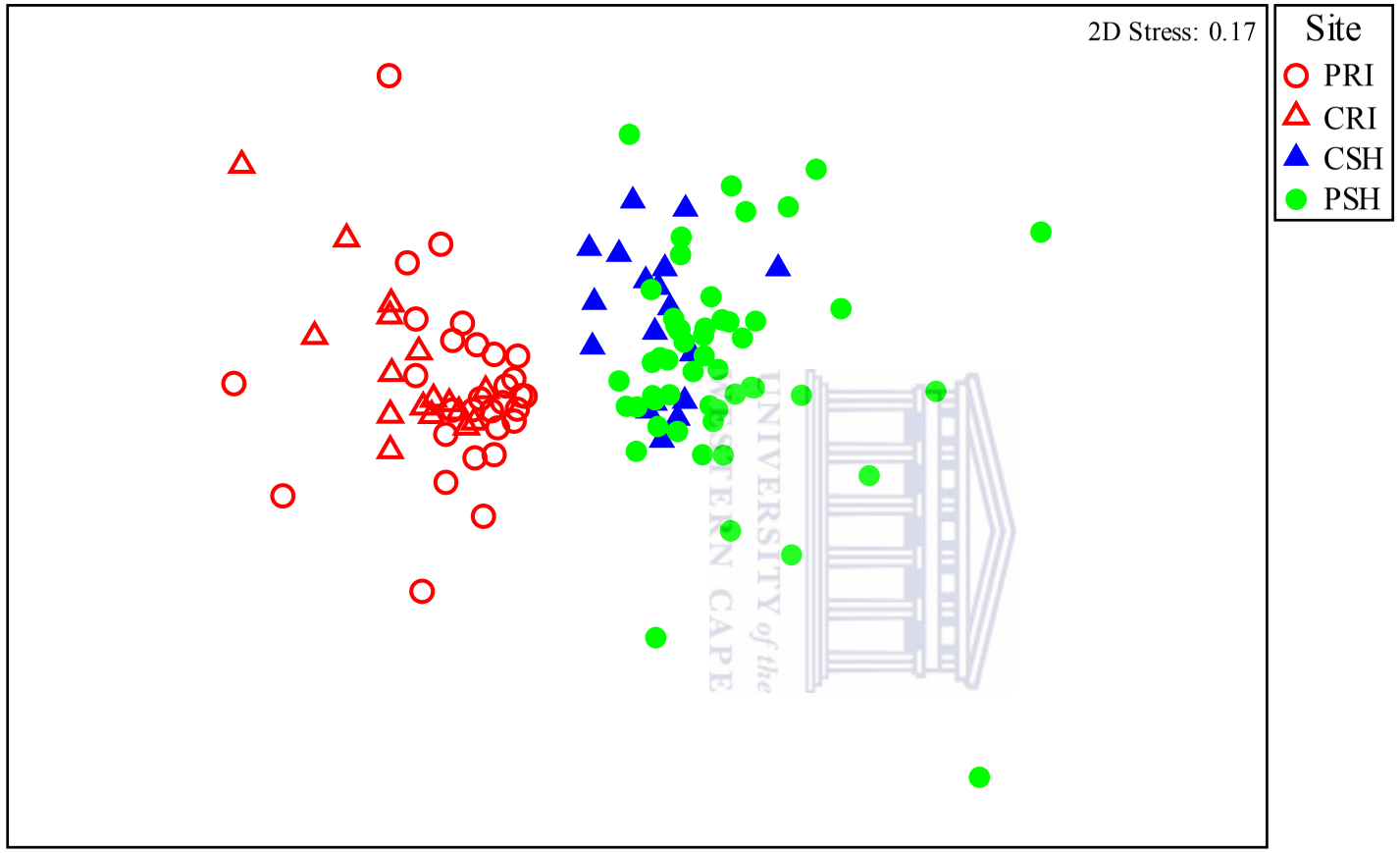

Figure 3.10: MDS Ordination of all dead foraminiferal species. Species data were fourth root transformed and the MDS was produced using the Bray Curtis similarity index. PRI –Pipeline sites Robben Island, CRI – Control sites Robben Island, CSH – Control sites St Helena Bay and PSH – Pipeline sites St Helena Bay.

Table 3.19: The following are the results of a RELATE statistic in PRIMER which attempts to correlate the dead and live assemblages of all samples together (ALL) and St Helena Bay (SHB) and Robben Island (RI) separately. All p-values were statistically significant.

	ALL	**SHB**	**RI**
Rho	0.563	0.388	0.511
P	0.01*	0.01*	0.01*

Table 3.20: The following are the results of the SIMPER procedure in PRIMER between all species of the dead assemblages in all samples of St Helena Bay. The data were fourth root transformed and the Bray-Curtis similarity matrix was used to produce the SIMPER. The average similarity percentage of each of the two groups is in brackets and the species most responsible for determining community structure within each group is in bold (a). The average dissimilarity between the two groups is in brackets and the species most responsible for the dissimilarity is represented in (b).

(a)

Species	**% Contribution**	**% Contribution**
A. parkinsoniana	12.48	9.6
Elongated Bolivinids	11.25	9.97
E.articulatum	10.88	12.19
perforated bolivinids	10.62	8.45
E.advenum	9.36	10.52

(b)

Species	**Average dissimilarity**	**% Contribution**
P. nipponica	2.52	6.48
E. articulatum	2.18	5.61
B. pseudoplicata	2.07	5.31
C. lobatulus	2.07	5.31
R. globularis	1.82	4.69
B. elegantissima	1.81	4.66
B. elongata	1.78	4.58
E. macellum	1.63	4.19
B. pseudopunctata	1.61	4.13
F. lucida	1.55	3.99
Elongated Bolivinids	1.53	3.92
E. crispum	1.39	3.57

Table 3.21: The results of the SIMPER procedure in PRIMER between all species of the dead assemblages in all samples of Robben Island are represented. The data were fourth root transformed and the Bray-Curtis similarity matrix was used to produce the SIMPER. The average similarity percentage of each of the two groups is in brackets and the species most responsible for determining community structure within each group is in bold (a). The average dissimilarity between the two groups is in brackets and the species most responsible for the dissimilarity is represented in (b).

(a)

Species	**% Contribution Pipeline (63 %)**	**% Contribution Control (66.59 %)**
E.articulatum	11.48	10.78
Elongated Bolivinids	9.84	9.12
M. subrotunda	9.02	9.69
M. seminulum	8.62	6.51
C. lobatulus	7.82	8.09
E.advenum	6.34	3.81

(b)

Species	**Average**	**% Contribution**
G. australensis	2.25	6.06
B. pseudopunctata	1.62	4.37
B. pseudoplicata	1.58	4.26
Bolivinitidae	1.49	4.01
T. squamata	1.45	3.89
P.nipponica	1.44	3.87
B. elegantissima	1.34	3.61
E. advenum	1.28	3.46
T. trigonula	1.28	3.45
F. lucida	1.27	3.42
E. articulatum	1.26	3.38

Table 3.22: The following are the results of the SIMPER procedure in PRIMER between all species of the dead assemblages in the two study areas. The data were fourth root transformed and the Bray-Curtis similarity matrix was used to produce the SIMPER. The average similarity percentage of each of the two groups is in brackets and the species most responsible for determining community structure within each group is in bold (a). The average dissimilarity between the two groups is in brackets and the species most responsible for the dissimilarity is represented in (b).

(a)

SITE **Species**	**RI (63.61 %)** **% Contribution**	**Species**	**SHB (60.95 %)** **% Contribution**
E.articulatum	11.32	*A. parkinsoniana*	11.8
Elongated Bolivinids	9.75	*E. articulatum*	11.41
M. subrotunda	9.43	Elongated Bolivinids	11.01
C. lobatulus	8.05	Perforated Bolivinids	10.07
M. seminulum	7.92	*E. Advenum*	9.78

(b)

Species	**RI** **Average Abundance**	**SHB** **Average Abundance**	**Average dissimilarity** **% Contribution**
Perforated Bolivinids	0	1.68	6.38
A. parkinsoniana	0.18	1.83	6.36
M. subrotunda	1.73	0.19	6.05
M. seminulum	1.59	0.31	5.01
Q. isabellei	1.06	0	4
G. australensis	0.94	0	3.59
B. pseudoplicata	1.01	0.95	3.39
E. articulatum	2.22	2.08	3.29
C. lobatulus	1.65	1.33	3.08
E. macellum	0.3	0.9	3.03
B. pseudopunctata	1.07	0.85	2.98
R. globularis	1.1	0.98	2.9

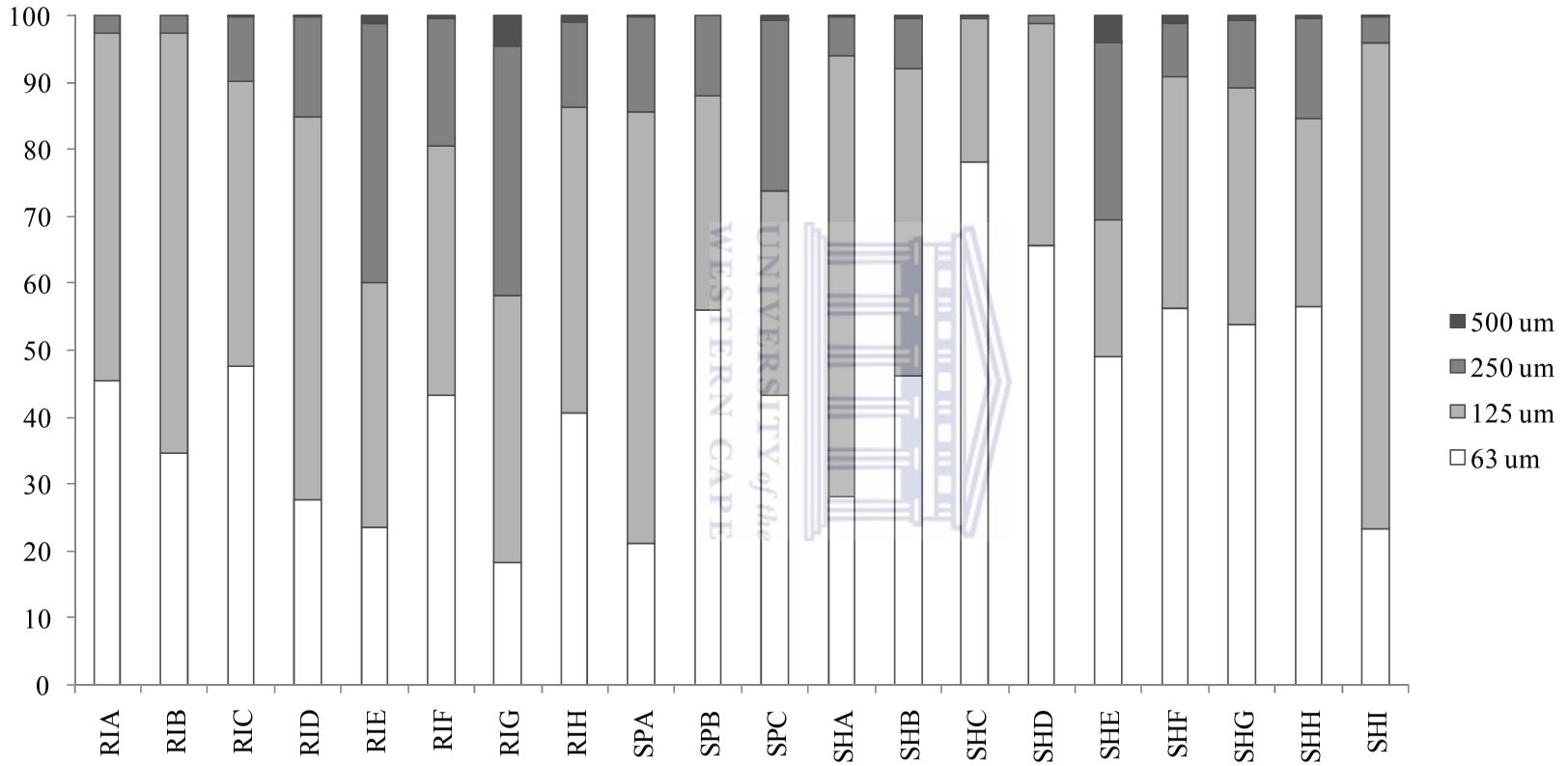

Figure 3.11: The percentage contribution of the total of each size class of foraminifera in the dead assemblages for each station in St Helena Bay and Robben Island. The mean of each foraminiferal size class for each of the samples per station was used.

Table 3.23: The following represents the results of a one-way ANOVA between the control and pipeline sites of both Robben Island and St Helena Bay in terms of the abundance of dead foraminifera per size class. The Tukey Honest Significant Difference Tests provided significant values at $p < 0.05$ after the Bonferroni adjustment.

		Size class	**Control**	**Pipeline**	**p-value**	**F(df1,2)1,68**
St Helena Bay	DEAD	> 63 um	295.72	220.63	0.48	0.49
		>125 um	367.72	151.62	0.04	4.5
		>250 um	130.22	18.90	0.000 1*	18.4
		>500 um	1.44	1.15	0.67	0.17
Robben Island	DEAD	> 63 um	123.1	132.6	0.85	0.03
		>125 um	129.1	172.3	0.49	0.49
		>250 um	64.85	21.4	0.005*	8.97
		>500 um	2.57	0.2	0.000005*	29.01

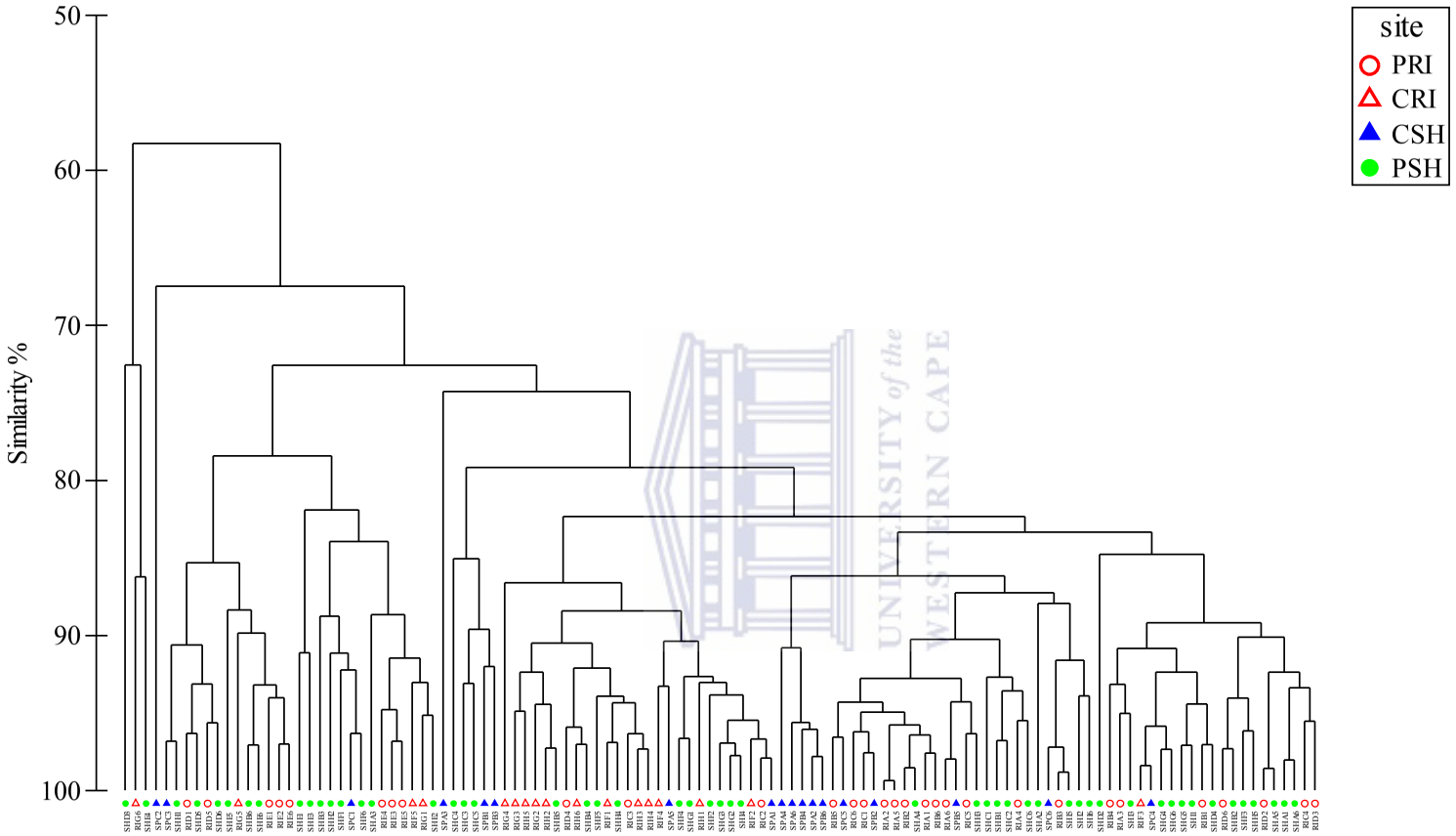

Figure 3.12: Dendrogram of the Bray-Curtis similarity index between all sites using the abundance of dead foraminifera per size classes. Data were root-root transformed and the cluster analysis used Group-Average linkage. PRI –Pipeline sites Robben Island, CRI – Control sites Robben Island, CSH – Control sites St Helena Bay and PSH – Pipeline sites St Helena Bay.

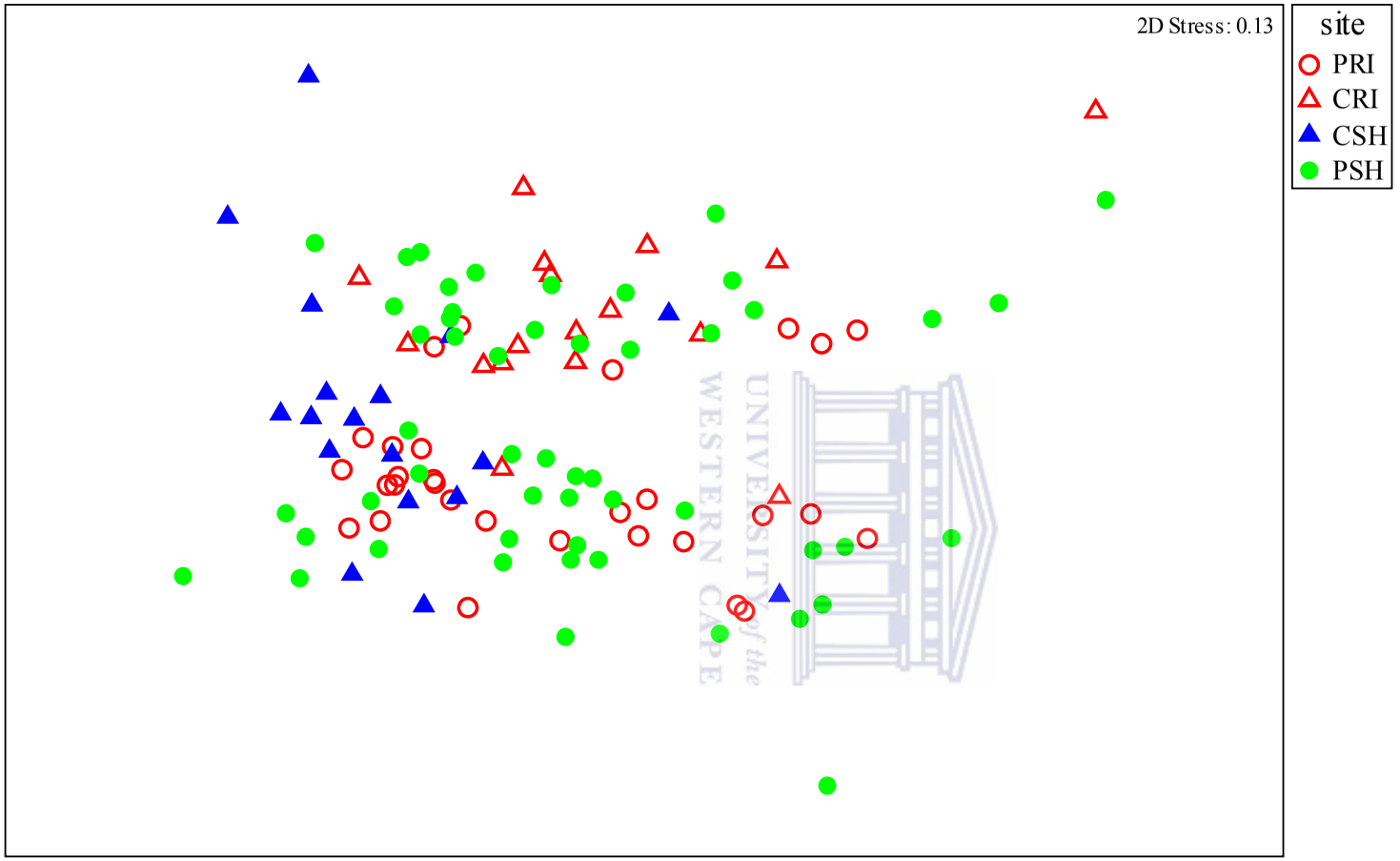

Figure 3.13: MDS Ordination of the total abundance of dead foraminifera of polluted and control sites in Robben Island and St Helena Bay using Bray-Curtis similarity and fourth root transformation. PRI –Pipeline sites Robben Island, CRI – Control sites Robben Island, CSH – Control sites St Helena Bay and PSH – Pipeline sites St Helena Bay.

Table 3.24: The following are the results of a RELATE statistic in PRIMER which attempts to correlate the dead and live foraminiferal abundance of all samples together (ALL) and St Helena Bay (SHB) and Robben Island (RI) separately. All p-values were statistically significant.

	ALL	**SHB**	**RI**
Rho	0.473	0.458	0.426
p	0.01*	0.01*	0.01*

Table 3.25: Non-parametric spearman rank order correlations between the live and dead mean foraminiferal size. All correlations were significant at $p < 0.05$.

	R
ALL	0.66*
Robben Island	0.68*
St Helena Bay	0.69*

Table 3.26: One-way ANOVA of the mean size of live and dead foraminifera between St Helena Bay (SHB) and Robben Island (RI). Significant differences are at $p < 0.05$.

	Mean size live	**p**	**Mean Size Dead**	**p**
SHB	118.49	0.43	111.74	0.001*
RI	122.08		128.85	

Chapter 4

A study linking foraminiferal communities to their environment at two study sites of the west coast of South Africa

Abstract

Sediment samples from around the Robben Island sewage pipeline and a fish factory pipeline in St Helena Bay were examined for foraminifera, as well as for a suite of environmental factors. The top 5 cm of each core was examined from a total of twenty cores. In St Helena Bay samples, species diversity, richness and abundance were negatively correlated with trace metals. The percentage nitrogen and all trace metals were negatively correlated with diversity, richness and diversity while the mean grain size was positively correlated. However, few of these relationships were significant (Fe, Pb, Zn and mean grain size), and those that were had very low correlations.

There were no significant correlations between the environmental conditions and richness and diversity in the samples from Robben Island. The abundance of foraminifera was positively significantly correlated with Cd, Cr, Zn, percentage nitrogen and the mean grain size. In the St Helena Bay and Robben Island samples, the factors which together most influenced community structure were the percentage nitrogen, the mean grain size and Cd, Cr and Cu concentrations.

The dominant genera in St Helena Bay *Ammonia, Bolivina, Elphidium* and *Cibicides* were negatively correlated with trace metals and percentage nitrogen, although *Cibicides* had a positive correlation the mean sediment grain size. *Rosalina* was positively correlated with all environmental variables, however, these correlations were not significant. The dominant genera from around Robben Island were *Bolivina, Elphidium, Cibicides, Quinqueloculina* and *Rosalina,* few correlations were found and were mostly with Cd, Cr, Fe and % N and *Bolivina, Elphidium* and *Quinqueloculina. Bolivina, Elphidium* and *Quinqueloculina* may be regarded as good bio-

indicators. *Ammonia,* although dominant was less correlated with environmental factors and because it is considered an opportunist, it has a wide tolerance range and would not be indicative of environmental changes. Both study areas were dominated by small foraminifera and there was no correlation between the size of the foraminifera and the mean grain size of the sediments, though the small foraminifera could be indicative of a polluted environment or the cold temperate waters of both study areas. Robben Island showed very different environmental conditions to St Helena Bay and did not show signs of a polluted environment.

Morphological abnormalities in both study areas were low and were not found to be a reliable method of identifying a polluted environment. The trace metal content of the shells did not display a significant difference between the two study areas and did not appear to correspond with the trace metal concentrations of the sediments. The foraminiferal assemblage structure of Robben Island was also not indicative of pollution, unlike that of St Helena Bay.

4.1 Introduction

Benthic infaunal organisms, because of their habitation of the sediment water interface, often reflect local sedimentary conditions in their abundance and diversity (Mucha *et al*., 2003). Benthic foraminifera have been used as bio-indicators for chemical and biological environmental factors because of the incorporation of chemicals into their shells and their changes in abundance or composition in the presence of certain environmental conditions (Murray, 2001). The factors that control foraminiferal distribution are still poorly understood and the critical response threshold for environmental factors may differ between species (Murray, 2001). Foraminiferal abundance and diversity may be influenced by a number of factors such as depth, water temperature, salinity, pH, organic matter content or sediment grain size (Duleba & Debenay, 2003).

Foraminiferal abundance appears to vary with sediment grain size structure, and increases with a higher percentage of finer sediments, as fine sediments and organic matter tend to accumulate in the same area (Frontalini & Coccioni, 2008). On the other hand, coarse sediments have been found to provide more substrata for foraminifera, particularly those that are attached (du Châtelet *et al.*, 2009). Although, benthic species composition has been linked to sediment grain size its effect in influencing abundance and diversity has been found to vary from study to study (Bremner *et al*., 2006).

Many studies have shown that a decrease in the abundance and density of foraminifera can be used as a measure of environmental stress (Frontalini & Coccioni, 2008). Pollution studies using these organisms have been conducted in bays, harbours and coastal margins worldwide (Burone *et al.*, 2006). Foraminifera have been found to be affected by anthropogenic contaminators like organic enrichment, heavy metals and petroleum hydrocarbons (Burone *et al.*, 2006). Some studies on the effect of sewage discharge on foraminifera have reported an increase and others a decrease in abundance and diversity of foraminifera (Topping *et al*., 2006). Topping *et al.* (2006) have hypothesized that in some studies other factors like localized oxygen depletion or changes in salinity or grain size as a result of sewage pollution may have masked the effects of an increase in organic matter.

Unlike the variable effects of sewage pollution, only negative impacts have been observed from heavy metal contamination (Scott *et al*., 2001; Frontalini *et al*., 2009). Ferraro *et al*. (2006) have found a correlation between the level of chemical pollutants and foraminifera, with a totally barren assemblage in a highly polluted harbour. Similar effects were observed by Yanko *et al*. (1994) in sites exposed to heavy metal and coal pollution; in addition, these authors also observed that assemblages were dominated by species with smaller tests. The environmental factor or factors which are close to the threshold of tolerance for any species will therefore limit its distribution (Murray, 2001).

While many authors have reported test abnormalities as an indication of a polluted environment (Yanko *et al.*, 1994; Alve, 1991 and Sharifi *et al*., 1991), test abnormalities are found in all foraminiferal species under normal environmental conditions (Burobe *et al.*, 2006). These may be due to environmental stresses (including temperature, pH, salinity, food availability, high wave action etc.), which may slow down or change the rate of growth of chambers (Alve, 1991). Test abnormalities may also merely be intraspecific variation, as in *Pararotalia nipponica* which presents itself in many different forms in South African samples (Toefy *et al.*, 2005). Marginal and shallow marine environments have variable environmental conditions and have been found to possess species with much ecophenotypic variation (Murray, 1991). Therefore, it may be difficult to pinpoint the reason(s) for morphological abnormalies when observed, and specifically regard the anthropogenic pollutant as the cause for the defect. Only controlled laboratory experiments can conclusively eliminate certain factors. Samir & El-Din (2001,) in X-Ray analysis of deformed and normal tests of the same species showed that species that were deformed showed a higher concentration of trace metals within their shells than specimens that were normal, implying that trace metals might have been responsible for the deformities present.

This chapter examines the influence of environmental factors (mean grain size, percentage nitrogen and trace metals) measured within the sediments on the foraminiferal assemblages at two study areas on the west coast of South Africa, St Helena Bay and Robben Island. Morphological abnormalities and trace metal concentrations, found in the foraminiferal tests are presented. The aim of the chapter is to determine whether foraminiferal assemblages can be used as proxies for environmental conditions.

4.2 Materials & Methods

4.2.1 Laboratory Analyses

All laboratory analyses have been explained in detail in the previous chapters.

4.2.1.1 Shell Morphology

Any morphological abnormalities in live foraminifera were noted and counted from the 300 specimens that were picked per core. Morphological abnormalities were regarded as any change in structure i.e. regrowth of chambers in an abnormal way (protuberances, distortion of chambers, difference in size or shape of one or more chambers), double apertures, wrong coiling direction or Siamese twins (Samir *et al*., 2001) . Broken or abraded tests which did not display any re-growth were not counted as abnormal. Representatives of these abnormal tests were photographed using Scanning Electron Microscopy.

4.2.1.2 Scanning Electron Microscopy and Elemental Analysis

Representative examples of foraminifera were scanned to examine any morphological abnormalities as well as to perform elemental analysis on the shells. Scanning was performed using a Hitachi X650 SEM in conjunction with the X-analysis EDAX utilizing the computer program Genesis 2000. Samples were carbon coated rather than gold coated using the EMITECH K950X. For elemental analysis, 1 cm^2 of scan area and 100 s live time analysis was used to collect and identify the elements present. The atomic % of each element measured was recorded. At least 10 live specimens of *Elphidium articulatum* were examined per site. This species alone was chosen as it appeared most frequently in all samples and the use of more species introduces other variables (e.g. shape, chamber size or number, etc) that would make the interpretation of results difficult.

4.2.2 Statistical Analyses

In order to determine whether the species richness, diversity and abundance of live foraminifera and all measured environmental variables were correlated, the non-

parametric Spearman correlation was used. Significant values of less than 0.05 were used after calculating a Bonferroni p- value.

The BIOENV BEST procedure was conducted to explain the environmental variables which were most responsible for the assemblage structure (Clarke & Gorley, 2006). Non-parametric Spearman Rank Order correlations between the dominant genera of both study areas and the environmental variables were performed. Genera and not individual species were used as the relate function in PRIMER revealed a significant correlation (see Chapter 3).

An MDS Ordination of the concentration of the measured elements in the foraminiferal tests of control and pipeline sites of both study areas was produced. Data were fourth root transformed and Euclidean distance was used to produce the resemblance matrix. Non-parametric Spearman Correlations of trace metals in sediment samples and trace metals of shells per site were determined. ANOVA was used to determine any differences in the trace metal concentrations of the shells between stations as well as between sites and the two different study areas.

4.3 Results

Summary of results from Chapter 2

Environmental variables

The mean sediment grain size of both St Helena Bay and Robben Island samples was large (> 1 Phi), but the sediment samples from Robben Island were larger.

Trace metal concentrations of the sediments from St Helena Bay samples were higher than those of Robben Island but concentrations were not higher than those of the USEPA sediment quality guidelines for ERM where toxicity would affect biota. The percentage carbon from Robben Island samples were higher than those from St Helena Bay, but the percentage nitrogen was higher in St Helena Bay than Robben Island samples.

Summary of results from Chapter 3

Foraminiferal assemblages

The diversity and species richness of the live foraminiferal assemblages was higher in the samples from around Robben Island but the abundance of foraminifera from St Helena Bay samples was higher than from the sediments of Robben Island samples. The dominant genera in St Helena Bay samples were *Ammonia, Bolivina, Elphidium, Cibicides and Rosalina*. In the Robben Island samples *Bolivina, Elphidium, Cibicides, Quinqueloculina* and *Rosalina* were dominant genera.

4.3.1 Community Structure

Significant negative correlations were found between the species richness, species diversity and the abundance of live foraminifera and most sediment trace metals except Cd, Cr and Cu in the St Helena Bay samples (Table 4.1). The percentage nitrogen was significantly negatively correlated with the species diversity and species richness, but not with the abundance of the live foraminifera. The mean grain size was not significantly correlated with species richness, diversity or the abundance of the live foraminifera.

Significant correlations were fewer in Robben Island samples and no significant correlations were found between richness and diversity and the measured environmental variables. (Table 4.2). The abundance of live foraminifera was significantly correlated with Cd, Cr, Zn and the mean sediment grain size.

When pooling samples from both study areas, significant negative correlations were found between the species richness and diversity and Fe, Pb, Zn and the percentage nitrogen (Table 4.3). Although the abundance of foraminifera followed more or less the same pattern, it was not significantly correlated with the percentage nitrogen. All correlations were low and were greater than the Bonferroni p-value of 0.001.

The BIOENV BEST procedure revealed that the environmental variables that appeared to most influence community structure in the St Helena Bay samples were the percentage nitrogen, the mean grain size and Cd, Cu and Pb concentrations in the sediments (Table 4.4). The results of the BIOENV BEST on Robben Island samples revealed much the same, except Pb did not feature as an important environmental factor (Table 4.5). The BIOENV of the pooled samples placed the percentage nitrogen and Cd

as being very large contributors (42 %) to the assemblage structure, additionally, the mean sediment grain size, Cr and Cu concentrations play a smaller role (Table 4.6). This contrasts with the results from St Helena samples in that Pb is also listed as an important factor.

4.3.2 Genera

The dominant genera in the assemblages of St Helena Bay samples were *Ammonia, Bolivina, Elphidium, Cibicides* and *Rosalina.* Non-parametric Spearman rank order correlations between the measured environmental variables and the abundance for each of the dominant genera showed mostly negative correlations with the trace metals and the percentage nitrogen (Table 4.7). The relationship with the mean grain size was variable. Most correlations were not significant or had very low correlation coefficients. The abundance of *Elphidium* and *Cibicides* followed the same pattern with negative significant correlations with Fe, Pb and Zn and positive significant correlations with the mean sediment grain size. The abundance of *Ammonia* was negatively significantly correlated with Cd, Zn and the mean sediment grain size. The abundance of *Bolivina* showed no significant correlations and *Rosalina* was only significantly correlated with the mean sediment grain size.

The dominant genera in the Robben Island samples were *Bolivina, Elphidium, Cibicides, Quinqueloculina* and *Rosalina.* Non-parametric Spearman rank order correlations revealed *Bolivina, Elphidium* and *Quinqueloculina* as being negatively significantly correlated with Cd, Cr, Fe concentrations in the sediments, while additionally the abundance of *Bolivina* and *Elphidium* were negatively significantly correlated with the percentage nitrogen (Table 4.8). The abundance of *Rosalina* was only negatively significantly correlated with the mean grain size. The abundance of *Cibicides* did not correlate with the environmental variables. The effect of the environmental variables appeared to be most prevalent in *Elphidium, Quinqueloculina* and *Bolivina*, while the mean grain size appeared to be the least important factor influencing the abundance of the dominant genera in Robben Island.

4.3.3 Foraminiferal size structure

Foraminifera were most abundant in the 63 µm and 125 µm size classes in the St Helena Bay samples, these size classes did not correspond with the dominant sediment size class (Table 4.9). The dominant size class of foraminiferal tests in the Robben Island stations was 125 µm, though the dominant sediment size class which was 500 µm (Table 4.10). A Spearman Rank Correlation which related the abundance of foraminifera per size class to the sediment structure yielded a Rho value of -0.002 and a p-value of 0.51 (St Helena Bay) and Rho value of -0.003 and a p-value of 0.58 (Robben Island) showing no significant correlation between size structure of the sediments and that of the live foraminifera.

4.3.4 Morphological Abnormalities

Test abnormalities were not found in large numbers and varied from 0.6 % to 4% in all stations (Table 4.11). The main abnormalities observed were broken chambers with some regrowth, Siamese twins and abnormal chamber growth. These abnormalities were mainly observed in the family Cibicididae and a few in the Elphididae (Appendix 4.1). Large numbers of broken or abraded tests were found.

4.3.5 Elemental Analysis of Shells

An MDS Ordination of all the measured elements of the foraminiferal tests showed a large amount of overlap between the control and pipeline sites of both Robben Island and St Helena Bay (Fig 4.1; Appendix 4.2). No clear structure or differences between the elemental composition of the shells of the two study sites was evident. The concentrations of the trace metals within the foraminiferal tests of the pipeline sites of St Helena Bay appeared to display a larger degree of variation than those of the other sites.

Comparisons of all Robben Island stations showed no significant differences in the elemental composition of the shells, except in station RIE where shells had a significantly higher concentration of Cr than those from all other stations (Appendix 4.3.1 – 4.3.8) no significant differences were found between the control and pipeline sites. Comparisons of all control and all pipeline sites of Robben Island showed no significant

difference between the analyzed shell elements (Appendix 4.3.9). In St Helena Bay, a comparison of elements within the shells revealed that shells within station SHH had a significantly lower concentration of calcium with a significantly higher concentration of Zn and Fe than the other sites (Appendix 4.3.10 – 4.3.17). Significantly higher concentrations of Mg and Fe were found when the control and pipeline sites were analyzed in St Helena Bay (Appendix 4.3.19).

When the concentrations of elements of the shells were compared between the two sites, Mg concentrations were significantly higher and Ca significantly lower in St Helena Bay than in Robben Island specimens. No significant differences were apparent in the trace metal concentrations but an expected higher concentration due to higher sediment trace metal concentration did not occur in St Helena Bay except for Fe and Pb (Appendix 4.3.19).

Non-parametric Spearman correlations performed to relate the trace metal contents of the shells with that of the sediments between all samples revealed a no significant correlation with all the trace metals (Fig. 4.2). The St Helena Bay samples did not have any significant correlations between the trace metals of the sediments and the concentrations of trace metals in the tests, while those of the Robben Island samples showed significant negative correlations between Cd, Cr, Cu and Zn concentrations of the tests and the sediments (Table 4.12). The control sites showed no significant correlation while the pipeline sites only had a significant negative correlation with Cr concentration in the sediments. These significant correlations were quite low.

4.4 Discussion

4.4.1 Community Structure

The abundance, species richness and diversity of foraminifera increased with an increase in the mean grain size of the sediments, although these correlations were not significant. A high abundance of species and individuals have been found in fine, silty sands as opposed to coarse sand or clay and this is thought to be a result of higher organic enrichment in fine sediments and therefore greater food availability (Samir & El- Din, 2001). That said, Frontalini & Coccioni (2008) have found that this is not always true when examining individual species like *Ammonia parkinsoniana.* The relationship

between foraminifera and grain size appears to change depending on the individual species present and the species dominating in these study areas appear to be able to take advantage of the greater habitats offered by coarser grain sizes.

The percentage nitrogen in sediments is often an indication of organic matter input, however, the percentage nitrogen was negatively correlations with richness, diversity and the abundance of foraminifera in St Helena Bay samples, but positively correlated in Robben Island samples. These differing results may be a result of the higher percentage nitrogen concentrations found in St Helena Bay as opposed to Robben Island and may be a result of increased eutrophication as a result of increased organic carbon loading. Bacteria break down organic compounds to carbon dioxide, water and ammonia, when organic matter input increases, the amount of nitrogen produced by benthic organisms also increases (Mojtahid *et al.,* 2009). While this increase in nitrogen leads to more phytoplankton production, too much organic matter can lead to an increase in eutrophication. Nitrogen pollution has been found to be highest near agricultural activity and urban development, and is the leading cause of the increase in eutrophication observed in coastal systems (Howarth & Marino, 2006). An increase in eutrophication can lead to changes in the biotic community structure in marine ecosystems (Smith *et al.,* 2006).

The BIOENV BEST procedure in PRIMER revealed a high contribution of the percentage nitrogen in the sediments in determining community structure. Besides the input of organic matter into the system from the processing of the fish, St Helena Bay is sheltered and has a long retention time of water, which traps and accumulates organic matter that has been deposited there (Walker & Pitcher, 1991). Anthropogenically sourced organic matter has been found to produce above-background foraminiferal population densities, evident in the large abundance of foraminifera in St Helena Bay as opposed to Robben Island (Bernhard, 1986; Yanko *et al.,* 1994; Scott *et al.*, 2001). In St Helena Bay, the effect of the increased organic matter may not be found near the source of pollution because oxidation of organic matter near the source may be high enough to cause local anoxia and therefore a decrease in population density but populations further from the point may have larger population sizes (Scott *et al.*, 2001).

Both study areas normally have high levels of organic carbon as a result of upwelling events, they may have large phytoplankton blooms and eventually high levels of phytodetritus these effects, however, are seasonal (more so in St Helena Bay than Table Bay) and may not have a permanent effect on the community structure (Scott *et al*., 2001). Opportunistic benthic foraminiferal species take advantage of high levels of phytodetritus and increase in abundance (Scott *et al*., 2001). Upwelled areas that experience seasonal increases in organic matter input (phytodetitritus) to the sediments, may experience variable increases in the abundance of foraminifera, this results in spatial variability and a patchy distribution of foraminiferal species (Diz *et al*., 2006).

In a study of an upwelling region in NW Spain, it was found that seasonal variability of organic carbon flux to the seafloor (especially during upwelling and downwelling events) made assessing the correlation between foraminiferal abundance, biomass and assemblage composition difficult, as foraminifera respond quickly to even small changes in organic matter over short time periods (Diz *et al*., 2006). Most foraminifera that increased in abundance during upwelling events were considered to be r-strategists that reproduced quickly in response to phytoplankton blooms, a change in the abundance of k-strategists was found to be a long-term response to low oxygen concentrations or reducing microenvironmental conditions (Diz *et al*., 2006). Because sampling took place in spring and summer when upwelling occurs in the study area, the correlations with foraminiferal abundance and diversity with organic carbon were significant, an assessment after upwelling events may be different as organic carbon could be depleted.

Iron, Pb and Zn concentrations in the sediment appeared to negatively impact the diversity and richness and abundance of foraminifera in St Helena Bay samples. All other trace metals also showed a negative impact. In studies of foraminifera, the trace metal concentrations have only been found to negatively impact communities (Scott *et al*., 2001) No significant correlations were found between the richness and diversity of Robben Island samples and the trace metals in the sediments. The concentrations of trace metals in Robben Island samples were much lower than those of St Helena Bay which may account for the fact that foraminifera did not appear to be impacted. Other pollution studies have also reported lower foraminiferal diversity in response to high trace metal concentrations (Ferraro *et al*., 2006). Cadmium, Cu and Cr were the trace metals most

responsible for the community structure of both study areas although none of the trace metals displayed any significant correlations with species diversity or species richness of foraminifera. The effects of trace metals on the community structure appears to be more marked when there is a concurrent input of organic matter, but on their own appear to have minor effects on foraminiferal diversity (Scott *et al*., 2001). Ferraro *et al*. (2006) reported an area completely devoid of foraminifera in Diaz dock, Naples where the concentrations of trace metals were higher than USEPA ERM levels. In both study areas, there was not a complete absence of foraminiferal specimens, although, some stations especially in St Helena Bay had extremely low numbers. While this suggests that the levels of trace metals in this area are generally tolerable for foraminifera, some localized effects particularly in the St Helena Bay stations may be occurring.

4.4.2 Genera

The correlations between the abundance of all the dominant genera varied in the samples from St Helen Bay and Robben Island and correlations were not very high. The grain size does not appear to be an important factor influencing these organisms, as it appears that different types of foraminifera could inhabit different sediment microhabitats. Grain size influences the depth to which foraminifera are able to live, fine sand and mud are often anoxic deeper than 1 cm and coarser sediments are less anoxic allowing deeper penetration of foraminifera (Murray, 1991).

The percentage nitrogen, however, had significant negative correlations with *Bolivina* and *Elphidium* (Robben Island) and *Ammonia* (St Helena Bay). These species may not be as tolerant to the increased nitrogen input into the system. *Ammonia* has been found to dominate shallow water assemblages irrespective of substrate type or percentage carbon input (Frontalini & Coccioni, 2007) and is therefore a species with wide tolerance ranges and could be regarded as opportunistic.

All the dominant genera from St Helena Bay had a negative relationship with trace metal concentration of the sediments, but only *Elphidium* and *Cibicides* were significantly correlated with Fe, Pb and Zn and *Ammonia* with Zn and Cd. while *Bolivina, Elphidium* and *Quinqueloculina* in Robben Island had significantly negative correlations with Cd, Cr and Fe. In an attempt to identify proxies for the two study areas

for trace metals concentrations in sediments, it appears that different species should be used. *Rosalina* does not appear to be a good indicator of environmental conditions as it does not appear to respond to changes in environmental conditions. *Cibicides* and *Bolivina* appear to have different responses in the two study areas and may be responding to conditions other than those which have been measured. Specimens of bolivinids in the sites of St Helena Bay were also glassy or transparent (personal observation) which has been commonly found in foraminifera in low oxygen environments. High acidicity in normally leads to reduced carbonate uptake and therefore glassy or transparent tests (Bernhard, 1986). Acidity was not measured in this study; but could possibly be implied by the presence of these test types.

Elphidium has the same reponse in both study areas and appears to be the only species which can be used as an indicator, although, *Quinqueloculina* (Robben Island) and *Ammonia* (St Helena Bay) also appear affected by environmental conditions. *Elphidium excavatum* have been found to be facultative anaerobes and able to develop even under stressed conditions (Burone *et al*., 2006). In some temperate regions it has been found that species of Elphidium flourish in near-shore polluted environments (Samir *et al.,* 2000; Scott *et al.,* 2001).

Ammonia and more specifically *Ammonia parkinsoniana* identified in this study has been found to be sensitive to heavy metal pollution even at low concentrations (Frontalini & Coccioni, 2008). *Ammonia becarii* forma *tepida* has been found to dominate areas close to sewage, fertilizer and industrial outfalls (Seiglie, 1971; Alve, 1987; Yanko *et al*., 1994; Scott *et al*., 2001). *A. tepida* has been globally used as an indicator of high trace metal concentrations and appears to be an important indicator of chemical stress (Bergin *et al*., 2006; Ferraro *et al*., 2006). The genus *Ammonia* therefore appears to be able to respond to many different stressors and therefore could be used as an indicator as identified in the St Helena Bay samples. *Ammonia* and *Elphidium* are both adapted to marginal and shallow marine environments and are able to survive in highly polluted waters, and easily survive low oxygen conditions (Thomas *et al*., 2004). *Quinqueloculina* are unable to tolerate high levels of toxic trace metals therefore their absence in an area may be indicative of a polluted environment, as in St Helena Bay.

4.4.3 Foraminiferal Size Structure

The dominant size class of the foraminiferal assemblages of both study areas did not appear to be influenced by the dominant sediment grain size. Foraminiferal assemblages in St Helena Bay and Robben Island were dominated by the size classes 63 μm 125 μm. The smaller of the size classes dominated in both live and dead specimens around the pipeline despite the fact that sediment size was dominated by a larger size class, implying that sediment size had very little to do with the size of foraminifera that are being supported in this environment. Sediment grain size has been shown to influence the size of organisms found in the sediment (McLachlan, 1978), however, in a system not strongly influenced by factors like increased organic carbon, nitrogen and trace metals this would probably be the case.

The sediments at both study areas were coarse, indicative of a well-aerated environment; this may explain why all the foraminiferal size classes were not correlated with the corresponding sediment size class in terms of abundance. All size classes of foraminifera were able to penetrate through the loosely packed coarse sand grains. Sediment size therefore appears to have very little impact on overall foraminiferal size structure. Benthic foraminifera can be epifaunal or infaunal and their shape and size and orientation are often linked to the nature of their substrate within their environment, because the size of the grains will influence their ability to move and their ability to feed (Murray, 1991). The coarse grain size may also provide more habitats for even small foraminifera particularly those that attach to substrates (du Châtelet *et al*., 2009).

The presence of heavy metals is thought to stunt growth and cause a physiological disturbance in the growth of foraminifera (Samir *et al.,* 2001). All trace metals, except Cd and Cr, in the sediments were found to be negatively significantly correlated with the abundance of foraminifera of St Helena Bay samples but played a more positive role in Robben Island samples. Bernhard (1986) also suggests that smaller lighter foraminifera stand less of a chance of sinking deeper into anoxic sediments than foraminifera that are larger and heavier and that smaller tests have a larger surface area: volume ratio enhancing uptake of oxygen. Therefore the dominance of the smaller size class of foraminifera found in both study areas may be due to the high trace metal content of the sediments or even an oxygen poor environment. Bernhard (1986) has further suggested

that smaller foraminifera would be more successful in an oxygen deficient environment than larger foraminifera as sufficient oxygen would be available for their metabolic activities.

4.4.4. Shell Morphology

Test deformities in St. Helena Bay and Robben Island samples were not high, ranging from 0.6 % – 4 % of the total 300 picked foraminifera per sample. It has been found in previous studies that test deformities were usually less than 10 % (Scott *et al*., 2001). It therefore appears as if the level of pollutants is not high enough to have caused this phenomenon. Alve and Olsgard (1999) also reported no increased abundance of deformed tests in experiments where foraminifera were exposed to high concentrations of copper.

These abnormalities (abnormal chamber growth and Siamese twins) although observed in different families were mainly observed in the family Cibicidae and a few in the Elphididae. The Cibicidae, however, have been known to have varying test morphology determined by their environment and the substrate to which they attach themselves, these perceived abnormalities may therefore merely be this variation. Samir & El-Din (2001) observed most abnormalities in the Miliolids; suggesting that Miliolids were most sensitive to pollutants. Miliolids were absent in St. Helena Bay samples which may be a direct result of pollution or may be that Miliolids are most abundant in shallow warm-water and coral reef regions (Cushman, 1959). In an unpublished thesis (Toefy *et al.*, 2002) found that Miliolids increased in abundance on the south coast of South Africa which is characterized by warmer more stable water temperatures than the west coast which is subject to cold temperatures and many temperature fluctuations during upwelling.

Studies by Yanko *et al.* (1994), Alve (1991) and Sharifi *et al*. (1991) have correlated morphological abnormalities with trace metal concentrations. Sharifi *et al*., 1991 has also concluded in laboratory experiments using Cu that certain concentrations of copper cause morphological abnormalities.

Foraminiferal tests can be used as indicators of wave turbulence and bottom currents, as high velocities often cause broken or abraded tests (Scott *et al*., 2001). The

foraminifera in the St Helena Bay samples had a large number of broken or abraded tests which attests to their position in wave turbulent area; this is not an indication of a high velocity current as it has already been established that currents in St Helena Bay and resident time of water is very slow (Walker & Pitcher, 1991). Toler & Hallock (1998) suggest that large numbers of broken specimens are a result of stress which compromises biomineralization in shells of foraminifera.

It is extremely difficult when doing a once-off study and only studying the top few centimetres of a core to conclusively say whether morphological abnormalities are a result of chemical factors within the sediments. Morphological abnormalities could also be caused by a range of factors both natural and anthropogenic and it would be difficult to isolate any specific cause. In a study conducted by Elberling *et al*. (2003), a core was examined where pre-, during and post-pollution foraminiferal tests were examined. This study could then examine natural background abnormalities comparing it to occurrences of abnormalities during pollution events, and could therefore conclude that higher trace metals contributed to an increase in morphological abnormalities.

4.4.5 Elemental Analysis

From the analysis of the trace metals concentration in the shells of foraminifera, it appeared as if there was no correlation between the concentration of the metals in the sediment and the concentration of the metals in the foraminiferal tests. The trace metal concentration of the sediments does play some role in determining the trace metal content of the foraminiferal tests, however, the conflicting results from the two sites and the low correlations may mean that some other factor is controlling the trace metal uptake. Marsden & Rainbow (2004) found that in crustaceans, the bioavailability of trace metals did not necessarily follow the absolute concentrations of trace metals in the sediments in the same order of magnitude.

Metals entering organisms are either excreted or detoxified, detoxification occurs when metals are bound so that they are unavailable to metabolites within the organism, however, when excretion and detoxification is less than uptake, the trace metal becomes toxic to the organism (Marsden & Rainbow, 2004). Metals are concentrated into protein – rich tissues such as the liver and muscle in organisms as they tend to bind with sulphydryl

groups of proteins (Islam & Tanaka, 2004). This could possibly explain why the concentration of metals is not high in the shells which consist mainly of calcium carbonate, a hard substance. The fact that foraminifera have such a small mass of cytoplasm might also be a contributing factor for it being less able to take up trace metals. The other important factor may be that some metals have an inhibitory effect on toxic metal uptake by aquatic organisms, for example, Zinc has been found to inhibit the uptake of lead and some other metals (Elberling, *et al.,* 2003; Marsden & Rainbow 2004). That is, one has to determine the bio-availability of these trace metals which depends on a number of factors. These factors may be the chemical speciation of metals, the control of metal concentration by Fe-oxides and organic compounds which scavenge metals, competition between trace metals, bioturbation by benthic fauna, changes in pH or redox reactions (Bryan & Langston, 1992).

Another factor which could be playing a role in the lack of strong correlations between the sediments and the tests could also be that foraminifera may be able to regulate the concentrations of the trace metals within their shells, that is, trace metals will not be absorbed exponentially but will level off at a certain point. This was evident in correlations where the concentrations in the tests remained low despite an increase in the trace metal concentrations of the sediments. This has been found to occur in some mussels which have been found to be partial regulators of copper and / or zinc (Rainbow & Phillips, 1993), and decapods which tend to regulate all trace metals in their tissues in varying trace metal concentrations (Marsden & Rainbow, 2004). In a study on polychaets in S.W. England, there was no clear relationship with Fe, Mn and Zn concentrations in the sediments and the tissues, but Cu concentrations reflected more bio-availability (Bryan & Langston, 1992). Trace metals also display competition for attachment sites in organisms, for example, Cu with Ag, and Zn with Cd, and Pb was found to bind strongly with Fe-oxyhydroxides which may regulate their bio-availability and uptake (Bryan & Langston, 1992).

The foraminiferal shells of SHH showed a significantly higher concentration of trace metals than other sites but a lower concentration of Calcium. Yanko & Kronfeld (1992) in Samir & El-Din (2001) suggested that high trace metal concentration weakens biological barriers that distinguish between the uptake of Mg and Ca, therefore shells

formed in highly polluted areas often have a lower Calcium and higher Magnesium concentration in their shells and are weaker. This was apparent in the shells from the St Helena Bay samples which displayed a significantly higher concentration of Mg and significantly lower concentration of Ca than those from Robben Island. Magnesium modifies the morphology of calcite crystals, forming triangular crystals as well as affecting the organic matrix of glycosaminoglycans which weaken the test structure (Toler et al., 2001). A similarity was found to be the case in an experiment on oyster shells where Calcium: magnesium ratios were affected by pollutants (Almeida *et al*., 1998).

The foraminiferal shells of RIE had a higher chromium concentration. Chromium, along with copper and zinc has been found to be more easily absorbed than lead (Samir & El- Din, 2001). Elberling *et al.* (2003) reports that Zinc is one of the essential metals which inhibits the toxicity of lead and other metals, and may have an inhibitory effect on toxic metal uptake by aquatic organism. Zinc and Lead were two trace metals important in the grouping of sites according to trace metal content in Robben Island samples.

Biomonitors of trace metals cannot be regulators but have to be net accumulators of trace metals in order to make a proper assessment of the environment.

4.4 Conclusions

The trace metal concentrations of St Helena Bay samples were much higher than those of Robben Island. Therefore, the probability that some of these sediments could be toxic to living organisms has to be considered. This is evident in the decrease in the abundance, species richness and diversity of foraminifera with increasing trace metal concentrations in St Helena Bay, while Robben Island showed mostly positive correlations, which were significant for abundance. The percentage nitrogen had negative correlations with abundance, diversity and richness in St Helena Bay but positive correlations in Robben Island. As the grain size increased in both study areas diversity, richness and abundance decreased except for the abundance of foraminfera in Robben Island which actually increased with increasing grain size. The two study areas had obvious differences with regards to their diversity, richness and abundance which appear to be influenced by their differences in trace metal concentrations of the sediments as

well as the percentage nitrogen. The mean grain size does not appear to have a very strong influence over the diversity, abundance and richness.

When examining the community structure it became clear that the most important factors determining this structure were the percentage nitrogen and Cd, while the Cr and Cu concentrations and the mean grain size played a smaller role. The presence of the mean grain size in this structure may appear contradictory to previous statements regarding diversity, richness and abundance but community structure refers more to the abundance of foraminiferal specimens within each species and is thus a different parameter which is being examined.

Genera which appear to be related to the environmental conditions within the sediments were *Elphidium* and *Ammonia*, as well as the presence/absence of *Quinqueloculina.* These genera appear could possibly be used as proxies for the environmental factors, as bio-indicators are normally the ones which are most affected by the changes in environmental factors.

Both assemblages were dominated by small foraminifera despite being found in an environment dominated by a large mean grain size. This may be a result of the high trace metal content or low oxygen environments known to limit growth of foraminifera or the temperate waters which support smaller foraminifera than warmer waters.

Morphological abnormalities in both study areas were negligible and below 5 %, the foraminifera in both study areas do not appear to be affected although it is difficult to conclusively comment as no baseline studies of the area exists. The trace metal content of the shells seem largely unrelated to that of the sediments and as trace metals have been known to cause morphological abnormalities, this may be the reason for the low percentage of abnormality. Foraminifera may be affected by trace metals but it appears that foraminifera are able to regulate trace metals within their tissues or that the bioavailability of trace metals within this system is low.

Table 4.1: The following are the results of the non-parametric Spearman Rank Order correlations between Species Richness, Species Diversity and the abundance of live foraminifera in all samples and all environmental variables in St Helena Bay. Significant R-values are at $p < 0.05$*.

	Species Richness	Species Diversity	Abundance
Cd	-0.218	-0.218	-0.180
Cr	-.0773	-0.112	-0.099
Cu	-0.178	-0.189	-0.203
Fe	-0.282*	-0.310*	-0.269*
Pb	-0.260*	-0.286*	-0.332*
Zn	-0.298*	-0.324*	-0.323*
% N	-0.243*	-0.296*	-0.205
Mean Grain Size	0.219	0.146	0.166

Table 4.2: The results of the Non-parametric Spearman Rank Order correlations between Species Richness, Species Diversity and the abundance of live foraminifera and all environmental variables for the Robben Island samples are represented. Significant R-values are at $p < 0.05$*.

	Species Richness	Species Diversity	Abundance
Cd	-0.123	-0.182	0.299
Cr	0.086	0.053	0.296
Cu	-0.054	0.033	0.137
Fe	0.089	0.125	0.243
Pb	0.140	0.151	-0.093
Zn	0.117	0.083	0.425*
Mean Grain Size	-0.086	-0.098	0.416*
% N	0.168	0.031	0.561*

Table 4.3: The results of the Pearson Product Moment correlations between Species Richness, Species Diversity and the abundance of live foraminifera and all environmental variables using pooled data from both study areas. Significant R- values are at $p < 0.05$ *.

	Species Richness	Species Diversity	Abundance
Cd	-0.22	-0.22	-0.18
Cr	-0.08	-0.11	-0.10
Cu	-0.18	-0.19	-0.20
Fe	-0.28*	-0.31*	-0.27*
Pb	-0.26*	-0.29*	-0.33*
Zn	-0.30*	-0.32*	-0.32*
% N	-0.24*	-0.30*	-0.20
Mean Grain Size	0.22	0.15	0.17

Table 4.4: The BIOENV BEST procedure in PRIMER for St Helena Bay samples which attempted to explain the environmental variables most responsible for assemblage structure. Data was log x+1 transformed. Spearman rank correlation was performed using Euclidean distance.

Percentage Contribution	Variable (s)
23.1	Cd, Cu, % N
23.1	Cd, Cu
23.1	Cd, Cu, % N, Mean Grain Size
23.1	Cd, Cu, Mean Grain Size
22.9	Cu, % N
22.9	Cu, % N, Mean Grain Size
22.9	Cu, Mean Grain Size
22.9	Cu
22.2	Cd, Cu, Pb, % N, Mean Grain Size
22.2	Cd, Cu, Pb, Mean Grain Size

Table 4.5: Results of the BIOENV BEST procedure in PRIMER for Robben Island samples, which attempted to explain the environmental variables most responsible for assemblage structure. Data was log x+1 transformed. Spearman rank correlation was performed using Euclidean distance.

Percentage Contribution	Variable (s)
16.4	Cd, % N
11.9	% N
11.4	Cd, Cu
11.4	Cd, Cu, % N
11.3	Cu
11.3	Cu, % N
10.5	Cd, Cu, % N, Mean Grain Size
10.5	Cd, Cu, Mean Grain Size
10.4	Cu, % N, Mean Grain Size
10.4	Cu, Mean Grain Size

Table 4.6: BIOENV BEST was used to explain the environmental variables most responsible for the assemblage structure of both Robben Island and St Helena Bay samples. Data were log x+1 transformed and Euclidean distance and Spearman rank correlation was performed.

Percentage Contribution	Variable (s)
42.7	Cd
42	Cd, % N
29.3	Cd, Mean Grain Size
29.3	Cd, % N, Mean Grain Size
29.2	Cd, Cr, Cu, % N, Mean Grain Size
29.1	Cd, Cr, Cu, Mean Grain Size
29	Cr, Cu, % N, Mean Grain Size
29	Cr, Cu, Mean Grain Size
29	Cd, Cr, Cu, % N
29	Cd, Cr, Cu

Table 4.7: Results of the Non-parametric, Spearman Rank Order Correlation between all environmental variables and the abundance of the dominant genera for St Helena Bay. Significant R-values are at $p < 0.05$*

	Ammonia	*Bolivina*	*Elphidium*	*Cibicides*	*Rosalina*
Cd	-0.358*	-0.165	-0.210	-0.210	0.006
Cr	-0.123	-0.097	-0.064	-0.059	0.083
Cu	-0.146	-0.053	-0.173	-0.225	0.153
Fe	-0.194	-0.166	-0.273*	-0.282*	0.015
Pb	-0.225	-0.120	-0.319*	-0.368*	0.019
Zn	-0.290*	-0.226	-0.373*	-0.403*	0.057
% N	-0.246*	-0.102	-0.199	-0.207	0.051
Mean Grain Size	-0.008	0.054	0.262*	0.265*	0.351*

Table 4.8: Results of the Non-parametric Spearman Rank Order Correlation between all environmental variables and the dominant genera of Robben Island. Significant R-values are at $p < 0.05$*.

	Bolivina	*Elphidium*	*Cibicides*	*Quinqueloculina*	*Rosalina*
Cd	-0.338	-0.356*	-0.108	-0.347*	-0.252
Cr	-0.391*	-0.417*	0.042	-0.366*	-0.145
Cu	-0.222	-0.236	-0.028	-0.219	0.062
Fe	-0.333	-0.356*	-0.011	-0.324	-0.234
Pb	-0.037	-0.039	0.021	-0.030	-0.059
Zn	-0.230	-0.240	0.018	-0.212	0.017
% N	-0.313	-0.342*	0.227	-0.254	-0.255
Mean Grain Size	-0.195	-0.218	-0.103	-0.222	-0.376*

Table 4.9: The following represents the dominant size classes of foraminiferal specimens in the live assemblages and the dominant sediment size class. The percentages are of the total found at each of the St Helena Bay stations.

SITE	LIVE		SEDIMENT	
SPA	>125 µm	64%	>125 µm	45%
SPB	>125 µm	40%	>125 µm	42%
SPC	>125 µm	52%	>125 µm	40%
SHA	>125 µm	38%	>125 µm	49%
SHB	>125 µm	49%	>500 µm	35%
SHC	>63 µm	76%	>63 µm	50%
SHD	>63 µm	61%	>500 µm	62%
SHE	>63 µm	44%	>500 µm	70%
SHF	>125 µm	46%	>500 µm	50%
SHG	>63 µm	52%	>500 µm	42%
SHH	>63 µm	65%	>500 µm	22%
SHI	>125 µm	72%	>125 µm	50%

Table 4.10: The following represents the dominant size classes of foraminiferal specimens in the live assemblages and the dominant sediment size class in each of the Robben Island stations. The percentage represents that of the total.

STATION	LIVE Foraminifera		SEDIMENT	
RIA	>125 µm	56 %	>500 µm	44 %
RIB	>125 µm	68 %	>500 µm	74 %
RIC	>125 µm	51 %	>500 µm	51 %
RID	>125 µm	56 %	>500 µm	85 %
RIE	>63 µm	46 %	>500 µm	50 %
	>125 µm	54 %	>500 µm	72 %
RIG	>125 µm	43 %	>500 µm	57 %
RIH	>63 µm	48 %	>500 µm	80 %

Table 4.11: Represents the % tests that displayed abnormalities (chamber regrowth or deformation) and the percentage of broken or abraded tests for each site. Only live foraminifera were examined. (Appendix – plates of normal, abraded and broken foraminifera).

STUDY AREA	STATION	% abnormalities tests	% broken/ abraded tests
Robben Island	RIA	0.64	3
	RIB	0.98	2
	RIC	1	3.5
	RID	1.8	6
	RIE	0.97	4
	RIF	1.86	4
	RIG	2	6
	RIH	0.89	3
St Helena Bay	SPA	1	10
	SPB	3	18
	SPC	2	20
	SHA	1	25
	SHB	1	23
	SHC	2	18
	SHD	3	16
	SHE	4	18
	SHF	3	18
	SHG	2	15
	SHH	1	20
	SHI	1	22

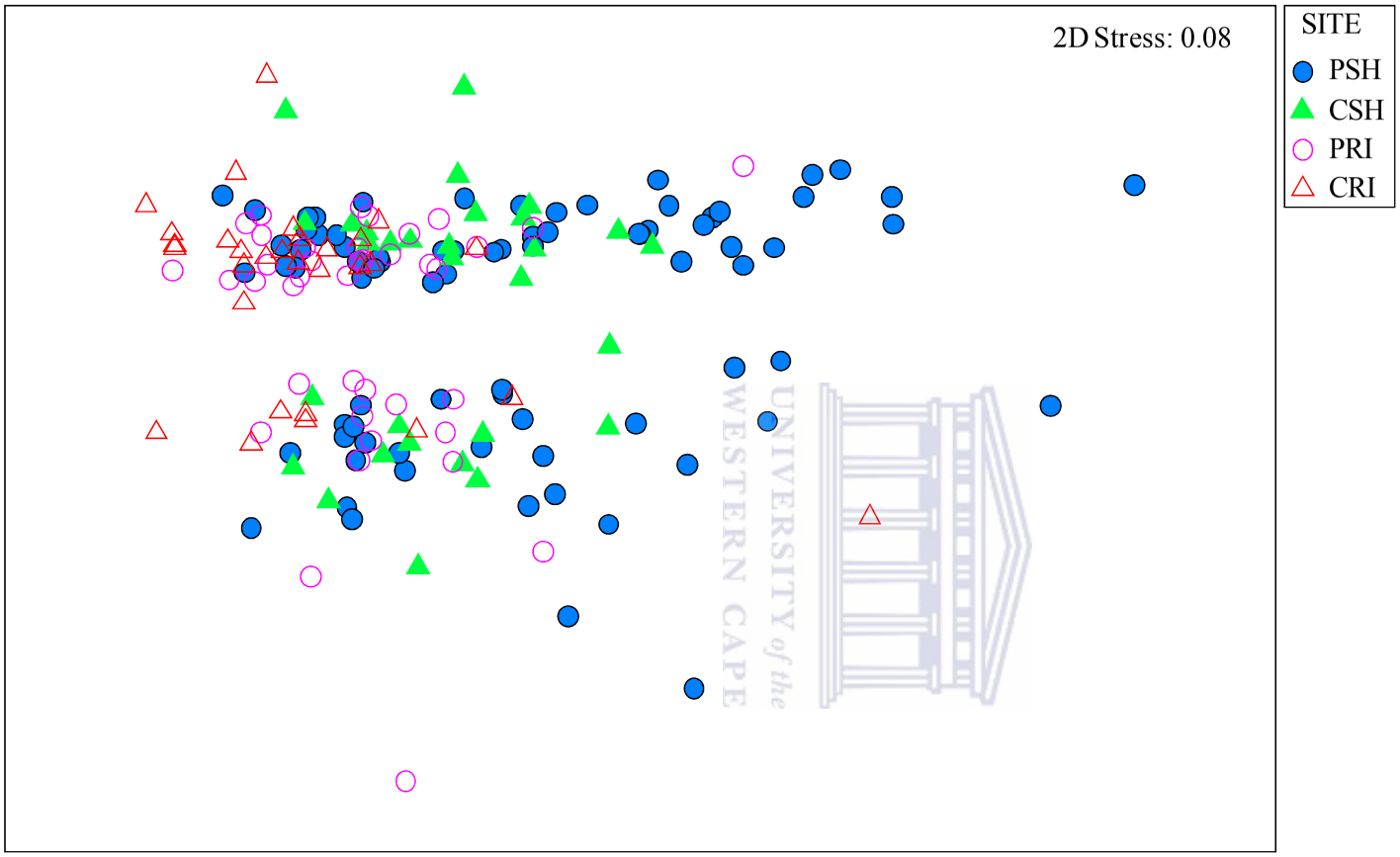

Figure 4.1: MDS Ordination of all measured elements in the analysis of foraminiferal tests. Data were square root transformed and Euclidean distance was used to produce a resemblance matrix. CSH – Control sites St Helena Bay; PSH – Pipeline Sites St Helena Bay. CRI - Control sites Robben Island; PRI – Pipeline Sites Robben Island.

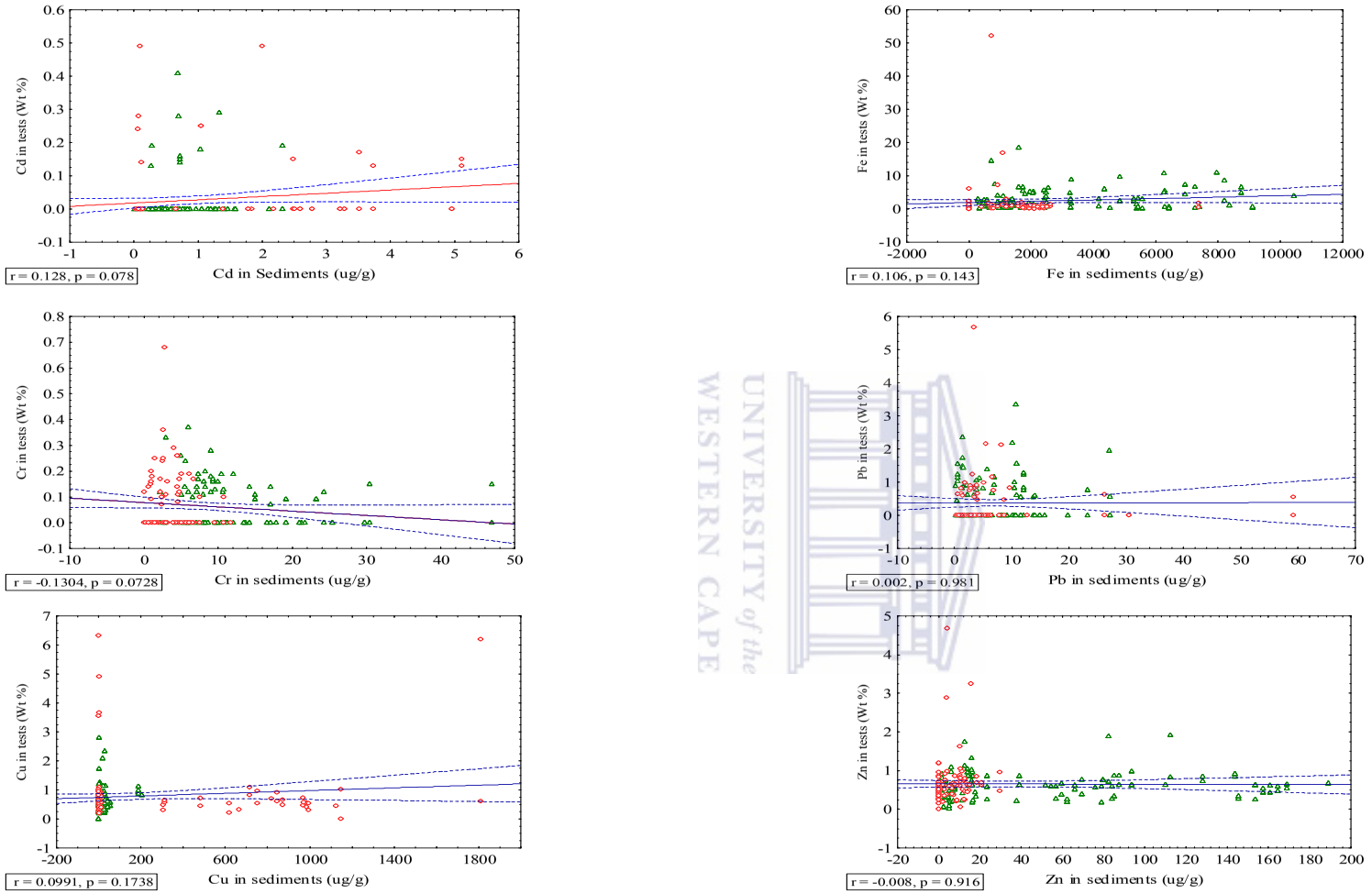

Figure 4.2: Results of the Non-parametric, Spearman Rank Order Correlation between the trace metal concentrations in the sediments and the trace metal concentration in the tests. Spearman R- values are represented. The red symbols represent Robben Island samples while the green symbols represent St Helena Bay samples

Table 4.12: Results of the Non-parametric, Spearman Rank Order Correlation between the trace metal concentrations in the sediments and the trace metal concentration in the tests. Spearman R- values are represented, significant at $p < 0.05$.

SH – St Helena Bay; CSH – Control sites St Helena Bay; PSH – Pipeline Sites St Helena Bay

RI – Robben Islands; CRI - Control sites Robben Island; PRI – Pipeline Sites Robben Island

Trace Metal	SH	CSH	PSH	RI	CRI	PRI
Cd	0.180	0.217	0.216	-0.405*	0.040	-0.040
Cr	-0.133	-0.226	-0.001	-0.455*	0.174	-0.48*
Cu	0.070	0.295	-0.110	-0.27	-0.290	0.040
Fe	0.178	0.021	0.130	0.050	0.040	0.080
Pb	-0.070	0.362	-0.110	-0.234	-0.110	-0.120
Zn	0.080	0.241	-0.130	-0.56*	0.140	-0.190

Chapter 5
General Conclusions

The aim of the study was to examine foraminiferal assemblages on the west coast of South Africa and to investigate the environmental factors which may play a role in determining the structure of these foraminiferal assemblages. The study also attempted to evaluate their use as bio-indicators of trace metals, percentage nitrogen and sediment size structure. In order to achieve these aims two study sites, the area around a sewage pipeline off Robben Island and a fish factory pipeline in St Helena Bay were evaluated.

The mean sediment grain size of both areas was high, as little mud was present. The St Helena Bay sites had higher concentrations of all trace metals than those of Robben Island, with some stations showing concentrations higher than ERL and the SA SQG's, an indication of their accumulation within the sediments. The percentage nitrogen in sediment samples from St Helena Bay was also higher than recorded around Robben Island which could be indicative of an environment with increased eutrophication. One of the major differences between the two study areas, that may be causing environmental differences, is the length of time that each of the sites have been exposed to effluent. St Helena Bay has had a long history of fish factory processing since 1945 (Shannon *et al*., 1983) while Robben Island has only had a sewage pipeline since 2002 (Prochazka, 2003). The organic loading in St Helena Bay has thus been added and accumulated over a long period of time. The hydrodynamics of St Helena Bay are also very different to those around Robben Island. St Helena Bay is an enclosed embayment which has a long residence time of water increased by an anticyclonic gyre and very little wind (Walker & Pitcher, 1991). The area around Robben Island, on the other hand, is subjected to strong winds of variable direction (Van Ieperen, 1971), which changes the direction of the plume from the pipeline constantly. Very little settlement would occur in one particular area, around Robben Island. Wave turbulence and currents around the island cause water from the pipeline to join the general current out of Table Bay (Ove Arup Consulting Engineers, 2001).

The measured environmental variables indicated that St Helena Bay may be polluted and at risk of sediment toxicity. However, because no baseline for trace metal

concentrations has been done for the west coast of South Africa, it is not easy to assess whether the area is enriched above the normal concentrations for the area. Monitoring of the sediments within this area is essential and a lengthening of the pipeline should be considered to outside the bay. The companies which rely on the bay as a source of water for processing are polluting the immediate area with their byproducts. The environmental variables around Robben Island indicated that the area is not polluted and that there was no risk of sediment toxicity, however, monitoring of the area should continue as this study was conducted when the pipeline had only been operating for a short time.

The species richness in both locations was low but consistent with other studies in shallow, nearshore marine environments (Murray, 2007). Both locations had many of the same species, which is to be expected as they are both within the cold temperate waters of the Benguela province. The species diversity curves reached asymptote and the estimated richness using various diversity indices were close to those observed, meaning that sampling effort was sufficient to capture all species which would be present. The low species richness was also indicative of a homogenous environment (on a mesoscale) which often displays low diversity as a result of the dominance of more colonizing species (Hewitt *et al*., 2008; Airoldi *et al*., 2008). Robben Island also showed higher diversity and species richness than St Helena Bay but a lower abundance of foraminifera. Low diversity and richness is indicative of pollution while the abundance of organisms will vary according to the tolerance of certain species, that is, the richness was low but the dominant species was abundant. The diversity indices of both sites therefore signaled much the same as the environmental factors, that is that St Helena Bay is an area of increased chemical contamination while Robben Island is not.

On examination of foraminiferal assemblages on a species versus genus level, it was found that using genera as proxies for environmental studies was sufficient and yielded much the same results and reacted in the same way as when using individual species. Using foraminiferal genera would thus decrease the time required for evaluation of an environment. The genus *Ammonia* which was dominant in St Helena Bay samples was not present in large abundance in Robben Island samples. *Elphidium* was dominant in both locations. Both these genera are regarded as opportunistic and can occupy a wide range of environmental conditions (Nagy & Alve, 1987; Yanko *et al*. 1994; Samir *et al*.,

2000; Scott *et al.,* 2001). The bolivinids were found in large abundance in St Helena Bay samples and were rare in those from around Robben Island, this taxa is often associated with a polluted environment (Bernhard, 1986; Frontalini *et al*., 2009). Robben Island had a large abundance of miliolids which were absent in St Helena Bay, this taxon is known for its sensitivity to pollutants and its absence in an assemblage could be a warning of an environment that is polluted (Ferraro *et al*., 2006). *Ammonia, Elphidium* and *Quinqueloculina* were identified as good indicators of environmental conditions.

Although some errors may occur in distinguishing live from dead foraminifera, the error appears small as differences between the two assemblages were evident. The live assemblages showed differences between the Robben Island and St Helena Bay study sites, and some separation between the control and pipeline sites. The dead assemblages, on the other hand showed no structure and samples from both study areas grouped together in no particular pattern. This shows that the dead assemblages were not subjected to the same processes as the live assemblages. There was also an absence of exotic species or species different from live assemblages in the dead assemblages, an indication that both areas were not a depositional environment (Alve & Murray, 1997).

The number of test deformities in both sites was not high, this could indicate that the areas are not polluted, as in previous studies test deformities were displayed in areas with high trace metal concentrations (Yanko *et al*., 1994). It could also be that the foraminifera have developed a tolerance to the levels of pollutants and as such do not display morphological abnormalities. The trace metal content of the shells did not correlate with the trace metals concentrations of the sediments and may be the reason for the low percentage of test abnormalities.

The response to the percentage nitrogen by foraminiferal abundance, diversity and richness was negative in both locations, although previous studies of foraminifera predict an increase in abundance when nitrogen is high due to an increase in phytodetritus (Scott *et al*., 2001). The percentage nitrogen can be linked to the percentage of organic carbon present; foraminifera display a variable response to organic carbon levels, if the amount is too high or too low, the abundance of foraminifera is low but there appears to be a level at which they can take advantage of the organic carbon and increase in numbers (Scott *et al*., 2001).

Dale & Beyeler (2001) provided a comprehensive checklist for evaluating the use of ecological indicators in monitoring and providing early warning signals, the choice of indicators needs to be carefully considered. As such this study will be evaluated against this checklist, which appears in italics in subsequent paragraphs.

The indicator must be easily measured. Although only the top 5 cm of sediments were used in this study, the abundance of foraminifera in these samples was high enough for statistical analysis. Six replicates were used for each core, making the study time-consuming. However, the six replicates were used because of the amount of variation normally found in foraminiferal communities where cores from the same station could have completely different community structures. The shape of a rarefraction curve depends on the relative abundance of sampled species and the fitted model provides a prediction of the increase in richness with additional sampling effort; the fact that the plotted graph reached asymptote is indicative that sampling effort was sufficient (Colwell & Coddington, 1994).

Foraminifera are microscopic and identification is often difficult (except when a scanning electron microscope is used), mistakes can easily be made in determining community structure. However, a simple abundance and presence/ absence study seems enough to determine ecological conditions as they appear to consistently react to environmental conditions in terms of their abundance and the presence of certain indicator taxa. Morphotypes are often considered to be equivalent to species for the purpose of biodiversity studies (Lambshead *et al.,* 2003). In this study the use of generic data appears to be as robust as using species data.

The indicator must be sensitive to stresses of the system as well as respond in a predictable manner. In this study foraminifera consistently showed a negative response to trace metal concentrations by decreasing in abundance, diversity and richness. This was consistent with other studies conducted on foraminifera and therefore it appears that this response does not change irrespective of other ecological parameters like global position, water temperature or depth (Yanko *et al*., 1994; Scott *et al*., 2001; Ferraro *et al*., 2006; Frontalini *et al*., 2009). The richness, diversity and abundance displayed a positive response to organic matter input in both locations while the percentage nitrogen displayed

a negative response. The response of both these parameters has been found to be consistent with other studies.

The genera that could possibly be used as indicators were *Elphidium, Ammonia* and *Quinqueloculina* as they displayed the strongest relationship with the measured environmental variables. The presence of an opportunistic species in large abundance can be indicative of a stressed system but could also be indicative of a healthy system as this species could proliferate in any conditions.

Indicators should be anticipatory, can predict changes that can be averted by management actions and provide a measure of key gradients across the ecological system. Benthic foraminifera occupy the sediments and any substance present in the water column settles in the sediments (Fricke & Flemming, 1983). Foraminifera have been found to react to organic matter input, trace metals and sediment size. The presence or absence of a high abundance of foraminifera or individual genera and sometimes even species is a normal response to changes in these environmental conditions. Thus investigation of the chemistry and physical structure of the sediments as well as the foraminifera present can provide a management and monitoring tool for ecological systems.

Indicators should have a known response to natural disturbances, anthropogenic stresses and changes over time. Numerous studies have been conducted and are increasing with respect to foraminiferal response to ecological conditions (Yanko *et al*., 1994; Samir *et al*., 2000; Scott *et al.,* 2001). Although there are still many unanswered questions regarding the ecology of individual species of foraminifera, the surge in new studies is providing new useful information which can be used for future monitoring.

Indicators should have low variability in response. Although the foraminifera have been found to display predictable response to environmental conditions, foraminifera themselves are known for their patchy distribution within their microhabitat. In this study, high variability was found between cores of the same station. Studies would therefore, require many replicates in order to make conclusive observations and studying one core only per station as done by many previous studies is not sufficient. Other studies conducted also reported high morphological abnormalities in test morphology which was not observed in this study. The possible use of test morphology as indicative of

environmental stress should be used cautiously as morphological abnormalities have been reported under natural conditions in unpolluted environments.

No relationship could be found between the trace metal content of the sediments and the concentration found in the shells. There could have been for a number of reasons for this, organisms normally take up trace metals into their tissues and foraminifera have a limited amount of protoplasm, foraminifera have the ability to limit the uptake trace metals into their shells or the type of trace metal complex present in these environments limits its bio-availability. Biomonitors, that is, species which accumulate trace metals in their tissues, which have most successfully been used as monitors belonged to taxa which are suspension feeders and detritivores (Rainbow & Phillips, 1993). Of these taxa, *Mytilus, Perna* and *Crassostrea* appear to be the most reliable in reflecting environmental conditions, many of the organisms like crustaceans (barnacles) and polychaetes appear to regulate either their intake or the accumulation of trace metals in their tissues and have been found to have variable responses even between species (Rainbow and Phillips, 1993). It appears that macrofauna because of their larger body size are measurably affected by trace metals whereas the response of smaller organisms and particularly meiofauna may experience variable or negligible effects.

Foraminifera can be successfully used as bio-indicators locally as they have displayed much the same results as have been reported in other studies globally. However, shell abnormalities and shell trace metal concentrations as indicators should be used cautiously and would need to be backed up by environmental data and experimental studies. While this study examined foraminifera on a micro-, meso and macroscale (only a few 100 km), a larger scale study examining the biogeographic provinces around South Africa would be useful. This study also does not take temporal variability into account; conditions on the south west coast of South Africa vary greatly between seasons and a very different assemblage structure could be encountered during different seasons.

The number of marine pollution studies in South Africa has not historically been very high and could possibly be due to the perception that the marine environment is able to absorb much of the land-based pollutants, as a result more impact studies have focused on freshwater and terrestrial pollution. O' Donoghue & Marshall (2003) reviewed marine pollution research in South Africa and found that between 1960 and 2002; fewer than 100

pollution studies were conducted on marine pollution, which is fewer than three per year. This has become a concern for the National Research Foundation (NRF) in South Africa, which funds scientific research in South Africa; it has reported that only 4 % of research applied for in their Sea and Coast Programme has been related to marine pollution-related projects (NRF & SANCOR, 2010). In 2010, the NRF and SANCOR held a joint workshop with scientists and other stakeholders interested in marine pollution research. The main outcomes from this workshop were that there was a lack of specific coordinated research in South Africa and as such it was recommended that a National Marine Pollution Forum be established to facilitate research (NRF & SANCOR, 2010). Most importantly, the results of research and monitoring should be made accessible to the public. In this study it was particularly difficult to access historical data on the two locations as these were conducted for private companies, information/ data gathered by private consultants is not open to public perusal and therefore scientific studies are often conducted in isolation. Research-specific gaps identified were the economic evaluations of coastal resources, the identification of novel technologies for assessments (monitoring devices, predictive modeling, remote sensing and biomarkers) and risk analysis of the consumption of fish and shellfish and contact recreation as a result of marine pollution (NRF & SANCOR, 2010)

This study could therefore contribute to these identified gaps and assist in increasing our understanding of how environmental factors react in different environments, in this particular case, in upwelled, cold temperate waters and the effects these environmental factors have on specific taxa. Studies must however have both a biological and a physical/ environmental component as it is very difficult to make comprehensive conclusions from only one aspect. A study such as this one should also be repeated in the same area to provide information on temporal variability and in other 'normal' areas around the west coast to obtain baseline information.

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Appendix 1.1: Species of foraminifera identified by studies in South Africa

Species	Author	Location	Age
Acarinina esnaensis	Siesser & Miles, 1979	Birbury	Lower Eocene
Acarinina nitida	Siesser & Miles, 1979	Birbury	Lower Eocene
Acarinina primitiva	Siesser & Miles, 1979	Birbury	Lower Eocene
Acarinina pseudotopilensis	Siesser & Miles, 1979	Birbury	Lower Eocene
Acarinina soldadoensis soldadoensis	Siesser & Miles, 1979	Birbury	Lower Eocene
Ammobaculites sp	Phleger, 1973	St. Lucia Bay, Natal	?unspecified
Ammodiscus tenuis Brady	Chapman, 1924	S. A. Coast	?unspecified
Ammodiscus incertus d'Orbigny	Chapman, 1924	S. A. Coast	?unspecified
Ammonia becarii (Linne, 1767)	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
	Biesiot, 1957	Umfolozi River, Natal	Miocene
	Albani, 1965	Durban Bay	Recent
	Phleger, 1973	St. Lucia Bay, Natal	?unspecified
	Martin, 1974	W.coast SA	?unspecified
	Salmon, 1979a	S. W. Indian Ocean	Quaternary
	Salmon, 1981	S. W. Indian Ocean	Quaternary
Ammonia japonica (Hada, 1931)	McMillan, 1990	Cape Town	Late Pleistocene
	McMillan, 1998	W.coast SA	Holocene
	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Early Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Holocene
*Ammonia parkinsoniana (*d'Orbigny, 1839)	McMillan, 1990	Cape Town	Late Pleistocene
	Dale & McMillan1999	Saldanha Region	Late Pleistocene

Species	Author	Location	Age
*Ammonia parkinsoniana (*d'Orbigny, 1839)	Dale & McMillan, 1999	Saldanha Region	Holocene
Ammotium salsum	Phleger, 1973	St. Lucia Bay, Natal	?unspecified
Amphicoryna scalaris Batsch	Martin, 1974	W.coast SA	?unspecified
Amphistegina lessoni d' Orbigny	Biesiot, 1957	Umfolozi River, Natal	Miocene
Amphistegina radiata (Fichtel & Moll, 1798)	Parr, 1958	Durban	Pleistocene
Amphistegina uloaensis Biesiot, 1957	Biesiot, 1957	Umfolozi River, Natal	Miocene
Angulogerina halkyardi Cushman & Edwards	Biesiot, 1957	Umfolozi River, Natal	Miocene
Anomalina ammonoides Reuss, 1845	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
	Chapman, 1930	Alexandria Formation	Upper Eocene
Anomalina ariminensis d'Orbigny	Chapman, 1924	S. A. Coast	?unspecified
Anomalina globulosa (Chapman & Parr)	Martin, 1974	W.coast SA	?unspecified
cf. *Anomalina* sp.	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
Arenodosaria antipoda Stache, 1865	Salmon, 1979b	Agulhas Passage	Eocene
Arenoparella mexicana	Phleger, 1973	St. Lucia Bay, Natal	?unspecified
Asterorotalia inflata (Millet, 1904)	Albani, 1965	Durban Bay	Recent
Astorhiza arenaria Norman	Chapman, 1924	S. A. Coast	?unspecified
Astorhiza compressiuscula	Chapman, 1924	S. A. Coast	?unspecified
Astorhiza crassatina Brady	Chapman, 1924	S. A. Coast	?unspecified
Astrononion echolsi Kennet, 1967	McMillan, 1990	Cape Town	Late Pleistocene
Aristerospira globigerina	Ehrenberg, 1863	Agulhas Bank	?unspecified
Aristerospira megastoma	Ehrenberg, 1863	Agulhas Bank	?unspecified
Aristerospira nidulus	Ehrenberg, 1863	Agulhas Bank	?unspecified
Aristerospira phanerostoma	Ehrenberg, 1863	Agulhas Bank	?unspecified
Baggina phillipinensis (Cushman, 1921)	Albani, 1965	Durban Bay	Recent
Bathysiphon filiformis	Chapman, 1924	S.A. Coast	?unspecified
Biloculina bradii Schlumberger	Chapman, 1924	S.A. Coast	?unspecified

Species	Author	Location	Age
Biloculina depressa d' Orbigny	Chapman, 1925	S.A. Coast	?unspecified
Biloculina vespertilio Schlumberger	Chapman, 1924	S.A. Coast	?unspecified
Bolivina dilatata Brady	Chapman, 1924	S.A. Coast	?unspecified
Bolivina fossa McMillan, 1987	Toefy *et al.*, 2003	False Bay	Recent
Bolivina globulosa Cushman	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Bolivina inflata Seguenza	Chapman, 1924	S.A. Coast	?unspecified
Bolivina mtubatubanensis Biesiot, 1957	Biesiot, 1957	Umfolozi River, Natal	Miocene
Bolivina pseudoplicata Heron-Allen & Earland	Toefy *et al.*, 2003	False Bay	Recent
Bolivina punctata d'Orbigny	Chapman, 1924	S.A. Coast	?unspecified
Bolivina quadrilatera Schwager	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Bolivina sp	Phleger, 1973	St. Lucia Bay, Natal	?unspecified
Botellina pinnata Pearcey	Chapman, 1924	S. A. Coast	?unspecified
Botellina radiciformis	Chapman, 1924	S. A. Coast	?unspecified
Brizalina pseudopunctata (Hoglund)	McMillan, 1998	W.coast SA	Holocene
Brizalina rocklandsensis McMillan, 1987	Dale & McMillan, 1999	Saldanha Region	Holocene
	Toefy *et al.*, 2003	False Bay	Recent
Brizalina spathulata Williamson	Martin, 1974	W.coast SA	?unspecified
	McMillan, 1990	Cape Town	Late Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
Bulimina aculeata d' Orbigny	Martin, 1974	W.coast SA	?unspecified
	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Bulimina alazaensis Cushman	Martin, 1974	W.coast SA	?unspecified
Bulimina elongata d' Orbigny	McMillan, 1998	W.coast SA	Holocene
Bulimina gibba	Dale & McMillan, 1999	Saldanha Region	Early Pleistocene

Species	Author	Location	Age
Bulimina gibba	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
Bulimina inflata Seguenza	Martin, 1974	W.coast SA	?unspecified
	Salmon, 1979a	S. W. Indian Ocean	Quaternary
	Chapman, 1924	S. A. Coast	?unspecified
Bulimina marginata d' Orbigny, 1826	Albani, 1965	Durban Bay	Recent
Bulimina marginata d' Orbigny, 1826	Martin, 1974	W.coast SA	?unspecified
	McMillan, 1990	Cape Town	Late Pleistocene
Bulimina pupoides	Chapman, 1930	Alexandria Formation	Upper Eocene
Bulimina rostrata Brady	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Bulimina spinifera Cushman, 1947	Biesiot, 1957	Umfolozi River, Natal	Miocene
Bulimina striata var. *mexicana* (Cushman)	Martin, 1974	W.coast SA	?unspecified
Bulimina trigonula var. *inornata* Chapman, 1904	Chapman, 1904	E. Pondoland	Cretaceous
Buliminella elegantissima	Dale & McMillan, 1999	Saldanha Region	Holocene
Calcarina rotula Egger	Chapman, 1923	Uzamba River, Natal	Cretaceous
Cancris oblongus (Williamson, 1858)	Albani, 1965	Durban Bay	Recent
Cancris auriculus (Fichtel & Moll)	Biesiot, 1957	Umfolozi River, Natal	Miocene
	Martin, 1974	W.coast SA	?unspecified
	McMillan, 1998	W.coast SA	Holocene
Candeina nitida d' Orbigny, 1839	Salmon, 1979a	S. W. Indian Ocean	Quaternary
	Giraudeau, 1993	Benguela	Recent
Cassidulina bradyi (Norman)	Martin, 1974	W.coast SA	?unspecified
Cassidulina crassa d' Orbigny, 1839	McMillan, 1990	Cape Town	Late Pleistocene
Cassidulina calabra Seguenza	Chapman, 1924	S. A. Coast	?unspecified
Cassidulina carinata Silvestri	McMillan, 1998	W.coast SA	Holocene
Cassidulina laevigata d' Orbigny	Salmon, 1979a	S. W. Indian Ocean	Quaternary

Species	Author	Location	Age
Cassidulina laevigata d' Orbigny	McMillan, 1990	Cape Town	Late Pleistocene
	McMillan, 1998	W.coast SA	Holocene
	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Holocene
Cassidulina laevigata var. *carinata* (Cushman)	Martin, 1974	W.coast SA	?unspecified
Cassidulina subglobosa producta Chapman & Parr	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Cenchridum capense	Ehrenberg, 1863	Agulhas Bank	?
Chitinosaccus zuluensis Smitter, 1956	Smitter, 1956	St. Lucia Bay, Natal	?Recent
Cibicides fletcheri Galloway & Wissler, 1927	McMillan, 1990	Cape Town	Late Pleistocene
Cibicides lobatula (Walker & Jacob, 1784)	Chapman, 1930	Alexandria Formation	Upper Eocene
	Biesiot, 1957	Umfolozi River, Natal	Miocene
	Albani, 1965	Durban Bay	Recent
	Martin, 1974	Alexandria Formation	?unspecified
	McMillan, 1990	Cape Town	Late Pleistocene
	McMillan, 1998	W.coast SA	Holocene
	Toefy *et al*., 2003	False Bay	Recent
Cibicides nucleatus (Seguenza)	Biesiot, 1957	Umfolozi River, Natal	Miocene
Cibicides pseudoungeriana (Cushman)	Martin, 1974	W.coast SA	?unspecified
Cibicides refulgens Montfort, 1808	Parr, 1958	Durban	Pleistocene
	Albani, 1965	Durban Bay	Recent
	Martin, 1974	W.coast SA	?unspecified
	Salmon, 1981	S. W. Indian Ocean	Quaternary
Cibicides uloaensis Biesiot, 1957	Biesiot, 1957	Umfolozi River, Natal	Miocene
Cibicides wuellerstorfi (Schwager)	Salmon, 1979a	S. W. Indian Ocean	Quaternary

Species	Author	Location	Age
Cibicides zuluensis Biesiot, 1957	Biesiot, 1957	Umfolozi River, Natal	Miocene
	Salmon, 1981	S. W. Indian Ocean	Quaternary
Cibicidella variabilis (d' Orbigny, 1826)	Albani, 1965	Durban Bay	Recent
Cibicidoides sp	McMillan, 1990	Cape Town	Late Pleistocene
Cibicidoides pseudoungerianus	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
Cibroelphidium translucens	Phleger, 1973	St. Lucia Bay, Natal	?unspecified
Clavulina parisiensis d'Orbigny	Chapman, 1924	S. A. Coast	?unspecified
Clavulina rudis Costa	Chapman, 1924	S. A. Coast	?unspecified
Cornuspira foliacea Phillipi	Chapman, 1924	S. A. Coast	?unspecified
Crisbrostomoides subglosum (G. O Sars)	Martin, 1974	W.coast SA	?unspecified
Cristellaria calcar Fichtel & Moll	Chapman, 1924	S.A. Coast	?unspecified
Cristellaria cultrata Montfort	Chapman, 1924	S.A. Coast	?unspecified
Cristellaria crepidula Fichtel & Moll	Chapman, 1930	Alexandria Formation	Upper Eocene
Cristellaria elegantissima Costa	Chapman, 1924	S.A. Coast	?unspecified
Cristellaria intermedia Reuss, 1845	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
Cristellaria italica Defrance	Chapman, 1924	S.A. Coast	?unspecified
Cristellaria mammiligera Karrer	Chapman, 1924	S.A. Coast	?unspecified
Cristellaria parallela Reuss, 1862	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
Cristellaria regulator	Ehrenberg, 1863	Agulhas Bank	?unspecified
Cristellaria rotulata Lamarck	Chapman, 1924	S.A. Coast	?unspecified
Cristellaria schloenbachi Reuss	Chapman, 1923	Uzamba River, Natal	Cretaceous
Cristellaria secans Reuss, 1860	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
Cristellaria subalata Reuss, 1854	Chapman, 1904	E. Pondoland	Cretaceous
	Chapman, 1923	Uzamba River, Natal	Cretaceous
Cristellaria tricarinella Reuss	Chapman, 1924	S.A. Coast	?unspecified
Cristellaria wetherelli Jones	Chapman, 1924	S.A. Coast	?unspecified

Species	Author	Location	Age
Cymbaloporella tabellaeformis (Brady, 1884)	Albani, 1965	Durban Bay	Recent
Dentalina filiformis (d' Orbigny, 1826)	Albani, 1965	Durban Bay	Recent
	Martin, 1974	W.coast SA	?unspecified
Dentalina pauperata (d' Orbigny)	Martin, 1974	W.coast SA	?unspecified
Discocyclina pratti (Mich.)	Chapman, 1930	Alexandria Formation	Upper Eocene
Discocyclina varians (Kaufmann)	Chapman, 1930	Alexandria Formation	Upper Eocene
Discorbina globularis d' Orbigny	Chapman, 1924	S.A. Coast	?unspecified
Discorbina obtusa d' Orbigny	Chapman, 1924	S.A. Coast	?unspecified
Discorbina pileolus d'Orbigny, 1839	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
Discorbina rosacea d' Orbigny	Chapman, 1923	Uzamba River, Natal	Cretaceous
Eggerella propinqua (Brady, 1884)	Albani, 1965	Durban Bay	Recent
	Martin, 1974	W.coast SA	?unspecified
Eggerella bradyi (Cushman)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Ehrenbergina carinata Eade	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Ellipsonodosaria nuttali Cushman & Jarvis, 1936	Salmon, 1979b	Agulhas Passage	Eocene
Elphidium advenum (Cushman, 1922)	Albani, 1965	Durban Bay	Recent
	Martin, 1974	W.coast SA	?unspecified
	Salmon, 1979a	S. W. Indian Ocean	Quaternary
	Salmon, 1981	S. W. Indian Ocean	Quaternary
	McMillan, 1990	Cape Town	Late Pleistocene
	McMillan, 1998	W.coast SA	Holocene
	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Early Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Holocene

Species	Author	Location	Age
Elphidium advenum (Cushman, 1922)	Toefy *et al.*, 2003	False Bay	Recent
Elphidium alvarezianum	Dale & McMillan, 1999	Saldanha Region	Holocene
Elphidium articulatum (d'Orbigny, 1839)	McMillan, 1990	Cape Town	Late Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Holocene
Elphidium craticulatum (Fictel & Moll, 1798)	Chapman, 1930	Alexandria Formation	Upper Eocene
	Albani, 1965	Durban Bay	Recent
	Salmon, 1981	S. W. Indian Ocean	Quaternary
Elphidium crispum Montfort, 1808	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
	Parr, 1958	Durban	Pleistocene
	Albani, 1965	Durban Bay	Recent
	Martin, 1974	W.coast SA	?unspecified
	Salmon, 1979a	S. W. Indian Ocean	Quaternary
	Salmon, 1981	S. W. Indian Ocean	Quaternary
	McMillan, 1990	Cape Town	Late Pleistocene
	Dale & McMillan, 1999, Dale &	Saldanha Region	Late Pleistocene
	McMillan, 1999	Saldanha Region	Early Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Holocene
Elphidium cf. *fimbriatulum* (Cushman)	Biesiot, 1957	Umfolozi River, Natal	Miocene
Elphidium macellum (Fichtel & Moll, 1798)	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
	Albani, 1965	Durban Bay	Recent
	McMillan, 1990	Cape Town	Late Pleistocene
	McMillan, 1998	W.coast SA	Holocene
	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene

Species	Author	Location	Age
Elphidium macellum (Fichtel & Moll, 1798)	Dale & McMillan, 1999	Saldanha Region	Holocene
	Toefy *et al.*, 2003	False Bay	Recent
Eponides crebbsi Hedberg, 1937	Salmon, 1981	S. W. Indian Ocean	Quaternary
Eponides umbonata (Reuss)	Martin, 1974	W.coast SA	?unspecified
Eponides zuluensis Biesiot, 1957	Biesiot, 1957	Umfolozi River, Natal	Miocene
Fabularia discolithes	Chapman, 1930	Alexandria Formation	Upper Eocene
Fissurina laevigata (Reuss)	Martin, 1974	W.coast SA	?unspecified
Fissurina lucida (Williamson, 1848)	McMillan, 1990	Cape Town	Late Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Holocene
Fissurina marginata (Walker & Boys, 1784)	McMillan, 1990	Cape Town	Late Pleistocene
Florilus boueanum (d' Orbigny)	Martin, 1974	W.coast SA	?unspecified
Frondicularia complanata Defrance	Chapman, 1924	S.A. Coast	?unspecified
Fursenkoina schrekbersiana (Czjzek)	Martin, 1974	W.coast SA	?unspecified
Fursenkoina subsquamosa (Egger)	Martin, 1974	W.coast SA	?unspecified
Gaudryina cf bradyi Cushman	Chapman, 1930	Alexandria Formation	Upper Eocene
Gaudryina exilis	Phleger, 1973	St. Lucia Bay, Natal	?unspecified
Gavelinopsis praegeri	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
Glabratella australensis (Heron-Allen & Earland, 1932)	McMillan, 1990	Cape Town	Late Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Early Pleistocene
Glabratella australensis (Heron-Allen & Earland, 1932)	Toefy *et al.*, 2003	False Bay	Recent
Glandulina laevigata var. *torrida* (Cushman)	Martin, 1974	W.coast SA	?unspecified

Species	Author	Location	Age
Globigerina aequilateralis Brady	Siesser & Miles, 1979	Zululand	Upper Miocene
Globigerina altispira Cushman & Jarvis, 1936	Salmon, 1979b	Agulhas Passage	Miocene
Globigerina baroemoensis var *quadrata* Le Roy, 1944	Biesiot, 1957	Umfolozi River, Natal	Miocene
Globigerina bulloides d' Orbigny, 1826	Chapman, 1924	S.A. Coast	?unspecified
	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
	Chapman, 1930	Alexandria Formation	Upper Eocene
	Albani, 1965	Durban Bay	Recent
	Salmon, 1979a	S. W. Indian Ocean	Quaternary
	McMillan, 1990	Cape Town	Late Pleistocene
	Giraudeau, 1993	Benguela	Recent
Globigerina calida Parker, 1962	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Globigerina canaliculata Reuss, 1854	Chapman, 1904	E. Pondoland	Cretaceous
Globigerina conglobatus Brady	Chapman, 1924	S.A. Coast	?unspecified
	Siesser & Miles, 1979	Zululand	Upper Miocene
Globigerina digitata Brady, 1879	Salmon, 1979a	S. W. Indian Ocean	Quaternary
	Giraudeau, 1993	Benguela	Recent
Globigerina eggeri Rhumbler, 1900	Albani, 1965	Durban Bay	Recent
Globigerina falconensis	Giraudeau, 1993	Benguela	Recent
Globigerina linnaeana d' Orbigny	Chapman, 1923	Uzamba River, Natal	Cretaceous
Globigerina mexicana Cushman, 1925	Salmon, 1979b	Agulhas Passage	Eocene
Globigerina obliquus extermus Bolli & Bermudez	Siesser & Miles, 1979	Zululand	Upper Miocene
Globigerina oceanica	Ehrenberg, 1863	Agulhas Bank	?unspecified
*Globigerina pachyderma (*Ehrenberg, 1861)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Globigerina cf. *praedigitata* Parker	Siesser & Miles, 1979	Zululand	Upper Miocene
Globigerina pygmaea	Ehrenberg, 1863	Agulhas Bank	?unspecified
Globigerina quinqueloba	Giraudeau, 1993	Benguela	Recent

Species	Author	Location	Age
Globigerina quinqueloba	McMillan, 1998	W.coast SA	Holocene
Globigerina ruber d' Orbigny, 1939	Salmon, 1979b	Agulhas Passage	Miocene
Globigerina subcretacea Chapman	Chapman, 1924	S.A. Coast	?unspecified
Globigerina tenellus	Giraudeau, 1993	Benguela	Recent
Globigerina trilobus (Reuss)	Chapman, 1924	S.A. Coast	?unspecified
	Siesser & Miles, 1979	Zululand	Upper Miocene
Globigerina venezuelana Hedberg, 1937	Salmon, 1979b	Agulhas Passage	Eocene
Globigerinella aequilateralis (Brady)	Biesiot, 1957	Umfolozi River, Natal	Miocene
Globigerinella aequilateralis (Brady)	Giraudeau, 1993	Benguela	Recent
Globigerinella siphonifera (d' Orbigny, 1839)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Globigerinita glutinata (Egger, 1893)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
	Giraudeau, 1993	Benguela	Recent
Globigerinita unicavus Bolli, Loeblich & Tappan, 1957	Salmon, 1979b	Agulhas Passage	Eocene
Globigerinoides conglobata (Brady, 1879)	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
	Chapman, 1930	Alexandria Formation	Upper Eocene
	Albani, 1965	Durban Bay	Recent
	Salmon, 1979a	S. W. Indian Ocean	Quaternary
	Giraudeau, 1993	Benguela	Recent
Globigerinoides glomerosa Blow, 1956Finlay, 1939	Salmon, 1979b	Agulhas Passage	Miocene
Globigerinoides index Finlay, 1939	Salmon, 1979b	Agulhas Passage	Eocene
Globigerinoides quadrilobata sacculifera (Brady, 1877)	Albani, 1965	Durban Bay	Recent
Globigerinoides ruber (d' Orbigny, 1939)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
	Giraudeau, 1993	Benguela	Recent
Globigerinoides sacculiferus (Brady, 1879)	Biesiot, 1957	Umfolozi River, Natal	Miocene
	Salmon, 1979a	S. W. Indian Ocean	Quaternary
	Salmon, 1979b	Agulhas Passage	Miocene
	Giraudeau, 1993	Benguela	Recent

Species	Author	Location	Age
Globigerinoides semiinvoluta Keijer, 1945	Salmon, 1979b	Agulhas Passage	Eocene
Globigerinoides sicanus de Stefani, 1952	Salmon, 1979b	Agulhas Passage	Miocene
Globigerinoides transitoria Blow, 1956	Salmon, 1979b	Agulhas Passage	Miocene
Globigerinoides trilocularis (d' Orbigny)	Biesiot, 1957	Umfolozi River, Natal	Miocene
Globobulimina pyrula var. spinescens (Brady)	Martin, 1974	W.coast SA	?unspecified
Globoquadrina altispira altispira (Cushman & Jarvis)	Siesser & Miles, 1979	Zululand	Upper Miocene
Globoquadrina altispira globosa Bolli	Siesser & Miles, 1979	Zululand	Upper Miocene
Globoquadrina dutertrei (d' Orbigny, 1839)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Globorotalia bullbrooki Bolli, 1957	Salmon, 1979b	Agulhas Passage	Eocene
Globorotalia crassaformis	Giraudeau, 1993	Benguela	Recent
Globorotalia dehiscens Chapman, Parr & Collins, 1934	Salmon, 1979b	Agulhas Passage	Miocene
Globorotalia hirsuta	Giraudeau, 1993	Benguela	Recent
Globorotalia inflata (d' Orbigny)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
	McMillan, 1990	Cape Town	Late Pleistocene
	Giraudeau, 1993	Benguela	Recent
	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
Globorotalia menardii (d' Orbigny, 1939)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Globorotalia menardii (d' Orbigny, 1939)	Giraudeau, 1993	Benguela	Recent
Globorotalia obesa Bolli, 1957	Salmon, 1979b	Agulhas Passage	Miocene
Globorotalia peripheronda Blow & Banner, 1966	Salmon, 1979b	Agulhas Passage	Miocene
Globorotalia scitula Brady, 1882	Salmon, 1979b	Agulhas Passage	Miocene
	Giraudeau, 1993	Benguela	Recent
Globorotalia spinulosa Cushman, 1927	Salmon, 1979b	Agulhas Passage	Eocene
Globorotalia tumida (Brady, 1877)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Globorotalia tumida flexuosa (Koch, 1923)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Globorotalia truncatulinoides (d' Orbigny)	Salmon, 1979a	S. W. Indian Ocean	Quaternary

Species	Author	Location	Age
Globorotalia truncatulinoides (d' Orbigny)	Giraudeau, 1993	Benguela	Recent
Globulina gibba d' Orbigny	Biesiot, 1957	Umfolozi River, Natal	Miocene
Globulina inaequalis Reuss	Biesiot, 1957	Umfolozi River, Natal	Miocene
Grammostomum angustipes	Ehrenberg, 1863	Agulhas Bank	?unspecified
Grammostomum bulligerum	Ehrenberg, 1863	Agulhas Bank	?unspecified
Grammostomum fasciatum	Ehrenberg, 1863	Agulhas Bank	?unspecified
Grammostomum verrucosum	Ehrenberg, 1863	Agulhas Bank	?unspecified
Guttulina problema (d' orbigny, 1826)	Biesiot, 1957	Umfolozi River, Natal	Miocene
	Albani, 1965	Durban Bay	Recent
Gyroidina orbicularis (d' Orbigny)	Martin, 1974	W.coast SA	?unspecified
Gyroidina soldanii (d' Orbigny)	Martin, 1974	W.coast SA	?unspecified
	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Hantkenina australis Finlay, 1939	Salmon, 1979b	Agulhas Passage	Eocene
Hantkenina liebusi Shokina, 1937	Salmon, 1979b	Agulhas Passage	Eocene
Hantkenina longispina Cushman, 1952	Salmon, 1979b	Agulhas Passage	Eocene
Haplophragmium cf. canariense d' Orbigny, 1839	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
Haplophragmium crassimargo Norman	Chapman, 1924	S. A. Coast	?unspecified
Haplophragmium globigeriniforme Parker & Jones	Chapman, 1924	S. A. Coast	?unspecified
Haplophragmium glomeratum Brady	Chapman, 1924	S. A. Coast	?unspecified
Haplophragmium latidorsatum Bornemann	Chapman, 1924	S. A. Coast	?unspecified
Haplophragmium neocomianum Chapman, 1894	Chapman, 1904	E. Pondoland	Cretaceous
	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
Haplophragmium meridionale Chapman, 1904	Chapman, 1904	E. Pondoland	Cretaceous
Haplophragmoides hilberti	Phleger, 1973	St. Lucia Bay, Natal	?unspecified
Hastigerina pelagica	Giraudeau, 1993	Benguela	Recent
Hyalinea balthica (Schroeter, 1783)	Martin, 1974	W.coast SA	?unspecified
	Salmon, 1981	S. W. Indian Ocean	Quaternary

Species	Author	Location	Age
Hyalinea balthica (Schroeter, 1783)	cMillan, 1990	Cape Town	Late Pleistocene
Hyalinea balthica (Schroeter, 1783)	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
Hyperammina elongata Brady	Chapman, 1924	S. A. Coast	?unspecified
Hyperammina ramosa Brady	Chapman, 1924	S. A. Coast	?unspecified
Hyperammina vagans Brady	Chapman, 1924	S. A. Coast	?unspecified
Karreriella bradyi (Cushman)	Martin, 1974	W.coast SA	?unspecified
	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Lagena costata (Williamson)	Biesiot, 1957	Umfolozi River, Natal	Miocene
Lagena gracilis Williamson	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Lagena gracillima (Seguenza)	Martin, 1974	W.coast SA	?unspecified
Lagena lagenoides (Williamson)	Martin, 1974	W.coast SA	?unspecified
Lagena marginata Walker & Boys	Chapman, 1924	S.A. Coast	?unspecified
Lagena perlucida (Montagu)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Lagena quadrilata (Williamson) var.	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Lagena semilineata Wright, 1886	McMillan, 1990	Cape Town	Late Pleistocene
	Toefy *et al.*, 2003	False Bay	Recent
Lagena semistriata Williamson, 1858	Albani, 1965	Durban Bay	Recent
	Martin, 1974	W.coast SA	?unspecified
Lagena striata (d' Orbigny, 1839)	Albani, 1965	Durban Bay	Recent
Lagena striata (d' Orbigny, 1839) var *strumosa*	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Lagena sulcata (Walker & Jacob)	Martin, 1974	W.coast SA	?unspecified
	Chapman, 1924	S.A. Coast	?unspecified
Lagena sulcata (Walker & Jacob) var *spiculata*	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Laticarinina pauperata (Parker & Jones)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Lenticulina d'Orbignii (Bailey)	Martin, 1974	W.coast SA	?unspecified

Species	Author	Location	Age
Lenticulina occidentalis var. novangliae (Cushman)	Martin, 1974	W.coast SA	?unspecified
Lobatula lobatula	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Early Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Holocene
Loxostomum limbatum (Brady, 1879)	Albani, 1965	Durban Bay	Recent
Marsipella chapmani Heron-Allen & Earland	Chapman, 1924	S. A. Coast	?unspecified
Marsipella cylindrica Brady	Chapman, 1924	S. A. Coast	?unspecified
Martinotiella communis (d'Orbigny)	Martin, 1974	W.coast SA	?unspecified
Melonis pompiloides (Fichtel & Moll)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Miliammina fusca	Phleger, 1973	St. Lucia Bay, Natal	?unspecified
Miliolina cf. circularis Bornemann	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
Miliolina circularis Bornemann	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
Miliolina cuvieriana d' Orbigny	Chapman, 1924	S. A. Coast	?unspecified
Miliolina cf. ferusacii d' Orbigny	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
Miliolina subrotunda Montagu, 1803	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
	Chapman, 1930	Alexandria Formation	Upper Eocene
	McMillan, 1990	Cape Town	Late Pleistocene
	Toefy *et al.*, 2003	False Bay	Recent
Morozovella subbotinae	Siesser & Miles, 1979	Birbury	Lower Eocene
Neogloboquadrina humerosa (Takayangi & Saito)	Siesser & Miles, 1979	Zululand	Upper Miocene
Neogloboquadrina pachyderma (Ehrenberg, 1861)	McMillan, 1990	Cape Town	Late Pleistocene
	Giraudeau, 1993	Benguela	Recent
	McMillan, 1998	W.coast SA	Holocene

Species	Author	Location	Age
Nodosaria antillea Cushman, 1923	Salmon, 1979b	Agulhas Passage	Eocene
Nodosaria communis D'Orbigny	Chapman, 1924	S.A. Coast	?unspecified
Nodosaria filiformis D'Orbigny	Chapman, 1924	S.A. Coast	?unspecified
Nodosaria obliqua Linne	Chapman, 1924	S.A. Coast	?unspecified
Nodosaria pauperata D'Orbigny	Chapman, 1924	S.A. Coast	?unspecified
Nodosaria prismatica Reuss, 1860	Chapman, 1904	E. Pondoland	Cretaceous
	Chapman, 1923	Uzamba River, Natal	Cretaceous
Nodosaria pyrula d'Orbigny	Chapman, 1924	S.A. Coast	?unspecified
Nodosaria radicula (Linne)	Martin, 1974	W.coast SA	?unspecified
Nodosaria scalaris Batsch	Chapman, 1924	S.A. Coast	?unspecified
Nodosaria subscalaris pauci-costata Cushman, 1917	Albani, 1965	Durban Bay	Recent
Nodosaria sulacata Nilsson, 1825	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
Nodosaria zippei Reuss, 1845	Chapman, 1904	E. Pondoland	Cretaceous
	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
Nonion boueanum (d' Orbigny, 1846)	Biesiot, 1957	Umfolozi River, Natal	Miocene
	Albani, 1965	Durban Bay	Recent
	McMillan, 1998	W.coast SA	Holocene
	Dale & McMillan, 1999	Saldanha Region	Early Pleistocene
Nonion elongatum (d' Orbigny)	Biesiot, 1957	Umfolozi River, Natal	Miocene
Nonion micrus Cole, 1927	Salmon, 1979b	Agulhas Passage	Eocene
*Nonion scaphum (*Fichtel & Moll, 1798)	Salmon, 1981	S. W. Indian Ocean	Quaternary
Nonion umbilicatula (Montagu)	Chapman, 1924	S.A. Coast	?unspecified
	Martin, 1974	W.coast SA	?unspecified
Nonionella turgida (Williamson)	Martin, 1974	W.coast SA	?unspecified
Nonionella turgida (Williamson)	McMillan, 1998	W.coast SA	Holocene
Nonionellina labradorica (Dawson)	Martin, 1974	W.coast SA	?unspecified

Species	Author	Location	Age
Notorotalia clathrata	Dale & McMillan, 1999	Saldanha Region	Holocene
Orbulina universa d' Orbigny	Chapman, 1924	S.A. Coast	?unspecified
	Biesiot, 1957	Umfolozi River, Natal	Miocene
Orbulina universa d' Orbigny	Salmon, 1979a	S. W. Indian Ocean	Quaternary
	Siesser & Miles, 1979	Zululand	Upper Miocene
	Giraudeau, 1993	Benguela	Recent
	McMillan, 1998	W.coast SA	Holocene
Orthomorphina scalaris (Batsch)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Oolina hexagona (Williamson)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Oolina melo d'Orbigny	Toefy *et al*., 2003	False Bay	Recent
Oolina sp A, McMillan, 1987	McMillan, 1990	Cape Town	Late Pleistocene
Oolina squamososulcata (Heron-Allen & Earland, 1922)	McMillan, 1990	Cape Town	Late Pleistocene
Palmula borroi Bermudez, 1949	Biesiot, 1957	Umfolozi River, Natal	Miocene
Patellina corrugata Williamson	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
	Toefy *et al*., 2003	False Bay	Recent
Pararotalia inermis (Terquem, 1882)	Salmon, 1981	S. W. Indian Ocean	Quaternary
Pararotalia nipponica (Asano, 1936)	McMillan, 1990	Cape Town	Late Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Early Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Holocene
Pelosina cylindrica Brady	Chapman, 1924	S. A. Coast	?unspecified
Pelosina variabilis Brady	Chapman, 1924	S. A. Coast	?unspecified
Planorbulina mediterranensis d' Orbigny, 1826	Parr, 1958	Durban	Pleistocene

Species	Author	Location	Age
Planorbulina mediterranensis d' Orbigny, 1826	Toefy *et al.*, 2003	False Bay	Recent
Planulina ariminensis d' Orbigny	McMillan, 1998	W.coast SA	Holocene
	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
Planulina wuellerstorfi (Schwager)	Martin, 1974	W.coast SA	?unspecified
Planulinoides biconcavus (Jones & Parker, 1862)	McMillan, 1990	Cape Town	Late Pleistocene
Pleurostomella bierigi Palmer & Bemudez	Salmon, 1979a	S. W. Indian Ocean	Quaternary
	Salmon, 1979b	Agulhas Passage	Eocene
Pleurostomella subnodosa Reuss, 1851	Chapman, 1904	E. Pondoland	Cretaceous
Polymorphina armata	Ehrenberg, 1863	Agulhas Bank	?unspecified
Polymorphina gibba d' Orbigny, 1826	Chapman, 1904	E. Pondoland	Cretaceous
	Chapman, 1924	S. A. Coast	?unspecified
Polymorphina lactea Walker & Jacobs	Chapman, 1930	Alexandria Formation	Upper Eocene
Poroeponides lateralis	Albani, 1965	Durban Bay	Recent
Proroporus squamatus	Ehrenberg, 1863	Agulhas Bank	?unspecified
Pseudohastigerina micra (Cole)	Salmon, 1979b	Agulhas Passage	Eocene
Pseudoparella barnwelli Biesiot, 1957	Biesiot, 1957	Umfolozi River, Natal	Miocene
Pullenia marssoni Cushman & Todd, 1943	Biesiot, 1957	Umfolozi River, Natal	Miocene
Pullenia quinqueloba Reuss	Martin, 1974	W.coast SA	?unspecified
	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Pullenia obliquilocuta	Chapman, 1924	S. A. Coast	?unspecified
	Giraudeau, 1993	Benguela	Recent
Pullenia sphaeroides (d'Orbigny)	Martin, 1974	W.coast SA	?unspecified
Pulleniatina obliquiloculata (Parker & Jones, 1865)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Pulvulina auricula Fichtel & Moll	Chapman, 1924	S.A. Coast	?unspecified
Pulvulina carpenteri Reuss, 1862	Chapman, 1904	E. Pondoland	Cretaceous
	Chapman, 1923	Uzamba River, Natal	Cretaceous

Species	Author	Location	Age
Pulvulina concetrica Parker & Jones	Chapman, 1924	S.A. Coast	?unspecified
Pulvulina elegans d' Orbigny, 1826	Chapman, 1904	E. Pondoland	Cretaceous
	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
	Chapman, 1924	S.A. Coast	?unspecified
Pulvulina karsteni Reuss, 1855	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
Pulvulina patagonica d'Orbigny	Chapman, 1924	S.A. Coast	?unspecified
Pulvulina pondensis Chapman, 1904	Chapman, 1904	E. Pondoland	Cretaceous
	Chapman, 1923	Uzamba River, Natal	Cretaceous
Pulvulina reticulata Reuss, 1862	Chapman, 1904	E. Pondoland	Cretaceous
	Chapman, 1923	Uzamba River, Natal	Cretaceous
Pulvulina truncatulinoides d'Orbigny	Chapman, 1924	S.A. Coast	?unspecified
Pulvulina sp.	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
Pyrgo bulloides d' Orbigny	Martin, 1974	W.coast SA	?unspecified
Pyrgo murrhina (Schwager)	Martin, 1974	W.coast SA	?unspecified
	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Pyrgo serrata	Martin, 1974	W.coast SA	?unspecified
Pyrulina cylindroides	Biesiot, 1957	Umfolozi River, Natal	Miocene
Quinqueloculina aff. *akneriana* d' Orbigny	Biesiot, 1957	Umfolozi River, Natal	Miocene
Quinqueloculina agglutinans d' Orbigny, 1839	Albani, 1965	Durban Bay	Recent
	Martin, 1974	W.coast SA	?unspecified
Quinqueloculina boueana d' Orbigny	Biesiot, 1957	Umfolozi River, Natal	Miocene
Quinqueloculina candiena d'Orbigny	Martin, 1974	W.coast SA	?unspecified
Quinqueloculina contorta d'Órbigny, 1846	McMillan, 1990	Cape Town	Late Pleistocene
Quinqueloculina dunkerquiana Heron-Allen & Earland	McMillan, 1990	Cape Town	Late Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene

Species	Author	Location	Age
Quinqueloculina dunkerquiana Heron-Allen & Earland	Dale & McMillan, 1999	Saldanha Region	Early Pleistocene
	Toefy et al, 2003	False Bay	Recent
Quinqueloculina isabellei d'Órbigny, 1846	McMillan, 1990	Cape Town	Late Pleistocene
	Toefy et al, 2003	False Bay	Recent
Quinqueloculina lamarckiana d' Orbigny, 1839	Albani, 1965	Durban Bay	Recent
Quinqueloculina aff. *lata* Terquem	Biesiot, 1957	Umfolozi River, Natal	Miocene
	McMillan, 1990	Cape Town	Late Pleistocene
Quinqueloculina aff. *lata* Terquem	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
Quinqueloculina seminulum (Linne, 1767)	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
	Albani, 1965	Durban Bay	Recent
	Martin, 1974	W.coast SA	?unspecified
	McMillan, 1990	Cape Town	Late Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Early Pleistocene
	Toefy et al, 2003	False Bay	Recent
Quinqueloculina semireticulosa Cushman, 1932	Albani, 1965	Durban Bay	Recent
Quinqueloculina striata d' Orbigny, 1826	Albani, 1965	Durban Bay	Recent
Quinqueloculina triangularis d'Órbigny, 1846	McMillan, 1990	Cape Town	Late Pleistocene
Quinqueloculina cf. *undulata* d'Órbigny, 1852	McMillan, 1990	Cape Town	Late Pleistocene
	Toefy *et al,* 2003	False Bay	Recent
Quinqueloculina vulgaris d' Orbigny, 1826	Ehrenberg, 1863	Agulhas Bank	?unspecified
	Parr, 1958	Durban	Pleistocene
	Toefy *et al,* 2003	False Bay	Recent

Species	Author	Location	Age
Ramulina globulifera Brady	Chapman, 1924	S. A. Coast	?unspecified
Rectuvigerina nicoli (Mathews)	Martin, 1974	W.coast SA	?unspecified
	McMillan, 1998	W.coast SA	Holocene
Reophax dentaliniformis Brady	Chapman, 1924	S. A. Coast	?unspecified
Reophax pilulifera Brady	Chapman, 1924	S. A. Coast	?unspecified
Reophax nanus	Phleger, 1973	St. Lucia Bay, Natal	?unspecified
Reophax scorpiurus Montfort	Chapman, 1924	S. A. Coast	?unspecified
Rhabdammina discreta Brady	Chapman, 1924	S. A. Coast	?unspecified
Rhabdammina linearis Brady	Chapman, 1924	S. A. Coast	?unspecified
Rhaphidoscene texturata	Chapman, 1924	S. A. Coast	?unspecified
Rhizammina indivisa Brady	Chapman, 1924	S. A. Coast	?unspecified
Robulus convergens (Bornemann)	Biesiot, 1957	Umfolozi River, Natal	Miocene
Robulus insulus Cushman, 1947	Biesiot, 1957	Umfolozi River, Natal	Miocene
Robulus limbosus (Reuss, 1863)	Albani, 1965	Durban Bay	Recent
Robulus nuttali Cushman & Renz	Biesiot, 1957	Umfolozi River, Natal	Miocene
Rosalina bertheloti d Orbigny, 1839	Albani, 1965	Durban Bay	Recent
Rosalina bradyi Cushman, 1915	McMillan, 1990	Cape Town	Late Pleistocene
Rosalina "diazvillea"	Dale & McMillan, 1999	Saldanha Region	Early Pleistocene
Rosalina globularis d' Orbigny	Chapman, 1930	Alexandria Formation	Upper Eocene
	Dale & McMillan, 1999	Saldanha Region	Early Pleistocene
	Dale & McMillan, 1999	Saldanha Region	Holocene
	Toefy *et al,* 2003	False Bay	Recent
Rotalia audouini d'Orbigny, 1850	Salmon, 1981	S. W. Indian Ocean	Quaternary
Rotalia australis	Ehrenberg, 1863	Agulhas Bank	?unspecified

Species	Author	Location	Age
Rotalia calcar d' Orbigny	Chapman, 1930	Alexandria Formation	Upper Eocene
Rotalia dentata Parker & Jones, 1865	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
Rotalia haliotina	Ehrenberg, 1863	Agulhas Bank	?unspecified
Rotalia globulosa	Ehrenberg, 1863	Agulhas Bank	?unspecified
Rotalia orbicularis d' Orbginy, 1826	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
Rotalia quaternaria	Ehrenberg, 1863	Agulhas Bank	?unspecified
Rotalia senaria	Ehrenberg, 1863	Agulhas Bank	?unspecified
Rotalia soldanii Reuss, 1844	Chapman, 1924	S.A. Coast	?unspecified
Rotalia soldanii var. *nitida* Reuss, 1844	Chapman, 1904	E. Pondoland	Cretaceous
	Chapman, 1923	Uzamba River, Natal	Cretaceous
Rotalia sp.	Parr, 1958	Durban	Pleistocene
Sagraina bifrons Brady	Chapman, 1924	S.A. Coast	?unspecified
Saracenaria cf. *italica* Defrance	Biesiot, 1957	Umfolozi River, Natal	Miocene
	Martin, 1974	W.coast SA	?unspecified
Sigmoilina schlumbergeri Silvestri	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Sigmoilopsis schlumbergeri (Silvestri)	Martin, 1974	W.coast SA	?unspecified
Siphogenerina striata (Schwager, 1866)	Albani, 1965	Durban Bay	Recent
Siphogenerina striatula Cushman, 1913	Albani, 1965	Durban Bay	Recent
Siphonaperta 'martinae' McMillan	McMillan, 1998	W.coast SA	Holocene
	Dale & McMillan, 1999	Saldanha Region	Late Pleistocene
Sphaerogypsina globulus (Reuss, 1848)	McMillan, 1990	Cape Town	Late Pleistocene
Sphaeroidina bulloides d' Orbigny	Martin, 1974	W.coast SA	?unspecified
Sphaeroidina nebulosa	Ehrenberg, 1863	Agulhas Bank	?unspecified
Sphaeroidinella dehiscens (Parker & Jones, 1865)	Chapman, 1924	S.A. Coast	?unspecified
	Salmon, 1979a	S. W. Indian Ocean	Quaternary
	Giraudeau, 1993	Benguela	Recent

Species	Author	Location	Age
Spiroloculina alveata Cushman & Todd, 1944	Biesiot, 1957	Umfolozi River, Natal	Miocene
Spiroloculina antillarum d' Orbigny, 1839	Albani, 1965	Durban Bay	Recent
Spiroloculina communis Cushman & Todd, 1944	Albani, 1965	Durban Bay	Recent
Spiroloculina depressa d' Orbigny	Biesiot, 1957	Umfolozi River, Natal	Miocene
Spiroloculina dorsata Reuss	Chapman, 1924	S. A. Coast	?unspecified
Spiroloculina excavata d' Orbigny, 1846	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
Spiroloculina laevigata Cushman & Todd, 1944	Albani, 1965	Durban Bay	Recent
Spiroloculina limbata Brady	Chapman, 1930	Alexandria Formation	Upper Eocene
	Martin, 1974	W.coast SA	?unspecified
Spiroloculina planulata Lamarck, 1805	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
Spiroloculina tenuis (Czjzek)	Martin, 1974	W.coast SA	?unspecified
Spiroplecta anceps Reuss, 1845	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
Spiroplecta capensis	Ehrenberg, 1863	Agulhas Bank	?unspecified
Spiroplecta deflata Chapman, 1916	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
Spiroplecta gramen	Chapman, 1924	S. A. Coast	?unspecified
Spiroplecta spectabilis	Salmon, 1979b	Agulhas Passage	Eocene
Spiroplectammina sp.	McMillan, 1990	Cape Town	Late Pleistocene
Subbotina eocaena	Siesser & Miles, 1979	Birbury	Lower Eocene
Stilostimella lepidula (Schwager)	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Textularia agglutinans d' Orbigny	Chapman, 1930	Alexandria Formation	Upper Eocene
Textularia aspera Brady, 1884	Albani, 1965	Durban Bay	Recent
Textularia cf. gramens d'Orbigny	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
	Chapman, 1930	Alexandria Formation	Upper Eocene
Textularia globulosa	Ehrenberg, 1863	Agulhas Bank	?unspecified
Textularia hauerii d'Orbigny, 1846	Albani, 1965	Durban Bay	Recent
Textularia sagittula Defrance	Martin, 1974	W.coast SA	?unspecified
Trifarina angulosa (Williamson, 1858)	McMillan, 1990	Cape Town	Late Pleistocene

Species	Author	Location	Age
Trifarina bradyi Cushman	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Triloculina tricarinata d' Orbigny, 1826	Biesiot, 1957	Umfolozi River, Natal	Miocene
	Albani, 1965	Durban Bay	Recent
Triloculina tricarinata d' Orbigny, 1826	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Triloculina trigonula d' Orbigny, 1826	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
	Chapman, 1930	Alexandria Formation	Upper Eocene
	Parr, 1958	Durban	Pleistocene
	Albani, 1965	Durban Bay	Recent
	Dale & McMillan, 1999	Saldanha Region	Early Pleistocene
Triloculina striatotrigonula Parker & Jones	Biesiot, 1957	Umfolozi River, Natal	Miocene
Triplasia tricarinata d' Orbigny	Chapman, 1924	S. A. Coast	?unspecified
Trochammina galeata Brady	Chapman, 1924	S. A. Coast	?unspecified
Trochammina inflata	Phleger, 1973	St. Lucia Bay, Natal	?unspecified
	Dale & McMillan, 1999	Saldanha Region	Holocene
Trochamminita irregularis	Phleger, 1973	St. Lucia Bay, Natal	?unspecified
Truncatulina haidingeri d' Orbigny, 1846	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
Truncatulina lobatula Walker & Jacob, 1798	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
	Chapman, 1924	S. A. Coast	?unspecified
Truncatulina pygmaea Hautken, 1875	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
Truncatulina refulgens Montfort, 1808	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
Truncatulina schloenbachi Reuss, 1862	Chapman, 1904	E. Pondoland	Cretaceous
	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous
	Chapman, 1923	Uzamba River, Natal	Cretaceous
Truncatulina ungeriana d' Orbigny, 1846	Chapman, 1907	Buffalo River, Cape Province	Pleistocene
	Chapman, 1916	Buffalo River, Cape Province	Upper Cretaceous

Species	Author	Location	Age
Truncatulina wuellerstorfi Schwager	Chapman, 1924	S.A. Coast	?unspecified
Truncorotaloides rohri Bronniman & Bermudez, 1953	Salmon, 1979b	Agulhas Passage	Eocene
Truncorotalia inflata (d'Orbigny)	McMillan, 1998	W.coast SA	Holocene
Truncorotalia truncatulinoides (d'Orbigny)	McMillan, 1998	W.coast SA	Holocene
Uvigerina aculeata d' Orbigny	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Uvigerina asperula (Czjzek)	Martin, 1974	W.coast SA	?unspecified
Uvigerina canariensis d' Orbigny	Martin, 1974	W.coast SA	?unspecified
Uvigerina aff. *costellata* Morozova, 1939	Biesiot, 1957	Umfolozi River, Natal	Miocene
Uvigerina eocaena Gumbel, 1968	Salmon, 1979b	Agulhas Passage	Eocene
Uvigerina peregrina (Cushman)	Martin, 1974	W.coast SA	?unspecified
Uvigerina porrecta var. *fimbriata* Brady	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Uvigerina proboscidea Schwager	Salmon, 1979a	S. W. Indian Ocean	Quaternary
Vaginula humilis Reuss, 1862	Chapman, 1904	E. Pondoland	Cretaceous
Vaginula intumescens Reuss, 1862	Chapman, 1904	E. Pondoland	Cretaceous
Vaginula legumen Linne, 1758	Chapman, 1904	E. Pondoland	Cretaceous
	Chapman, 1923	Uzamba River, Natal	Cretaceous
Vaginulina linearis Montagu	Chapman, 1924	S.A. Coast	?unspecified
Vaginulina spinigera Brady	Martin, 1974	W.coast SA	?unspecified
*Vaginulopsis robusta (*Galloway & Wissler), 1927	Albani, 1965	Durban Bay	Recent
Valvulineria kingi Biesiot, 1957	Biesiot, 1957	Umfolozi River, Natal	Miocene
Valvulineria putnami Biesiot, 1957	Biesiot, 1957	Umfolozi River, Natal	Miocene
Verneuilina spinulosa Reuss	Chapman, 1924	S. A. Coast	?unspecified
Virgulina spinicostata	Phleger, 1973	St. Lucia Bay, Natal	?unspecified
Zeaflorilus chiliensis	Dale & McMillan, 1999	Saldanha Region	Holocene

Appendix 2.1: Environmental variables measured from the sediments of St Helena Bay and Robben Island.

Sample	Phi 5	Phi 4	Phi 3	Phi 2	Phi 1	Mean Grain Size	Cd (µg/g)	Cr (µg/g)	Cu (µg/g)	Fe (µg/g)	Pb (µg/g)	Zn (µg/g)
RIA1	0.90	14.24	11.63	6.20	67.02	1.30	0.09	5.08	4.74	1956.08	1.79	12.28
RIA2	2.74	28.18	23.14	16.11	29.83	2.08	0.11	4.63	2.80	2288.38	2.62	12.69
RIA3	2.09	5.57	14.25	4.95	73.14	1.11	0.10	5.76	2.59	1942.11	3.96	10.31
RIA4	1.39	55.37	19.67	5.83	17.74	2.59	0.09	6.37	4.74	2418.54	2.85	20.96
RIA5	3.14	18.43	31.98	13.06	33.39	1.96	0.10	4.67	3.18	1953.61	2.80	14.69
RIA6	1.00	12.68	11.05	20.90	54.37	1.33	0.10	5.49	5.64	1665.30	1.93	8.79
RIB1	0.61	5.17	8.30	5.56	80.36	0.83	0.07	11.73	3.91	1989.20	7.74	11.59
RIB2	2.74	6.85	14.23	12.25	63.93	1.19	0.14	4.80	4.67	2209.22	5.99	12.66
RIB3	1.84	7.28	11.37	2.93	76.59	1.09	0.09	6.68	4.05	2626.14	6.27	10.26
RIB4	0.50	8.18	12.82	5.32	73.18	1.11	0.03	2.55	1.90	924.74	2.56	2.23
RIB5	0.60	5.53	9.89	8.29	75.69	0.96	0.07	6.56	3.32	2098.69	5.85	8.98
RIB6	1.03	10.08	13.84	3.73	71.32	1.19	0.09	9.51	4.97	2510.36	6.78	15.11
RIC1	0.83	6.93	17.44	11.13	63.67	1.19	0.11	4.32	4.51	1384.65	8.17	15.73
RIC2	1.14	7.59	19.85	14.59	56.82	1.27	0.10	7.45	2.96	1814.97	6.56	10.33
RIC3	0.27	1.35	8.15	23.53	66.70	0.91	0.09	4.57	2.22	1205.48	3.99	7.31
RIC4	2.85	10.35	2.00	11.70	73.10	0.94	0.12	7.55	8.29	2370.64	8.69	18.58
RIC5	0.70	37.29	24.50	17.16	20.34	2.30	0.12	5.08	2.56	1592.70	3.23	8.93
RIC6	0.47	2.31	15.32	36.64	45.26	1.21	0.09	4.07	2.67	1195.03	5.50	29.71
RID1	0.10	0.28	0.64	0.74	98.24	0.51	0.12	4.29	7.01	1714.69	9.60	11.50
RID2	0.32	1.50	4.27	3.91	90.01	0.56	0.05	4.79	6.73	1752.67	5.06	10.55
RID3	0.20	0.87	2.40	2.78	93.75	0.53	0.05	6.15	14.48	1787.73	5.19	14.23
RID4	0.39	3.19	14.61	7.12	74.69	1.01	0.05	4.49	2.79	1689.47	3.90	5.15
RID5	1.26	2.67	6.34	5.10	84.63	0.59	0.06	10.73	13.25	7385.28	26.18	15.13
RID6	0.09	4.23	13.32	9.35	73.02	1.01	0.05	3.90	3.70	1747.25	59.15	6.42
RIE1	0.05	0.16	12.36	39.42	48.01	1.10	0.14	2.56	1.08	633.82	3.04	7.83

Appendix 2.1: Environmental variables measured from the sediments of St Helena Bay and Robben Island.

Sample	Phi 5	Phi 4	Phi 3	Phi 2	Phi 1	Mean Grain Size	Cd (µg/g)	Cr (µg/g)	Cu (µg/g)	Fe (µg/g)	Pb (µg/g)	Zn (µg/g)
RIE2	0.05	0.25	13.80	36.21	49.68	1.09	0.07	2.44	0.81	793.58	3.11	10.58
RIE3	0.11	0.29	11.75	37.89	49.96	1.07	0.06	2.78	0.49	1085.42	3.40	4.22
RIE4	0.06	0.14	10.00	33.66	56.13	1.00	0.07	2.21	0.70	728.42	1.13	3.30
RIE5	0.09	0.30	11.70	36.34	51.57	1.06	0.07	2.54	1.00	716.90	3.09	3.93
RIE6	0.03	0.11	19.34	35.27	45.25	1.22	0.05	0.98	0.01	410.07	0.32	2.90
RIF1	0.08	0.42	3.43	18.32	77.75	0.73	0.06	5.11	1.94	986.15	7.97	3.38
RIF2	0.65	2.97	12.69	15.74	67.95	1.00	0.03	1.38	0.01	305.95	0.55	1.34
RIF3	0.40	1.79	4.96	9.87	82.98	0.63	0.06	3.73	1.64	1148.38	6.94	3.56
RIF4	0.51	3.88	13.72	33.45	48.43	1.18	0.13	3.51	1.11	969.22	4.05	12.67
RIF5	0.17	0.29	2.54	17.55	79.46	0.70	0.02	4.96	3.20	482.13	3.46	0.75
RIG1	0.05	0.14	1.89	26.19	71.72	0.80	0.02	2.48	1.19	751.18	2.27	0.60
RIG2	0.05	0.48	6.15	47.38	45.94	1.08	0.01	0.65	0.21	312.26	0.68	1.80
RIG3	0.11	0.59	4.91	36.84	57.54	0.96	0.02	2.59	0.73	996.10	9.39	4.79
RIG4	0.13	0.84	6.33	39.91	52.80	1.01	0.01	1.05	0.68	620.17	1.11	1.14
RIG5	0.05	0.17	2.95	35.19	61.65	0.90	0.01	1.84	1.45	973.27	3.37	1.68
RIG6	0.03	0.21	5.14	43.46	51.16	1.02	0.02	2.18	1.16	1126.16	2.44	2.66
RIH1	0.28	0.67	1.80	18.01	79.24	0.70	0.03	3.29	2.95	1811.27	4.01	30.55
RIH2	0.65	2.97	12.69	15.74	67.94	1.00	0.01	1.79	0.59	872.62	3.02	0.80
RIH3	0.77	2.23	3.34	16.63	77.02	0.76	0.03	3.22	1.46	845.06	4.79	2.92
RIH4	0.15	0.55	1.39	12.03	85.87	0.58	0.03	2.78	0.95	714.59	3.22	1.42
RIH5	0.12	0.73	2.05	17.55	79.56	0.69	0.02	2.00	0.92	664.45	2.45	1.15
RIH6	0.13	1.00	1.69	11.36	85.82	0.58	0.02	2.50	1.01	820.05	2.47	4.36
SPA1	15.07	34.02	85.99	21.35	16.13	2.58	0.42	9.61	1.80	1180.80	1.29	6.15
SPA2	91.29	103.53	140.24	11.60	4.14	3.29	0.35	10.02	1.68	1393.37	1.41	3.62
SPA3	0.76	10.77	36.52	21.99	29.77	1.78	0.29	5.56	1.69	1206.38	0.54	4.84

Appendix 2.1: Environmental variables measured from the sediments of St Helena Bay and Robben Island.

Sample	Phi 5	Phi 4	Phi 3	Phi 2	Phi 1	Mean Grain Size	Cd (µg/g)	Cr (µg/g)	Cu (µg/g)	Fe (µg/g)	Pb (µg/g)	Zn (µg/g)
SPA4	1.67	12.48	32.76	7.90	2.10	2.62	0.30	8.01	1.27	969.35	0.76	2.64
SPA5	1.60	12.07	40.91	11.91	3.40	2.45	1.04	21.72	8.78	4532.30	4.39	23.45
SPA6	0.15	8.60	30.21	7.06	15.58	1.96	0.32	5.61	1.82	1199.05	0.14	3.30
SPB1	1.45	43.20	56.38	57.98	35.68	2.08	0.39	8.25	1.43	1222.43	1.12	5.33
SPB2	1.00	18.30	30.24	5.10	4.87	2.70	0.02	9.31	2.44	1107.50	2.12	6.94
SPB3	0.39	20.65	41.18	9.97	27.56	2.04	0.02	5.08	0.21	603.20	0.43	1.65
SPB4	2.91	18.37	34.43	8.77	9.80	2.43	0.58	13.66	2.23	1812.39	2.29	8.06
SPB5	0.80	20.43	29.65	4.43	3.63	2.78	0.49	10.47	1.70	1450.39	1.42	5.11
SPB6	0.91	22.76	47.09	8.46	6.67	2.62	0.58	10.44	1.60	1084.70	1.57	7.27
SPC1	1.24	23.95	39.83	15.78	14.70	2.29	0.84	11.32	3.76	1427.74	2.76	14.68
SPC2	1.48	34.90	38.07	9.69	14.68	2.45	0.77	10.78	3.70	2060.97	1.86	16.06
SPC3	1.27	34.78	40.25	14.67	8.03	2.59	0.28	5.72	0.59	534.90	0.17	2.17
SPC4	1.43	35.90	37.30	7.56	7.96	2.76	0.23	4.23	0.32	474.04	0.52	1.67
SPC5	2.95	12.23	21.14	6.85	9.14	2.32	0.72	13.50	4.45	3282.86	5.71	16.87
SPC6	1.77	12.80	25.56	12.13	9.25	2.26	0.29	6.59	1.87	921.86	0.43	3.47
SHA1	3.80	15.57	25.29	6.81	5.81	2.59	0.28	9.08	0.62	307.29	1.39	1.16
SHA2	2.12	24.36	31.27	9.62	9.14	2.51	0.31	9.64	1.78	1337.49	0.53	23.55
SHA3	0.12	15.99	42.22	17.82	23.61	1.96	0.26	5.89	0.89	668.75	5.63	11.77
SHA4	7.04	15.70	42.79	27.06	1.50	2.47	0.27	7.05	0.44	334.37	3.83	5.89
SHA5	0.03	7.06	44.12	41.20	7.58	2.01	0.28	8.20	1.33	1003.12	2.51	17.66
SHA6	0.12	19.33	35.99	9.13	0.52	2.71	0.30	8.01	0.67	501.56	3.62	8.83
SHB1	0.05	14.88	43.31	12.76	0.54	2.54	0.69	30.49	24.50	7412.97	12.03	79.67
SHB2	0.05	6.89	32.13	25.51	2.84	2.12	1.46	46.93	23.47	7265.86	13.78	168.98
SHB3	1.24	13.31	40.09	22.25	6.10	2.25	1.15	29.85	24.37	9120.51	14.96	145.54
SHB5	0.17	1.21	1.82	4.81	26.46	0.79	0.49	7.46	1.90	1115.11	2.14	7.24

Appendix 2.1: Environmental variables measured from the sediments of St Helena Bay and Robben Island.

Sample	Phi 5	Phi 4	Phi 3	Phi 2	Phi 1	Mean Grain Size	Cd (µg/g)	Cr (µg/g)	Cu (µg/g)	Fe (µg/g)	Pb (µg/g)	Zn (µg/g)
SHB6	0.53	16.49	39.66	13.40	28.67	1.94	0.70	9.91	23.96	6433.32	6.57	78.96
SHC1	1.53	6.74	8.42	10.02	28.89	1.40	1.57	24.29	31.68	3309.33	9.16	84.29
SHC2	1.90	8.87	9.68	9.41	21.24	1.71	0.83	14.30	8.94	1940.32	5.59	39.18
SHC3	1.33	10.96	10.19	12.76	15.28	1.90	1.27	14.29	10.04	2546.59	6.17	66.16
SHC4	1.09	8.85	13.96	10.08	24.11	1.79	1.20	21.26	20.65	4186.89	10.18	82.45
SHC5	15.36	96.44	29.22	10.61	3.91	3.20	0.79	9.93	8.38	1667.48	4.00	37.93
SHC6	6.58	17.68	10.54	6.22	2.49	2.95	0.97	11.07	11.51	2124.21	4.47	51.74
SHD2	7.44	44.41	22.14	10.84	4.60	2.97	1.34	7.39	188.91	1975.73	27.17	143.70
SHD3	15.04	27.32	8.72	3.62	1.22	3.47	1.41	19.16	32.07	4849.83	8.32	153.59
SHD4	11.84	23.52	10.59	4.46	1.20	3.32	1.58	17.09	33.94	6306.29	6.90	128.26
SHD5	16.37	14.92	12.69	5.78	5.23	3.11	0.72	6.14	5.96	2441.97	1.96	59.86
SHE1	12.11	37.38	15.65	6.92	3.11	3.15	0.88	23.30	55.63	8211.21	12.09	160.96
SHE2	0.22	16.29	16.05	16.28	46.72	1.49	0.47	8.33	30.28	2486.53	9.11	56.94
SHE3	0.12	5.71	7.70	7.74	76.76	0.85	0.50	12.10	29.82	2501.07	7.92	62.32
SHE4	0.12	0.81	0.69	0.70	1.81	1.68	0.71	21.03	26.00	6958.63	10.47	85.13
SHE5	0.22	0.57	7.74	1.07	7.27	1.71	0.61	17.88	33.54	8373.69	12.13	110.01
SHE6	0.33	0.82	1.16	1.92	5.15	1.30	1.26	10.70	23.05	7956.32	15.83	54.45
SHF1	0.20	4.84	6.67	5.54	27.54	1.25	1.27	13.71	11.66	5573.26	11.59	69.48
SHF2	2.62	17.40	11.00	12.26	17.16	2.08	2.32	17.13	23.72	5397.32	10.91	93.60
SHF3	0.43	0.60	1.03	2.41	6.07	1.17	2.11	16.63	17.12	3246.94	11.55	87.51
SHF4	0.37	1.28	1.03	2.37	4.70	1.49	0.14	2.26	11.36	829.81	1.85	16.43
SHF5	1.20	1.09	1.86	3.70	70.00	0.56	0.51	5.42	4.24	1930.85	5.59	20.88
SHF6	0.13	4.47	1.20	3.38	50.50	0.59	0.53	9.04	13.45	4353.67	10.46	75.94
SHG1	0.96	1.62	2.02	4.64	29.91	0.84	0.64	8.69	28.36	5301.85	14.02	93.68
SHG2	0.95	4.41	3.02	4.79	29.72	1.15	0.27	7.13	4.33	2071.69	3.37	16.50

Appendix 2.1: Environmental variables measured from the sediments of St Helena Bay and Robben Island.

Sample	Phi 5	Phi 4	Phi 3	Phi 2	Phi 1	Mean Grain Size	Cd (µg/g)	Cr (µg/g)	Cu (µg/g)	Fe (µg/g)	Pb (µg/g)	Zn (µg/g)
SHG3	1.09	10.83	33.06	24.44	18.71	1.91	0.32	25.44	43.99	8758.59	19.81	164.61
SHG4	1.17	9.47	7.97	7.34	71.58	1.09	0.27	15.00	44.88	5439.46	23.31	157.47
SHG5	4.48	5.06	5.12	6.14	6.80	2.28	0.39	13.56	205.90	10439.42	27.10	189.14
SHG6	4.74	10.81	11.29	10.04	43.27	1.49	0.16	6.01	3.94	2417.33	3.48	18.33
SHH1	0.39	2.66	11.77	4.20	68.22	0.97	0.45	6.04	2.48	1617.50	3.40	14.44
SHH2	0.56	9.66	15.37	16.05	8.40	2.07	0.68	8.12	31.10	6282.53	10.70	112.49
SHH3	2.07	8.08	14.10	11.37	36.16	1.41	1.06	2.96	4.61	733.97	3.84	16.05
SHH4	1.24	8.65	30.33	28.52	84.07	1.24	0.60	2.83	4.98	1272.07	4.95	14.18
SHH5	0.70	97.96	7.74	99.93	106.94	1.82	0.45	4.99	2.60	1742.24	2.86	12.68
SHI1	0.31	3.22	4.19	3.89	20.52	1.22	0.40	2.90	2.54	1081.12	2.32	9.74
SHI2	3.18	1.35	1.96	2.38	4.03	2.29	0.55	5.02	4.13	1811.33	2.69	21.12
SHI3	0.65	5.28	5.89	5.85	13.64	1.63	0.50	5.14	3.27	1441.35	2.97	14.38
SHI4	1.22	23.29	10.02	28.11	45.84	1.65	0.35	5.79	3.86	1393.05	2.59	20.36
SHI5	3.83	17.84	31.57	29.24	17.21	2.12	0.46	5.21	3.96	1375.63	2.92	15.83
SHI6	0.86	0.98	17.33	32.72	38.73	1.28	0.40	2.93	4.07	1475.36	1.90	14.44

Appendix 3.1: Abundance of live foraminifera per species in both Robben Island and St Helena Bay

SPECIES	RIA1	RIA2	RIA3	RIA4	RIA5	RIA6	RIB1	RIB2	RIB3	RIB4	RIB5	RIB6
A. parkinsoniana	0	0	0	0	0	0	0	0	0	0	0	0
Elongated Bolivinids	2	3	5	20	1	4	6	11	5	5	22	7
B. elegantissima	0	3	1	0	0	1	0	0	0	1	3	0
perforated bolivinids	0	0	0	0	0	0	0	0	0	0	0	0
B. elongata	0	2	4	0	0	0	0	3	2	0	1	0
B. pseudoplicata	0	3	2	3	2	0	1	0	1	4	5	2
B. pseudopunctata	1	2	0	3	0	1	1	1	1	0	0	8
Bolivinitidae	1	1	1	1	0	0	0	4	0	3	6	0
E. crispum	0	0	0	0	0	0	0	0	0	0	0	0
E. gunteri	0	0	0	0	0	0	0	0	0	0	0	0
E. advenum	2	3	0	1	2	2	4	2	0	5	5	4
E. articulatum	40	37	40	24	11	7	35	13	31	56	34	35
E. macellum	1	0	0	0	0	0	0	0	1	0	0	0
F. lucida	0	0	0	1	0	0	0	0	0	0	0	0
F. marginata	0	0	0	2	0	0	0	0	0	0	0	0
L. semilineata	0	0	0	2	0	0	0	0	0	0	0	0
C. lobatulus	10	17	7	6	10	7	10	13	22	20	12	18
M. seminulum	3	10	10	8	2	4	1	5	10	0	6	7
M. subrotunda	0	4	10	4	2	3	1	4	1	2	3	1
O. hexagona	0	0	0	1	0	0	0	0	0	0	0	0
O. melo	0	1	2	0	0	0	0	0	0	0	0	0
O. sp A	0	0	1	0	0	0	0	0	0	0	0	0
O. tasmanica	0	0	0	0	0	0	0	0	0	0	0	0
P. nipponica	0	0	0	0	0	0	0	1	1	0	1	0
R. globularis	9	2	3	5	2	7	11	9	3	3	4	9
T. squamata	1	0	1	0	0	1	0	8	3	1	2	7
Elphidiella	1	0	0	0	0	0	0	1	0	0	0	0
P. corrugata	0	2	0	0	0	0	0	0	0	0	0	1
R. brady	0	0	0	0	0	0	0	0	0	0	0	0
Q. dunkerquiana	0	0	0	0	0	0	0	0	0	0	2	2
elongated *Quinqueloculina*	5	0	0	2	0	0	0	0	0	0	1	0
Q. isabellei	1	1	0	2	2	1	0	0	0	0	0	3
Q. undulata	0	0	0	0	0	0	0	1	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0	0	0	1	0
T. trigonula	1	0	0	0	0	0	2	2	0	0	2	3
G. australensis	0	0	0	0	1	0	0	0	0	0	1	0
Guttulina	0	0	0	0	0	0	0	0	0	0	1	0

Appendix 3.1: Abundance of live foraminifera per species in both Robben Island and St Helena Bay

SPECIES	RIC1	RIC2	RIC3	RIC4	RIC5	RIC6	RID1	RID2	RID3	RID4	RID5	RID6
A. parkinsoniana	0	0	0	0	0	0	0	0	0	2	0	0
Elongated Bolivinids	3	7	14	10	5	3	0	4	9	7	8	11
B. elegantissima	1	2	0	5	0	0	0	0	0	1	0	1
perforated bolivinids	0	0	0	0	0	0	0	0	0	0	0	0
B. elongate	0	2	0	0	0	0	0	0	0	0	0	0
B. pseudoplicata	0	7	0	6	1	3	0	0	0	0	1	3
B. pseudopunctata	2	0	0	3	3	4	0	0	0	0	0	1
Bolivinitidae	4	8	2	13	0	5	21	10	0	5	3	3
E. crispum	0	0	0	0	0	0	0	0	0	0	0	0
E. gunteri	0	0	0	0	0	0	0	0	0	0	0	0
E. advenum	0	5	0	13	3	1	0	1	1	3	2	2
E. articulatum	16	34	28	24	7	28	14	34	28	19	10	27
E. macellum	1	0	3	3	0	0	0	0	0	0	0	0
F. lucida	2	0	0	0	0	1	0	0	0	0	0	0
F. marginata	0	2	0	0	0	1	0	1	0	3	0	1
L. semilineata	0	0	1	0	0	0	0	0	0	0	0	0
C. lobatulus	11	22	21	21	19	39	3	11	18	37	12	12
M. seminulum	2	16	8	17	4	8	0	6	10	17	5	8
M. subrotunda	6	13	11	14	3	6	0	9	9	8	3	12
O. hexagona	0	0	0	0	0	0	0	0	1	0	0	0
O. melo	0	0	0	0	0	0	0	0	0	0	0	0
O. sp A	0	1	4	0	0	0	0	0	0	1	1	0
O. tasmanica	0	0	0	0	0	0	0	0	0	0	0	0
P. nipponica	0	1	4	5	0	0	0	0	5	1	0	0
R. globularis	2	11	4	6	4	14	25	13	19	11	0	6
T. squamata	2	1	2	2	1	1	2	12	0	6	6	3
Elphidiella	0	0	0	0	0	0	0	0	0	0	0	0
P. corrugata	0	3	1	0	0	0	1	2	1	0	0	1
R. brady	0	0	0	0	0	0	0	0	0	0	0	0
Q. dunkerquiana	0	0	0	0	4	5	0	0	0	3	2	2
elongated *Quinqueloculina*	0	1	2	0	0	0	0	3	0	0	1	0
Q. isabellei	1	0	0	9	2	9	0	0	0	3	3	2
Q. undulata	1	3	0	0	0	0	0	0	0	0	0	0
Q. vulgaris	1	0	0	0	0	0	0	0	0	0	0	0
Spiroloculina	0	2	0	0	0	0	1	1	0	0	0	0
T. trigonula	0	2	1	1	0	0	2	2	0	0	1	0
G. australensis	0	0	4	9	1	0	0	0	1	0	0	0
Guttulina	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 3.1: Abundance of live foraminifera per species in both Robben Island and St Helena Bay

SPECIES	RIE1	RIE2	RIE3	RIE4	RIE5	RIE6	RIF1	RIF2	RIF3	RIF4	RIF5	RIG1
A. parkinsoniana	0	1	1	0	0	1	0	0	0	0	0	0
Elongated Bolivinids	0	0	4	1	1	2	2	1	9	0	2	4
B. elegantissima	0	0	0	0	0	0	0	0	0	1	0	0
perforated bolivinids	0	0	0	0	0	0	0	0	0	0	0	0
B. elongate	0	0	0	0	0	0	0	0	0	0	0	0
B. pseudoplicata	0	0	0	0	0	0	4	0	3	0	0	0
B. pseudopunctata	0	1	0	0	0	0	0	0	8	1	1	0
Bolivinitidae	0	0	0	0	0	0	14	3	3	5	2	0
E. crispum	0	0	0	0	0	0	0	0	0	0	0	1
E. gunteri	0	0	0	0	0	0	0	0	0	0	0	0
E. advenum	1	0	0	1	5	0	1	0	3	0	2	1
E. articulatum	4	12	4	6	0	2	11	14	35	9	9	6
E. macellum	0	0	0	0	0	0	2	0	0	1	0	0
F. lucida	0	0	0	0	0	1	0	0	0	0	0	0
F. marginata	0	0	0	0	0	0	0	2	0	0	0	0
L. semilineata	0	0	0	1	0	0	0	0	0	0	0	0
C. lobatulus	1	2	5	2	1	5	14	38	48	10	11	2
M. seminulum	3	5	1	9	2	33	9	6	9	2	2	2
M. subrotunda	21	9	9	11	10	6	0	27	13	4	5	8
O. hexagona	0	0	0	0	0	0	0	1	0	0	0	0
O. melo	0	0	0	0	0	0	0	0	0	0	0	0
O. sp A	0	1	0	0	0	0	0	0	0	0	0	0
O. tasmanica	0	0	0	0	0	0	0	0	0	0	0	0
P. nipponica	0	1	0	4	5	0	1	0	0	0	1	1
R. globularis	6	14	0	6	2	2	8	3	7	8	6	5
T. squamata	0	0	4	0	1	0	1	5	5	1	1	10
Elphidiella	0	0	0	0	0	0	2	0	0	0	0	0
P. corrugata	1	5	2	1	0	0	0	1	0	0	0	1
R. brady	0	0	0	0	0	0	0	0	0	0	0	0
Q. dunkerquiana	0	0	0	1	1	8	0	0	0	2	6	0
elongated *Quinqueloculina*	0	0	0	0	0	0	0	0	0	0	0	0
Q. isabellei	0	0	1	1	0	13	2	0	7	1	7	1
Q. undulata	0	0	0	0	0	0	0	0	1	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	2	0	2	0	0
Spiroloculina	0	0	0	0	0	0	0	0	0	2	0	0
T. trigonula	1	0	0	2	0	3	0	0	2	2	0	0
G. australensis	0	3	0	2	0	0	0	1	5	2	0	10
Guttulina	0	0	0	0	0	0	0	1	1	0	0	0

Appendix 3.1: Abundance of live foraminifera per species in both Robben Island and St Helena Bay

SPECIES	RIG2	RIG3	RIG4	RIG5	RIG6	RIH1	RIH2	RIH3	RIH4	RIH5	RIH6	SPA1
A. parkinsoniana	3	0	0	0	0	0	1	0	1	1	1	25
Elongated Bolivinids	2	2	5	0	1	8	2	24	27	4	14	0
B. elegantissima	0	1	0	1	0	5	0	0	0	1	0	0
perforated bolivinids	0	0	0	0	0	0	0	0	0	0	0	0
B. elongate	0	0	0	0	0	0	0	3	0	0	0	2
B. pseudoplicata	0	0	1	0	0	2	1	0	3	2	4	4
B. pseudopunctata	0	0	2	0	0	3	0	8	4	0	0	0
Bolivinitidae	0	0	1	0	0	2	1	3	6	4	1	0
E. crispum	0	0	0	0	0	1	0	0	0	0	0	2
E. gunteri	0	0	0	0	0	0	0	0	0	0	0	1
E. advenum	0	2	0	0	0	1	0	1	1	0	0	111
E. articulatum	8	32	22	8	5	20	15	32	29	21	25	10
E. macellum	0	2	0	0	0	0	1	0	0	0	0	8
F. lucida	1	0	0	0	1	0	0	0	1	1	1	2
F. marginata	0	0	0	0	0	1	0	0	0	0	1	1
L. semilineata	0	0	0	0	0	0	0	0	0	0	0	0
C. lobatulus	7	34	15	13	5	10	15	7	37	19	11	16
M. seminulum	13	8	6	12	1	4	8	18	6	7	0	0
M. subrotunda	25	29	24	10	2	11	18	6	10	13	5	0
O. hexagona	0	0	0	0	0	1	0	0	0	0	0	0
O. melo	0	0	0	0	0	0	0	0	1	0	0	0
O. sp A	0	0	0	0	0	0	0	1	6	0	1	0
O. tasmanica	0	0	0	0	0	0	0	0	6	0	0	0
P. nipponica	3	13	5	1	0	2	13	4	8	2	1	10
R. globularis	18	21	16	4	3	11	11	18	6	16	23	11
T. squamata	3	2	0	2	0	9	0	16	8	1	3	1
Elphidiella	0	0	0	0	0	0	0	0	0	0	0	2
P. corrugata	0	3	0	0	3	0	0	0	0	0	1	0
R. brady	0	0	0	0	0	0	0	0	0	0	0	6
Q. dunkerquiana	0	0	5	6	3	0	0	0	5	4	0	0
elongated *Quinqueloculina*	0	1	0	0	0	2	0	6	1	0	0	0
Q. isabellei	2	1	5	4	0	0	5	0	5	2	4	0
Q. undulata	0	0	5	0	0	0	0	0	0	0	0	0
Q. vulgaris	4	0	0	0	0	0	0	0	1	0	0	0
Spiroloculina	0	0	1	0	1	0	0	1	1	0	0	0
T. trigonula	8	4	4	1	0	0	0	1	7	5	0	0
G. australensis	14	38	13	8	6	4	15	2	7	5	0	0
Guttulina	0	1	0	0	0	0	2	0	1	0	0	0

Appendix 3.1: Abundance of live foraminifera per species in both Robben Island and St Helena Bay

SPECIES	SPA2	SPA3	SPA4	SPA5	SPA6	SPB1	SPB2	SPB3	SPB4	SPB5	SPB6	SPC1
A. parkinsoniana	41	35	28	22	22	28	50	48	66	60	62	44
Elongated Bolivinids	1	4	6	6	6	1	1	4	8	8	9	0
B. elegantissima	16	2	8	0	0	6	1	5	9	5	3	8
perforated bolivinids	1	0	0	8	8	1	0	2	0	2	0	1
B. elongate	0	3	0	0	0	1	0	1	1	0	3	3
B. pseudoplicata	0	4	3	0	0	2	0	2	3	0	3	3
B. pseudopunctata	0	0	2	1	1	0	0	1	3	0	0	1
Bolivinitidae	0	0	0	0	0	0	0	0	0	0	0	0
E. crispum	9	2	1	3	3	1	2	6	2	2	2	0
E. gunteri	0	0	0	0	0	0	0	1	0	0	0	4
E. advenum	0	0	1	16	16	9	8	11	7	18	7	16
E. articulatum	12	1	7	59	59	11	3	4	56	50	46	1
E. macellum	10	21	8	7	7	10	8	16	6	11	11	5
F. lucida	0	3	0	2	2	0	0	0	3	1	0	0
F. marginata	0	0	3	0	0	0	0	0	2	0	0	8
L. semilineata	0	0	1	0	0	0	0	0	1	0	0	0
C. lobatulus	2	10	12	8	8	9	2	15	21	15	0	22
M. seminulum	2	0	2	1	1	0	0	0	0	0	0	0
M. subrotunda	0	1	0	0	0	0	0	0	0	0	0	1
O. hexagona	0	0	1	0	0	0	0	1	1	0	1	0
O. melo	0	0	1	0	0	0	0	0	0	0	1	0
O. sp A	1	4	4	0	0	0	1	0	3	3	1	4
O. tasmanica	0	0	0	0	0	0	0	0	0	0	0	1
P. nipponica	4	10	7	21	21	3	3	4	3	4	7	8
R. globularis	7	3	6	1	1	9	1	15	1	2	0	20
T. squamata	1	0	0	0	0	0	0	0	0	0	0	0
Elphidiella	0	1	0	0	0	2	0	2	3	1	0	0
P. corrugata	0	0	0	0	0	0	0	0	0	0	0	0
R. brady	0	0	0	0	0	0	0	0	0	0	0	4
Q. dunkerquiana	0	0	0	0	0	0	0	0	0	0	0	0
elongated *Quinqueloculina*	0	0	0	0	0	0	0	0	0	0	0	0
Q. isabellei	0	0	0	0	0	0	0	0	0	0	0	0
Q. undulata	0	0	0	0	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	0	0	0	0	0	0
G. australensis	0	0	0	0	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 3.1: Abundance of live foraminifera per species in both Robben Island and St Helena Bay

SPECIES	SPC2	SPC3	SPC4	SPC5	SPC6	SHA1	SHA2	SHA3	SHA4	SHA5	SHA6
A. parkinsoniana	38	10	32	26	64	2	5	6	10	9	2
Elongated Bolivinids	10	1	6	21	15	1	0	1	1	0	2
B. elegantissima	5	10	6	5	7	0	3	1	9	0	0
perforated bolivinids	1	1	0	21	15	0	0	0	0	0	2
B. elongate	1	1	5	0	0	0	1	1	2	0	0
B. pseudoplicata	4	4	0	2	0	0	1	0	1	0	0
B. pseudopunctata	0	0	0	0	3	0	0	0	1	0	1
Bolivinitidae	0	0	0	0	0	0	0	0	0	0	0
E. crispum	0	0	2	1	0	0	0	1	3	1	0
E. gunteri	0	1	0	1	0	1	2	3	0	0	2
E. advenum	4	6	2	15	18	0	2	2	4	0	5
E. articulatum	2	5	33	42	22	0	3	0	12	0	5
E. macellum	5	3	3	3	9	0	3	1	1	0	3
F. lucida	10	0	0	5	1	0	0	0	0	0	1
F. marginata	0	2	0	2	0	0	0	0	1	0	0
L. semilineata	0	0	1	0	0	0	0	0	1	0	1
C. lobatulus	20	6	12	15	10	1	2	5	5	0	5
M. seminulum	0	0	0	0	0	0	0	0	0	0	0
M. subrotunda	0	0	0	0	0	0	0	0	0	0	0
O. hexagona	0	0	1	0	0	0	0	0	1	0	0
O. melo	0	0	0	0	0	0	0	0	1	0	0
O. sp A	1	0	1	0	2	0	1	0	2	0	0
O. tasmanica	0	0	1	1	0	0	0	0	0	0	1
P. nipponica	1	4	0	3	8	0	1	1	0	0	0
R. globularis	6	3	4	2	1	2	5	1	3	0	1
T. squamata	0	0	3	0	0	0	0	0	0	0	0
Elphidiella	2	0	0	0	0	0	2	1	1	0	0
P. corrugata	0	0	0	0	0	0	0	0	0	0	0
R. brady	0	0	0	0	0	0	0	0	0	0	0
Q. dunkerquiana	0	0	0	0	0	0	0	0	0	0	0
elongated *Quinqueloculina*	0	0	0	0	0	0	0	0	0	0	0
Q. isabellei	0	0	0	0	0	0	0	0	0	0	0
Q. undulata	0	0	0	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	0	0	0	0	0
G. australensis	0	0	0	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0	0	0	0

Appendix 3.1: Abundance of live foraminifera per species in both Robben Island and St Helena Bay

SPECIES	SHB1	SHB2	SHB3	SHB4	SHB5	SHB6	SHC1	SHC2	SHC3	SHC4	SHC5	SHC
A. parkinsoniana	24	18	17	57	28	20	20	5	14	15	15	7
Elongated Bolivinids	0	0	3	14	4	0	4	2	2	14	2	11
B. elegantissima	12	2	9	19	0	3	8	0	15	2	2	8
perforated bolivinids	0	0	2	0	0	0	1	0	0	0	0	0
B. elongate	4	0	0	0	0	0	0	0	1	12	0	3
B. pseudoplicata	5	0	8	1	0	0	2	0	9	4	0	0
B. pseudopunctata	1	0	3	0	0	0	0	0	2	2	0	0
Bolivinitidae	0	0	0	0	0	0	0	0	0	0	0	0
E. crispum	4	0	0	2	0	0	0	0	1	2	0	0
E. gunteri	1	0	1	0	0	0	0	0	0	0	0	0
E. advenum	3	1	0	0	1	1	1	2	2	0	0	3
E. articulatum	0	12	0	15	2	2	0	2	2	3	0	15
E. macellum	0	1	0	0	1	1	0	0	3	0	0	0
F. lucida	0	0	0	2	0	1	0	0	0	0	0	0
F. marginata	0	0	0	3	0	0	1	0	1	0	0	0
L. semilineata	0	0	0	0	0	0	0	0	0	0	0	0
C. lobatulus	9	1	2	9	0	1	0	0	3	0	0	0
M. seminulum	0	1	0	0	0	0	0	0	0	0	0	0
M. subrotunda	0	0	0	0	0	0	0	0	0	0	0	0
O. hexagona	0	0	0	1	0	0	0	0	0	0	0	0
O. melo	0	0	0	0	0	0	0	0	0	0	0	0
O. sp A	0	0	0	4	0	0	0	0	0	0	0	0
O. tasmanica	0	0	0	0	1	0	0	0	0	0	0	0
P. nipponica	0	0	0	0	0	0	0	0	0	0	0	0
R. globularis	14	0	4	8	2	0	6	10	5	22	7	5
T. squamata	2	0	2	0	4	0	0	2	3	2	1	0
Elphidiella	1	0	0	1	0	0	0	0	0	2	0	0
P. corrugata	0	0	0	0	0	0	0	0	0	0	0	0
R. brady	0	0	0	0	0	0	0	0	0	0	0	0
Q. dunkerquiana elongated	0	0	0	0	0	0	0	0	0	0	0	0
Quinqueloculina	0	0	0	0	0	0	0	0	0	0	0	0
Q. isabellei	0	0	0	0	0	0	0	0	0	0	0	0
Q. undulata	0	0	0	0	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	0	0	0	0	0	0
G. australensis	0	0	0	0	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 3.1: Abundance of live foraminifera per species in both Robben Island and St Helena Bay

SPECIES	SHD2	SHD3	SHD4	SHD5	SHD6	SHE1	SHE2	SHE3	SHE4	SHE5	SHE6	SHF
A. parkinsoniana	0	3	1	1	0	0	14	3	3	2	7	6
Elongated Bolivinids	1	3	5	0	0	0	0	0	2	0	0	0
B. elegantissima	1	2	3	0	0	0	1	2	0	0	0	2
perforated bolivinids	0	0	0	0	0	0	0	0	0	0	0	3
B. elongata	0	0	0	0	0	0	0	0	0	0	0	0
B. pseudoplicata	0	0	0	0	0	0	0	0	0	0	0	0
B. pseudopunctata	0	0	2	0	0	0	0	0	0	0	0	0
Bolivinitidae	0	0	0	0	0	0	0	0	0	0	0	0
E. crispum	0	0	1	0	0	0	0	0	0	0	0	0
E. gunteri	0	0	0	0	0	0	0	0	0	0	0	0
E. advenum	0	0	0	0	0	0	0	0	1	0	0	0
E. articulatum	0	0	1	0	0	0	0	0	1	0	0	0
E. macellum	0	0	1	0	0	0	1	0	0	1	0	0
F. lucida	1	0	0	0	0	0	0	0	0	0	0	0
F. marginata	2	0	1	0	0	0	0	0	0	0	0	1
L. semilineata	0	0	0	0	0	0	0	0	0	0	0	0
C. lobatulus	0	2	1	0	0	1	0	0	0	0	0	0
M. seminulum	0	0	0	0	0	0	0	0	0	0	0	0
M. subrotunda	0	0	0	0	0	0	0	0	0	0	0	0
O. hexagona	0	0	1	0	0	0	0	0	0	0	0	0
O. melo	0	0	0	0	0	0	0	0	0	0	0	0
O. sp A	0	0	1	0	0	0	0	0	0	0	0	0
O. tasmanica	0	0	0	0	0	0	0	0	0	0	0	0
P. nipponica	0	0	1	0	0	0	0	0	0	0	0	0
R. globularis	13	1	0	2	0	1	0	1	0	0	1	2
T. squamata	1	1	2	0	0	0	7	0	0	1	1	0
Elphidiella	0	0	0	0	0	0	2	0	0	0	0	0
P. corrugata	0	0	0	0	0	0	0	0	0	0	0	0
R. brady	0	0	0	0	0	0	0	0	0	0	0	0
Q. dunkerquiana	0	0	0	0	0	0	0	0	0	0	0	0
elongated *Quinqueloculina*	0	0	0	0	0	0	0	0	0	0	0	0
Q. isabellei	0	0	0	0	0	0	0	0	0	0	0	0
Q. undulata	0	0	0	0	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	0	0	0	0	0	0
G. australensis	0	0	0	0	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 3.1: Abundance of live foraminifera per species in both Robben Island and St Helena Bay

SPECIES	SHF2	SHF3	SHF4	SHF5	SHF6	SHG1	SHG2	SHG3	SHG4	SHG5	SHG6
A. parkinsoniana	28	23	44	10	1	29	42	29	73	13	19
Elongated Bolivinids	0	5	6	2	3	3	5	3	5	3	2
B. elegantissima	0	8	9	4	4	11	5	8	4	1	9
perforated bolivinids	0	2	0	0	0	0	0	0	0	0	0
B. elongate	0	3	1	0	0	3	0	0	3	0	0
B. pseudoplicata	0	4	0	0	0	0	0	0	0	0	0
B. pseudopunctata	0	4	0	0	0	0	0	1	0	0	0
Bolivinitidae	0	0	0	0	0	0	0	0	0	0	0
E. crispum	0	1	8	1	0	0	2	0	1	1	1
E. gunteri	0	0	0	0	0	0	0	1	0	0	0
E. advenum	0	1	3	2	0	0	0	2	0	0	0
E. articulatum	0	5	4	1	4	0	7	3	3	3	0
E. macellum	0	1	2	0	0	2	1	1	4	1	0
F. lucida	0	0	0	1	0	1	0	0	0	1	0
F. marginata	0	0	0	0	0	1	0	0	0	0	0
L. semilineata	0	0	0	0	0	0	0	0	2	0	0
C. lobatulus	0	1	1	0	0	0	0	2	0	0	0
M. seminulum	0	0	0	0	0	0	0	1	0	0	0
M. subrotunda	0	0	0	0	0	0	0	0	0	0	0
O. hexagona	0	0	0	0	0	0	0	0	0	1	0
O. melo	0	0	0	0	0	0	0	1	0	0	0
O. sp A	0	0	0	1	0	0	0	3	0	0	0
O. tasmanica	0	0	0	0	0	0	0	0	0	0	0
P. nipponica	0	0	0	0	0	0	0	0	0	0	0
R. globularis	0	0	0	4	0	6	0	14	1	3	6
T. squamata	0	0	7	1	0	1	3	1	2	1	1
Elphidiella	0	1	0	0	0	0	0	1	0	0	1
P. corrugate	0	0	0	0	0	0	0	0	0	0	0
R. brady	0	0	0	0	0	0	0	0	0	0	0
Q. dunkerquiana	0	0	0	0	0	0	0	0	0	0	0
elongated *Quinqueloculina*	0	0	0	0	0	0	0	0	0	0	0
Q. isabellei	0	0	0	0	0	0	0	0	0	0	0
Q. undulata	0	0	0	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	0	0	0	0	0
G. australensis	0	0	0	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0	0	0	0

Appendix 3.1: Abundance of live foraminifera per species in both Robben Island and St Helena Bay

SPECIES	SHH1	SHH2	SHH3	SHH4	SHH5	SHI1	SHI2	SHI3	SHI4	SHI5	SHI6
A. parkinsoniana	4	28	65	11	9	27	8	7	15	1	6
Elongated Bolivinids	0	4	6	9	1	4	0	3	3	0	1
B. elegantissima	1	12	10	15	1	20	0	9	11	0	1
perforated bolivinids	0	0	0	9	1	2	0	0	0	0	0
B. elongate	0	0	2	0	0	0	0	0	0	0	1
B. pseudoplicata	0	1	2	1	0	3	0	1	0	0	0
B. pseudopunctata	0	0	0	0	0	0	0	0	0	0	0
Bolivinitidae	0	0	0	0	0	0	0	0	0	0	0
E. crispum	0	2	3	2	1	0	0	0	0	0	0
E. gunteri	1	0	1	0	0	1	1	0	0	0	0
E. advenum	0	0	2	0	1	3	0	2	1	0	4
E. articulatum	0	0	0	6	0	0	0	4	1	0	0
E. macellum	0	2	0	1	2	3	7	0	0	0	3
F. lucida	0	1	0	0	0	0	0	0	0	0	0
F. marginata	0	0	0	0	0	0	0	0	0	0	0
L. semilineata	0	0	0	0	0	0	0	1	0	0	0
C. lobatulus	0	0	3	1	0	0	0	1	0	0	3
M. seminulum	0	0	0	0	0	0	0	0	0	0	0
M. subrotunda	0	0	0	0	0	0	0	0	0	0	0
O. hexagona	0	0	0	0	0	0	0	0	0	0	4
O. melo	0	0	0	0	0	0	0	0	1	0	0
O. sp A	0	0	0	0	1	4	0	1	0	0	0
O. tasmanica	0	0	0	0	0	0	0	3	0	0	0
P. nipponica	0	0	0	0	0	0	4	0	0	0	0
R. globularis	0	3	0	0	1	1	0	3	0	0	0
T. squamata	0	2	4	3	1	0	0	1	0	1	2
Elphidiella	0	2	1	0	0	0	0	1	1	0	0
P. corrugata	0	0	0	0	0	0	0	0	0	0	0
R. brady	0	0	0	0	0	0	0	0	0	0	0
Q. dunkerquiana elongated	0	0	0	0	0	0	0	0	0	0	0
Quinqueloculina	0	0	0	0	0	0	0	0	0	0	0
Q. isabellei	0	0	0	0	0	0	0	0	0	0	0
Q. undulata	0	0	0	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	0	0	0	0	0
G. australensis	0	0	0	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0	0	0	0

Appendix 3.2: The abundance of each species in the dead assemblages

	SPA1	SPA2	SPA3	SPA4	SPA5	SPA6	SPB1	SPB2
A. parkinsoniana	11	10	18	11	7	2	9	14
Elongated Bolivinids	1	1	10	2	6	12	6	34
B. elegantissima	2	3	0	1	6	0	1	0
perforated bolivinids	1	2	1	8	1	8	11	13
B. elongata	4	0	0	0	0	0	0	2
B. pseudoplicata	0	0	17	4	0	0	3	0
B. pseudopunctata	0	0	4	0	0	2	0	0
Bolivinitidae	0	0	0	0	0	0	0	0
E. crispum	1	5	0	0	4	2	1	3
E. gunteri	1	0	0	2	0	0	1	0
E. advenum	15	15	10	11	13	10	14	14
E. articulatum	18	142	40	7	47	61	17	132
E. macellum	5	7	6	0	4	1	5	11
F. lucida	1	0	1	6	0	0	0	1
F. marginata	3	2	5	14	0	0	6	1
L. semilineata	0	0	3	0	0	0	0	0
C. lobatulus	9	13	26	21	11	14	29	10
M. seminulum	2	0	2	8	0	2	1	0
M. subrotunda	2	0	1	2	2	6	0	1
O. hexagona	0	0	0	1	0	2	0	2
O. melo	1	1	0	0	1	0	0	0
Oolina sp A	3	0	2	1	1	1	0	0
O. tasmanica	1	0	2	1	0	0	0	0
P. nipponica	5	9	8	13	10	14	4	6
R. globularis	8	3	9	9	5	1	8	4
T. squamata	0	0	1	0	0	0	0	2
Elphidiella	1	0	1	0	0	0	0	0
P. corrugata	1	0	0	0	1	0	1	0
R. brady	9	0	0	0	0	0	2	0
Q. dunkerquiana	0	0	0	0	0	0	0	0
Q. isabellei	0	0	0	0	0	0	0	0
Q. undulata	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	0	0
G. australensis	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0

	SPB3	SPB4	SPB5	SPB6	SPC1	SPC2	SPC3	SPC4
A. parkinsoniana	18	1	7	8	3	4	20	4
Elongated Bolivinids	5	6	26	9	16	15	5	14
B. elegantissima	0	0	0	0	1	1	2	0
perforated bolivinids	2	2	2	6	2	6	8	11
B. elongata	1	2	0	0	0	0	0	0
B. pseudoplicata	3	5	0	0	11	9	5	2
B. pseudopunctata	3	3	0	1	0	1	3	2
Bolivinitidae	0	0	0	0	0	0	0	0
E. crispum	0	0	0	0	0	0	1	0
E. gunteri	2	0	0	0	0	0	0	0
E. advenum	10	3	10	11	7	13	2	4
E. articulatum	17	16	51	91	1	4	2	14
E. macellum	3	3	5	1	0	4	0	0
F. lucida	3	2	3	0	1	0	3	2
F. marginata	9	4	7	6	3	6	5	2
L. semilineata	0	1	0	4	2	0	0	1
C. lobatulus	27	1	10	0	6	16	6	4
M. seminulum	0	1	0	0	0	0	0	0
M. subrotunda	0	0	0	0	0	0	0	0
O. hexagona	4	0	2	0	1	0	0	3
O. melo	1	0	0	3	1	0	0	0
Oolina sp A	0	0	1	0	0	2	0	0
O. tasmanica	2	0	0	1	0	0	0	0
P. nipponica	8	1	1	3	2	0	1	2
R. globularis	13	0	2	0	1	2	6	0
T. squamata	0	0	0	0	0	0	0	0
Elphidiella	2	0	0	0	0	0	0	0
P. corrugata	0	0	0	0	0	0	0	0
R. brady	0	0	0	0	0	0	0	0
Q. dunkerquiana	0	0	0	0	0	0	0	0
Q. isabellei	0	0	0	0	0	0	0	0
Q. undulata	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	0	0
G. australensis	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0

	SPC5	SPC6	SHA1	SHA2	SHA3	SHA4	SHA5	SHA6
A. parkinsoniana	6	4	40	30	2	19	25	9
Elongated Bolivinids	22	24	4	3	0	2	0	11
B. elegantissima	22	24	4	0	0	0	0	11
perforated bolivinids	11	8	2	5	1	4	3	3
B. elongata	3	3	0	1	0	2	0	0
B. pseudoplicata	1	0	0	4	0	1	1	0
B. pseudopunctata	3	3	1	0	0	1	0	0
Bolivinitidae	0	0	0	0	0	0	0	0
E. crispum	0	2	0	0	1	4	3	0
E. gunteri	0	0	3	0	2	0	0	0
E. advenum	5	8	8	44	18	25	19	26
E. articulatum	22	69	11	19	15	61	86	84
E. macellum	0	2	3	3	4	6	6	4
F. lucida	1	1	7	0	0	3	0	1
F. marginata	9	7	9	4	0	5	2	1
L. semilineata	0	0	0	0	0	0	0	0
C. lobatulus	16	4	19	49	19	17	12	28
M. seminulum	1	0	0	0	0	0	0	0
M. subrotunda	0	1	1	0	1	0	0	0
O. hexagona	0	0	0	2	0	1	3	0
O. melo	0	1	0	0	0	3	0	0
Oolina sp A	0	0	2	6	0	0	3	1
O. tasmanica	0	0	0	2	0	0	1	0
P. nipponica	0	2	0	1	1	2	0	1
R. globularis	1	0	11	16	4	10	0	0
T. squamata	0	0	0	0	1	0	0	0
Elphidiella	0	0	0	0	1	0	2	0
P. corrugata	1	0	0	0	0	0	0	0
R. brady	0	0	0	2	0	0	0	0
Q. dunkerquiana	0	0	0	0	0	0	0	0
Q. isabellei	0	0	0	0	0	0	0	0
Q. undulata	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	0	0
G. australensis	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0

	SHB1	SHB2	SHB3	SHB4	SHB5	SHB6	SHC1	SHC2
A. parkinsoniana	36	10	12	13	58	5	20	11
Elongated Bolivinids	3	18	6	20	25	13	27	54
B. elegantissima	2	0	0	0	0	0	2	0
perforated bolivinids	20	4	11	15	17	6	11	15
B. elongata	4	0	3	0	4	0	1	3
B. pseudoplicata	19	0	10	4	4	0	32	0
B. pseudopunctata	2	0	7	0	0	0	6	3
Bolivinitidae	0	0	0	0	0	0	0	0
E. crispum	4	0	0	0	3	0	0	0
E. gunteri	1	0	0	0	0	0	0	0
E. advenum	18	4	4	15	12	4	4	10
E. articulatum	28	46	4	28	42	9	3	67
E. macellum	1	2	1	1	1	2	2	1
F. lucida	0	0	1	7	6	0	7	3
F. marginata	2	0	7	11	22	0	9	5
L. semilineata	1	1	0	0	2	0	1	1
C. lobatulus	21	0	1	31	8	7	6	0
M. seminulum	0	1	0	0	0	0	1	0
M. subrotunda	0	0	0	0	0	0	0	0
O. hexagona	1	1	0	1	2	0	0	3
O. melo	1	0	0	1	1	0	0	1
Oolina sp A	0	0	0	1	1	0	0	2
O. tasmanica	0	0	0	0	1	0	0	1
P. nipponica	0	0	0	0	1	0	0	1
R. globularis	10	1	3	5	3	0	10	9
T. squamata	0	0	0	0	0	0	0	0
Elphidiella	2	0	0	0	0	0	2	0
P. corrugata	2	0	1	0	1	0	2	1
R. brady	0	0	0	0	0	0	0	0
Q. dunkerquiana	0	0	0	0	0	0	0	0
Q. isabellei	0	0	0	0	0	0	0	0
Q. undulata	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	0	0
G. australensis	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0

	SHC3	SHC4	SHC5	SHC6	SHD2	SHD3	SHD4	SHD5
A. parkinsoniana	16	6	10	8	1	3	2	2
Elongated Bolivinids	19	30	60	78	18	4	26	18
B. elegantissima	1	0	0	0	0	0	0	0
perforated bolivinids	12	9	29	10	1	8	19	7
B. elongata	3	12	2	3	8	0	4	0
B. pseudoplicata	23	7	1	0	12	14	14	2
B. pseudopunctata	4	5	5	1	10	0	4	1
Bolivinitidae	0	0	0	0	0	0	0	0
E. crispum	0	1	1	1	1	0	1	0
E. gunteri	1	0	1	0	0	0	0	1
E. advenum	6	5	20	16	4	4	12	9
E. articulatum	7	26	51	58	6	6	7	7
E. macellum	0	0	3	4	0	0	0	3
F. lucida	4	6	7	3	4	1	0	0
F. marginata	12	12	15	7	12	5	10	4
L. semilineata	1	2	1	1	1	0	0	1
C. lobatulus	10	10	7	2	6	3	11	0
M. seminulum	1	2	1	1	0	0	0	0
M. subrotunda	1	0	0	0	1	0	0	0
O. hexagona	1	1	0	0	0	1	0	0
O. melo	0	0	0	0	1	0	0	0
Oolina sp A	0	0	1	1	0	0	0	0
O. tasmanica	0	0	0	0	0	0	0	0
P. nipponica	0	0	0	0	0	0	0	0
R. globularis	11	8	8	3	13	6	0	0
T. squamata	3	1	0	1	2	0	7	0
Elphidiella	0	0	0	1	0	0	0	0
P. corrugata	2	1	1	3	0	1	0	0
R. brady	0	0	0	0	3	0	1	0
Q. dunkerquiana	0	0	0	0	0	0	0	0
Q. isabellei	0	0	0	0	0	0	0	0
Q. undulata	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	0	0
G. australensis	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0

	SHD6	SHE1	SHE2	SHE3	SHE4	SHE5	SHE6	SHF1
A. parkinsoniana	3	2	16	8	2	6	6	4
Elongated Bolivinids	5	0	1	1	4	1	2	6
B. elegantissima	0	0	1	0	0	1	2	1
perforated bolivinids	1	0	0	2	1	2	2	7
B. elongata	0	0	3	0	0	0	1	7
B. pseudoplicata	0	0	1	0	0	0	0	5
B. pseudopunctata	0	1	0	0	1	0	0	3
Bolivinitidae	0	0	0	0	0	0	0	0
E. crispum	0	0	0	0	0	1	0	0
E. gunteri	0	0	0	1	0	0	0	0
E. advenum	1	1	0	0	1	3	0	3
E. articulatum	28	0	0	0	1	2	10	1
E. macellum	0	0	0	0	0	3	1	0
F. lucida	0	0	1	0	2	0	4	4
F. marginata	6	0	5	0	2	0	6	8
L. semilineata	1	0	0	0	0	1	0	0
C. lobatulus	0	0	4	0	0	1	0	3
M. seminulum	1	0	3	0	0	0	0	0
M. subrotunda	0	0	0	0	0	0	0	0
O. hexagona	0	0	0	0	0	0	0	0
O. melo	0	0	0	1	0	0	1	0
Oolina sp A	0	0	0	1	0	0	1	0
O. tasmanica	0	0	0	0	0	0	0	0
P. nipponica	0	0	0	0	0	0	0	1
R. globularis	3	0	0	1	0	0	0	1
T. squamata	0	0	3	0	2	0	0	0
Elphidiella	0	0	0	0	0	0	1	0
P. corrugata	1	0	0	0	0	0	0	0
R. brady	0	0	1	0	0	0	0	0
Q. dunkerquiana	0	0	0	0	0	0	0	0
Q. isabellei	0	0	0	0	0	0	0	0
Q. undulata	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	0	0
G. australensis	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0

	SHF2	SHF3	SHF4	SHF5	SHF6	SHG1	SHG2	SHG3
A. parkinsoniana	12	17	27	16	20	38	54	17
Elongated Bolivinids	52	28	60	22	48	16	47	18
B. elegantissima	6	4	0	0	3	3	0	0
perforated bolivinids	40	19	23	15	20	16	45	12
B. elongata	2	3	4	6	5	4	0	3
B. pseudoplicata	0	26	3	2	0	20	0	20
B. pseudopunctata	1	5	1	3	0	9	2	4
Bolivinitidae	0	0	0	0	0	0	0	0
E. crispum	1	0	1	0	1	1	0	0
E. gunteri	0	2	1	0	0	0	0	0
E. advenum	18	2	33	10	4	15	7	5
E. articulatum	54	9	32	20	40	21	96	16
E. macellum	1	2	3	0	3	3	3	0
F. lucida	3	10	1	2	6	4	3	1
F. marginata	5	18	3	6	16	10	5	9
L. semilineata	0	0	0	0	0	2	0	0
C. lobatulus	1	4	0	0	1	19	0	25
M. seminulum	0	0	1	0	0	1	0	0
M. subrotunda	0	0	0	0	0	0	0	1
O. hexagona	2	0	0	0	0	2	0	1
O. melo	0	0	0	0	1	1	2	0
Oolina sp A	0	0	0	1	1	1	1	1
O. tasmanica	0	0	1	0	0	0	0	1
P. nipponica	0	0	0	0	0	0	0	1
R. globularis	6	0	0	3	3	6	3	9
T. squamata	0	1	4	0	0	0	0	1
Elphidiella	0	1	0	0	0	0	0	2
P. corrugata	0	0	0	1	1	1	0	0
R. brady	0	1	0	0	0	0	0	0
Q. dunkerquiana	0	0	0	0	0	0	0	0
Q. isabellei	0	0	0	0	0	0	0	0
Q. undulata	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	0	0
G. australensis	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0

	SHG4	SHG5	SHG6	SHH1	SHH2	SHH3	SHH4	SHH5
A. parkinsoniana	11	23	39	6	6	11	40	19
Elongated Bolivinids	28	27	55	5	16	20	36	32
B. elegantissima	0	0	0	0	4	1	36	32
perforated bolivinids	11	10	21	9	42	12	43	23
B. elongata	3	1	1	1	3	1	5	0
B. pseudoplicata	1	0	0	2	28	22	4	4
B. pseudopunctata	5	1	1	6	9	8	6	5
Bolivinitidae	0	0	0	0	0	0	0	0
E. crispum	3	1	3	0	0	0	5	0
E. gunteri	0	1	0	3	2	1	0	2
E. advenum	27	13	20	1	6	3	9	11
E. articulatum	44	81	79	0	7	13	38	23
E. macellum	1	2	2	0	2	0	3	5
F. lucida	2	3	4	0	1	0	4	7
F. marginata	6	5	8	10	7	4	12	13
L. semilineata	0	0	4	0	0	0	0	1
C. lobatulus	0	5	6	0	10	8	0	3
M. seminulum	0	0	1	0	0	0	0	0
M. subrotunda	0	0	0	0	0	0	0	0
O. hexagona	0	32	1	0	2	1	0	0
O. melo	0	0	1	1	0	0	0	0
Oolina sp A	0	0	2	0	0	0	0	0
O. tasmanica	1	0	0	0	0	0	0	0
P. nipponica	0	0	0	0	0	1	0	0
R. globularis	0	0	6	0	7	2	2	8
T. squamata	8	0	0	0	5	7	3	0
Elphidiella	0	0	0	0	1	2	0	0
P. corrugata	0	1	0	2	0	1	1	0
R. brady	0	0	1	0	0	0	1	0
Q. dunkerquiana	0	0	0	0	0	0	0	0
Q. isabellei	0	0	0	0	0	0	0	0
Q. undulata	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	0	0
G. australensis	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0

	SHI1	SHI2	SHI3	SHI4	SHI5	SHI6	RIA1	RIA2
A. parkinsoniana	11	32	5	30	26	39	0	0
Elongated Bolivinids	26	47	23	23	44	23	33	10
B. elegantissima	6	6	0	0	0	0	4	2
perforated bolivinids	41	32	39	19	23	24	0	0
B. elongata	13	3	7	4	10	9	0	2
B. pseudoplicata	28	0	12	4	0	2	14	11
B. pseudopunctata	1	0	1	4	2	5	5	14
Bolivinitidae	0	0	0	0	0	0	5	3
E. crispum	1	0	1	4	4	0	0	0
E. gunteri	2	0	0	3	3	0	0	0
E. advenum	0	18	8	32	27	12	11	9
E. articulatum	0	100	17	107	78	98	96	62
E. macellum	2	0	0	7	20	10	0	0
F. lucida	0	2	4	5	11	1	0	3
F. marginata	0	8	22	11	25	3	0	6
L. semilineata	0	0	2	2	2	2	0	3
C. lobatulus	0	4	15	3	6	12	7	6
M. seminulum	0	0	1	0	1	0	12	45
M. subrotunda	0	0	0	0	0	0	3	5
O. hexagona	0	2	2	4	0	2	0	2
O. melo	0	0	1	2	1	4	0	1
Oolina sp A	0	0	0	0	1	1	0	2
O. tasmanica	0	0	1	0	1	0	0	0
P. nipponica	0	4	0	0	0	1	2	0
R. globularis	0	0	9	0	0	0	4	1
T. squamata	0	0	1	1	0	0	0	0
Elphidiella	0	0	0	2	1	0	1	1
P. corrugata	0	0	0	0	0	0	3	0
R. brady	0	0	0	0	0	0	0	0
Q. dunkerquiana	0	0	0	0	0	0	0	0
Q. isabellei	0	0	0	0	0	0	3	2
Q. undulata	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	0	0	0	1	2
G. australensis	0	0	0	0	0	0	1	0
Guttulina	0	0	0	0	0	0	0	0

	RIA3	RIA4	RIA5	RIA6	RIB1	RIB2	RIB3	RIB4
A. parkinsoniana	3	1	1	1	0	0	0	0
Elongated Bolivinids	33	48	21	43	43	25	24	29
B. elegantissima	4	8	6	1	4	0	2	5
perforated bolivinids	0	0	0	0	0	0	0	0
B. elongata	1	2	1	3	1	3	6	0
B. pseudoplicata	0	0	6	5	13	6	13	2
B. pseudopunctata	9	11	7	9	13	8	23	0
Bolivinitidae	0	1	1	0	1	0	0	7
E. crispum	0	0	0	0	6	0	0	0
E. gunteri	0	0	0	0	0	0	0	0
E. advenum	1	4	12	4	10	8	4	10
E. articulatum	65	36	37	52	61	59	59	57
E. macellum	0	0	0	0	2	0	0	3
F. lucida	3	7	3	3	3	4	5	4
F. marginata	1	5	3	7	7	2	2	4
L. semilineata	1	5	1	0	1	0	2	0
C. lobatulus	9	17	11	29	11	19	16	16
M. seminulum	13	20	18	25	13	16	15	5
M. subrotunda	13	8	16	15	1	13	8	7
O. hexagona	0	1	2	0	0	2	1	0
O. melo	0	0	4	0	0	5	0	0
Oolina sp A	1	0	3	4	0	0	0	2
O. tasmanica	0	0	0	0	0	0	0	0
P. nipponica	4	1	1	0	1	2	0	1
R. globularis	2	5	1	5	0	4	1	2
T. squamata	0	0	2	0	0	9	4	1
Elphidiella	0	0	5	0	0	1	3	1
P. corrugata	0	0	0	0	0	0	2	0
R. brady	0	0	0	0	0	0	0	0
Q. dunkerquiana	1	0	1	0	0	0	0	0
Q. isabellei	1	2	2	1	4	2	3	0
Q. undulata	0	0	0	0	0	0	2	0
Q. vulgaris	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0
T. trigonula	0	0	0	2	4	0	3	1
G. australensis	1	0	1	1	0	1	0	2
Guttulina	0	0	0	0	0	0	0	0

	RIB5	RIB6	RIC1	RIC2	RIC3	RIC4	RIC5	RIC6
A. parkinsoniana	0	2	0	0	0	0	0	0
Elongated Bolivinids	21	21	23	7	20	5	28	14
B. elegantissima	3	4	3	0	1	3	2	3
perforated bolivinids	0	0	0	0	0	0	0	0
B. elongata	3	5	4	8	1	0	6	2
B. pseudoplicata	7	6	11	7	5	1	14	7
B. pseudopunctata	7	6	5	2	4	2	2	4
Bolivinitidae	2	3	4	8	8	0	11	2
E. crispum	0	0	0	0	0	0	0	0
E. gunteri	0	0	0	0	2	0	0	0
E. advenum	5	4	8	11	6	10	5	10
E. articulatum	26	36	74	23	44	18	31	41
E. macellum	0	0	0	0	2	0	0	2
F. lucida	7	4	2	0	2	2	2	3
F. marginata	0	6	7	5	2	0	9	4
L. semilineata	0	4	5	2	1	0	0	8
C. lobatulus	9	8	21	11	18	12	32	26
M. seminulum	10	9	13	15	5	3	13	14
M. subrotunda	4	9	4	22	20	3	16	14
O. hexagona	3	1	1	1	1	5	0	0
O. melo	0	0	1	1	0	0	0	3
Oolina sp A	0	1	1	0	1	0	3	1
O. tasmanica	0	0	1	0	0	0	0	0
P. nipponica	1	1	1	0	0	2	1	1
R. globularis	3	2	9	0	0	0	6	4
T. squamata	3	0	1	0	2	0	1	1
Elphidiella	2	0	1	2	1	0	1	2
P. corrugata	0	0	0	0	0	0	0	1
R. brady	0	0	0	0	0	0	0	0
Q. dunkerquiana	3	1	0	0	0	1	4	0
Q. isabellei	3	1	16	0	2	1	3	0
Q. undulata	0	0	5	0	0	0	1	0
Q. vulgaris	0	1	0	0	0	0	0	0
Spiroloculina	0	2	1	0	1	0	0	4
T. trigonula	4	0	1	8	3	1	4	0
G. australensis	0	0	4	7	2	5	4	1
Guttulina	2	0	0	2	0	0	0	0

	RID1	RID2	RID3	RID4	RID5	RID6	RIE1	RIE2
A. parkinsoniana	0	0	0	1	0	0	0	0
Elongated Bolivinids	9	1	20	17	6	18	3	3
B. elegantissima	0	0	0	0	0	0	0	0
perforated bolivinids	0	0	0	0	0	0	0	0
B. elongata	0	0	0	0	0	1	0	0
B. pseudoplicata	2	2	0	1	2	6	1	0
B. pseudopunctata	0	0	3	6	7	4	0	4
Bolivinitidae	5	4	2	0	2	2	0	0
E. crispum	0	0	0	0	0	0	0	0
E. gunteri	0	0	0	0	0	0	0	0
E. advenum	6	2	4	3	3	3	0	1
E. articulatum	36	39	47	44	20	42	13	7
E. macellum	0	1	1	0	0	1	0	2
F. lucida	0	3	0	3	3	2	0	1
F. marginata	3	4	1	6	6	2	0	0
L. semilineata	0	0	0	2	0	0	0	0
C. lobatulus	2	5	17	14	8	9	0	1
M. seminulum	3	2	6	18	10	7	1	6
M. subrotunda	0	4	11	16	5	10	8	14
O. hexagona	0	1	1	2	0	0	1	1
O. melo	0	0	0	0	0	0	0	0
Oolina sp A	1	3	1	3	0	0	0	0
O. tasmanica	0	0	0	0	0	0	0	0
P. nipponica	0	1	0	0	0	0	0	2
R. globularis	7	4	6	3	1	3	3	14
T. squamata	2	2	1	0	3	1	0	0
Elphidiella	4	0	0	0	0	1	2	0
P. corrugata	0	0	0	0	0	0	0	0
R. brady	0	0	0	0	0	0	0	0
Q. dunkerquiana	0	0	0	1	2	0	0	0
Q. isabellei	1	2	1	2	3	1	2	0
Q. undulata	0	0	0	0	0	0	0	0
Q. vulgaris	0	0	0	0	0	0	0	0
Spiroloculina	1	0	0	2	0	0	0	1
T. trigonula	0	1	2	0	0	0	1	2
G. australensis	0	0	0	0	0	0	0	2
Guttulina	0	0	0	0	0	0	0	0

	RIE3	RIE4	RIE5	RIE6	RIF1	RIF2	RIF3	RIF4
A. parkinsoniana	0	0	0	0	0	0	1	0
Elongated Bolivinids	5	4	2	1	12	49	19	11
B. elegantissima	0	1	1	0	1	0	3	3
perforated bolivinids	0	0	0	0	0	0	0	0
B. elongata	0	0	0	0	1	4	0	2
B. pseudoplicata	0	1	0	0	3	0	4	0
B. pseudopunctata	1	2	0	0	2	0	7	1
Bolivinitidae	0	0	0	0	14	2	3	7
E. crispum	0	0	0	0	0	0	0	0
E. gunteri	0	0	0	0	0	0	0	0
E. advenum	0	3	4	0	4	0	9	3
E. articulatum	2	7	0	1	39	23	20	33
E. macellum	0	1	1	0	0	0	0	0
F. lucida	0	0	0	1	0	3	4	4
F. marginata	4	0	1	0	1	12	2	3
L. semilineata	0	0	0	0	2	2	2	1
C. lobatulus	2	1	0	4	17	17	19	35
M. seminulum	6	5	0	4	12	10	6	4
M. subrotunda	11	12	7	8	3	19	11	25
O. hexagona	0	0	0	0	1	0	0	0
O. melo	0	0	0	0	0	0	0	2
Oolina sp A	1	0	0	0	0	1	3	3
O. tasmanica	0	0	0	0	0	0	0	0
P. nipponica	0	4	2	0	2	2	2	3
R. globularis	0	1	0	1	7	5	1	15
T. squamata	3	0	1	0	5	0	5	3
Elphidiella	1	0	0	0	2	1	4	2
P. corrugata	0	0	0	0	1	0	0	0
R. brady	0	0	0	0	0	0	0	0
Q. dunkerquiana	0	0	2	3	0	0	0	3
Q. isabellei	0	0	1	4	4	6	2	3
Q. undulata	0	0	0	0	0	1	0	2
Q. vulgaris	0	0	0	0	0	0	0	0
Spiroloculina	0	0	0	0	2	4	2	3
T. trigonula	0	2	0	0	0	3	0	2
G. australensis	0	0	0	1	5	3	4	7
Guttulina	0	0	0	0	0	0	0	0

	RIF5	RIG1	RIG2	RIG3	RIG4	RIG5	RIG6	RIH1
A. parkinsoniana	0	0	1	0	0	0	0	0
Elongated Bolivinids	2	6	4	6	21	3	3	16
B. elegantissima	0	0	0	0	1	0	1	1
perforated bolivinids	0	0	0	0	0	0	0	0
B. elongata	0	0	0	0	0	0	0	1
B. pseudoplicata	0	0	0	0	1	2	0	2
B. pseudopunctata	3	0	0	0	3	1	0	4
Bolivinitidae	6	0	1	0	0	0	0	6
E. crispum	0	0	0	0	0	0	0	0
E. gunteri	0	0	0	0	0	0	0	0
E. advenum	6	1	0	2	3	1	0	3
E. articulatum	17	5	15	21	30	8	2	27
E. macellum	1	0	1	0	0	0	0	0
F. lucida	0	0	0	2	6	3	0	1
F. marginata	1	1	0	1	2	1	0	4
L. semilineata	0	0	1	1	2	0	0	0
C. lobatulus	6	7	6	3	11	5	1	5
M. seminulum	1	8	4	1	4	3	0	15
M. subrotunda	13	14	20	23	24	4	4	18
O. hexagona	1	0	0	0	0	0	0	0
O. melo	0	0	0	0	0	0	0	0
Oolina sp A	0	0	4	2	0	0	0	0
O. tasmanica	0	0	0	0	0	0	0	0
P. nipponica	2	6	6	9	10	2	1	4
R. globularis	2	0	3	7	4	1	0	4
T. squamata	0	9	0	0	1	0	0	5
Elphidiella	0	0	0	0	1	0	0	2
P. corrugata	0	0	0	0	0	0	0	0
R. brady	0	0	0	0	0	0	0	0
Q. dunkerquiana	2	0	0	0	1	0	0	0
Q. isabellei	3	2	1	1	2	2	0	3
Q. undulata	0	0	0	0	0	0	0	0
Q. vulgaris	3	0	4	1	0	0	0	0
Spiroloculina	0	0	2	0	2	0	0	0
T. trigonula	2	0	0	2	0	1	1	1
G. australensis	2	10	35	29	19	2	7	11
Guttulina	0	1	1	0	2	0	0	0

	RIH2	RIH3	RIH4	RIH5	RIH6
A. parkinsoniana	0	0	0	0	0
Elongated Bolivinids	8	12	39	17	31
B. elegantissima	0	0	0	0	0
perforated bolivinids	0	0	0	0	0
B. elongata	0	3	2	0	0
B. pseudoplicata	3	1	9	3	7
B. pseudopunctata	0	5	9	0	5
Bolivinitidae	1	3	3	0	0
E. crispum	0	0	0	0	0
E. gunteri	0	0	0	0	0
E. advenum	6	3	3	0	5
E. articulatum	30	17	23	27	27
E. macellum	0	0	0	0	1
F. lucida	1	4	4	2	4
F. marginata	1	2	5	3	8
L. semilineata	0	1	1	1	1
C. lobatulus	7	1	4	3	13
M. seminulum	9	4	5	7	3
M. subrotunda	8	6	15	9	9
O. hexagona	0	0	0	0	0
O. melo	0	0	0	0	0
Oolina sp A	0	4	3	2	0
O. tasmanica	0	0	3	0	0
P. nipponica	2	3	1	0	0
R. globularis	1	1	3	1	5
T. squamata	0	0	1	4	9
Elphidiella	0	1	0	3	0
P. corrugata	1	0	0	0	0
R. brady	0	0	0	0	0
Q. dunkerquiana	0	0	0	2	8
Q. isabellei	8	2	1	2	14
Q. undulata	0	0	0	0	0
Q. vulgaris	0	0	0	0	0
Spiroloculina	0	1	2	2	0
T. trigonula	5	2	0	1	6
G. australensis	19	3	3	4	3
Guttulina	1	1	0	0	0

Appendix 3.3 (a): Species Richness of foraminifera found in some studies similar to the present study with the location and a short description of environmental conditions, the number and type of samples, depth where provided (N/A where no depth profiles were given).

Location of Study	No. of Samples	Depth	**Species Richness**	**Author (s)**
Israel - Hadera (effluent from coal power station)	8	17.5 – 24 m	0 - 42	Yanko *et al*., 1994
Israel - Haifa Bay (heavy metal contamination)	2	6 – 12 m	55	Yanko *et al*., 1994
Israel - Plamahim (sewage)	7	20 – 50 m	0 - 61	Yanko *et al*., 1994
Israel - Nitzanim (unpolluted)	4	20 – 50 m	71	Yanko *et al*., 1994
Californian Margin (methane cold seeps)	2	450 – 600 m	28 - 43	Rathburne *et al*., 2000
Havstens Fjord, Sweden (Hypoxic)	19 samples over 3 months	12 – 40 m	9 - 27	Gustafsson & Nordberg, 20
Monterey Bay (methane seeps)	15 over 3 years	906 – 1003 m	39	Bernhard *et al*., 2001
Vendeé, France (harbours)	18 from 5 harbours	N/A	4 - 34	du Châtelet *et al*., 2004
Odiel estuary, Spain (polluted)	17	7 – 25 m	19	Ruiz *et al*., 2004
Gulf of Izmir, Aegean Sea	16	15 – 70 m	67 (2 – 20 sp per sample)	Bergin *et al*., 2006
Naples Harbour, Italy	90 – top 20 cm of sediment	6 – 56 m	39	Ferraro *et al*., 2006
Osaka Bay, Japan (industrial, agricultural and domestic waste)	1 x 84 cm core (does not distinguish between live & dead assemblages	N/A	76	Tsujimoto *et al*., 2006
Adriatic Sea, Italy (low pollutant and nutrient budget)	42 – over summer for 3 years	11.5 m	40	Frontalini & Coccioni, 200
Bagnoli, Italy (industrial pollution)	27 (2 sampling trips)	1.2 – 25.5 m	113	Romano *et al*., 2008
Firth of Clyde, Scotland (organic pollution)	11	58 – 178 m	2 - 26	Mojtahid *et al*., 2008

Appendix 3.3 (b): Number of species in shelf seas around the Atlantic (from shoreline to shelf break) (Murray 2007).

Location	Eastern Seaboard		Western Seaboard		
	Europe	Africa	N. America	Gulf of Mexico	S. America
Dominant	72	28	35	21	7
Subsidiary	39	8	17	22	14
Minor	195	81	186	124	104
Sum = species pool	305	117	238	167	125
% Minor species	64	69	78	74	83

Appendix 3.4: Abundance of specimen within each genus within the live assemblages

Genus	RIA1	RIA2	RIA3	RIA4	RIA5	RIA6	RIB1	RIB2	RIB3	RIB4	RIB5	RIB6
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0
Bolivina	4	14	13	27	3	6	8	19	9	13	37	17
Elphidium	43	40	40	25	13	9	39	15	32	61	39	39
Fissurina	0	0	0	3	0	0	0	0	0	0	0	0
Glabratella	0	0	0	0	1	0	0	0	0	0	1	0
Guttulina	0	0	0	0	0	0	0	0	0	0	1	0
Lagena	0	0	0	2	0	0	0	0	0	0	0	0
Cibicides	10	17	7	6	10	7	10	13	22	20	12	18
Oolina	0	1	3	1	0	0	0	0	0	0	0	0
Patellina	0	2	0	0	0	0	0	0	0	0	0	1
Planorbulina	1	0	0	0	0	0	0	1	0	0	0	0
Pararotalia	0	0	0	0	0	0	0	1	1	0	1	0
Rosalina	9	2	3	5	2	7	11	9	3	3	4	9
Spiroloculina	0	0	0	0	0	0	0	0	0	0	1	0
Trochammina	1	0	1	0	0	1	0	8	3	1	2	7
Miliolinella	10	15	20	16	6	8	4	12	11	2	14	16
Elphidiella	0	0	0	0	0	0	0	0	0	0	0	0
Pararotalia	0	0	0	0	0	0	0	0	0	0	0	0

Genus	RIC1	RIC2	RIC3	RIC4	RIC5	RIC6	RID1	RID2	RID3	RID4	RID5	RID6
Ammonia	0	0	0	0	0	0	0	0	0	2	0	0
Bolivina	10	26	16	37	9	15	21	14	9	13	12	19
Elphidium	17	39	31	40	10	29	14	35	29	22	12	29
Fissurina	2	2	0	0	0	2	0	1	0	3	0	1
Glabratella	0	0	4	9	1	0	0	0	1	0	0	0
Guttulina	0	0	0	0	0	0	0	0	0	0	0	0
Lagena	0	0	1	0	0	0	0	0	0	0	0	0
Cibicides	11	22	21	21	19	39	3	11	18	37	12	12
Oolina	0	1	4	0	0	0	0	0	1	1	1	0
Patellina	0	3	1	0	0	0	1	2	1	0	0	1
Planorbulina	0	0	0	0	0	0	0	0	0	0	0	0
Pararotalia	0	1	4	5	0	0	0	0	5	1	0	0
Rosalina	2	11	4	6	4	14	25	13	19	11	0	6
Spiroloculina	0	2	0	0	0	0	1	1	0	0	0	0
Trochammina	2	1	2	2	1	1	2	12	0	6	6	3
Miliolinella	11	35	22	41	13	28	2	20	19	31	15	24
Elphidiella	0	0	0	0	0	0	0	0	0	0	0	0
Pararotalia	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 3.4: Abundance of specimen within each genus within the live assemblages

Genus	RIE1	RIE2	RIE3	RIE4	RIE5	RIE6	RIF1	RIF2	RIF3	RIF4	RIF5	RIG1
Ammonia	0	1	1	0	0	1	0	0	0	0	0	0
Bolivina	0	1	4	1	1	2	20	4	23	7	5	4
Elphidium	5	12	4	7	5	2	14	14	38	10	11	8
Fissurina	0	0	0	0	0	1	0	2	0	0	0	0
Glabratella	0	3	0	2	0	0	0	1	5	2	0	10
Guttulina	0	0	0	0	0	0	0	1	1	0	0	0
Lagena	0	0	0	1	0	0	0	0	0	0	0	0
Cibicides	1	2	5	2	1	5	14	38	48	10	11	2
Oolina	0	1	0	0	0	0	0	1	0	0	0	0
Patellina	1	5	2	1	0	0	0	1	0	0	0	1
Planorbulina	0	0	0	0	0	0	2	0	0	0	0	0
Pararotalia	0	1	0	4	5	0	1	0	0	0	1	1
Rosalina	6	14	0	6	2	2	8	3	7	8	6	5
Spiroloculina	0	0	0	0	0	0	0	0	0	2	0	0
Trochammina	0	0	4	0	1	0	1	5	5	1	1	10
Miliolinella	25	14	11	24	13	63	11	35	32	13	20	11
Elphidiella	0	0	0	0	0	0	0	0	0	0	0	0
Pararotalia	0	0	0	0	0	0	0	0	0	0	0	0

Genus	RIG2	RIG3	RIG4	RIG5	RIG6	RIH1	RIH2	RIH3	RIH4	RIH5	RIH6	SPA1
Ammonia	3	0	0	0	0	0	1	0	1	1	1	25
Bolivina	2	3	9	1	1	20	4	38	40	11	19	6
Elphidium	8	36	22	8	5	22	16	33	30	21	25	132
Fissurina	1	0	0	0	1	1	0	0	1	1	2	3
Glabratella	14	38	13	8	6	4	15	2	7	5	0	0
Guttulina	0	1	0	0	0	0	2	0	1	0	0	0
Lagena	0	0	0	0	0	0	0	0	0	0	0	0
Cibicides	7	34	15	13	5	10	15	7	37	19	11	16
Oolina	0	0	0	0	0	1	0	1	13	0	1	0
Patellina	0	3	0	0	3	0	0	0	0	0	1	0
Planorbulina	0	0	0	0	0	0	0	0	0	0	0	0
Pararotalia	3	13	5	1	0	2	13	4	8	2	1	0
Rosalina	18	21	16	4	3	11	11	18	6	16	23	17
Spiroloculina	0	0	1	0	1	0	0	1	1	0	0	0
Trochammina	3	2	0	2	0	9	0	16	8	1	3	1
Miliolinella	52	43	49	33	6	17	31	31	35	31	9	0
Elphidiella	0	0	0	0	0	0	0	0	0	0	0	2
Pararotalia	0	0	0	0	0	0	0	0	0	0	0	10

Appendix 3.4: Abundance of specimen within each genus within the live assemblages

Genus	SPA2	SPA3	SPA4	SPA5	SPA6	SPB1	SPB2	SPB3	SPB4	SPB5	SPB6	SPC1
Ammonia	41	35	28	22	22	28	50	48	66	60	62	44
Bolivina	18	13	19	15	15	11	2	15	24	15	18	16
Elphidium	31	24	17	85	85	31	21	38	71	81	66	26
Fissurina	0	3	3	2	2	0	0	0	5	1	0	8
Glabratella	0	0	0	0	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0	0	0	0	0
Lagena	0	0	1	0	0	0	0	0	1	0	0	0
Cibicides	2	10	12	8	8	9	2	15	21	15	0	22
Oolina	1	4	6	0	0	0	1	1	4	3	3	5
Patellina	0	0	0	0	0	0	0	0	0	0	0	0
Planorbulina	0	0	0	0	0	0	0	0	0	0	0	0
Pararotalia	0	0	0	0	0	0	0	0	0	0	0	0
Rosalina	7	3	6	1	1	9	1	15	1	2	0	24
Spiroloculina	0	0	0	0	0	0	0	0	0	0	0	0
Trochammina	1	0	0	0	0	0	0	0	0	0	0	0
Miliolinella	2	1	2	1	1	0	0	0	0	0	0	1
Elphidiella	0	1	0	0	0	2	0	2	3	1	0	0
Pararotalia	4	10	7	21	21	3	3	4	3	4	7	8

Genus	SPC2	SPC3	SPC4	SPC5	SPC6	SHA1	SHA2	SHA3	SHA4	SHA5	SHA6	SHB1
Ammonia	38	10	32	26	64	2	5	6	10	9	2	24
Bolivina	21	17	17	49	40	1	5	3	14	0	5	22
Elphidium	11	15	40	62	49	1	10	7	20	1	15	8
Fissurina	10	2	0	7	1	0	0	0	1	0	1	0
Glabratella	0	0	0	0	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0	0	0	0	0
Lagena	0	0	1	0	0	0	0	0	1	0	1	0
Cibicides	20	6	12	15	10	1	2	5	5	0	5	9
Oolina	1	0	3	1	2	0	1	0	4	0	1	0
Patellina	0	0	0	0	0	0	0	0	0	0	0	0
Planorbulina	0	0	0	0	0	0	0	0	0	0	0	0
Pararotalia	0	0	0	0	0	0	0	0	0	0	0	0
Rosalina	6	3	4	2	1	2	5	1	3	0	1	14
Spiroloculina	0	0	0	0	0	0	0	0	0	0	0	0
Trochammina	0	0	3	0	0	0	0	0	0	0	0	2
Miliolinella	0	0	0	0	0	0	0	0	0	0	0	0
Elphidiella	2	0	0	0	0	0	2	1	1	0	0	1
Pararotalia	1	4	0	3	8	0	1	1	0	0	0	0

Appendix 3.4: Abundance of specimen within each genus within the live assemblages

Genus	SHB2	SHB3	SHB4	SHB5	SHB6	SHC1	SHC2	SHC3	SHC4	SHC5	SHC6	SHD2
Ammonia	18	17	57	28	20	20	5	14	15	15	7	0
Bolivina	2	25	34	4	3	15	2	29	34	4	22	2
Elphidium	14	1	17	4	4	1	4	8	5	0	18	0
Fissurina	0	0	5	0	1	1	0	1	0	0	0	3
Glabratella	0	0	0	0	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0	0	0	0	0
Lagena	0	0	0	0	0	0	0	0	0	0	0	0
Cibicides	1	2	9	0	1	0	0	3	0	0	0	0
Oolina	0	0	5	1	0	0	0	0	0	0	0	0
Patellina	0	0	0	0	0	0	0	0	0	0	0	0
Planorbulina	0	0	0	0	0	0	0	0	0	0	0	0
Pararotalia	0	0	0	0	0	0	0	0	0	0	0	0
Rosalina	0	4	8	2	0	6	10	5	22	7	5	13
Spiroloculina	0	0	0	0	0	0	0	0	0	0	0	0
Trochammina	0	2	0	4	0	0	2	3	2	1	0	1
Miliolinella	1	0	0	0	0	0	0	0	0	0	0	0
Elphidiella	0	0	1	0	0	0	0	0	2	0	0	0
Pararotalia	0	0	0	0	0	0	0	0	0	0	0	0

Genus	SHD3	SHD4	SHD5	SHD6	SHE1	SHE2	SHE3	SHE4	SHE5	SHE6	SHF1	SHF2
Ammonia	3	1	1	0	0	14	3	3	2	7	6	28
Bolivina	5	10	0	0	0	1	2	2	0	0	5	0
Elphidium	0	3	0	0	0	1	0	2	1	0	0	0
Fissurina	0	1	0	0	0	0	0	0	0	0	1	0
Glabratella	0	0	0	0	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0	0	0	0	0
Lagena	0	0	0	0	0	0	0	0	0	0	0	0
Cibicides	2	1	0	0	1	0	0	0	0	0	0	0
Oolina	0	2	0	0	0	0	0	0	0	0	0	0
Patellina	0	0	0	0	0	0	0	0	0	0	0	0
Planorbulina	0	0	0	0	0	0	0	0	0	0	0	0
Pararotalia	0	0	0	0	0	0	0	0	0	0	0	0
Rosalina	1	0	2	0	1	0	1	0	0	1	2	0
Spiroloculina	0	0	0	0	0	0	0	0	0	0	0	0
Trochammina	1	2	0	0	0	7	0	0	1	1	0	0
Miliolinella	0	0	0	0	0	0	0	0	0	0	0	0
Elphidiella	0	0	0	0	0	2	0	0	0	0	0	0
Pararotalia	0	1	0	0	0	0	0	0	0	0	0	0

Appendix 3.4: Abundance of specimen within each genus within the live assemblages

Genus	SHF3	SHF4	SHF5	SHF6	SHG1	SHG2	SHG3	SHG4	SHG5	SHG6
Ammonia	23	44	10	1	29	42	29	73	13	19
Bolivina	26	16	6	7	17	10	12	12	4	11
Elphidium	8	17	4	4	2	10	7	8	5	1
Fissurina	0	0	1	0	2	0	0	0	1	0
Glabratella	0	0	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0	0	0
Lagena	0	0	0	0	0	0	0	2	0	0
Cibicides	1	1	0	0	0	0	2	0	0	0
Oolina	0	0	1	0	0	0	4	0	1	0
Patellina	0	0	0	0	0	0	0	0	0	0
Planorbulina	0	0	0	0	0	0	0	0	0	0
Pararotalia	0	0	0	0	0	0	0	0	0	0
Rosalin	0	0	4	0	6	0	14	1	3	6
Spiroloculina	0	0	0	0	0	0	0	0	0	0
Trochammina	0	7	1	0	1	3	1	2	1	1
Miliolinella	0	0	0	0	0	0	1	0	0	0
Elphidiella	1	0	0	0	0	0	1	0	0	1
Pararotalia	0	0	0	0	0	0	0	0	0	0

Genus	SHH1	SHH2	SHH3	SHH4	SHH5	SHI1	SHI2	SHI3	SHI4	SHI5	SHI6
Ammonia	4	28	65	11	9	27	8	7	15	1	6
Bolivina	1	17	20	34	3	29	0	13	14	0	3
Elphidium	1	4	6	9	4	7	8	6	2	0	7
Fissurina	0	1	0	0	0	0	0	0	0	0	0
Glabratella	0	0	0	0	0	0	0	0	0	0	0
Guttulina	0	0	0	0	0	0	0	0	0	0	0
Lagena	0	0	0	0	0	0	0	1	0	0	0
Cibicides	0	0	3	1	0	0	0	1	0	0	3
Oolina	0	0	0	0	1	4	0	4	1	0	4
Patellina	0	0	0	0	0	0	0	0	0	0	0
Planorbulina	0	0	0	0	0	0	0	0	0	0	0
Pararotalia	0	0	0	0	0	0	0	0	0	0	0
Rosalina	0	3	0	0	1	1	0	3	0	0	0
Spiroloculina	0	0	0	0	0	0	0	0	0	0	0
Trochammina	0	2	4	3	1	0	0	1	0	1	2
Miliolinella	0	0	0	0	0	0	0	0	0	0	0
Elphidiella	0	2	1	0	0	0	0	1	1	0	0
Pararotalia	0	0	0	0	0	0	4	0	0	0	0

Appendix 3.5: Total abundance of live foraminifera in the different size classes for all samples of Robben Island and St Helena Bay

Sample	> 63 µm	> 125 µm	> 250 µm	> 500 µm	TOTAL
RIA1	240	318	19	0	577
RIA2	178	284	18	0	480
RIA3	160	157	5	0	322
RIA4	211	235	7	0	453
RIA5	116	328	7	0	451
RIA6	249	248	13	0	510
RIB1	115	185	9	0	309
RIB2	180	206	22	0	408
RIB3	118	502	18	0	638
RIB4	80	334	6	0	420
RIB5	47	136	4	1	188
RIB6	91	101	14	0	206
RIC1	158	209	36	0	403
RIC2	220	212	46	0	478
RIC3	56	71	31	1	159
RIC4	29	138	10	0	177
RIC5	58	116	33	0	207
RIC6	124	113	33	0	270
RID1	81	72	3	0	156
RID2	75	99	6	0	180
RID3	51	55	14	0	120
RID4	46	165	51	0	262
RID5	18	82	14	0	114
RID6	54	79	19	0	152
RIE1	34	6	16	0	56
RIE2	39	27	8	1	75
RIE3	20	8	9	0	37
RIE4	8	23	10	0	41
RIE5	18	8	5	0	31
RIE6	16	31	7	1	55
RIF1	80	136	18	3	237
RIF2	96	228	45	0	369
RIF3	44	77	34	1	156
RIF4	50	42	27	0	119
RIF5	15	32	21	1	69
RIG1	31	32	10	1	74

Appendix 3.5: Total abundance of live foraminifera in the different size classes for all samples of Robben Island and St Helena Bay

Sample	> 63 µm	> 125 µm	> 250 µm	> 500 µm	TOTAL
RIG2	25	142	35	1	203
RIG3	44	72	40	9	165
RIG4	66	49	128	6	249
RIG5	16	27	13	0	56
RIG6	8	14	5	5	32
RIH1	358	107	33	1	499
RIH2	75	103	56	2	236
RIH3	84	62	17	0	163
RIH4	87	64	46	4	201
RIH5	32	52	19	2	105
RIH6	58	160	18	1	237
SPA1	713	1397	209	7	2326
SPA2	244	623	544	1	1412
SPA3	100	3655	69	3	3827
SPA4	303	38	173	0	514
SPA5	513	377	84	3	977
SPA6	271	256	384	2	913
SPB1	1016	1489	79	0	2584
SPB2	385	551	64	2	1002
SPB3	3443	953	117	1	4514
SPB4	327	667	125	2	1121
SPB5	435	453	91	0	979
SPB6	355	479	376	0	1210
SPC1	673	531	68	3	1275
SPC2	1703	1390	68	1	3162
SPC3	168	66	10	0	244
SPC4	49	312	26	1	388
SPC5	167	346	15	0	528
SPC6	227	826	48	1	1102
SHA1	14	6	4	0	24
SHA2	16	42	5	1	64
SHA3	6	16	7	0	29
SHA4	126	33	15	0	174
SHA5	3	16	7	0	26
SHA6	15	25	11	0	51
SHB1	112	211	22	0	345
SHB2	22	26	17	3	68
SHB3	52	3	10	0	65
SHB5	22	36	27	3	88
SHB6	18	12	18	0	48
SHC1	64	124	2	0	190
SHC2	144	199	11	1	355
SHC3	1072	96	12	1	1181
SHC4	1401	306	16	1	1724
SHC5	286	43	8	1	338

Sample	> 63 µm	> 125 µm	> 250 µm	> 500 µm	TOTAL
SHC6	72	89	7	2	170
SHD2	49	19	0	0	68
SHD3	23	10	1	1	35
SHD4	20	16	1	0	37
SHD5	13	3	2	0	18
SHE1	16	0	0	0	16
SHE2	19	16	6	4	45
SHE3	12	9	2	1	24
SHE4	4	1	2	1	8
SHE5	2	6	6	0	14
SHE6	3	1	6	0	10
SHF1	12	20	4	0	36
SHF2	106	162	23	0	291
SHF3	57	48	24	2	131
SHF4	46	23	13	0	82
SHF5	7	26	2	1	36
SHF6	35	22	8	0	65
SHG1	120	44	15	4	183
SHG2	71	45	33	1	150
SHG3	224	75	21	2	322
SHG4	15	70	35	2	122
SHG5	16	16	10	2	44
SHG6	45	43	20	1	109
SHH1	30	10	6	1	47
SHH2	134	60	5	0	199
SHH3	94	12	8	1	115
SHH4	32	14	13	2	61
SHH5	16	20	12	0	48
SHI1	28	70	14	0	112
SHI2	23	254	18	0	295
SHI3	8	79	2	1	90
SHI4	101	25	5	1	132
SHI5	61	287	12	0	360
SHI6	22	165	42	0	229

Appendix 3.6: The abundance of live and dead foraminifera within each size class in samples from Robben Island and St Helena Bay

sample	63 µm		125 µm		250 µm		500 µm		TOTAL	
	live (l)	dead (d)	l	d	l	d	l	d	Live	Dead
SPA1	713	176	1397	191	209	48	7	2	2326	417
SPA2	244	169	623	318	544	206	1	0	1412	693
SPA3	100	170	3655	3016	69	130	3	2	3827	3318
SPA4	303	239	38	62	173	133	0	0	514	434
SPA5	513	427	377	399	84	138	3	2	977	966
SPA6	271	175	256	155	384	272	2	0	913	602
SPB1	1016	546	1489	74	79	5	0	0	2584	625
SPB2	385	252	551	274	64	37	2	0	1002	563
SPB3	3443	1009	953	118	117	14	1	0	4514	1141
SPB4	327	163	667	239	125	145	2	0	1121	547
SPB5	435	370	453	372	91	58	0	0	979	800
SPB6	355	173	479	367	376	290	0	0	1210	830
SPC1	673	97	531	29	68	4	3	3	1275	133
SPC2	1703	981	1390	65	68	785	1	17	3162	1848
SPC3	168	31	66	13	10	3	0	0	244	47
SPC4	49	96	312	179	26	34	1	0	388	309
SPC5	167	136	346	243	15	13	0	0	528	392
SPC6	227	113	826	505	48	29	1	0	1102	647
SHA1	14	34	6	118	4	5	0	0	24	157
SHA2	16	26	42	338	5	22	1	0	64	386
SHA3	6	9	16	84	7	11	0	2	29	106
SHA4	126	277	33	201	15	19	0	0	174	497
SHA5	3	21	16	105	7	25	0	0	26	151
SHA6	15	44	25	126	11	6	0	0	51	176
SHB1	112	610	211	613	22	16	0	0	345	1239
SHB2	22	40	26	26	17	17	3	0	68	83
SHB3	52	83	3	2	10	17	0	2	65	104
SHB4	42	104	97	182	33	36	1	1	173	323
SHB5	22	72	36	85	27	63	3	5	88	225
SHB6	18	17	12	12	18	7	0	0	48	36
SHC1	64	357	124	465	2	1	0	0	190	823
SHC2	144	598	199	440	11	8	1	0	355	1046
SHC3	1072	1452	96	149	12	5	1	1	1181	1607
SHC4	1401	2609	306	380	16	5	1	0	1724	2994
SHC5	286	781	43	113	8	11	1	2	338	907
SHC6	72	472	89	194	7	6	2	0	170	672

sample	63 µm		125 µm		250 µm		500 µm		TOTAL	
	live (l)	dead (d)	l	d	l	d	l	d	Live	Dead
SHD2	49	154	19	41	0	1	0	0	68	196
SHD3	23	46	10	15	1	0	1	0	35	61
SHD4	20	97	16	71	1	3	0	0	37	171
SHD5	13	40	3	27	2	1	0	0	18	68
SHD6	1	12	10	23	2	2	0	0	13	37
SHE1	16	15	0	2	0	1	0	1	16	19
SHE2	19	25	16	16	6	19	4	4	45	64
SHE3	12	9	9	4	2	5	1	1	24	19
SHE4	4	17	1	3	2	0	1	1	8	21
SHE5	2	7	6	2	6	14	0	0	14	23
SHE6	3	13	1	9	6	8	0	0	10	30
SHF1	12	105	20	9	4	3	0	1	36	118
SHF2	106	220	162	299	23	20	0	4	291	543
SHF3	57	106	48	44	24	22	2	0	131	172
SHF4	46	396	23	105	13	73	0	8	82	582
SHF5	7	57	26	109	2	19	1	3	36	188
SHF6	35	101	22	43	8	7	0	2	65	153
SHG1	120	344	44	107	15	34	4	6	183	491
SHG2	71	218	45	148	33	52	1	3	150	421
SHG3	224	265	75	158	21	23	2	3	322	449
SHG4	15	91	70	114	35	45	2	0	122	250
SHG5	16	66	16	92	10	13	2	0	44	171
SHG6	45	82	43	77	20	40	1	0	109	199
SHH1	30	35	10	7	6	3	1	0	47	45
SHH2	134	106	60	18	5	35	0	2	199	161
SHH3	94	316	12	109	8	56	1	0	115	481
SHH4	32	86	14	111	13	45	2	2	61	244
SHH5	16	64	20	59	12	23	0	0	48	146
SHI1	28	89	70	119	14	12	0	0	112	220
SHI2	23	131	254	656	18	38	0	2	295	827
SHI3	8	64	79	224	2	7	1	0	90	295
SHI4	101	277	25	125	5	43	1	3	132	448
SHI5	61	136	287	663	12	27	0	0	360	826
SHI6	22	77	165	642	42	9	0	1	229	729
RIA1	240	217	318	210	19	16	0	0	577	443
RIA2	178	254	284	346	18	19	0	0	480	619
RIA3	160	126	157	171	5	6	0	0	322	303
RIA4	211	384	235	358	7	7	0	0	453	749

sample	63 µm		125 µm		250 µm		500 µm		TOTAL	
	live (l)	dead (d)	l	d	l	d	l	d	Live	Dead
RIA5	116	244	328	328	7	18	0	0	451	590
RIA6	249	367	248	408	13	34	0	0	510	809
RIB1	115	83	185	95	9	4	0	0	309	182
RIB2	180	360	206	204	22	19	0	0	408	583
RIB3	118	125	502	698	18	22	0	0	638	845
RIB4	80	88	334	259	6	1	0	0	420	348
RIB5	47	132	136	323	4	25	1	0	188	480
RIB6	91	189	101	189	14	10	0	0	206	388
RIC1	158	256	209	166	36	37	0	0	403	459
RIC2	220	207	212	198	46	55	0	1	478	461
RIC3	56	69	71	59	31	16	1	1	159	145
RIC4	29	26	138	81	10	9	0	0	177	116
RIC5	58	362	116	200	33	64	0	0	207	626
RIC6	124	191	113	287	33	52	0	0	270	530
RID1	81	28	72	28	3	2	0	0	156	58
RID2	75	19	99	106	6	19	0	0	180	144
RID3	51	30	55	41	14	8	0	0	120	79
RID4	46	102	165	242	51	83	0	1	262	428
RID5	18	15	82	43	14	2	0	0	114	60
RID6	54	47	79	39	19	18	0	0	152	104
RIE1	34	5	6	13	16	12	0	0	56	30
RIE2	39	14	27	22	8	16	1	0	75	52
RIE3	20	13	8	11	9	14	0	1	37	39
RIE4	8	10	23	18	10	25	0	1	41	54
RIE5	18	6	8	12	5	13	0	1	31	32
RIE6	16	10	31	15	7	16	1	0	55	41
RIF1	80	127	136	99	18	43	3	1	237	270
RIF2	96	324	228	208	45	46	0	1	369	579
RIF3	44	92	77	153	34	28	1	0	156	273
RIF4	50	259	42	206	27	225	0	3	119	693
RIF5	15	19	32	41	21	25	1	2	69	87
RIG1	31	13	32	17	10	26	1	7	74	63
RIG2	25	28	142	180	35	61	1	4	203	273
RIG3	44	25	72	59	40	33	9	14	165	131
RIG4	66	85	49	66	128	184	6	13	249	348
RIG5	16	6	27	29	13	30	0	0	56	65
RIG6	8	5	14	8	5	0	5	3	32	16

sample	63 µm		125 µm		250 µm		500 µm		TOTAL	
	live (l)	dead(d)	l	d	l	d	l	d	Live	Dead
RIH1	358	236	107	99	33	14	1	1	499	350
RIH2	75	51	103	115	56	62	2	6	236	234
RIH3	84	92	62	70	17	23	0	1	163	186
RIH4	87	91	64	60	46	32	4	2	201	185
RIH5	32	43	52	68	19	33	2	4	105	148
RIH6	58	97	160	278	18	28	1	1	237	404
RIH1	358	236	107	99	33	14	1	1	499	350
RIH2	75	51	103	115	56	62	2	6	236	234
RIH3	84	92	62	70	17	23	0	1	163	186

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

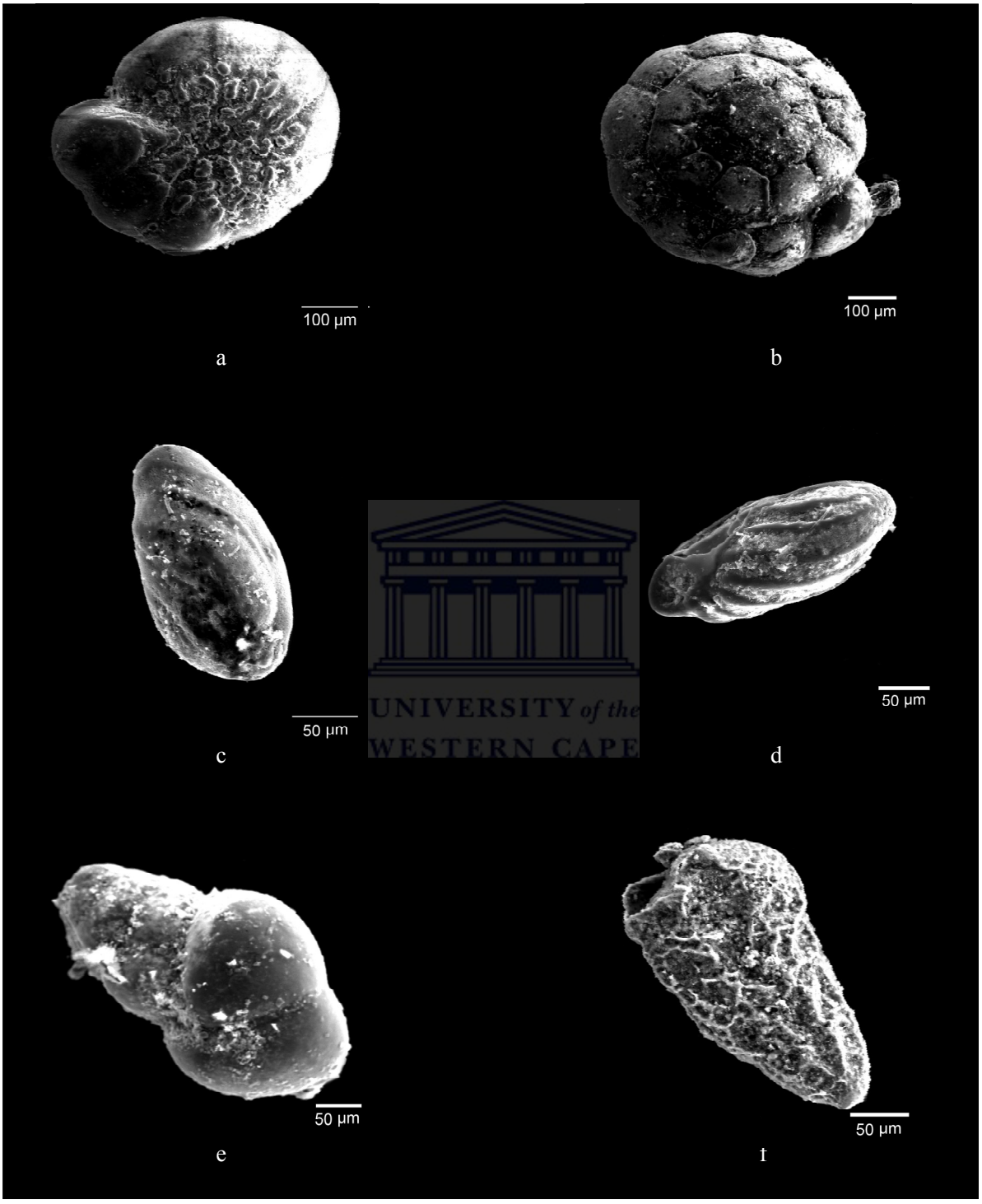

Plate 4.1.1 : a. *Ammonia parkinsoniana* ventral view b. *Ammonia parkinsoniana* ventral view
c,d. *Bolivina elegantissima*
e. *Bolivina elongata*
f. *Bolivina pseudoplicata*

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

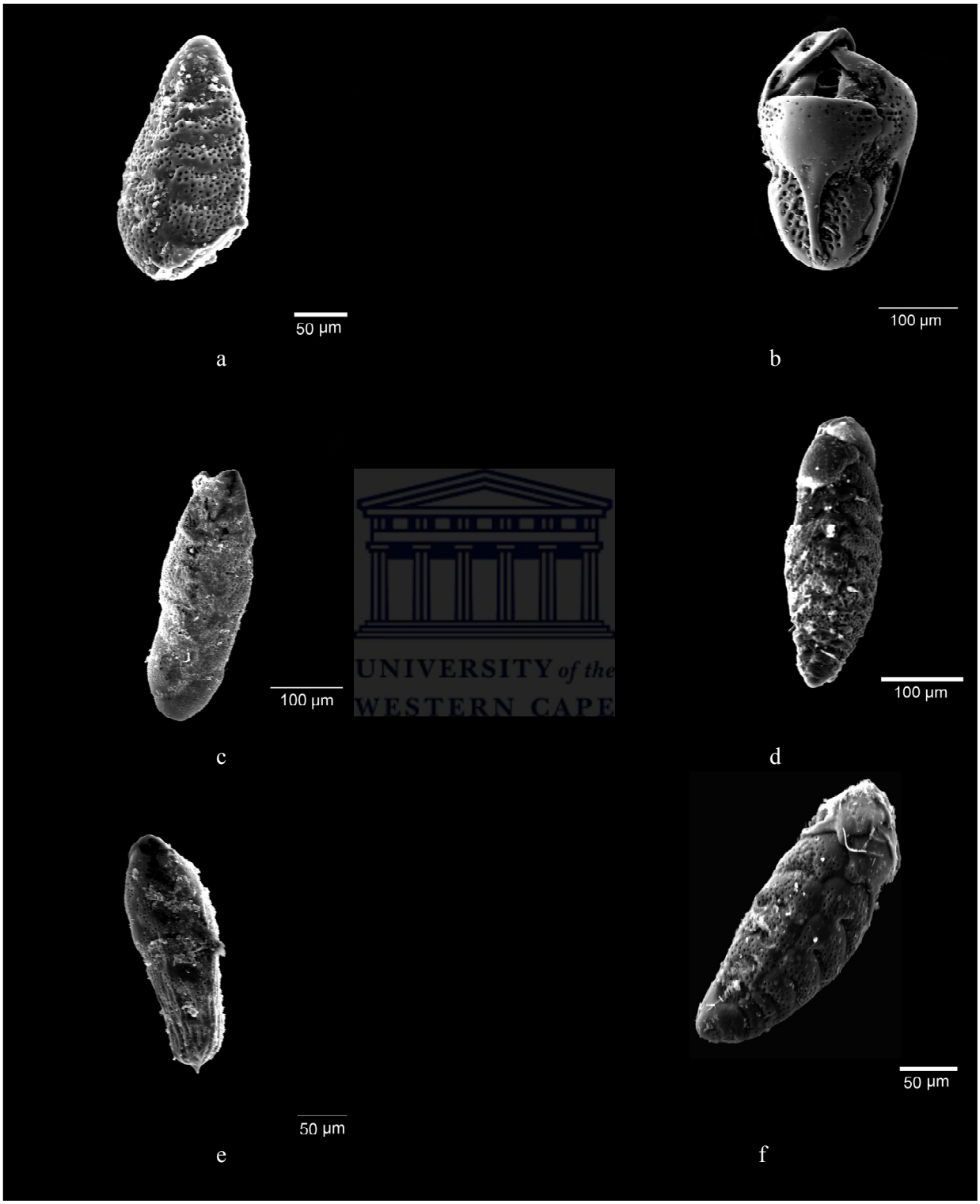

Plate 4.1.2: *a. Brizalina pseudopunctata* b. Bolivinitidae
c,d,e,f. examples of *Bolivina* grouped together as elongated *Bolivina*

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

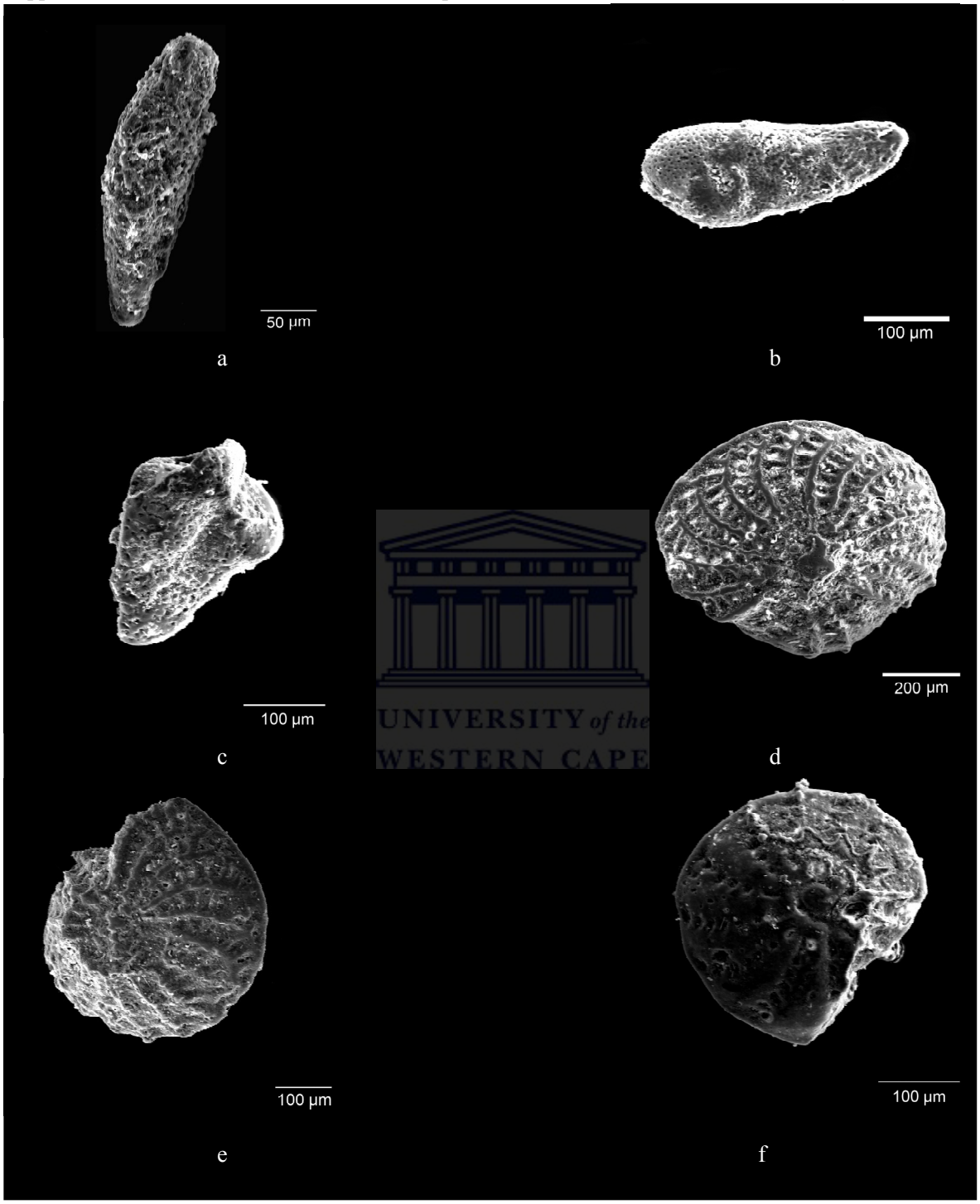

Plate 4.1.3: a, b, c. examples of *Bolivina* grouped together as perforated *Bolivina*
d. *Elphidium crispum* e. *Elphidium macellum*
f. *Elphidium articulatum*

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

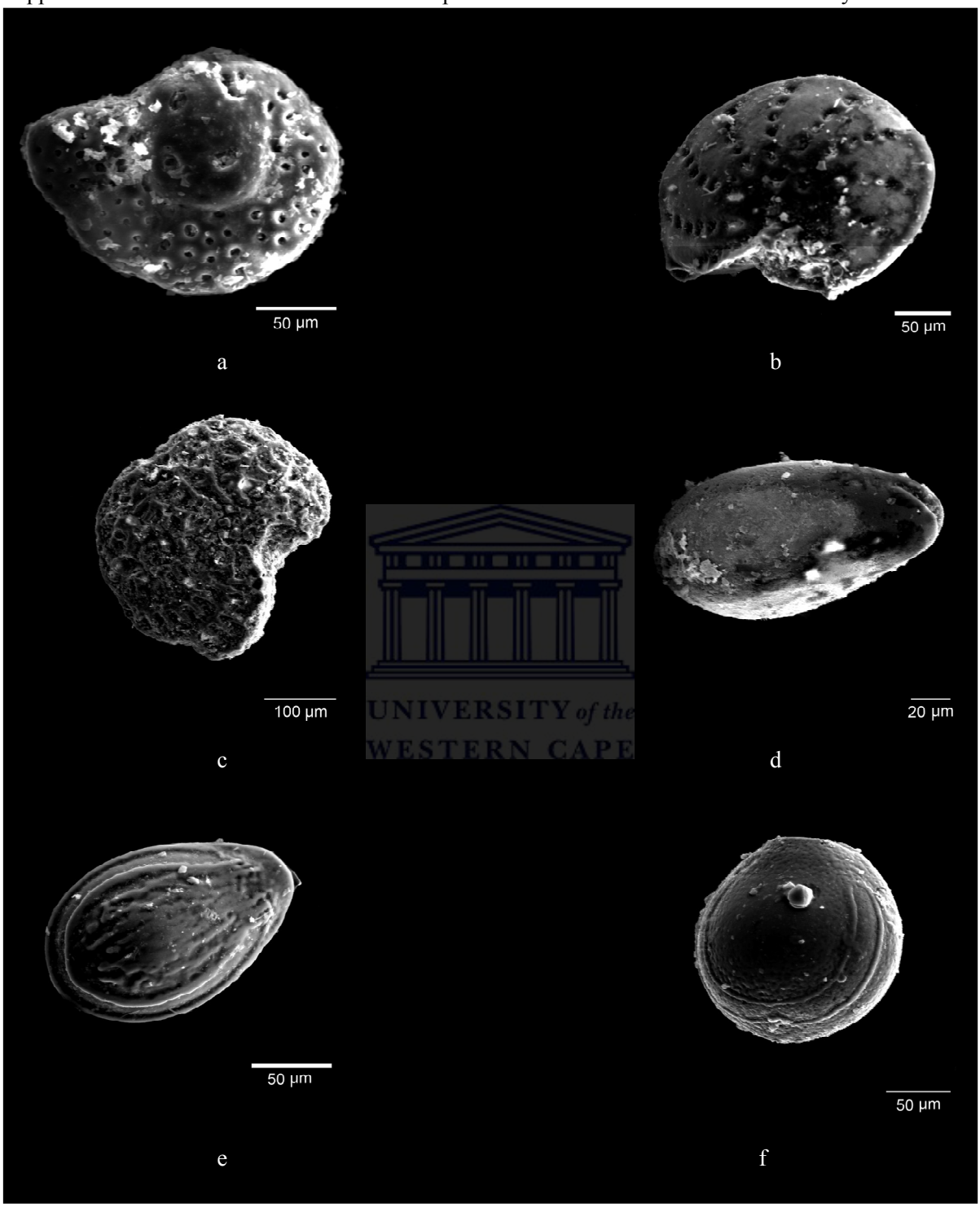

Plate 4.1.4 : a. *Elphidium gunteri* b. *Elphidium advenum*
c. *Elphidiella* sp A d. *Fissurina marginata*
e. *Fissurina lucida* f. *Fissurina* sp A

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

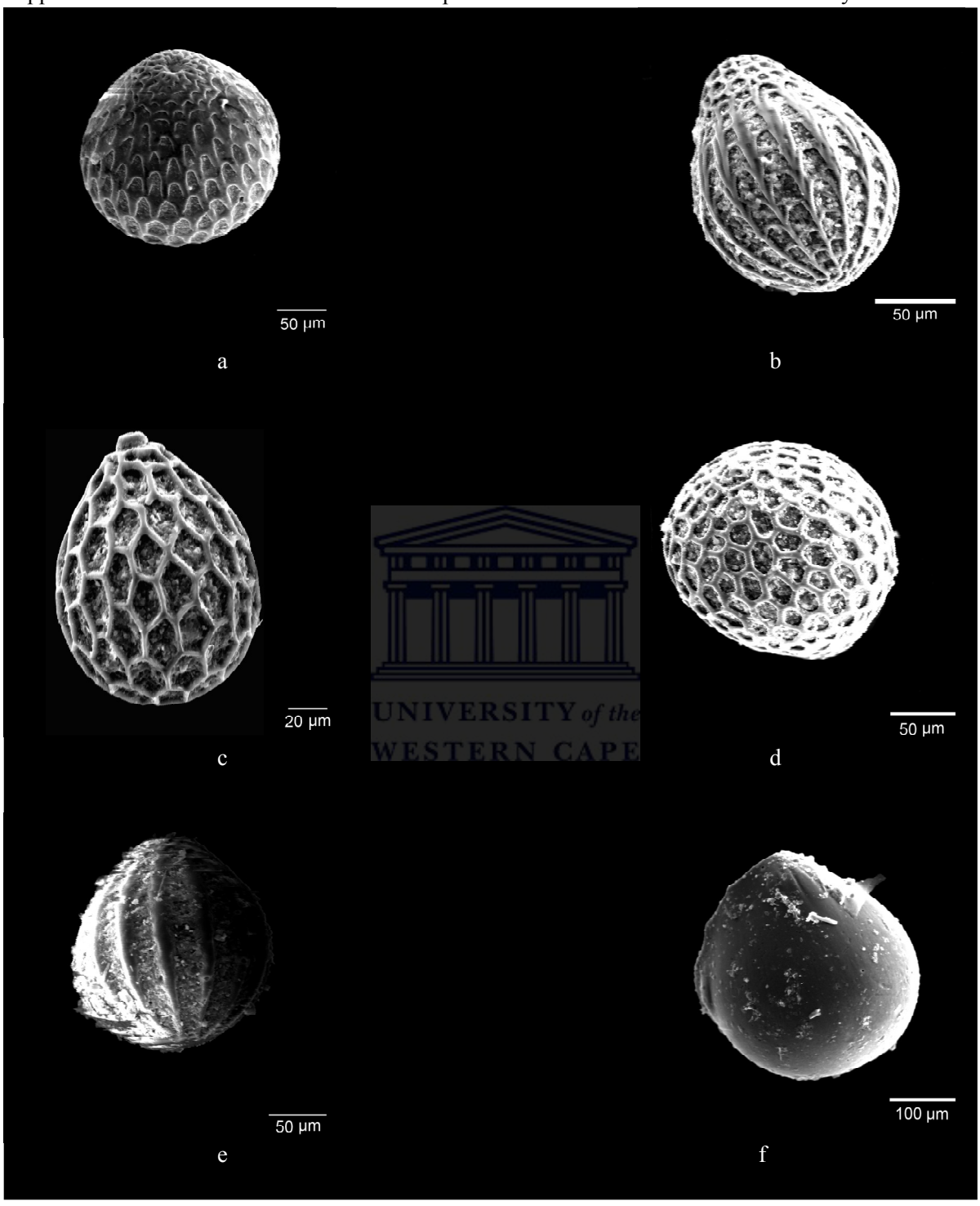

Plate 4.1.5: a, b. *Oolina melo* c. *Oolina* sp A
d. *Oolina hexagona* e. *Oolina tasmanica*
f. *Gutttulina irregularis*

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

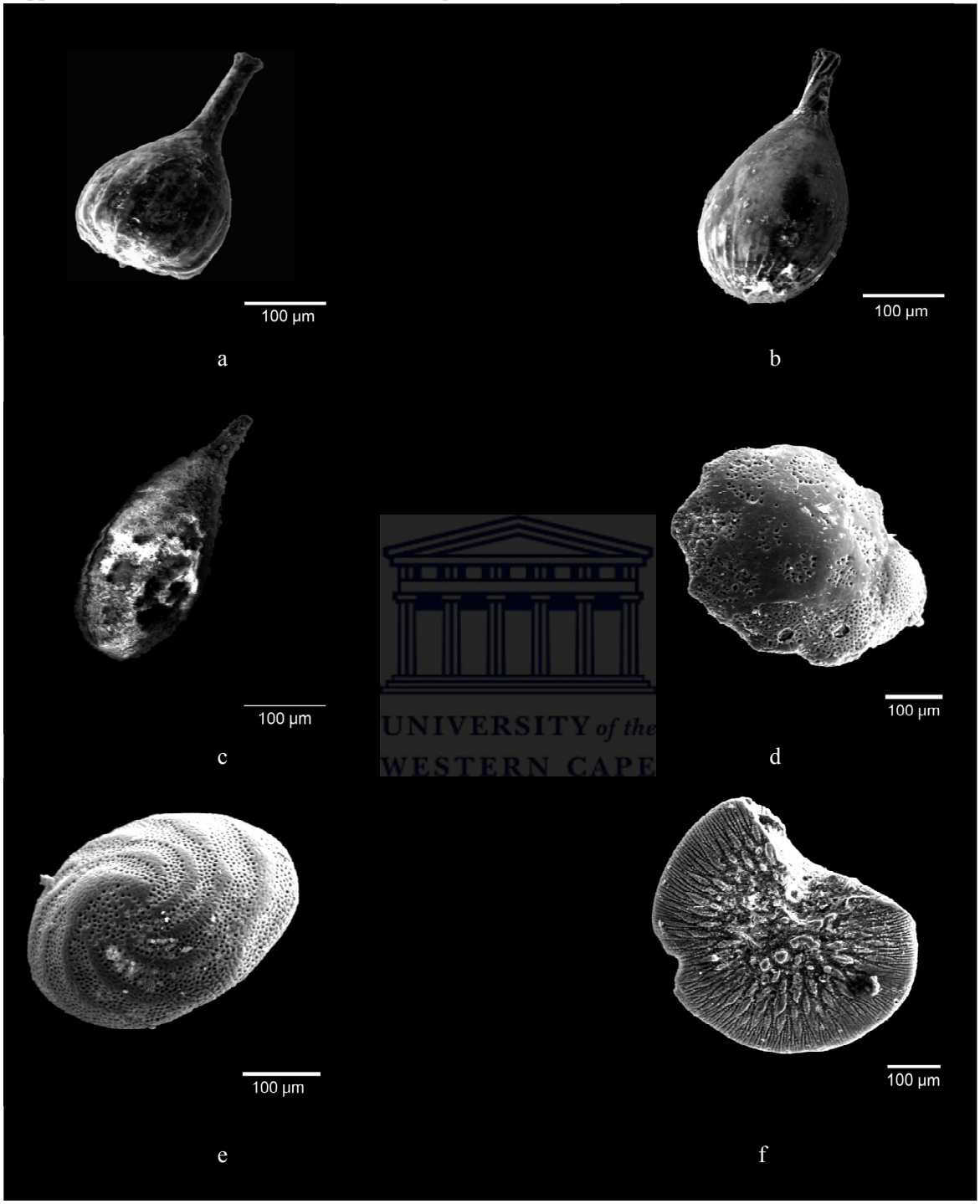

Plate 4.1.6: a. *Lagena semilineata* b. *Lagena sulcata*
c. *Lagena* sp A d. *Pararotalia nipponica*
e. *Glabratella australensis* dorsal view f. *Glabratella australensis* ventral view

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

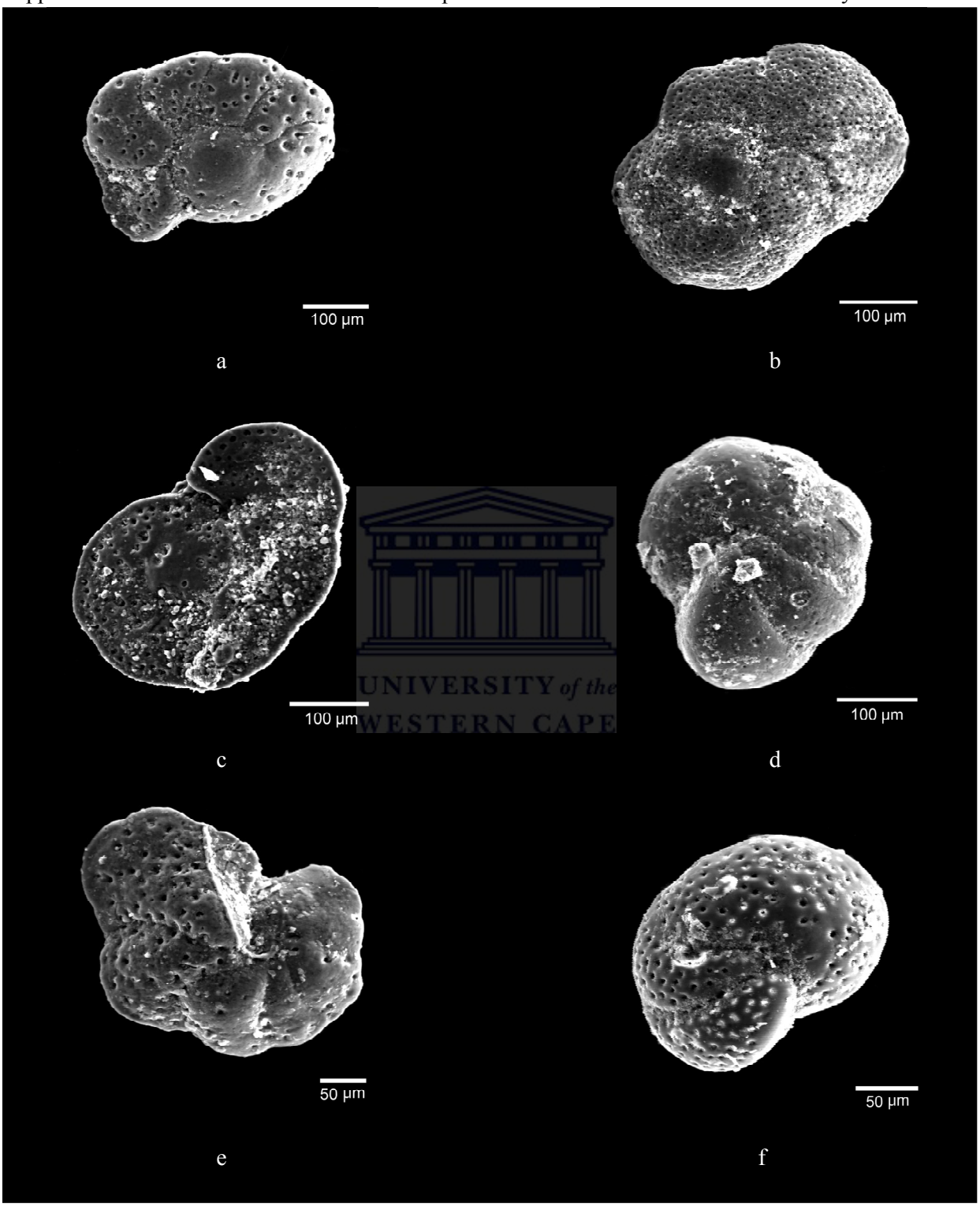

Plate 4.1.7: Variation in *Cibicides lobatulus*

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

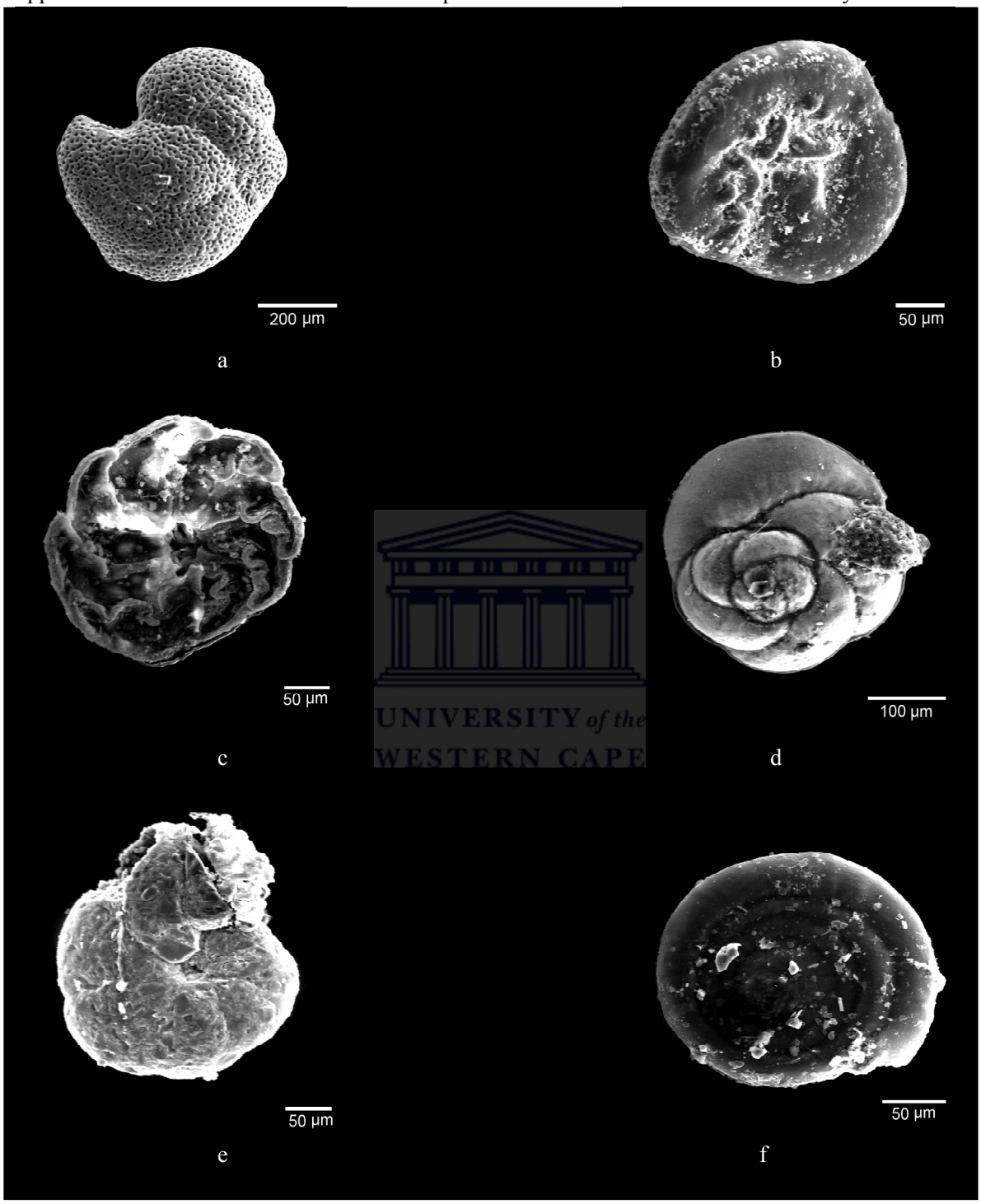

Plate 4.1.8: a. *Rosalina globularis* dorsal view b. *Rosalina globularis* ventral view
c. *Rosalina* sp A d. *Rosalina bradyi*
e. *Trochammina squamata* f. *Spiroloculina* sp A

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

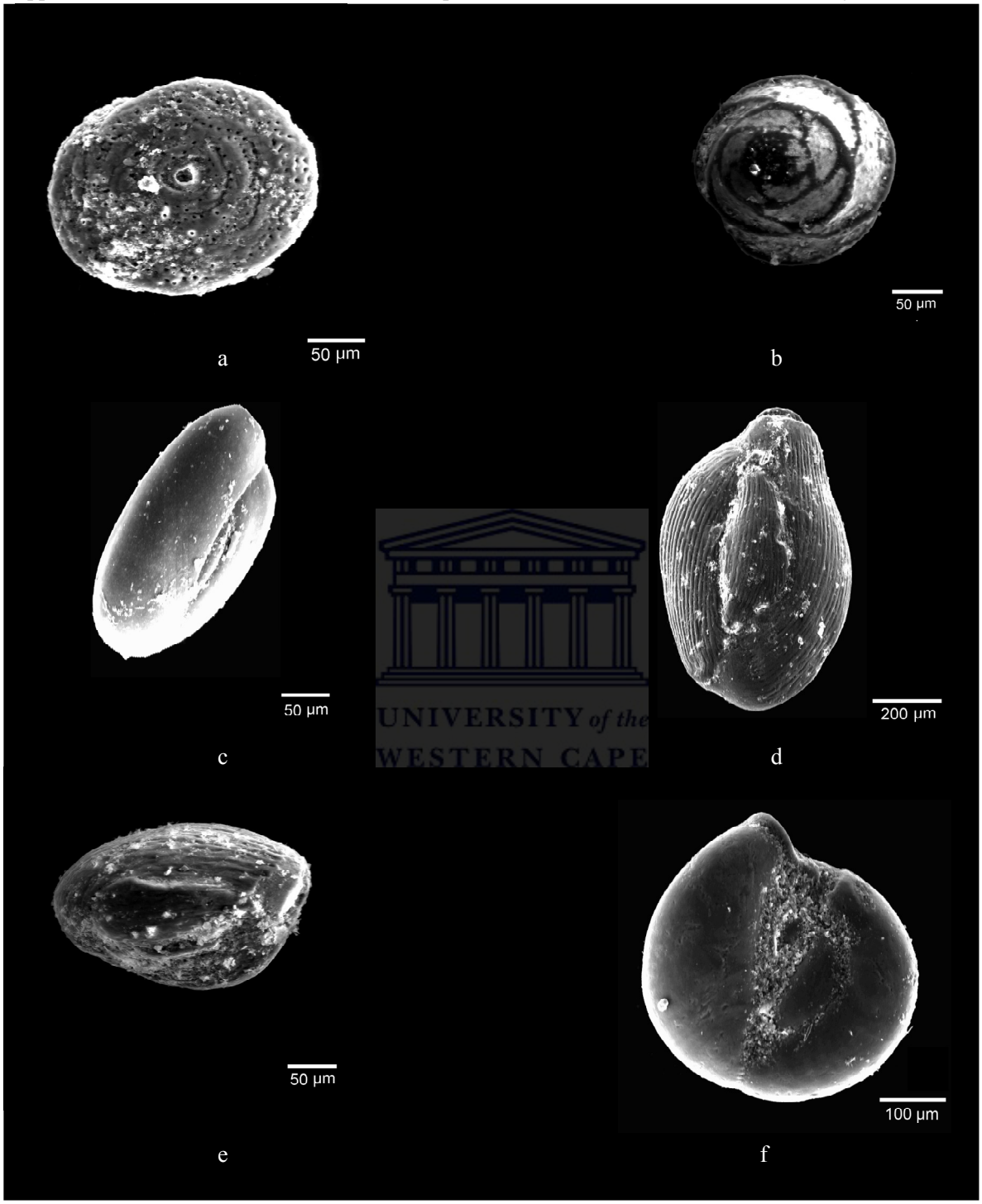

Plate 4.1.9: a. *Patellina corrugata* b. *Patellina* sp A
c. *Quinqueloculina seminulum* d. *Quinqueloculina undulata*
e. *Quinqueloculina vulgata* f. *Miliolinella subrotunda*

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

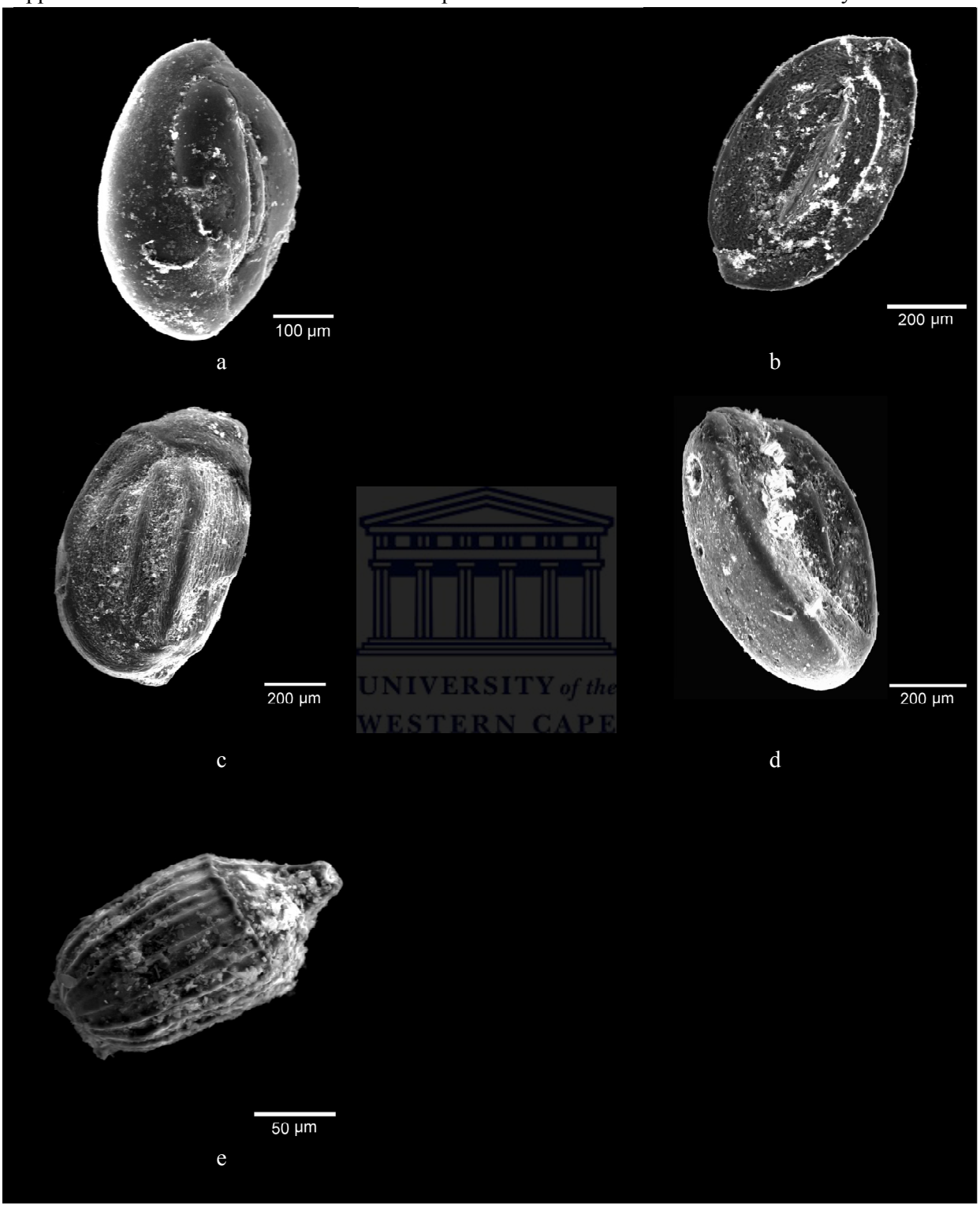

Plate 4.1.10: a. *Quinqueloculina dunkerquiana* b.c,d Miliolids
e. Unknown species

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

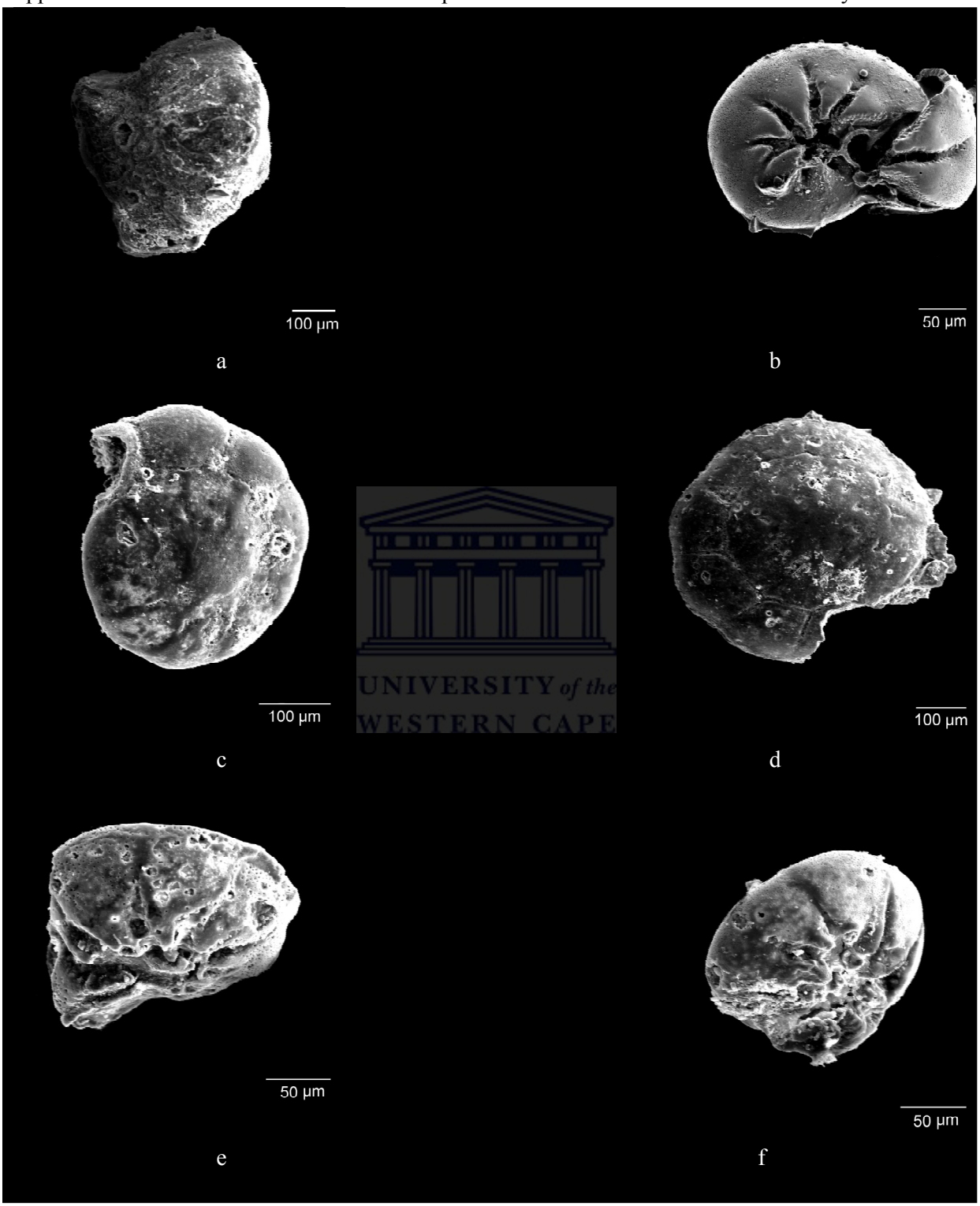

Plate 4.1.11: Some abnormal specimens of *Ammonia parkinsoniana*

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

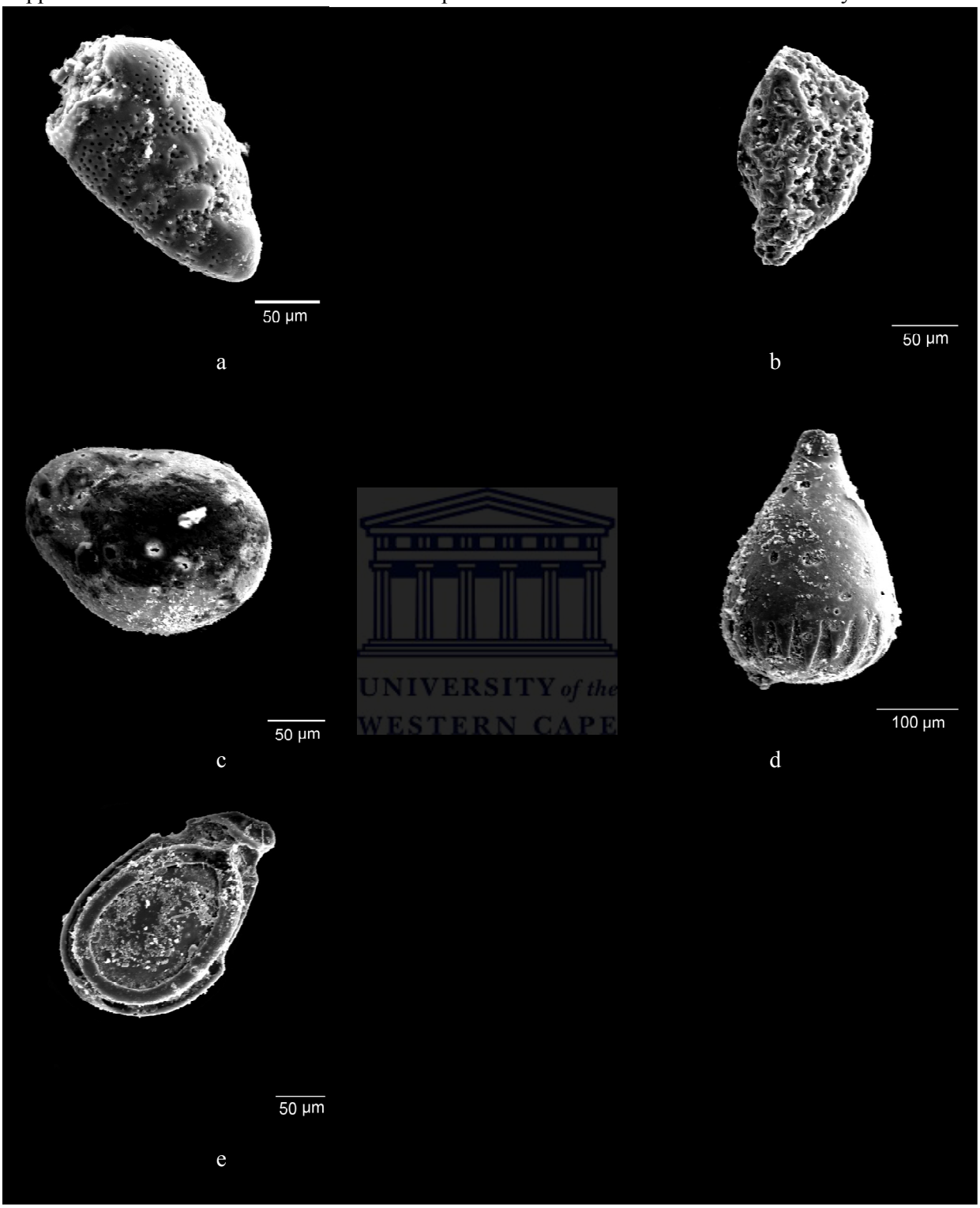

Plate 4.1.12: Abnormal tests
a. *Bolivina pseudoplicata*
b. *Brizalina pseudopunctata?*
c. *Fissurina marginata* abraded
d. *Lagena semilineata* broken neck
e. *Lagenosolenia*

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

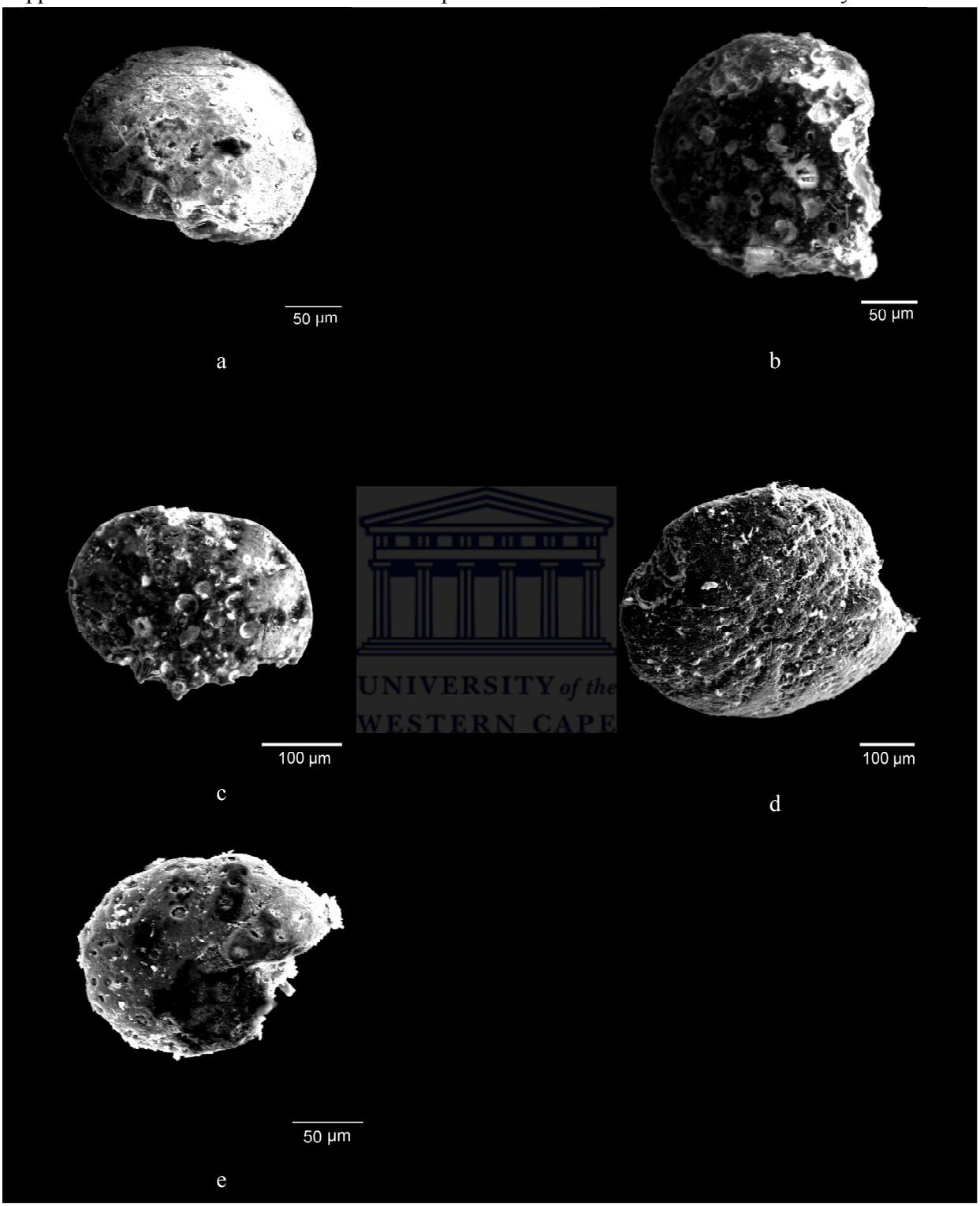

Plate 4.1.13: a-e. Abnormal *Elphidium*

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

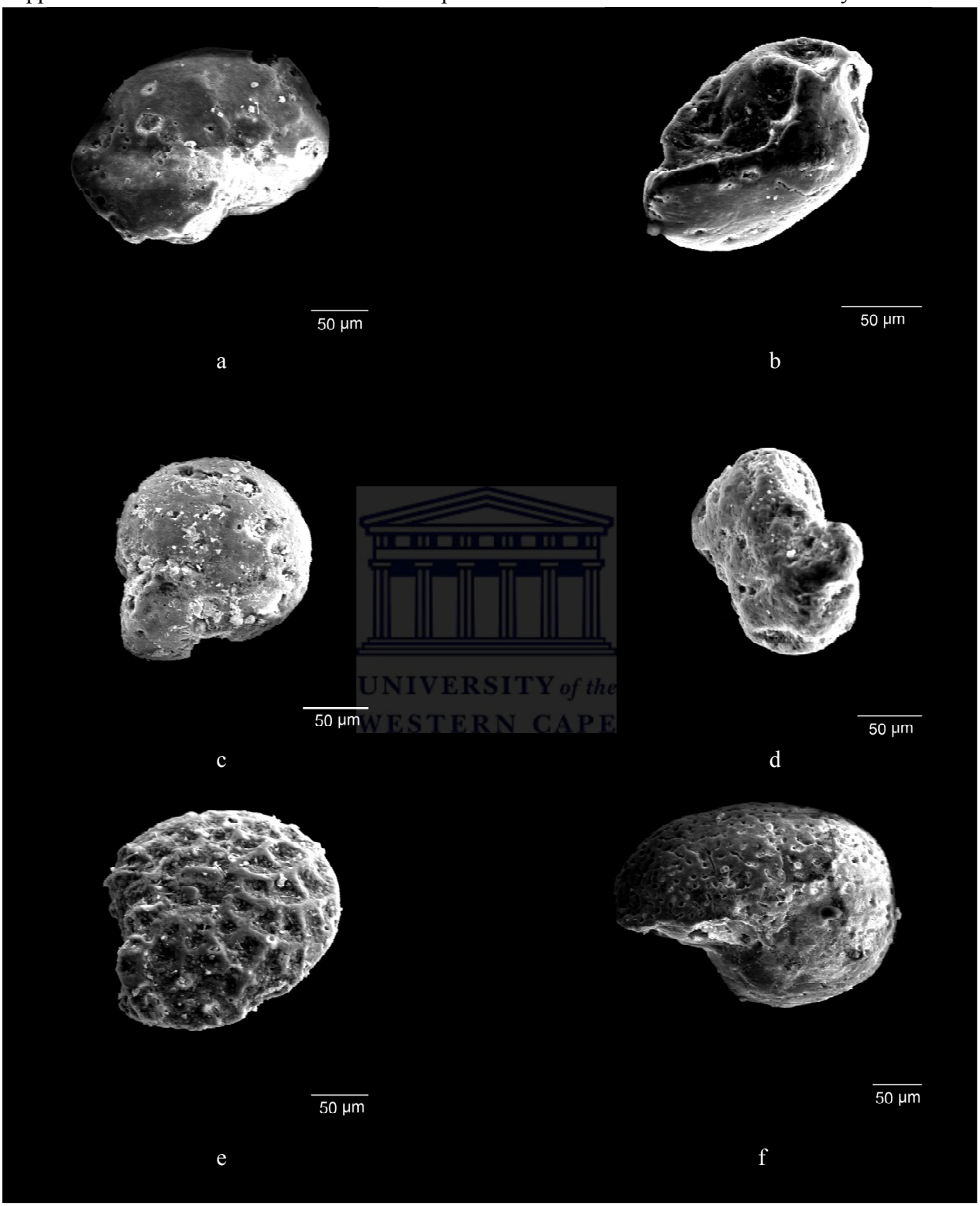

Plate 4.1.14: Abnormal tests of *Elphidium*

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

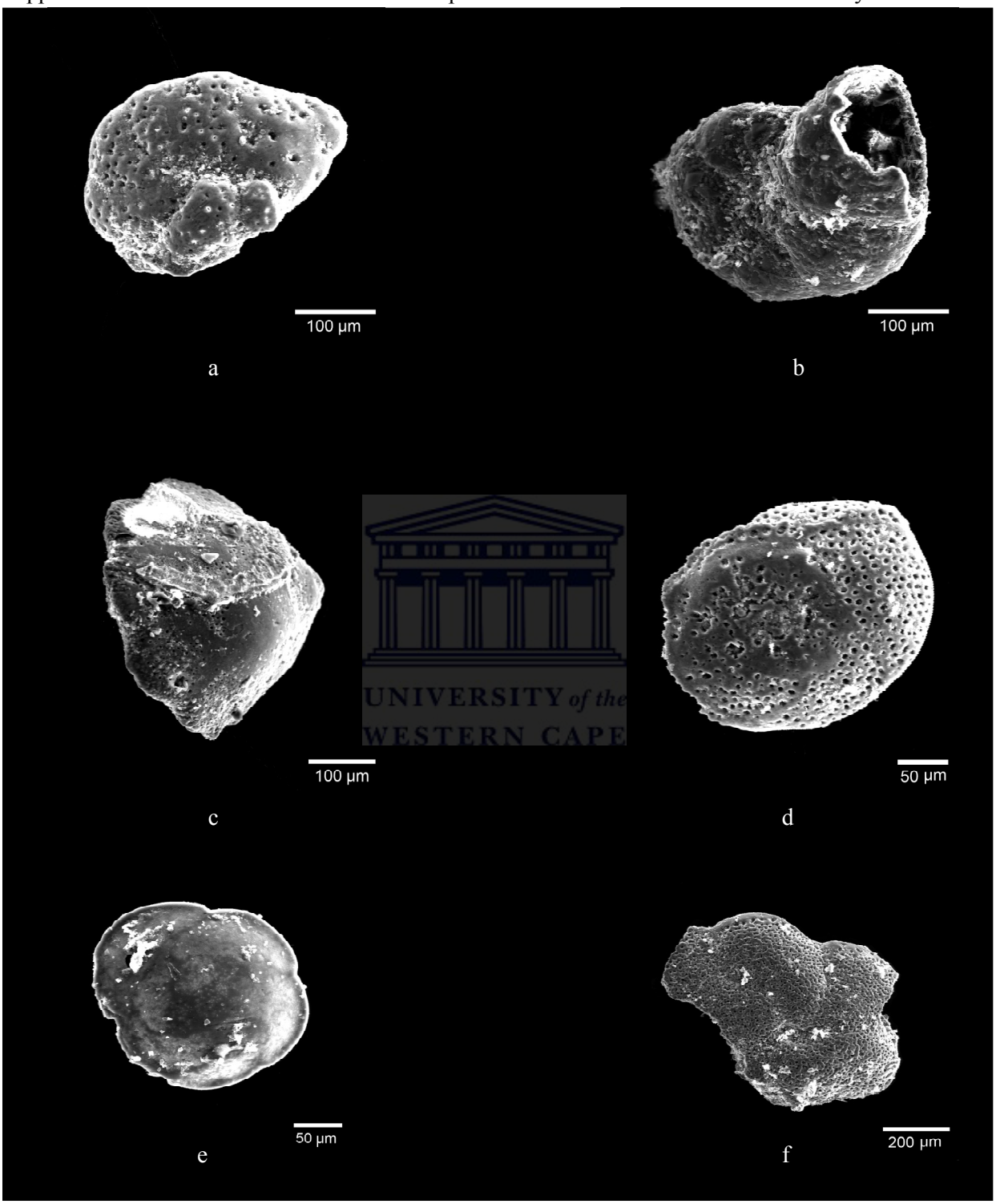

Plate 4.1.15: a - f. Abnormal and broken *Cibicides*?

Appendix 4.1: Foraminifera identified in samples from Robben Island and St Helena Bay

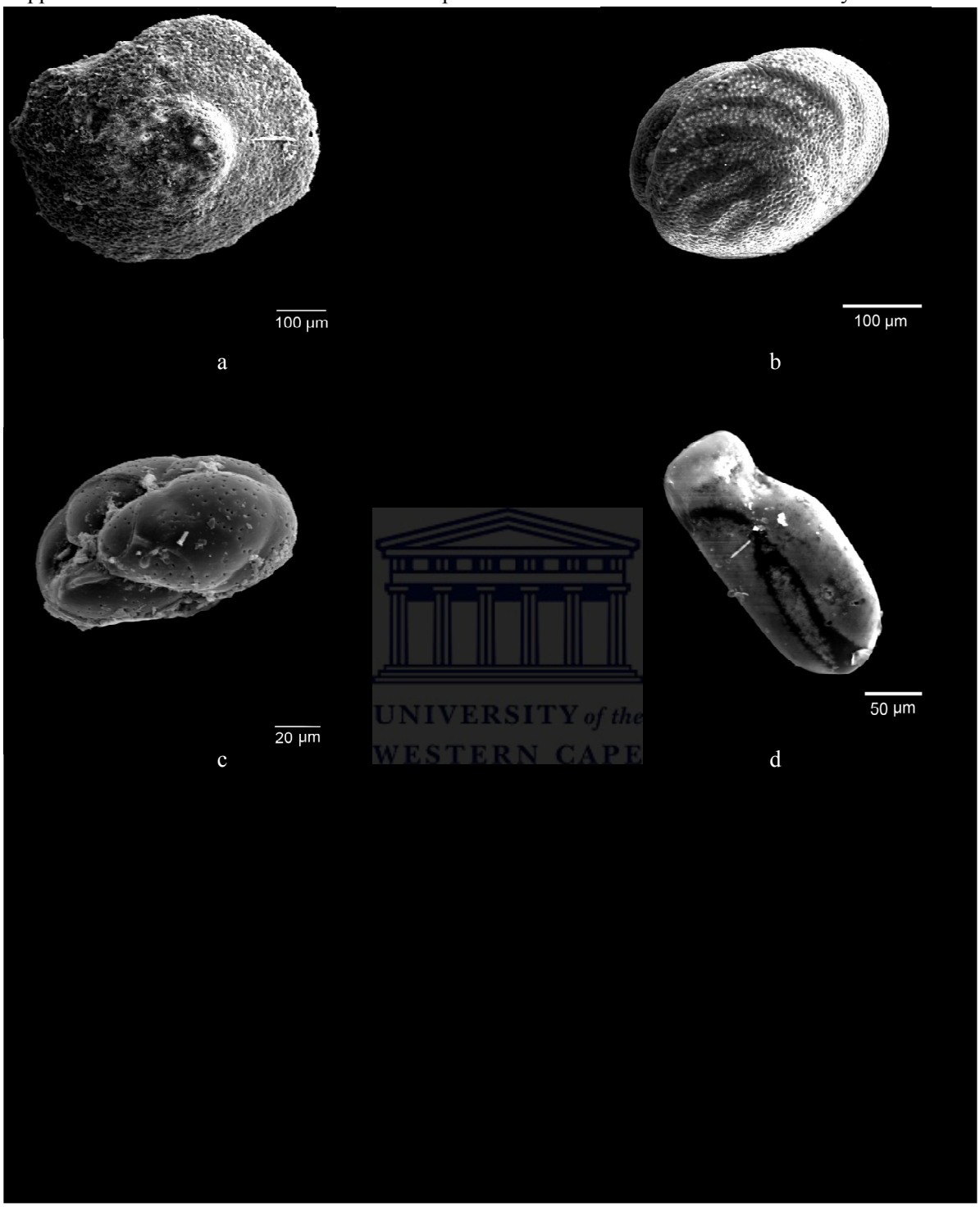

Plate 4.1.16: a. Abnormal *Pararotalia nipponica* twins
b. *Glabratella australensis* siamese
c. *Rosalina* siamese twins
d. *Miliolinella* abnormal?

Appendix 4.2: Elemental analysis of foraminiferal tests in wt %

	C	O	Mg	Al	Si	S	Cl	Cd	K	Ca	Cr	Fe	Cu	Zn	Pb
SHA201	8.99	5.57	0.48	0.45	14.25	2.59	0.72	0.00	0.09	61.81	0.12	2.55	0.65	0.57	1.74
SHA202	8.42	2.64	0.58	0.13	2.91	1.06	0.59	0.00	0.00	79.46	0.00	2.67	0.29	0.26	1.24
SHA203	5.09	2.27	0.32	0.00	1.05	1.20	2.40	0.00	0.00	86.52	0.00	0.65	0.49	0.42	0.00
SHA204	4.00	5.28	0.00	0.00	0.57	0.29	0.10	0.00	0.00	89.36	0.00	0.16	0.24	0.19	0.00
SHA205	11.71	6.03	0.24	0.00	0.53	1.02	0.89	0.00	0.00	78.73	0.00	0.34	0.51	0.45	0.00
SHA206	8.67	0.00	0.32	0.25	5.45	1.29	0.36	0.00	0.11	80.51	0.00	2.77	0.26	0.23	0.00
SHA207	11.07	3.19	0.79	0.30	4.14	1.82	0.96	0.00	0.21	71.87	0.18	2.96	1.00	0.65	1.49
SHA208	5.39	2.94	0.18	0.00	0.48	1.00	1.37	0.00	0.00	85.50	0.00	0.56	1.02	0.86	1.55
SHA209	4.61	6.52	0.31	0.00	0.89	0.69	0.27	0.00	0.00	85.66	0.00	0.46	0.59	0.23	0.00
SHA210	4.52	5.66	0.52	0.22	3.40	1.50	0.26	0.00	0.00	80.10	0.00	2.02	0.74	0.63	1.06
SHB201	2.81	2.87	0.21	0.00	0.63	0.53	0.13	0.41	0.00	89.38	0.15	0.74	0.89	0.77	1.24
SHB202	3.19	6.67	0.18	0.00	1.00	0.51	0.05	0.00	0.00	87.24	0.15	0.31	0.70	0.65	0.00
SHB203	2.84	8.70	0.00	0.12	1.07	0.84	0.19	0.00	0.06	85.39	0.00	0.38	0.39	0.28	0.00
SHB204	3.56	8.77	0.00	0.00	0.56	0.54	0.21	0.00	0.00	85.68	0.00	0.24	0.45	0.42	0.00
SHB205	3.05	3.79	0.28	0.09	1.89	1.28	0.24	0.00	0.00	87.36	0.00	0.69	0.67	0.59	0.67
SHB206	3.85	6.45	0.00	0.00	0.53	0.68	0.37	0.00	0.00	85.99	0.00	0.57	0.79	0.76	0.77
SHB207	4.21	6.99	0.29	0.27	3.90	1.42	0.39	0.00	0.00	74.62	0.00	6.71	0.66	0.54	0.54
SHB208	3.98	6.95	0.09	0.12	1.00	1.32	0.00	0.00	0.00	85.56	0.00	0.59	0.39	0.34	0.00
SHB209	3.98	6.98	0.25	0.00	0.47	0.46	0.45	0.00	0.00	86.63	0.00	0.45	0.31	0.22	0.00
SHB210	3.96	4.26	0.15	0.00	0.32	0.58	0.08	0.28	0.00	90.01	0.00	0.13	0.24	0.18	0.00
SHC201	7.36	8.85	0.99	0.40	13.59	1.27	0.50	0.00	0.23	57.52	0.12	8.87	0.31	0.27	0.00
SHC202	9.14	5.57	0.41	0.00	1.08	1.30	2.21	0.00	0.00	78.70	0.00	0.94	0.66	0.64	0.00
SHC203	32.04	8.31	0.99	0.93	18.19	5.31	2.04	0.00	0.41	24.80	0.00	6.43	0.56	0.51	0.00
SHC204	8.56	0.00	0.19	0.13	2.21	1.18	1.03	0.00	0.10	79.36	0.00	2.96	2.09	1.89	2.19
SHC205	3.58	10.87	0.19	0.12	1.77	0.44	0.28	0.00	0.00	82.05	0.00	0.40	0.31	0.22	0.00
SHC206	5.17	5.45	0.80	0.50	3.89	1.53	0.30	0.00	0.18	80.63	0.00	0.93	0.60	0.62	0.00
SHC207	9.55	3.01	0.39	0.12	2.46	1.97	0.80	0.00	0.07	79.24	0.00	1.80	0.60	0.59	0.00
SHC208	3.42	7.61	0.27	0.15	1.64	1.34	0.59	0.00	0.00	83.31	0.00	0.77	0.91	0.86	0.00
SHC209	3.77	7.30	0.13	0.10	2.66	0.88	0.54	0.00	0.12	82.99	0.14	0.73	0.64	0.62	0.00
SHC210	5.75	7.06	1.90	0.09	6.38	1.77	0.92	0.00	0.00	74.48	0.00	0.87	0.78	0.71	0.00
SHD201	4.80	6.29	0.24	0.00	1.30	1.03	0.39	0.29	0.00	83.28	0.19	0.74	0.87	0.85	0.57
SHD202	3.30	2.57	0.56	0.14	3.44	1.12	0.39	0.00	0.00	85.46	0.00	2.44	0.59	0.62	0.00
SHD203	4.63	8.93	0.25	0.10	2.05	0.54	0.29	0.00	0.00	80.76	0.07	0.68	0.79	0.73	0.93

	C	O	Mg	Al	Si	S	Cl	Cd	K	Ca	Cr	Fe	Cu	Zn	Pb
SHD204	7.58	8.53	0.35	0.27	4.06	1.08	1.07	0.14	0.00	73.22	0.00	3.29	0.41	0.38	0.00
SHD205	11.18	10.19	0.53	1.15	51.90	3.76	1.16	0.00	0.54	13.05	0.19	5.23	1.12	0.92	0.00
SHD206	5.89	8.06	1.19	0.43	21.53	1.94	0.73	0.00	0.33	49.89	0.09	9.63	0.30	0.26	0.00
SHD207	4.75	3.52	0.25	0.54	8.14	1.37	1.06	0.00	0.12	72.46	0.00	5.49	1.15	0.85	1.16
SHD208	8.10	9.11	0.15	0.00	1.90	0.88	0.24	0.15	0.07	78.34	0.00	0.35	0.70	0.66	0.00
SHD209	4.33	5.25	0.32	0.27	3.80	1.01	0.83	0.00	0.07	81.46	0.17	1.52	0.98	0.92	0.00
SHD210	5.11	10.87	0.63	0.94	10.63	0.98	0.57	0.00	0.09	67.21	0.00	2.32	0.66	0.63	0.00
SHE201	4.06	7.14	0.68	0.16	6.22	1.25	0.15	0.00	0.00	76.24	0.09	2.59	0.58	0.62	0.84
SHE202	4.56	4.19	0.59	0.30	5.79	1.58	0.27	0.00	0.06	78.36	0.20	3.77	0.32	0.27	0.00
SHE203	5.45	7.38	0.66	0.16	3.93	1.27	0.51	0.00	0.00	78.49	0.00	1.95	0.21	0.19	0.00
SHE204	17.97	8.46	0.73	0.52	11.46	1.51	1.32	0.00	0.37	48.55	0.00	7.34	0.95	0.88	0.83
SHE205	5.64	6.28	0.10	0.16	3.35	0.29	0.58	0.00	0.06	80.45	0.00	1.07	0.73	0.64	1.28
SHE206	7.20	6.57	0.67	0.67	16.76	2.28	0.79	0.00	0.38	53.02	0.12	10.96	0.57	0.59	0.00
SHE207	11.91	8.71	0.61	1.07	27.64	3.83	1.80	0.00	0.45	34.80	0.09	8.64	0.44	0.43	0.00
SHE208	9.41	9.81	0.50	0.75	20.01	1.92	0.44	0.00	0.28	51.25	0.14	4.95	0.55	0.59	0.00
SHE209	3.93	4.91	0.15	0.00	1.02	1.01	0.18	0.00	0.00	87.58	0.19	0.78	0.25	0.26	0.00
SHE210	3.29	5.78	0.40	0.15	6.68	0.67	0.16	0.00	0.08	77.07	0.00	4.38	0.32	0.34	1.00
SHF201	0.95	11.72	0.00	0.00	81.95	4.27	0.17	0.00	0.00	0.07	0.00	0.11	0.76	0.77	0.00
SHF202	2.89	7.42	0.25	0.00	1.08	0.82	0.26	0.19	0.00	84.22	0.00	0.16	1.14	0.98	1.57
SHF203	4.85	13.86	0.40	0.67	8.36	0.95	0.59	0.00	0.00	66.63	0.00	2.36	0.78	0.88	0.55
SHF204	4.59	11.91	0.46	0.21	3.00	0.84	0.24	0.00	0.00	75.79	0.12	0.96	0.92	0.87	0.96
SHF205	14.57	5.21	0.45	0.27	4.67	1.38	1.07	0.00	0.07	70.06	0.00	1.67	0.57	0.63	0.00
SHF206	5.41	5.96	0.88	0.48	12.76	1.43	0.39	0.00	0.20	65.60	0.28	5.97	0.66	0.57	0.00
SHF207	13.09	10.34	0.40	0.43	8.75	1.11	0.51	0.00	0.23	61.64	0.00	2.94	0.56	0.39	0.00
SHF208	7.49	6.61	0.40	0.30	5.01	1.07	0.80	0.00	0.06	75.29	0.14	1.48	0.72	0.61	0.61
SHF209	6.27	7.99	0.62	0.77	9.78	1.55	0.48	0.00	0.12	66.95	0.00	4.87	0.60	0.63	0.00
SHF210	10.91	10.09	0.62	0.95	48.48	7.46	1.06	0.00	0.92	10.98	0.00	7.52	1.01	0.97	0.00
SHG201	4.52	6.79	0.00	0.17	1.43	0.66	0.06	0.00	0.07	82.69	0.00	2.35	0.66	0.62	0.59
SHG202	2.85	7.47	0.80	0.26	9.66	0.72	0.17	0.00	0.11	72.39	0.12	5.23	0.23	0.18	0.00
SHG203	5.06	6.24	0.22	0.25	3.88	1.23	0.24	0.00	0.00	75.75	0.00	6.64	0.48	0.48	0.00
SHG204	5.51	8.25	0.21	0.14	1.29	0.60	0.44	0.13	0.00	81.23	0.09	0.70	0.64	0.54	0.77
SHG205	4.29	2.95	0.50	0.22	5.55	1.33	0.22	0.00	0.14	78.12	0.00	3.89	0.83	0.67	1.96
SHG206	3.46	6.02	0.44	0.08	6.61	0.84	0.46	0.00	0.10	76.04	0.00	5.56	0.40	0.33	0.00
SHG207	13.09	10.34	0.40	0.43	8.75	1.11	0.51	0.00	0.23	61.64	0.00	2.94	0.56	0.64	0.00

	C	O	Mg	Al	Si	S	Cl	Cd	K	Ca	Cr	Fe	Cu	Zn	Pb
SHG210	6.01	6.48	0.75	0.16	6.10	0.70	0.37	0.00	0.15	75.65	0.11	3.12	0.41	0.43	0.00
SHH201	10.16	3.73	0.46	0.56	10.00	3.40	0.55	0.00	0.31	63.22	0.12	6.55	0.93	0.86	0.00
SHH202	12.66	8.42	1.20	1.78	27.77	0.95	0.28	0.00	0.76	34.53	0.00	10.81	0.85	0.83	0.00
SHH203	9.07	9.10	1.35	2.18	35.12	2.42	0.00	0.00	0.99	22.45	0.33	14.48	1.74	1.33	0.78
SHH204	8.19	7.59	0.16	0.18	78.79	1.41	0.17	0.00	0.11	0.74	0.00	1.39	1.27	0.95	0.00
SHH205	37.48	0.00	1.05	0.67	9.07	12.93	2.38	0.00	1.04	26.75	0.26	5.55	2.81	1.75	0.00
SHH206	30.14	2.11	2.03	1.26	21.10	8.64	0.36	0.00	0.37	14.18	0.37	18.52	0.95	0.88	0.00
SHH207	63.47	0.00	0.35	0.46	22.08	1.66	0.17	0.00	0.14	0.81	0.16	5.02	2.34	1.92	3.35
SHH208	4.46	8.51	0.23	0.17	1.22	0.70	0.00	0.00	0.00	81.96	0.00	0.65	1.19	1.02	0.90
SHH209	2.77	8.71	0.13	0.19	0.00	0.08	0.00	0.00	0.00	85.91	0.00	0.25	1.14	1.05	0.81
SHH210	5.00	9.24	0.50	1.10	16.29	0.98	0.00	0.00	0.37	58.76	0.00	6.57	1.20	1.13	0.00
SPA201	2.85	2.17	0.11	0.22	3.57	0.90	0.10	0.00	0.12	86.31	0.00	2.44	1.22	1.09	0.00
SPA202	3.89	8.08	0.12	0.16	1.66	0.83	0.31	0.00	0.00	80.47	0.16	1.09	0.87	0.74	2.36
SPA203	4.96	9.14	0.27	0.00	0.49	0.83	0.07	0.00	0.00	83.55	0.00	0.38	0.33	0.28	0.00
SPA204	3.70	7.56	0.28	0.29	3.56	0.70	0.15	0.00	0.00	81.19	0.11	1.71	0.75	0.63	0.00
SPA205	2.96	8.72	0.21	0.11	1.60	0.52	0.18	0.18	0.00	83.43	0.00	0.37	0.60	0.58	1.12
SPA206	4.40	9.85	0.44	0.42	6.54	0.62	0.15	0.00	0.00	73.86	0.24	1.94	0.66	0.62	0.89
SPA207	11.04	3.83	0.56	0.19	3.03	1.08	0.88	0.00	0.00	76.34	0.13	1.07	1.01	0.97	0.83
SPA208	26.69	3.73	0.73	0.41	6.87	1.01	1.55	0.00	0.14	55.24	0.00	2.94	0.69	0.63	0.00
SPA209	4.68	13.44	0.15	0.24	3.02	0.66	0.19	0.00	0.00	76.21	0.14	0.80	0.47	0.31	0.00
SPA210	3.94	9.56	0.25	0.14	1.56	0.61	0.20	0.00	0.00	83.35	0.00	0.39	0.00	0.06	0.00
SPB401	38.34	0.00	0.64	0.28	5.63	2.16	3.06	0.00	0.10	47.79	0.00	1.99	0.00	0.02	0.00
SPB402	14.40	7.02	0.57	0.26	6.02	1.56	2.04	0.00	0.00	65.66	0.16	1.69	0.63	0.52	0.00
SPB403	7.00	9.71	0.21	0.20	3.88	1.21	0.56	0.00	0.07	75.36	0.11	1.25	0.46	0.43	0.00
SPB404	4.08	6.31	0.00	0.00	1.20	0.58	0.08	0.00	0.00	86.23	0.00	0.38	0.53	0.56	0.62
SPB405	3.87	6.99	0.20	0.13	2.80	1.00	0.00	0.00	0.00	83.30	0.19	1.00	0.53	0.48	0.00
SPB406	13.43	5.46	0.34	0.12	2.40	1.18	0.73	0.00	0.00	75.03	0.00	0.85	0.47	0.39	0.00
SPB407	8.76	11.51	0.59	0.61	11.79	1.57	0.32	0.00	0.22	58.89	0.17	3.98	0.72	0.67	0.90
SPB408	4.83	11.76	0.55	0.51	8.20	0.77	0.13	0.00	0.13	69.98	0.00	2.82	0.33	0.31	0.00
SPB409	13.50	8.77	0.53	0.55	13.79	1.07	0.96	0.00	0.29	55.46	0.00	4.49	0.58	0.52	0.00
SPB410	3.51	8.34	0.13	0.23	4.26	0.12	0.26	0.00	0.00	81.10	0.00	1.86	0.19	0.08	0.00
SPC401	3.51	0.00	0.09	0.27	4.69	0.51	0.00	0.00	0.00	86.89	0.00	1.92	0.68	0.56	1.44

	C	O	Mg	Al	Si	S	Cl	Cd	K	Ca	Cr	Fe	Cu	Zn	Pb
SPC402	2.90	3.13	0.14	0.19	2.50	0.74	0.07	0.00	0.00	87.73	0.00	1.04	0.68	0.61	0.87
SPC403	9.73	6.34	0.42	0.68	14.47	2.16	0.36	0.00	0.25	59.74	0.13	4.92	0.80	0.74	0.00
SPC405	3.60	6.38	0.30	0.36	5.84	0.85	0.12	0.00	0.09	78.71	0.00	1.75	0.86	0.91	1.14
SPC406	6.28	3.04	0.10	0.16	3.30	0.44	0.57	0.00	0.00	82.91	0.00	2.91	0.29	0.23	0.00
SPC407	13.63	6.51	0.44	0.27	6.05	1.08	0.96	0.00	0.13	68.44	0.10	2.08	0.29	0.25	0.00
SPC408	3.04	3.06	0.19	0.26	2.65	0.60	0.17	0.00	0.00	87.23	0.00	0.86	0.90	0.81	1.03
SPC409	3.05	1.39	0.07	0.11	1.13	0.71	0.00	0.16	0.00	90.53	0.00	0.54	0.91	0.86	1.39
SPC410	4.05	8.72	0.61	0.61	9.14	1.00	0.41	0.00	0.17	70.48	0.00	4.03	0.34	0.23	0.44
RIA101	5.99	4.75	0.10	0.00	1.00	0.57	0.20	0.00	0.00	86.15	0.19	0.17	0.88	0.73	0.00
RIA102	4.45	5.91	0.15	0.00	0.35	0.78	0.22	0.00	0.00	87.65	0.08	0.16	0.26	0.25	0.00
RIA103	3.07	4.27	0.18	0.00	0.31	1.03	0.33	0.00	0.00	89.51	0.00	0.34	0.97	0.88	0.00
RIA104	4.72	3.61	0.00	0.00	1.34	0.46	0.44	0.00	0.00	88.58	0.00	0.18	0.67	0.63	0.00
RIA105	6.73	10.50	0.20	0.08	0.35	0.63	0.13	0.00	0.00	79.83	0.00	0.16	0.51	0.49	0.89
RIA106	4.86	5.52	0.37	0.21	3.79	0.38	0.17	0.00	0.09	83.55	0.00	0.81	0.24	0.21	0.00
RIA107	4.33	4.47	0.14	0.00	0.55	0.72	0.18	0.00	0.00	89.20	0.00	0.12	0.30	0.26	0.00
RIA108	3.29	0.00	0.00	0.00	0.50	0.80	0.07	0.14	0.00	93.88	0.11	0.42	0.79	0.76	0.00
RIA109	4.76	6.74	0.32	0.10	1.05	0.68	0.35	0.00	0.00	83.64	0.00	1.01	0.72	0.71	0.65
RIA110	4.89	0.00	0.18	0.00	0.40	0.75	0.17	0.49	0.00	92.04	0.00	0.31	0.76	0.69	0.00
RIB101	4.79	5.90	0.30	0.28	4.75	1.34	0.53	0.00	0.00	80.48	0.00	1.05	0.58	0.52	0.00
RIB102	5.85	3.65	0.15	0.00	2.23	1.06	0.68	0.00	0.00	85.15	0.00	0.75	0.49	0.46	0.00
RIB103	22.35	0.00	0.12	0.00	0.69	0.00	0.00	0.00	0.00	71.93	0.17	0.87	3.67	1.62	0.00
RIB104	9.33	6.75	0.20	0.32	23.08	0.94	0.72	0.00	0.11	51.13	0.10	7.14	0.20	0.19	0.00
RIB105	5.69	5.00	0.21	0.15	2.01	1.07	0.41	0.28	0.00	83.72	0.00	0.92	0.55	0.62	0.00
RIB106	6.34	3.45	0.13	0.12	3.10	1.06	1.00	0.00	0.00	82.66	0.00	0.70	0.69	0.63	0.75
RIB107	5.12	3.43	0.28	0.00	1.01	1.05	0.19	0.00	0.00	87.33	0.12	0.65	0.83	0.79	0.00
RIB108	4.91	4.70	0.31	0.23	3.86	0.97	0.41	0.00	0.00	82.37	0.00	1.46	0.78	0.82	0.00
RIB109	5.39	7.10	0.27	0.12	1.99	0.76	0.46	0.00	0.00	82.52	0.00	0.75	0.64	0.64	0.00
RIB110	3.37	0.00	0.00	0.00	0.51	0.67	0.17	0.00	0.00	94.56	0.00	0.00	0.72	0.69	0.00
RIC101	48.33	0.00	0.00	0.30	2.71	0.33	0.11	0.00	0.00	40.27	0.00	0.92	4.91	3.25	2.12
RIC102	7.30	5.45	0.42	0.10	3.32	1.16	0.54	0.00	0.00	79.31	0.00	0.68	0.55	0.61	1.16
RIC103	9.30	3.06	0.62	0.27	5.37	1.14	1.10	0.00	0.10	75.67	0.00	2.96	0.41	0.37	0.00
RIC104	10.37	0.00	0.20	0.17	3.15	0.99	0.24	0.00	0.00	82.46	0.00	1.51	0.92	0.85	0.00
RIC105	14.18	0.00	0.00	0.15	3.40	1.33	0.29	0.00	0.00	78.67	0.00	1.62	0.36	0.23	0.00
RIC106	6.43	5.58	0.27	0.29	7.31	1.10	0.40	0.00	0.07	76.57	0.29	1.17	0.53	0.47	0.00

	C	O	Mg	Al	Si	S	Cl	Cd	K	Ca	Cr	Fe	Cu	Zn	Pb
RIC107	5.26	6.95	0.32	0.18	2.15	0.95	0.53	0.00	0.00	81.48	0.26	0.71	0.74	0.68	0.47
RIC108	4.71	9.31	0.24	0.10	1.58	0.68	0.09	0.00	0.00	81.48	0.10	0.62	0.61	0.69	0.47
RIC110	3.86	3.48	0.25	0.14	4.51	1.55	0.62	0.00	0.09	79.48	0.00	2.77	1.09	0.95	2.15
RID101	2.52	0.00	0.11	0.10	0.95	0.57	0.16	0.00	0.00	93.09	0.00	0.75	0.91	0.98	0.83
RID102	12.93	0.00	0.33	0.22	4.43	2.18	3.76	0.00	0.10	72.40	0.17	1.56	0.93	1.05	0.99
RID103	3.66	5.66	0.19	0.00	0.82	0.71	0.24	0.00	0.00	87.72	0.00	0.40	0.58	0.63	0.00
RID104	8.75	10.34	0.54	0.35	6.06	1.71	0.28	0.00	0.00	68.84	0.14	1.49	0.60	0.59	0.91
RID105	16.60	0.00	0.41	0.14	2.10	1.92	6.64	0.00	0.11	68.99	0.00	1.69	0.79	0.63	0.62
RID106	10.06	0.00	0.22	0.00	0.86	1.05	0.18	0.00	0.00	86.32	0.00	0.34	0.42	0.39	0.54
RID107	5.14	5.11	0.22	0.00	0.51	0.78	0.21	0.00	0.00	87.27	0.19	0.17	0.40	0.45	0.00
RID108	14.16	4.93	0.38	0.11	7.30	1.55	1.94	0.00	0.00	66.75	0.26	1.97	0.65	0.59	0.00
RID109	5.76	5.51	0.26	0.11	2.05	0.97	0.91	0.24	0.00	83.05	0.10	0.48	0.57	0.63	0.00
RID110	4.13	4.54	0.00	0.00	1.73	1.21	0.15	0.00	0.00	87.37	0.00	0.27	0.60	0.54	0.00
RIE101	4.82	2.95	0.31	0.00	1.21	0.96	0.19	0.00	0.00	86.35	0.36	1.26	0.97	0.65	0.00
RIE102	5.33	3.40	0.24	0.00	0.82	0.92	0.12	0.00	0.00	87.58	0.07	0.91	0.60	0.06	0.00
RIE103	37.44	0.00	0.22	0.89	18.41	0.56	0.73	0.00	1.50	10.65	0.68	16.92	6.32	4.68	5.67
RIE104	4.52	4.91	0.56	0.00	0.80	1.85	0.13	0.00	0.00	85.23	0.12	0.22	0.99	0.75	0.66
RIE105	8.00	2.50	0.78	0.86	13.26	1.13	1.01	0.00	0.24	15.03	0.24	52.17	3.55	2.89	1.23
RIE106	10.76	2.70	0.51	0.10	1.41	1.99	3.63	0.00	0.00	77.44	0.20	0.63	0.63	0.51	0.00
RIE107	7.03	0.00	0.27	0.13	3.06	1.20	1.43	0.00	0.00	83.85	0.25	1.78	1.00	0.86	0.00
RIE108	5.47	6.11	0.55	0.00	0.36	0.88	0.10	0.00	0.00	85.41	0.10	0.21	0.82	0.81	0.00
RIE109	13.12	0.00	0.29	0.24	5.15	1.41	3.68	0.00	0.13	72.95	0.00	1.20	1.02	0.98	0.81
RIE110	6.26	0.00	0.14	0.00	2.32	0.33	1.18	0.00	0.00	87.42	0.17	1.24	0.94	0.91	0.00
RIF101	7.75	4.20	0.31	0.09	1.05	0.47	0.30	0.15	0.00	84.89	0.00	0.38	0.42	0.38	0.00
RIF102	5.77	6.24	0.15	0.00	4.82	0.89	0.10	0.00	0.00	81.08	0.12	0.33	0.49	0.35	0.00
RIF103	4.35	3.22	0.24	0.00	0.95	0.68	0.25	0.00	0.00	88.42	0.00	0.33	1.02	0.96	0.55
RIF104	4.33	4.77	0.18	0.00	0.46	0.72	0.30	0.17	0.00	88.52	0.00	0.10	0.46	0.41	0.00
RIF105	3.71	4.59	0.07	0.00	0.28	1.03	0.18	0.00	0.00	89.71	0.00	0.00	0.44	0.43	0.00
RIF106	7.11	4.42	0.59	0.00	0.33	0.78	0.07	0.13	0.00	85.90	0.00	0.13	0.55	0.52	0.00
RIF107	6.21	2.87	0.28	0.00	0.72	0.82	0.19	0.00	0.00	88.60	0.00	0.00	0.30	0.33	0.00
RIF108	6.61	5.27	0.30	0.09	1.29	1.27	0.52	0.13	0.00	84.15	0.00	0.37	0.00	0.00	0.00
RIF109	4.98	4.75	0.24	0.00	1.03	1.07	0.87	0.00	0.00	85.68	0.18	0.45	0.74	0.68	0.00

	C	O	Mg	Al	Si	S	Cl	Cd	K	Ca	Cr	Fe	Cu	Zn	Pb
RIF110	5.58	5.25	0.15	0.11	1.98	1.06	0.59	0.00	0.00	83.68	0.16	0.74	0.71	0.65	0.00
RIG101	6.10	7.70	0.38	0.07	2.17	0.72	0.32	0.15	0.00	81.24	0.00	0.59	0.54	0.59	0.00
RIG102	6.30	0.00	0.30	0.00	1.88	1.54	0.20	0.00	0.00	88.12	0.00	0.12	0.57	0.51	0.98
RIG103	5.34	5.73	0.45	0.16	3.14	1.60	1.03	0.00	0.00	81.32	0.00	0.94	0.30	0.28	0.00
RIG104	5.84	9.73	0.14	0.00	0.41	1.02	0.24	0.25	0.00	82.16	0.00	0.00	0.21	0.15	0.00
RIG105	7.81	4.71	0.58	0.00	1.06	0.60	0.48	0.00	0.00	83.21	0.25	0.73	0.57	0.46	0.00
RIG106	5.55	2.55	0.27	0.00	0.25	0.88	0.15	0.00	0.00	88.92	0.00	0.25	0.44	0.39	0.75
RIG107	5.13	4.37	1.62	0.00	0.35	1.63	0.33	0.00	0.00	84.65	0.00	0.32	0.96	0.86	0.64
RIG108	5.97	3.83	0.09	0.00	3.81	0.88	0.28	0.00	0.00	84.41	0.00	0.10	0.64	0.71	0.00
RIG109	7.85	10.17	0.00	0.00	0.30	0.45	0.08	0.00	0.00	80.39	0.00	0.24	0.53	0.47	0.00
RIG110	8.45	12.66	0.39	0.00	0.13	1.02	0.12	0.25	0.00	75.62	0.00	0.00	0.54	0.53	0.81
RIH101	15.78	2.33	0.36	0.48	44.37	0.79	0.07	0.00	0.12	23.45	0.00	6.06	6.19	1.19	0.00
RIH102	3.44	1.96	0.00	0.00	0.16	0.79	0.25	0.00	0.00	92.28	0.14	0.32	0.66	0.56	0.00
RIH103	3.95	5.56	0.23	0.00	0.86	0.36	0.22	0.00	0.00	88.05	0.00	0.17	0.60	0.52	0.00
RIH104	4.78	0.00	0.05	0.00	0.21	1.24	0.39	0.00	0.00	92.06	0.00	0.18	1.09	1.20	0.00
RIH105	3.98	0.00	0.00	0.00	0.51	0.40	0.16	0.49	0.00	93.78	0.15	0.22	0.32	0.24	0.00
RIH106	3.60	3.26	0.12	0.08	3.99	0.52	0.44	0.00	0.00	86.37	0.09	0.82	0.70	0.63	0.00
RIH107	5.67	5.11	0.33	0.17	4.35	0.96	0.46	0.00	0.10	80.08	0.11	2.06	0.60	0.52	0.00
RIH108	3.40	2.68	0.33	0.00	0.24	0.56	0.07	0.00	0.00	92.24	0.00	0.00	0.48	0.36	0.00
RIH109	7.29	0.00	0.08	0.15	0.90	1.17	0.41	0.00	0.00	87.08	0.00	1.22	0.91	0.83	0.81
RIH110	5.28	7.28	0.33	0.19	2.50	1.66	0.82	0.00	0.11	77.84	0.16	2.42	0.83	0.65	0.59

Appendix 4.3: Results for the one-Way ANOVA performed on all trace metals measured in the tests of samples from Robben Island and St Helena Bay.

Appendix 4. 3.1:Results for the one-Way ANOVA performed on the Magnesium concentration of the tests of each station in Robben Island. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 72, MS error = 0.047. Significant differences at $p < 0.05$ are in bold*

	RIA	RIB	RIC	RID	RIE	RIF	RIG	RIH
Mean (wt %)	0.16	0.20	0.23	0.27	0.39	0.25	0.42	0.18
RIA								
RIB	1.00							
RIC	1.00	1.00						
RID	0.96	1.00	1.00					
RIE	0.31	0.52	0.75	0.92				
RIF	0.99	1.00	1.00	1.00	0.85			
RIG	0.15	0.30	0.52	0.75	1.00	0.65		
RIH	1.00	1.00	1.00	0.99	0.43	1.00	0.23	

Appendix 4.3.2: Results for the one-Way ANOVA performed on the Cadmium concentration of the tests of each station in Robben Island. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 72, MS error = 0.0099. Significant differences at $p < 0.05$ *.

	RIA	RIB	RIC	RID	RIE	RIF	RIG	RIH
Mean (wt %)	0.06	0.03	0.00	0.02	0.00	0.06	0.07	0.05
RIA								
RIB	0.99							
RIC	0.85	1.00						
RID	0.99	1.00	1.00					
RIE	0.85	1.00	1.00	1.00				
RIF	1.00	1.00	0.90	0.99	0.90			
RIG	1.00	0.99	0.83	0.98	0.83	1.00		
RIH	1.00	1.00	0.96	1.00	0.96	1.00	1.00	

Appendix 4.3.3: Results for the one-Way ANOVA performed on the Calcium concentration of the tests of each station in Robben Island. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 72, MS error = 224.09. Significant differences at $p < 0.05$ *.

	RIA	RIB	RIC	RID	RIE	RIF	RIG	RIH
Mean (Wt %)	87.40	80.19	76.39	80.18	69.19	86.06	83.00	81.32
RIA								
RIB	0.96							
RIC	0.72	1.00						
RID	0.96	1.00	1.00					
RIE	0.13	0.72	0.96	0.72				
RIF	1.00	0.99	0.83	0.99	0.20			
RIG	1.00	1.00	0.97	1.00	0.45	1.00		
RIH	0.98	1.00	1.00	1.00	0.61	1.00	1.00	

Appendix 4.3.4: Results for the one-Way ANOVA performed on the Chromium concentration of the tests of each station in Robben Island. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 72, MS error = 0.01069. Significant differences at $p < 0.05$ *

	RIA	RIB	RIC	RID	RIE	RIF	RIG	RIH
Mean (Wt %)	0.04	0.04	0.07	0.09	0.22	0.05	0.03	0.07
RIA								
RIB	1.00							
RIC	1.00	1.00						
RID	0.97	0.97	1.00					
RIE	0.00*	0.01*	0.03*	0.09				
RIF	1.00	1.00	1.00	0.99	0.01*			
RIG	1.00	1.00	0.99	0.89	0.00*	1.00		
RIH	1.00	1.00	1.00	1.00	0.03*	1.00	0.99	

Appendix 4.3.5: Results for the one-Way ANOVA performed on the Iron concentration of the tests of each station in Robben Island. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 72, MS error = 34.9. Significant differences at $p < 0.05$ *.

	RIA	RIB	RIC	RID	RIE	RIF	RIG	RIH
Mean (Wt %)	0.37	1.43	1.37	0.91	7.65	0.28	0.33	1.35
RIA								
RIB	1.00							
RIC	1.00	1.00						
RID	1.00	1.00	1.00					
RIE	0.12	0.28	0.27	0.19				
RIF	1.00	1.00	1.00	1.00	0.11			
RIG	1.00	1.00	1.00	1.00	0.12	1.00		
RIH	1.00	1.00	1.00	1.00	0.26	1.00	1.00	

Appendix 4.3.6: Results for the one-Way ANOVA performed on the Copper concentration of the tests of each station in Robben Island. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 72, MS error = 1.189. Significant differences at $p < 0.05$ *.

	RIA	RIB	RIC	RID	RIE	RIF	RIG	RIH
Mean (Wt %)	0.61	0.92	1.08	0.65	1.68	0.51	0.53	1.24
RIA								
RIB	1.00							
RIC	0.98	1.00						
RID	1.00	1.00	0.99					
RIE	0.36	0.76	0.91	0.41				
RIF	1.00	0.99	0.94	1.00	0.26			
RIG	1.00	0.99	0.95	1.00	0.27	1.00		
RIH	0.90	1.00	1.00	0.92	0.98	0.81	0.83	

Appendix 4.3.7: Results for the one-Way ANOVA performed on the Copper concentration of the tests of each station in Robben Island. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 72, MS error = 0.392. Significant differences at $p < 0.05$ *.

	RIA	RIB	RIC	RID	RIE	RIF	RIG	RIH
Mean (Wt %)	0.56	0.70	0.87	0.65	1.31	0.47	0.50	0.67
RIA								
RIB	1.00							
RIC	0.95	1.00						
RID	1.00	1.00	0.99					
RIE	0.15	0.37	0.77	0.28				
RIF	1.00	0.99	0.84	1.00	0.07			
RIG	1.00	1.00	0.88	1.00	0.09	1.00		
RIH	1.00	1.00	1.00	1.00	0.32	1.00	1.00	

Appendix 4.3.8: Results for the one-Way ANOVA performed on the Lead concentration of the tests of each station in Robben Island. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 72, MS error = 0.561. Significant differences at $p < 0.05$ *.

SITE	RIA	RIB	RIC	RID	RIE	RIF	RIG	RIH
	0.15	0.08	0.64	0.39	0.84	0.06	0.32	0.14
RIA								
RIB	1.00							
RIC	0.83	0.70						
RID	1.00	0.98	1.00					
RIE	0.46	0.32	1.00	0.88				
RIF	1.00	1.00	0.66	0.97	0.29			
RIG	1.00	1.00	0.98	1.00	0.78	0.99		
RIH	1.00	1.00	0.81	1.00	0.44	1.00	1.00	

Appendix 4.3.9: Results for the one-Way ANOVA performed on the trace metals and Ca and Mg concentration of the tests of the control (CRI) and pipeline (PRI) sites in Robben Island. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 72, MS error = 0.561. Significant differences at $p < 0.05$*.

	Mg			Cd			Ca			Cr		
Site	Mean	p	MS Error	Mean	p	MS Error	Mean	p	MS Error	Mean	p	MS Error
CRI	0.285	0.49	0.051	0.057	0.131	0.009	83.46	0.17	230.88	0.045	0.09	0.013
PRI	0.249			0.023			78.67			0.089		

	Fe			Cu			Zn			Pb		
Site	Mean	p	MS Error	Mean	p	MS Error	Mean	p	MS Error	Mean	p	MS Error
CRI	0.653	0.23	36.92	0.76	0.383	1.238	0.54	0.06	0.41	0.171	0.161	0.575
PRI	2.234			0.985			0.817			0.418		

Appendix 4.3.10: Results for the one-Way ANOVA performed on the Magnesium concentration of the tests of each station in St Helena Bay. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 99, MS error = 0.106. Significant differences at $p < 0.05$*

	SHA	SHB	SHC	SHD	SHE	SHF	SHG	SHH	SPA	SPB	SPC
Mean (Wt %)	0.374	0.145	0.626	0.447	0.509	0.448	0.434	0.746	0.312	0.376	0.244
SHA											
SHB	0.889										
SHC	0.814	0.048*									
SHD	1.000	0.596	0.977								
SHE	0.997	0.315	0.999	1.000							
SHF	1.000	0.591	0.978	1.000	1.000						
SHG	1.000	0.657	0.963	1.000	1.000	1.000					
SHH	0.284	0.004*	0.999	0.610	0.865	0.615	0.548				
SPA	1.000	0.986	0.538	0.997	0.956	0.997	0.999	0.113			
SPB	1.000	0.883	0.822	1.000	0.998	1.000	1.000	0.292	1.000		
SPC	0.998	1.000	0.249	0.947	0.764	0.945	0.966	0.032	1.000	0.998	

Appendix 4.3.11: Results for the one-Way ANOVA performed on the cadmium concentration of the tests of each station in St Helena Bay. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 99, MS error = 0.004. Significant differences at $p < 0.05$ *.

	SHA	SHB	SHC	SHD	SHE	SHF	SHG	SHH	SPA	SPB	SPC
Mean (Wt %)	0.000	0.069	0.000	0.058	0.000	0.019	0.013	0.000	0.018	0.000	0.035
SHA											
SHB	0.393										
SHC	1.000	0.393									
SHD	0.652	1.000	0.652								
SHE	1.000	0.393	1.000	0.652							
SHF	1.000	0.821	1.000	0.959	1.000						
SHG	1.000	0.698	1.000	0.899	1.000	1.000					
SHH	1.000	0.393	1.000	0.652	1.000	1.000	1.000				
SPA	1.000	0.803	1.000	0.951	1.000	1.000	1.000	1.000			
SPB	1.000	0.393	1.000	0.652	1.000	1.000	1.000	1.000	1.000		
SPC	0.981	0.984	0.981	0.999	0.981	1.000	1.000	0.981	1.000	0.981	

Appendix 4.3.12: Results for the one-Way ANOVA performed on the calcium concentration of the tests of each station in St Helena Bay. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 99, MS error = 310.85. Significant differences at $p < 0.05$ *.

	SHA	SHB	SHC	SHD	SHE	SHF	SHG	SHH	SPA	SPB	SPC
Mean (Wt %)	79.952	85.786	72.308	68.513	66.581	57.723	74.575	38.931	77.995	69.880	79.983
SHA											
SHB	1.000										
SHC	0.996	0.827									
SHD	0.932	0.517	1.000								
SHE	0.834	0.355	1.000	1.000							
SHF	0.166	**0.023***	0.747	0.953	0.988						
SHG	1.000	0.940	1.000	1.000	0.995	0.554					
SHH	**0.000***	**0.000***	**0.003***	**0.013***	**0.027***	0.388	**0.001***				
SPA	1.000	0.996	1.000	0.981	0.933	0.278	1.000	**0.000***			
SPB	0.971	0.638	1.000	1.000	1.000	0.902	1.000	**0.007***	0.994		
SPC	1.000	1.000	0.996	0.931	0.832	0.165	1.000	**0.000***	1.000	0.970	

Appendix 4.3.13: Results for the one-Way ANOVA performed on the chromium concentration of the tests of each station in St Helena Bay. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 99, MS error = 0.0070. Significant differences at $p < 0.05$ *.

	SHA	SHB	SHC	SHD	SHE	SHF	SHG	SHH	SPA	SPB	SPC
Mean (Wt %)	0.03	0.03	0.026	0.71	0.83	0.054	0.046	0.124	0.078	0.063	0.023
SHA											
SHB	1.00										
SHC	1.00	1.00									
SHD	0.99	0.99	0.98								
SHE	0.94	0.94	0.91	1.00							
SHF	1.00	1.00	1.00	1.00	1.00						
SHG	1.00	1.00	1.00	1.00	1.00	1.00					
SHH	0.31	0.31	0.25	0.94	0.99	0.73	0.59				
SPA	0.97	0.97	0.95	1.00	1.00	1.00	1.00	0.98			
SPB	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.87	1.00		
SPC	1.00	1.00	1.00	0.97	0.88	1.00	1.00	0.22	0.93	0.99	

Appendix 4.3.14: Results for the one-Way ANOVA performed on the iron concentration of the tests of each station in St Helena Bay. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 99, MS error = 7.69. Significant differences at $p < 0.05$ are in bold*

	SHA	SHB	SHC	SHD	SHE	SHF	SHG	SHH	SPA	SPB	SPC
Mean (Wt %)	1.514	1.081	2.47	3.169	4.643	2.804	3.678	6.979	1.313	2.031	2.086
SHA											
SHB	1.000										
SHC	1.000	0.989									
SHD	0.960	0.840	1.000								
SHE	0.304	0.147	0.804	0.982							
SHF	0.994	0.948	1.000	1.000	0.922						
SHG	0.808	0.584	0.996	1.000	0.999	1.000					
SHH	0.001*	0.000*	0.018*	0.091	0.726	0.041*	0.233				
SPA	1.000	1.000	0.997	0.918	0.222	0.981	0.711	0.001*			
SPB	1.000	1.000	1.000	0.998	0.576	1.000	0.962	0.006*	1.000		
SPC	1.000	0.999	1.000	0.999	0.607	1.000	0.970	0.007*	1.000	1.000	

Appendix 4.3.15: Results for the one-Way ANOVA performed on the copper concentration of the tests of each station in St Helena Bay. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 99, MS error = 0.113. Significant differences at $p < 0.05$ are in bold*

	SHA	SHB	SHC	SHD	SHE	SHF	SHG	SHH	SPA	SPB	SPC
Mean (Wt %)	0.579	0.549	0.746	0.757	0.492	0.772	0.553	1.442	0.662	0.444	0.628
SHA											
SHB	1.000										
SHC	0.989	0.965									
SHD	0.983	0.950	1.000								
SHE	1.000	1.000	0.838	0.800							
SHF	0.970	0.922	1.000	1.000	0.741						
SHG	1.000	1.000	0.970	0.956	1.000	0.931					
SHH	0.000	0.000	0.001	0.001	0.000	0.001	0.000				
SPA	1.000	1.000	1.000	1.000	0.989	1.000	1.000	0.000			
SPB	0.998	1.000	0.645	0.594	1.000	0.525	1.000	0.000	0.936		
SPC	1.000	1.000	0.999	0.999	0.998	0.997	1.000	0.000	1.000	0.978	

Appendix 4.3.16: Results for the one-Way ANOVA performed on the zinc concentration of the tests of each station in St Helena Bay. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 99, MS error = 0.0754. Significant differences at $p < 0.05$ *.

	SHA	SHB	SHC	SHD	SHE	SHF	SHG	SHH	SPA	SPB	SPC
Mean	0.449	0.475	0.693	0.682	0.481	0.73	0.51	1.172	0.591	0.398	0.562
SHA											
SHB	1.000										
SHC	0.658	0.791									
SHD	0.717	0.839	1.000								
SHE	1.000	1.000	0.818	0.862							
SHF	0.450	0.596	1.000	1.000	0.630						
SHG	1.000	1.000	0.920	0.945	1.000	0.782					
SHH	**0.000***	**0.000***	**0.008***	**0.006***	**0.000***	**0.020***	**0.000***				
SPA	0.986	0.997	0.999	1.000	0.998	0.988	1.000	**0.001***			
SPB	1.000	1.000	0.376	0.433	1.000	0.213	0.998	**0.000***	0.890		
SPC	0.998	1.000	0.992	0.996	1.000	0.953	1.000	**0.000***	1.000	0.960	

Appendix 4.3.17: Results for the one-Way ANOVA performed on the lead concentration of the tests of each station in St Helena Bay. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df = 99, MS error = 0.422. Significant differences at $p < 0.05$ *.

	SHA	SHB	SHC	SHD	SHE	SHF	SHG	SHH	SPA	SPB	SPC
Mean (Wt %)	0.708	0.322	0.219	0.266	0.395	0.369	0.393	0.584	0.52	0.152	0.631
SHA											
SHB	0.962										
SHC	0.841	1.000									
SHD	0.910	1.000	1.000								
SHE	0.992	1.000	1.000	1.000							
SHF	0.985	1.000	1.000	1.000	1.000						
SHG	0.991	1.000	1.000	1.000	1.000	1.000					
SHH	1.000	0.998	0.974	0.991	1.000	1.000	1.000				
SPA	1.000	1.000	0.994	0.999	1.000	1.000	1.000	1.000			
SPB	0.708	1.000	1.000	1.000	0.999	1.000	0.999	0.921	0.972		
SPC	1.000	0.992	0.941	0.974	0.999	0.998	0.999	1.000	1.000	0.858	

Appendix 4.3.18: Results for the one-Way ANOVA performed on the trace metals and Ca and Mg concentration of the tests of the control (CSH) and pipeline (PSH) sites in St Helena Bay. The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df =99. Significant differences at $p < 0.05$ *.

	Mg			Cd			Ca			Cr		
Site	Mean	p	MS	Mean	p	MS	Mean	p	MS	Mean	p	MS
CSH	0.31	0.036*	0.117	0.017	0.877	0.0044	75.95	0.07	426.72	0.054	0.855	0.007
PSH	0.466			0.019			68.04			0.058		

	Fe			Cu			Zn			Pb		
Site	Mean	p	MS	Mean	p	MS	Mean	p	MS	Mean	p	MS
CSH	1.81	0.025*	9.356	0.577	0.07	0.166	0.517	0.064	0.108	0.434	0.843	0.416
PSH	3.29			0.736			0.649			0.407		

Appendix 4.3.19: Results for the one-Way ANOVA performed on the trace metals and Ca and Mg concentration of the tests of the St Helena Bay (SH) and Robben Island (RI). The Tukey Honest Significant Difference (HSD) Test was performed to obtain a statistical significance, df =188. Significant differences at $p < 0.05$*.

	Mg			Cd			Ca			Cr		
Site	Mean	p	MS Error	Mean	p	MS Error	Mean	p	MS Error	Mean	p	MS Error
SH	0.424	**0.0003**	0.092	0.019	0.164	0.0066	70.202	**0.0001**	350.47	0.058	0.276	0.009
RI	0.263			0.035			80.467			0.072		

	Fe			Cu			Zn			Pb		
Site	Mean	p	MS Error	Mean	p	MS Error	Mean	p	MS Error	Mean	p	MS Error
SH	2.888	0.082	21.232	0.693	0.071	0.617	0.613	0.155	0.241	0.414	0.384	0.484
RI	1.712			0.901			0.715			0.326		