Technical Report

Adelaide Coastal Waters Study

***Stage 2** Research Program 2003 - 2005*

Technical Report No. 16 October 2007

Adelaide Coastal Waters Study - Sediment Budget

Final Technical Report

Government of South Australia

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Adelaide Coastal Waters Study Coastal Sediment Budget

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ISBN 1 92 1125 19 5

October 2007

Reference

This report can be cited as:

Bone, Y., Deer, L., Edwards, S. A., E. Campbell (2006). "*Adelaide Coastal Waters Study – Sediment Budget".* ACWS Technical Report No. 16 prepared for the Adelaide Coastal Waters Study Steering Committee, March 2007. Adelaide University, Department of Geology.

Acknowledgement

This report is a product of the Adelaide Coastal Waters Study. In preparing this report, the authors acknowledge the financial and other support provided by the ACWS Steering Committee including the South Australian Environment Protection Authority, SA Water Corporation, the Torrens Patawalonga and Onkaparinga Catchment Water Management Boards, Department for Transport Energy and Infrastructure, Mobil Refining Australia Pty Ltd, TRUenergy, Coast Protection Board and PIRSA. Non-funding ACWS Steering Committee members include the Conservation Council of SA, SA Fishing Industry Council Inc, Local Government Association, Department of Water Land and Biodiversity Conservation and Planning SA.

Acknowledgement

The project team (led by Yvonne Bone) was ably assisted throughout the life of the Study by research assistants Linda Deer and Sally Edwards, and by technical assistant Siobhan George. Elizabeth Campbell has assisted the team periodically, and her support has been greatly appreciated. In addition, the crew of Flinders University's research boat *RV Hero* and the crew of the *Divers Delight* diving boat worked with the project team to successfully and safely complete the challenging field research tasks, at many times against the odds of weather and competing commitments.

EXECUTIVE SUMMARY

Aims

The following aims were stated in the original proposal:

1. Quantify the sources of the sea-floor sediments and the volume derived from each source;
2. Experimentally determine the time factor involved in the production of sand-sized grains from each source;
3. Experimentally trace the movement of sand from each source to its sequence of temporary depositional sites to its permanent accumulation site;
4. Determine the sediment budget for different periods of time (includes age-dating of components), and the parameters controlling non-linear events.

However, as the project progressed, there was a request from the Technical Review Committee to delete the time-factor aims and to concentrate only on the spatial distribution, density and type of sediment throughout the ACWS area and on the sources of these sediments. Thus the new set of aims became:-

1: determine the physical, chemical, mineralogical and biological characteristics of the sediments veneering the sea-floor in the Adelaide Coastal Waters Study area.
2: determine, from these characteristics, the sediment source(s), and the probability of the ongoing supply of sediment from such a source(s), i.e. is the production of the sediments autochthonous or allochthonous?

These aims interact with the other ACWS Stage 2 research tasks inasmuch as they provide:

- grain size data for researchers modelling the hydrodynamics of the system;
- substrate data for researchers working on seagrass aspects of the system;
- ground-truthing for researchers working with remotely accessed data;
- appropriate sediment characteristics data to researchers working on the adsorption of nutrients, etc to sediment grains on the sea-floor;
- sea-floor correlation (geographic and type) of sediment input of terrigenous material via natural and anthropogenic sources for future management strategies;
- generalised timing of the processes affecting the sediments on the sea-floor to assist all tasks in our/their attempts to predict future patterns.

Further research was undertaken to:

(a) provide Penrice with data of the seafloor sediment characteristics resulting from their dump site
(b) provide the appropriate authorities, via the Stakeholders, with a scientifically accurate, comprehensive, easy to use, 21st century data bank of the Adelaide Coastal Waters sediment budget,
(c) provide suggestions for the ongoing management and/or monitoring of these sediments.

The aim to determine the source (area) of the sediments veneering the sea-floor in the ACWS area developed into a multi-faceted project in itself, with many unexpected types of sediment significant in localised areas, e.g. heavy mineral sands in the Sellicks Beach area, derived from the Cambrian age Kanmantoo Schist, transported to the site by Permian glacial ice; and the barytes grains in the Moana area, derived from an old barytes quarry situated in the upper reaches of Pedler Creek. Thus, these two examples are indicative of the complexity of answers to the subsidiary aim of assessing the continuing viability of areas as future sources of sediments, and to flag those either already unavailable or under threat of becoming unavailable. For example, in the former, the transport ceased over 200 Ma but many of the rocks that were transported then are still eroding to produce more of their component grains but at a diminishing rate. In the latter example as long as the quarry is part of the local drainage system, and as long as the deposit itself is not eroded away completely, barytes grains will continue to be transported to the coastal area.

Preliminary Work

Literature review

A review of the literature on prior research was undertaken to determine its relevance to the current study and was presented to the Managers. There is some excellent material, describing the painstaking work undertaken by many notable scientists, going right back to the late 1800s with the work of such researchers as Howchin, Tate, followed in the 1900s by Mawson, Sprigg, Shepherd, Hails, von der Borch, Gostin, Belperio, Harvey and many others.

Previously acquired sediment samples were assessed for their suitability for incorporation into the project. Understanding of the sedimentary processes involved in the production, deposition and accumulation of sediments of mixed origin such as those in the study area, i.e. a package of grains predominantly derived from allochthonous terrigenous sources and autochthonous biogenically produced particles, along with contributions from other sources such as physical erosion of the coastline, has undergone major advances during the last two decades. The archived material had neither been sampled nor processed in the laboratory by currently-acceptable methods, necessitating the collection of a new set of samples. Sediment cores collected by various researchers and samples collected for this study have been archived at the PESA Core Library Conyngham St, Glenside, and are a valuable resource, particularly if research on geological timing is needed.

Research

Transects were sited orthogonally along the coast, so that they covered the four different geological zones present in the ACWS area. Up to 8 sites were located on each transect, from the back of the beach to a maximum of 20 m water depth. Co-ordinates were recorded for each site so that a return could be made to each site for the second (Winter) field season. Circumstances, usually weather related, often precluded this, so the best attempt was made to duplicate the sites. A third shortened marine field season supplemented the earlier ones, and also provided underwater photography of sites to illustrate salient points.

Additional limited field work was undertaken to provide samples that would be representative of the sediment debouching on to the beach/sea-floor from a number of different drainage outlets, i.e. drains, creeks and rivers.

The two sets (Summer and Winter) of sediment samples collected provided the material needed for the laboratory research. All photos, maps and data generated are presented in the Appendices with representative examples in the Results chapter. Grain size, mineralogy and biogenic components analyses are best illustrated by pie diagrams. These show the percentage of each for all the samples taken across each transect, for both the Summer and Winter. They are more accurate than facies maps as they pinpoint small anomalies as well as showing the overall scenario. The maps illustrate the distribution of grain size fractions, mineralogy, individual biota, relict grains, terrestrial loads and heavy mineral sediment grains at each sample site, during Summer and Winter, so that seasonal differences can be noted.

The rationale for tables of data, maps and pie diagrams (rather than using complex statistical techniques) is that it was felt that all levels of management of the stakeholders would appreciate the simplicity and impact of these and understand immediately the implications of the data (An example is outlined in the Management Strategies chapter). Those who wish to use complex statistics can access the data and produce their preferred package.

Results

Grain size analysis

The physical characteristics of the sediments veneering the sea-floor in the ACWS area indicate that the size of the grains at any sample site is influenced more by the source of the grains than by any other factor. For example, if the grains were sourced from the River Torrens outflow, they are weighted towards the fine fraction; if they were sourced by the turnover of prolific gastropod activity, they consist of coarse skeletal carbonate grains. The hydrodynamics at each site also has a profound effect on the material that remains in place, with the finer or more buoyant grains moving elsewhere in response to water movement. Erosion, via abrasion, chemical alteration or dissolution and biological activity are minor contributory factors once the grains have accumulated.

The grains size distribution maps are a composite of grains that have accumulated and that will remain more or less permanently in place, and grains that are only temporarily in a particular site. The latter are the package that will respond to extrinsic parameters acting upon them, and be moved to a new location, particularly northwards by longshore drift. This is predominantly the fine sand fraction and the finer half of the medium sand fraction. Back-of-beach sand dunes are no longer present to act as natural reservoirs during storms and extra high-tides. The grain size in such sand dunes elsewhere in South Australia shows that the grain size in the dunes is coarser than in the adjacent intertidal area, due to the winnowing action of both water and wind.

So, if artificial sand replenishment is continued, there is no point in using sand with these grain sizes. It needs to be coarser, i.e. coarse and the upper limit of medium. Grit would be ideal. Hydrodynamic activity will cause the dilution of the coarser external sand by the local material, so that although the finer material will still be moved northwards, this will be compensated for by the external material remaining in place.

Ideally, this allochthonous material should be mineralogically comparable with the local material, particularly considering the necessity for a comparable substrate in which the local biota can flourish.

The sediment grains in the ACWS area are heterogeneous in terms of grain size. This has been the case for at least the last 125Ka.

Mineralogy of the sediment components

The mineralogy of the sediment veneer of the sea-floor in the ACWS area consists essentially of quartz and carbonate. Simplistically, the quartz is derived from the land and the carbonate grains are produced *in situ* by calcareous biota. These two minerals combined make up >90% of the sediment grains. The hardness of the quartz, together with the fact that it is not part of the life-cycle of any of the biota present (siliceous biota use amorphous silica, not crystalline quartz) predisposes it to a longer residence time within the ACWS area, once it has reached the sea-floor. However, carbonate is a renewable fraction on the sea-floor itself, so although it has a shorter residence time, it has a greater ongoing production aspect. Other minerals, all terrigenous in origin, play a minor role, other than in a few localised areas, such as the deposition of heavy minerals.

Each of these mineralogies - calcareous and siliceous - are equally important, and the balance must be maintained or else a healthy environment suitable for the current biota assemblage will not be maintained. One of the reasons that the coast of southern Australia has such extensive seagrass meadows is because of this mixed sediment substrate.

There is a marked decrease in the carbonate fraction in the sediment in the intertidal and beach areas in the ACWS area, except in the northern part. This is in contrast to other South Australian coastal areas that have extensive seagrass beds closer to shore. There is a correlation between mineralogical composition of the sediment grains and distance of the seagrass line from the shore. Note: this refers to seagrass, not to marine algae.

Overall in the ACWS area, the initial deposition rates of quartz and carbonate grains are similar. Accumulation rates of carbonate are greater than of quartz because of the chemically inert nature of quartz and its hardness in contrast to the softness and chemically-reactive nature of carbonate grains. Sandy beaches are dominated by quartz grains whereas the production of carbonate grains is much higher than the influx of quartz grains in the offshore area.

Biogenic components
The marine calcareous biota, once they are dead, contribute their skeletal elements to the sediment budget veneering the sea-floor in the ACWS area. The biota in the ACWS area play a major role in the production and turnover of the sediment grains. The most significant role is that of the calcareous-secreting biota. These grains are predominantly limited to the benthic environment, including a large infaunal component. The architecture of the organism/colony and the carbonate species used control the size of the resultant grains.

Other contributing factors, however, include the munching and ingestion of some calcareous biota by predators, thereby both recycling the carbonate and reducing the fragments in size. A healthy environment sees this activity as a constant recycling. Disruption of the healthy environment breaks this cycle and thus carbonate production declines and the cycle is broken.

Seagrass beds provide a favourable environment for biogenic carbonate production, and also supply an ideal substrate for calcareous epiphytes. Many of these are passively carried on to the beach with the shedding (or destruction/ death) of the seagrass leaves, where they remain as carbonate sand grains once the seagrass decays.

This continuous supply of carbonate fragments is only maintained when there is a healthy assemblage of biota (both calcareous and organic), which presupposes a healthy sea. The variety of biota in an assemblage decreases markedly in the shallow intertidal area in areas of pollution discharge. Comparisons of the highs and lows of diversity and distribution of biota in the pie diagrams depicted here with the results on pollution levels from IS 1, show a positive correlation. Earlier field studies (by the senior author) showed the degradation of the biota of the near-shore area at Trig Point, Seaford, following the installation of the stormwater drain. Prior to the drain emplacement, the assemblage was highly diverse and the distribution was moderate. Two years later the assemblage was restricted to a few species of robust gastropods, with *Turbo* sp. prolific, and the plant life was smothered by *Ulva* sp., and all the other beautiful marine life had gone. Five years later it has still not returned. The assemblage that is now present is not one that produces large volumes of sand-sized carbonate sediment grains, so the sediment budget from this source is severely depleted.

The removal of living and dead marine biota in the ACWS area needs to be limited. This includes dead *Posidonia* spp. washed up on the beach. Each blade is usually encrusted by calcareous epiphytes. When the grass rots away, the carbonate grains remain behind and supply the beach with more “sand”. This is a significant source of sediment grains. A kg of seagrass at Semaphore hosts, i.e. produces, ~ 1.089 kg of carbonate sediment in a single year, 0.307 kg at Marino and only 0.285 kg at Torrens Island, whilst at Ardrossan the rates are 1.093 kg and 0.693 kg at Normanville (Brown et al. 2000).

Diversity, density and distribution of biota in the marine realm are driven by a number of parameters, such as the chemical (e.g. the presence of sufficient necessary nutrients, salinity), and physical (e.g. temperature, depth, photic zone depth, hydrodynamic system) characteristics of the water column. The parameter that is most critical, however, is the sea-floor and its veneer of sediment.

The ongoing production of sediment grains by calcareous-secreting biota is dependent on the maintenance of a “healthy” sediment substrate. It is this substrate that is the lynch-pin for all biotic activity that occurs within, on and above it. In the near-shore ACWS area, seagrasses are the most visible biota. These seagrass meadows need a healthy substrate in which to, firstly, become established, and then to maintain healthy growth. The interaction between sediment, plants and fauna is a complex, interdependent web. The cyclicity of this web can only be maintained by attention to the ongoing stability of all members of the web. To view and treat the sediment as of secondary importance due to its inanimate nature is to risk breaking the cycle of a healthy coastal environment.

Sources of sediment components

Two sources of sediment grains: autochthonous and allochthonous are present.

Autochthonous grains are derived from, or formed, in the accumulation site, i.e. the sea-floor. The major group is the biogenic carbonate grains. These vary both within the autochthonous group and in the total sediment composition. Most deep-water sites have >70% biogenic carbonate (exceptions are disturbed sites such as Mid-Barker Inlet, North Haven and West Beach). At the other extreme, beach samples have mainly <10% biogenic carbonate (exceptions Port Gawler North and St Kilda). Healthy seagrass beds have a high biogenic carbonate component in the underlying sediment, but whether this is because the seagrass is there - or whether the seagrass is there because of the favourable carbonate-grain substrate - is not clear. Relict grains are a major component, making up to 98% of the total, but as they were originally biogenic carbonate grains, there is an apparent statistical conflict with the modern carbonate content. This is best exemplified in the high biogenic carbonate in the shallows of the northern part of the ACWS area, where the density of living molluscs, both infaunal and epifaunal, is very high compared to the high relict percentage in the deeper waters where there is an increase of fine silt, which is an unfavourable environment for most molluscs. Further supplies of relict grains will not be available.

Minor sources of autochthonous grains are authigenic minerals. These include authigenic feldspars and clays and also silica minerals such as opal-A, which are biogenically produced by biota such as sponges (spicules) and diatoms (tests). There are no dense siliceous sponge beds in the ACWS today, although there were in the past (James and Bone 2000).

Autochthonous grains can be long-lasting in the marine realm or they may disappear rapidly (James et al. 2005). The carbonate grains that have formed since the adjustment of sea-level down to its present level 6 Ka ago are today’s autochthonous carbonate fraction of the sediment grains veneering the sea-floor. Other equally significant carbonate grains are those that were stranded on the sea-floor during the last regression and then those that have been stranded and submerged through a number of glacial and inter-glacial episodes, so that they must be viewed as allochthonous in terms of ACWS PPM 1, although their primary production was as autochthonous grains.

Allochthonous grains are those formed elsewhere and transported to a new depositional site far-removed from their origin, e.g. quartz grains from the Aldgate Sandstone carried by the Onkaparinga River to the beach at Pt Noarlunga.

Relict grains are a significant fraction of the sediment components, but they are not renewable.

Heavy minerals occur as two entirely different groups:

- ilmenite grains sourced from the Neoproterozoic Aldgate Sandstone and transported to the coast mainly by the Onkaparinga River. This is a renewable source.

- a heavy mineral suite sourced from the physical erosion of Cambrian Kanmantoo Group rocks from the Encounter Bay area and transported as erratics by the Permian glaciation. This is a non-renewable group.

Both groups are concentrated locally, but overall are not significant.

Rivers, creeks and stormwater drains episodically debouch large volumes of sediment into the intertidal area. The fine fraction is environmentally significant as it precludes normal metabolic processes from occurring in the marine biota. These drainages are the source of most of the quartz fraction that forms a major component of the sediment budget. The source areas are widespread, but many are steadily becoming sterilised by new urban development, after an initial dramatic increase as the development is commenced. Urban development leads to depletion of the quartz grains in the fine to coarse size fractions and the renewing of "sandy" beaches.

Natural sources of sediment grains are a complex web, providing autochthonous and allochthonous grains to a common deposition site on the sea-floor. Anthropogenic activity over the last 200 years is an additional, "no-return" factor that has had an impact on the coastal area. Anthropogenic activity and natural processes change the rate of supply (slower or faster) and even the complete shut-off of supply of allochthonous grains. Many of the anthropogenic factors cannot be remedied, e.g. roads, sea-side housing after removal of sand dunes, stormwater drains, sea-walls, marinas, distant sources in the Mt Lofty Ranges, floodwater mitigation schemes, etc. Not all river loads are "bad". Indeed, the seafloor benefits from the bed-load of waterways that drain unpolluted countryside, including boulders to branches to dead biota – but not cigarette butts, plastic, bottles, cans, etc. If the unpolluted countryside is no longer available, then the load should still be debouching on to the sea-floor after it has been decontaminated.

Cliff-face erosion produces sediment grains in the interface area, so that they are neither autochthonous nor allochthonous. Yet this physical process is probably responsible for the largest portion of the non-carbonate sediment grains, and also carbonate grains where the cliffs are limestones.

Industrial sources of "sediment grains" are mainly unknown, emanating from a myriad of different industries. Environmentally-concerned industries ask to have their waste monitored, e.g. Penrice. This practice should be publicised to encourage other industries to do likewise.

Anthropogenic beach and marine activities carelessly contribute an array of unsightly material into the area. The quantity is unknown, but little of it appears to become part of the sediment budget.

Climate Change

The current concern about "global warming" warrants comment. Regardless of the individual scientist's perception of warming or cooling, the reality, indisputably obtained from the geological record, is that change is always occurring. Whichever way the global temperature goes, there will be a geomorphic response in the coastal region, and more significantly, in the drainage basin pattern. If climate warms, sea-level will rise and smaller loads of sediment will be delivered to the coastal area as the erosive power of the rivers and creeks will decrease in the low-lying areas, with the load deposited before it reaches the coast. On the other hand, if climate cools, sea-level will fall, and the drainage system will deliver a larger load due to the increased down-cutting power of the fluvial channels, but it will be delivered much further out than it does today, as the coast will have shifted downslope.

The coastal area is the most vulnerable and most fragile area at all times, rapidly responding, in the geological sense, to sea-level changes, even those of only a few centimetres.

Monitoring
Monitoring of the distribution and abundance of biota that is temperature-dependent is another method of predicting approaching change, but this must be differentiated between the aforementioned pollution links. Nevertheless, they are both activities in which the general community, particularly school children, could be involved, under the guidance of volunteer scientists.

Finally, those responsible for the future management of the ACWS area must decide and then publicise their decisions regarding the future plans for the sediment budget, in terms of:

- are there to be beautiful, permanent “sandy” beaches scattered throughout the area for use by the public?
- is the substrate to be mineralogically altered to increase the re-establishment of seagrass?
- is the removal of benthic biota to be allowed?
- is the mining of shell-grit in the north and sand in the south to be allowed?
- is the continuation of external sand-replenishment to continue?
- are further major geomorphologic changes to the sea-floor to be allowed with all their accompanying results?
- is there to be greater education of the general public about the sea-floor and all its ramifications?
- is there to be “purification” of river and other bed-loads before they debouch on to the beach or sea-floor?
- are suburban roads and footpaths going to be kept free of material that currently goes into the sea?

Each question impacts on the veneer of sediments on the sea-floor in the ACWS area. Without that veneer, there will soon be no sandy beaches, little marine biota and Adelaide will lose one of its most beautiful attractions - its beautiful beaches, where swimming, playing and relaxing are enjoyed for no monetary cost.

Conclusions
In all samples and for most parameters, heterogeneity is glaringly obvious, even within remarkably small areas. Thus, overarching recommendations for future management are difficult to make with any great confidence, although suggestions can be made.

Contents

1 INTRODUCTION

The Adelaide Coastal Waters Study (ACWS) is a multidisciplinary project designed to understand the various factors affecting the Adelaide coastal area. The major aims were to determine how to prevent further seagrass loss, reduce coastal erosion and improve water quality. The study area is the beach and offshore region extending up to 20 km from the shoreline between Port Gawler and Sellicks Beach.

This technical report concerns the work carried out by the PPM 1 Task of the ACWS.

1.1 Aims

The following aims were stated in the original proposal:-

1. Quantify the sources of the sea-floor sediments and the volume derived from each source;
2. Experimentally determine the time factor involved in the production of sand-sized grains from each source;
3. Experimentally trace the movement of sand from each source to its sequence of temporary depositional sites to its permanent accumulation site;
4. Determine the sediment budget for different periods of time (includes age-dating of components) and the parameters controlling non-linear events.

However, as the project progressed, there was a request from the Technical Review Group to delete the time-factor aims and to focus on the spatial distribution, density and type of sediment throughout the ACWS area and on the sources of these sediments. Thus the new set of aims became:-

1. Determine the physical, chemical, mineralogical and biological characteristics of the sediments veneering the sea-floor in the Adelaide Coastal Waters Study area.
2. Determine, from these characteristics, the sediment source(s), and the probability of the ongoing supply of sediment from such a source(s), i.e. is the production of the sediments autochthonous or allochthonous?

These aims would interact with the other Stage 2 research tasks inasmuch as they would:-

- provide grain size data to researchers working on modelling the hydrodynamics of the system (PPM 2);
- provide substrate data for researchers working on seagrass aspects of the system (EP 1);
- provide ground-truthing for researchers working with remotely accessed data;
- provide appropriate sediment characteristics data to researchers working on the adsorption of nutrients, etc. to sediment grains on the sea-floor;
- provide information, for future management strategies, on the source of terrigenous material via natural and anthropogenic means;
- provide generalised timing of the processes affecting the sediments on the sea-floor to assist all tasks in our/their attempts to predict future patterns.

Further aims were to:-

- provide Penrice with data of the seafloor sediment characteristics resulting from their dump site;
- provide the appropriate authorities, via the Stakeholders, with a scientifically accurate, comprehensive, easy to use, 21st century data bank of the ACW Sediment Budget;
- provide suggestions for the ongoing management and/or monitoring of these sediments.

The characteristics of sedimentary grains are dependent on their source, i.e. whether allochthonous (sediment formed elsewhere and transported to its deposition/accumulation site) or autochthonous (sediment formed within the depositional environment, i.e. *in situ*. The determination and quantification of the physical characteristics of the sediment grains was the lynch-pin upon which the other aims would hinge, so the first priority was to assess whether previous studies and the availability of previously collected sample material was appropriate to use for our study.

1.2 Previous Investigations

1.2.1 Previous research

Literature review
A review of the literature on prior research was undertaken to determine its relevance to current standards and was presented to the Managers. There is some excellent material, describing the painstaking work undertaken by many notable scientists, going right back to the late 1800s with the work of such giants as Howchin, Tate, followed in the 1900s by Mawson, Sprigg, Shepherd, Hails, von der Borch, Gostin, Belperio, Harvey and many others. Their publications are located in various places additional to libraries. All of them are worth reading, but only some of them contain information to help set the scene for determining what research is needed to provide the information that is needed for the management of the coastal environment in the 21^{st} Century.

Previous field work
Previously acquired sediment samples were assessed for their suitability for incorporation into the project. It was found that the field methodology used last century was inadequate to meet the demands of the scientific rigour now taken as the acceptable norm. Understanding of the sedimentary processes involved in the production, deposition and accumulation of sediments of mixed origin such as those in the study area, i.e. a package of grains predominantly derived from allochthonous terrigenous sources and autochthonous biogenically produced particles, along with contributions from other sources such as physical erosion of the coastline, has undergone major advances during the last two decades. The understanding of modern mixed carbonate-terrigenous sediments prior to 1990 was based on work undertaken in tropical environments or on earlier work on sediments derived from terrigenous sources only. Neither of these models is applicable to the ACWS area. For example, in the measurement of grain size, the biogenically derived grains are constrained by metabolic processes and can vary over many orders of magnitude.

Similarly, the archived material in existence had neither been sampled nor been processed in the laboratory by currently-acceptable methods, necessitating the collection of a new set of samples. Sediment cores collected by various researchers and held mainly at the PESA Core Library at Glenside, are a valuable resource and would have been ideal for study on time-frames had this continued as part of the study.

Special attention was paid to previous field studies, e.g. Hails et al. (1984), Sprigg and Stackler (1965). Some of these workers were contacted and their results discussed with them. It was found that they no longer felt that their results should be used, as their methods, although customarily used at the time, have now been superseded by newer technology. This newer technology, discussed below, was used throughout this study.

1.3 Research Plan

The project was sub-divided into four individual sections that would provide the answers to the questions posed by the Stakeholders.

1.3.1 Grain size analysis

The size of the sediment grains in all environments is the most important parameter when determining the hydrodynamic activity of sediments. Thus, the grain size analysis became the priority task in the laboratory research. Other grain parameters are also significant, e.g. composition (mineralogy) of grains, biogenic origin of grains and architecture, and so these are discussed separately.

Reconnaissance field and sampling research undertaken by PPM 1 showed the heterogeneity of both the sediments and the environments within the ACWS area, at all levels, i.e. from the micro to the macro.
The various physical characteristics can be either determined:-

- *qualitatively* by observation both in the field and in the laboratory and of photographs taken in both sites, or
- *quantitatively* by measuring the parameters in the laboratory on samples collected in the field.

Qualitative parameter observations undertaken in this study consisted of shape; colour; sorting; variability; local environment and associated biota. Quantitative parameters measured in the laboratory consisted of grain size.

The conventional subdivision into coarse sand and gravel, medium sand, fine sand and silt, and clay fractions were used throughout the study:-

>2mm	coarse
2mm - 0.25mm	medium
0.25mm - 0.063mm	fine
<0.06 (in collection pan)	very fine (includes silt and clay)

1.3.2 Mineralogy of the sediment components

The aim of this section was to determine the mineralogy of all the grains that form the sediment veneer of the sea-floor in the ACWS area. The mineralogy of the sediment grains is significant in that it affects the progression of the sediment grains, from their first appearance on the sea-floor to either their ultimate disappearance from that environment or their permanent retention as components in lithified rocks.

Mineralogy can be addressed in terms of an array of physical, chemical and biological changes. These may occur individually, e.g. physically - the simple breakage of a quartz grain into two pieces, chemically - the complete dissolution of a small aragonitic gastropod, and biologically - the consumption of a calcitic foraminifer by a predator. Examples of interacting processes are illustrated by the physical breakage of a heterogeneous grain into smaller particles that can then be partially dissolved in the sea-water, thereby making them indirectly available as nutrient for other biota.

Knowledge of the mineralogy provides the ability to predict the future budget (stability), spatially and time-wise, in the overall sea-floor ecosystem. All minerals react due to the elements they contain and according to how these are connected to one another in the individual atom, and whether these can or cannot be utilised by individual biota. All of these processes can be termed erosional processes when they occur on the sea-floor.

Physical erosion
The strength and arrangement of the bonds in a mineral determine how easily and in what manner a mineral will break and the subsequent shape of the smaller pieces of that mineral (grains). Thus, when a quartz grain is subjected to physical pressure due to the collision of two grains, the impact may result in the breakage of the grain into two smaller but similarly-shaped grains, with fractured surfaces and occasionally conchoidal fractures (Figure 1.1). This example can be seen in the Onkaparinga Estuary area where large quartz grains are transported from the Mt Lofty Ranges on to the beach and the sea-floor (Figure 1.2).

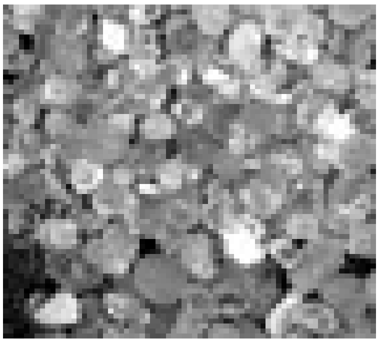


Figure 1.1 Quartz grains in marine sediments are well-sorted and rounded and have a polished surface. Sample is bulk fraction from Zone 3, transect p, 2m deep O'Sullivans Bch (x10)

Figure 1.2 Gravel patches at the back of the beach at Pt Noarlunga.

Platy, moderately-sorted pebbles, sourced from the Adelaide hills via the Onkaparinga River, show the effect of episodic movement, with transport phases causing diminution and still-times resulting in abrasion of current upper surface. In contrast, if the grain consisted of the mineral calcite, it will break into two, or frequently more, rhombohedral cleavage fragments, with planar faces and sharp corners, with the latter now having an increased susceptibility to further erosion (Figure 1.3). Examples of this can be seen at Marino Rocks where there are calcitic veins cutting the bedrock yet few small rhombs of calcite in the sediment grains forming in this high wave-energy zone.

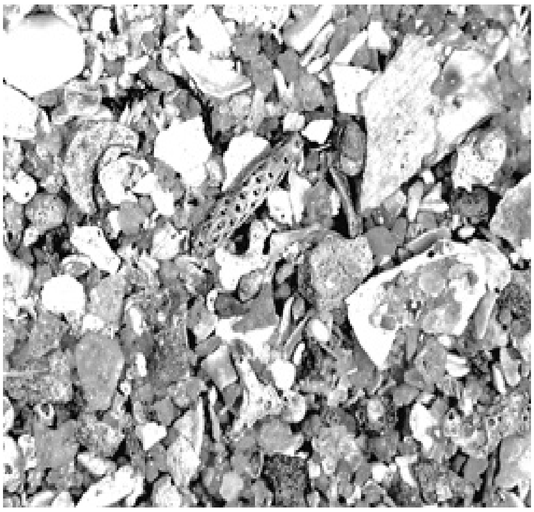


Figure 1.3 Biogenic fragments are readily eroded by physical, chemical and biological processes. This bulk sample from Zone 1, Transect d, 10m depth is almost entirely carbonate (x10).

Chemical erosion

The chemical composition (mineralogy) of the grains influences their disintegration by chemical (diagenetic) processes. Thus, a biogenic grain made of aragonite, such as a bed of intertidal mussels, which are frequently broken due to physical processes, are then readily chemically corroded (and dissolved) by the slightly acidic nature of meteoric waters. This example also occurs from Marino Rocks southwards.

Biological erosion

Many of the calcareous biota inhabiting the sea-floor obtain the carbonate they need for metabolic processes from pre-existing biogenic carbonate, such as skeletal carbonate fragments ("dead shells"), thus eventually eliminating any evidence of a prior primary organism. Other biota, e.g. whelks, are more predatory and will drill through the shell of a mollusc valve in order to eat the soft part of the "cockle". This biological erosion occurs at all size levels and both infaunally (living within the sediment) and epifaunally (living on or above the sediment). It is not limited to carbonate species, but is seen in examples of the feeding traces left on terrigenous and other rocks by such biota as long-spined echinoids etching a shallow bowl in which to anchor themselves in the supratidal area. The small chips excavated become eroded much easier than the original large rock. Good examples of this can be seen at Christies Beach.

1.3.3. Biogenic components of the sediment

This section aimed to determine which marine calcareous biota, once they are dead, contribute their skeletal elements to the sediment grains veneering the sea-floor in the ACWS area. A minor aim was to observe and record all non-calcareous biota in the samples and at the sample sites. Ancillary to these aims, a record of the living vs dead biota was kept.

A significant volume and weight of skeletal carbonate fragments is contributed to the sea-floor sediment veneer in the ACWS area. This is typical of cool-water environments across the temperate Australian region, particularly that part facing the Southern Ocean (James et al. 1992, 1996, 1997, 2001, Fuller *et al*. 1994). Indeed, in some environments the carbonate fraction is larger than all the other mineralogical fractions put together (Figure 1.4).

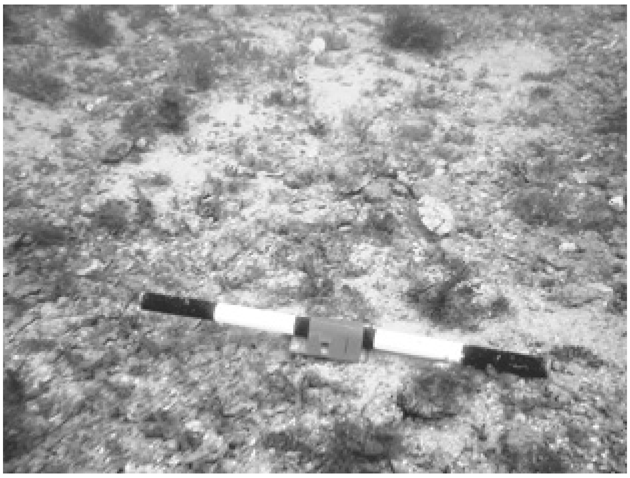


Figure 1.4 The sea-floor at a depth of 5 m off Christies Creek, O'Sullivans Beach.

The biodiversity at site in Figure 1.4 is high but the density is only moderate. There is no seagrass present and only stunted algae. Most of the surface biota is dead, and represents mainly the infaunal community. The open, shifting sandy substrate is not conducive to the establishment of a thriving benthic epifaunal community, as there are few hard substrates available for sessile invertebrates. Scale bar blocks are 10 cm.

One only has to observe Cenozoic-age limestone cliffs along the southern coast of Australia, to realise that the preservation of the sediments that veneered this area of the sea-floor throughout the last 60 My were dominated by biota (seen as preserved fossils) that used CO_3 species to construct their skeletons or cell walls i.e. that they were calcareous, having used one of the calcium carbonate minerals: high Mg calcite, intermediate Mg calcite, low Mg calcite or aragonite for their skeletal architecture. These minerals all have the same formula of CaCO3 but have different chemical and physical properties (James & Bone 1989, 1991, 1992, 1994, 2000, Gammon et al. 2000, Pufhal et al. 2004, Lukasik et al. 2000**,** Shubber et al. 1994, Li et al. 1996a & b, Schmidt & Bone 2003). Similarly, equivalent assemblages of biota are seen in samples of sediment collected today from the sea-floor off-shore from these cliffs across the entire southern margin of Australia. In other words, "the present is the key to the past", however this study is concentrated on what is there now and what we can expect in the near future.

Any assemblage of biota is affected by the state of the overall health of its environment. The overall health of the ACWS area is the lynch-pin of other Tasks, although at some levels of detail, the link is a little tenuous. One important link is the role of the sediments as the substrate for algae and plants, particularly seagrass, and for epifaunal and infaunal biota.

The expected assemblages of recently-dead calcareous biota from healthy environments in the near-shore area are well-documented (Cooper 1960, Farrell 1968, Burton 1984, Belperio et al. 1984, 1988, Gostin et al. 1984, Hageman *et al*. 1997, James et al. 2005, Ryan 1998, Shepherd and Sprigg 1976, Womersley 1974, Bone & James 1993). PPM 1 research compared current assemblages with those in both the literature and with personal observations over the last few decades.

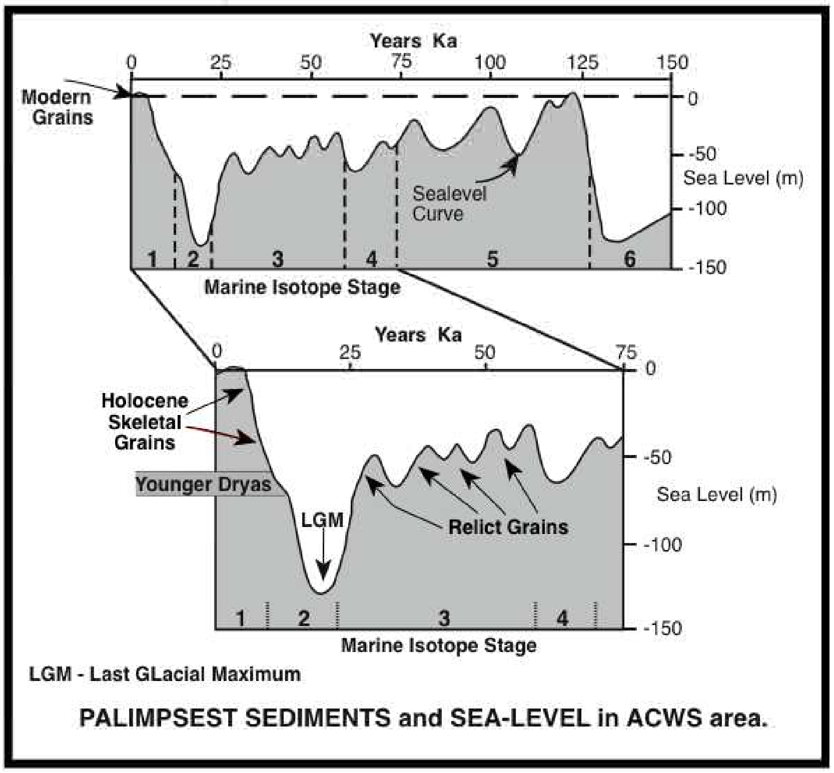


Figure 1.5 Sea-level over the last 150 Ka. The Adelaide coastal area was covered by the sea ~6 Ka and again ~125 Ka. The troughs in the curve are due to global glacial events, so that the present-day Gulf St Vincent was a terrestrial environment from ~11,000 to ~28,000 Ka ago (After Belperio *et al.* 1988).

1.3.4. Sources of sediment components

The major aim of this composite section was to determine the sources of the sediments, how and when those that are from elsewhere were transported to the sea-floor, which of the sediment grains are still available for further deposition and accumulation on the sea-floor and what is the significance and style of the *in-situ* production of sediment grains. Minor aims were to flag those fractions of the sediments that can no longer be replenished and suggest scenarios that might assist in management decisions.

One of the best ways to appreciate the fragility of the sea-floor is to consider the continental shelf as part of the continent of Australia, as indeed it is. A section of this area of Australia is currently covered by sea-water. Global sea-level is constantly changing, with this change climate dependent. Recently, i.e. only 6 Ka ago, sea-level at the western part of the metropolitan area, was 2 m higher; yet only 11 Ka ago it was 15 m lower (Figure 1.5). These constantly (but slowly) occurring changes subject the sea-floor to intense environmental stresses. The best way to appreciate the sea-floor and its fragility is to view it as land that is currently covered by the sea, complete with different soils (sediments) and erosion of the surface a constant process, removing the surficial material and depositing it elsewhere.

Allochthonous sediments

Physical, chemical and biological erosion on land produce smaller fragments of materials that can then be transported to a lower geomorphic level. Continuation of these processes often eventuates in the ultimate transport of such material to base level, i.e. the sea-floor. Heavy rain-storms are a major transportation mechanism whereby eroded material from the adjacent countryside is transported to a lower level. If there is no physical barrier, that base level will be the sea-floor. Thus, rivers draining the area are chutes along which enormous loads of sediment are transported, sometimes episodically, to the sea-floor. These rivers can have drainage basins that are many thousands of km^2, e.g. the Murray drainage basin is the 5^{th} largest in the world. Storm drains, roads, housing estate roofs, driveways, etc. also come into this category, albeit in a smaller capacity. Looking at the rubbish carried by the River Torrens after a storm, it is readily appreciated that here is one of the major sources of sediment supply to the ACWS sea-floor.

It was decided that we would make a cursory field and laboratory investigation at the completion of our major field and laboratory studies, as it was critical to the assessment of sediment sources.

Other important allochthonous sources include dust (researched by other Tasks), anthropogenic activities - especially dumping of rubbish at sea, glaciers and extraterrestrial activity. These are episodic events and do not have the same impact as the various drainage sources. The drainage sources are also viewed as episodic, but this is rather in intensity than in frequency.

Autochthonous sediments
Autochthonous sediment sources are primarily biogenic in temperate environments (Figure 1.6, 1.7). These are dominated by calcareous biota, with the majority of these invertebrates and coralline algae, and with important contributions from foraminifers. In addition, Opal-A, an amorphous form of quartz, is contributed to the sediments by sponge spicules and diatoms. Trace volumes consist of other biogenic minerals used by biota, such as apatite, the major mineral in teeth and bone.

Figure 1.6 Modern grains, shown in Sample ACWS 2f-bulk x 10 from the back of the beach at North Haven. Purple ‘rods’ are broken pieces of echinoid spines

Figure 1.7 Sample ACWS 2g-5-bulkx10 from 5 m water depth off Largs Bay dominated by stranded grains which are abraded and whitish in colour

Other important sediment grains forming part of the modern-day autochthonous sediment budget are those termed “relict” (Figure 1.8). These grains accumulated on the sea-floor during an earlier stage of the geological record, but they did not become lithified. They have often been through a number of glacially-induced sea-level rises and falls over the last 125 Ka (Figure 1.5 Rivers et al. *in press)* that were part of the Quaternary history of the ACWS area (Figure 1.5).

Figure 1.8 Sample ACWS 2h-7-bulk x 10 from 15m water depth contains numerous relict grains. These are the orange-brown stained grains that often lack any distinctive identifying features. Each group of grains is now present to varying degrees through-out the ACWS area, due to the repetitive mixing that has occurred during the ever-changing sea-level over the last 125 Ka (Figure 1.5).

They are usually Fe- or Mn-stained due to the activity of Fe- and Mn-oxidising bacteria, which gives them a distinctive orange-brown-grey colour. Bacterial activity is ubiquitous in the meteoric zone but also occurs on the sea-floor in association with the decay of organic matter (James et al. 2005). The relict grains are a mix of carbonate and quartz grains or lithic clasts, but usually their origin cannot be resolved unless the grains are made into a thin section.

The Pleistocene Bridgewater Formation (Figure 1.9), common from Portland (Cape Bridgewater in Victoria) to Head of Bight, consists almost entirely of relict grains that were bulldozed landwards during sea-level transgression following the last glacial maximum, to form stacked coarse/medium grained, cross-bedded sand dunes along the coast, particularly concentrated on coastlines facing the Southern Ocean. The formation is soft and friable so that it is readily eroded to become, once again, sediment grains on the sea-floor.

Figure 1.9 The Bridgewater Formation seen at Cape Spencer, Yorke Peninsula.

This formation does occur sporadically in the ACWS area, but the spectacular scene here clearly shows the changing climate. The lower half of the cliff (orange section) consists of coastal dunes interspersed with thin soils (reddened layers). Vegetation established itself, with the roots penetrating into the dune below. When these decayed the "space" became a solution pipe. Then a dramatic climate change occurred, with the onset of aridity. The dunes show evidence of stronger winds (large cross-beds) and with calcrete horizons intercalated between dunes. A different vegetation colonised the dunes, with the roots forming rhizocretions over time.

The formation does occur in the gulfs but is poorly represented in the ACWS area. However, the ubiquitous grains are part of the overall sediment budget in Gulf St Vincent and thus have become incorporated into the sediments in the ACWS area.

Other authigenic (formed *in situ)* grains that form in deeper, quiet environments or in backwaters and lagoons, include glauconite, feldspar, some of the clays and dolomite, but these were not found in any of the ACWS sediments.

Sea-land interface area

The intertidal or beach area (either term is appropriate) is a major source of sediment grains, but is also a temporary and/or permanent deposition site of grains. Sourced grains are derived from cliffs abutting the beach, weathering rocks and intertidal material (Figure 1.2, see Discussion Chapter 4).

Thus, PPM 1 divided the study area into zones that matched the potential source area. Zone 3 abuts Precambrian rocks that are predominantly quartzose, whereas Zone 4 abuts Cenozoic rocks that are predominately calcareous. The influence of these is shown in the mineralogy distribution maps (see Results, Section 3.3).

Time factors

It is difficult to quantify the delivery of material to the sea-floor without considering geological time. However, the brief for this research was to not quantify processes and parameters that occurred before European settlement. Thus, although time could not be ignored totally in the PPM 1 research, it has been relegated to the unquantified category.

2 METHODOLOGY

2.1 Location and Rationale of Sampling Transects for PPM 1

The collection of a comprehensive set of samples was the first stage of the field work program. The initial undertaking was to subdivide the area into meaningful sub-areas (Zones) based on the geological and morphological aspects of the area, and then select transect lines, positioned orthogonal to the coast, that would enable sufficient coverage of each of these areas (Figure 2.1). This was done in April 2003.

Zone 1 - Mangroves
1.a *Port Gawler North* - marks the northern extent of the Study Area, typical of this zone
1.b *Gawler River Estuary* - entry point of siliclastic fluvial load
1.c *North of Barker Inlet* - interface between mangroves and sand-only area
1.d *Mid Barker Inlet* - using a constructed starting point for the transect due North of Pelican Point Power station in middle of shipping lane
1.e *Outer Harbour* - will reflect Barker Inlet impact on sea-floor sediment

Zone 2 - Modern Sands
2.1.f *North Haven* - marina effects and sand deposition depot centre
2.1.g *Largs Bay* - deposition depot centre and offshore calcrete as basement
2.2.h *Semaphore Beach* - offshore calcrete as basement
2.3.i *Henley Beach* - typical of zone
2.3.j *West Beach* - north of the River Torrens Mouth, anthropogenic influence
2.3.k *North of Barcoo Outlet* - anthropogenic influence
2.3.L *North of the Patawalonga Creek Mouth* - current scouring, anthropogenic influence
2.3.m *South of Glenelg Breakwater* – sand deposition depot centre
2.3.n *Brighton Beach/Somerton* - typical of zone

Zone 3 - Precambrian Siliciclastic Cliffs
3.p *Marino Rocks* - typical of a rock-strewn sea-floor
3.q *Hallett Cove-Waterfall Creek* - disturbed Permian Till load
3.r *Port Stanvac* - anthropogenic influence, maritime disturbance
3.s *O'Sullivans Beach* - Christies Beach Sewage Outfall

Zone 4 - Tertiary Limestone Cliffs
4.t *Christies Beach* - northern extent of carbonate contribution from coastal area
4.u *Port Noarlunga-Onkaparinga Estuary* - mix of carbonate contribution from coastal area and siliciclastic contribution from fluvial load
4.w *Moana North* - off the beach, numerous stormwater entry points
4.x *Maslin Beach* - typical of this zone
4.y *Snapper Point* - rapid bathymetry change at drop-off, prolific calcareous biota
4.z *Sellicks Beach* - southern extent of the Study Area

The sample positions along the transects were then selected, including beach sites. The sampling sites covered all facies and sub-facies across the study area - from the coast to 5 km offshore. On each transect, samples were collected from the supratidal, intertidal and shallow subtidal, and then seawards at depths of 5m, 10m, 15m, 25m or at 2km and 5km distance from shore (Figure 2.2). Sites were sampled at times chosen to best portray the likely minimum and maximum variations, i.e. in mid-summer and mid-winter, over a two-year period. It was planned that opportunistic 'catastrophic' events would also be sampled.

The ACWS Scientific Committee, with input from the various research project teams presented a proposal for amended zones (Refer Table 2.1) in October, 2005. These zones were not inconsistent with the zones and transects that PPM I previously shared with the Flinders University team working on Task PPM 2 and which allowed crew and cost sharing of the Flinders University Research Vessel, *Hero.*

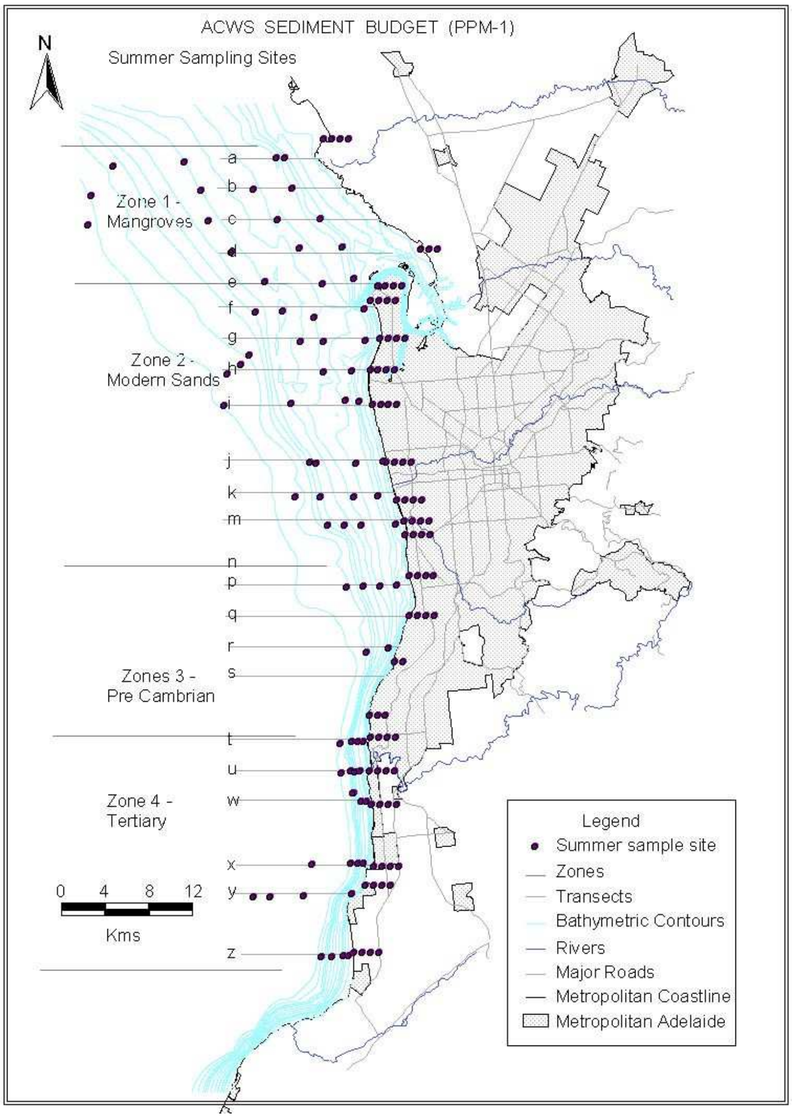


Figure 2.1 PPM 1 Proposed Zones, Transects and sampling sites plotted on the bathymetry.

Table 2.1 . Description of zones reclassified during meeting of ACWS Scientific Committee Thursday 27th October 2005

Zone	**Habitat**	**Hydrodynamics**	**Inputs**	Input type
Zone 1 (Northern & Barker Inlet)	Mangroves. Destabilised sediments. Intertidal seagrass and mud flats Offshore seagrass (*Posidonia*). Carbonate -rich. Fine grained. Changes in seagrass Ulva	Tidal. Low wave climate Wide mud flats. Seagrass loss influence Northerly currents (Summer) Southerly currents (Winter)	Bolivar WWTP (seasonal) Port River (continuous) Barker Inlet (stormwater) Gawler River	Nitrogen SS/NH^4 SS/NH^4 Highly seasonal (low inputs)
Zone 2 (Semaphore jetty to	Seagrass loss to 5 metre contour	Tidal. Medium wave climate. Seagrass loss influence	Port River gyre River Torrens (historically high impacts, now lower	

Zone	**Habitat**	**Hydrodynamics**	**Inputs**	Input type
Seacliff)		Northerly currents (Summer) Southerly currents (Winter)	impact	
Zone 3 (Seacliff to Sellick's Beach)	Relatively unimpacted seagrass	Relatively steep shelving with minimal impact	All remaining discharges from Marino to Sellicks Creek	
Zone 4 (offshore from Zone2)	Off-shore fragmented seagrass meadow		Offshore transfer from zone 2	
Zone 5 (Former Pt Adelaide sludge outfall site)	Port Adelaide sludge outfall zone	Tidal, median wave climate. Seagrass loss ceased with closure of outfall and some passive recolonisation noted	No current input	Decommissioned sludge outfall

This allocation of new zone boundaries was based on the ACWS area in terms of seagrass habitats, hydrodynamics, terrigenous inputs and pollution types. This new scheme restricted consideration of these from the northern boundary of the ACWS area to Seacliff, but not further south. PPM 1 retained the earlier Zone boundaries, as their fieldwork and about 90% of the laboratory research on the full ACWS area had been completed and they had prepared the bulk of their statistical analyses and maps, etc. to illustrate these at this time.

Determination of Sample Numbering System

Table 2.2 shows the development of a sample-specific number and the rationale for each part of the number. Thus the number itself contains information about the sample, from a simple site position through to such parameters as which photo (from a group of photos taken) is illustrated in the text

Table 2.2 Development and explanation of sample numbering system

Symbol	**Description**	**Depth**					
ACWS	Research Project Name -(ACWS)	1	Back of beach	**Size fraction**		**Magnification**	**Field of view**
(W)	Summer (S) or Winter (W)	2	Mid tide	bk	Bulk (composite)	x6.2	25 mm
1	Zone (1-4)	3	1 m	cs	Coarse (coarse sand/gravel	x10	10 mm
a	Transect identific-ation letter (a-z)	4	2 m	med	Medium (medium sand)	x20	6 mm
3	Sample depth (1-8)	5	5 m	fn	Fine (fine sand)	x32	4 mm
bk	Size fraction	6	10 m	v.fn	Silt and clay		
(1)	Photo number	7	15 m				

Symbol	Description	Depth		
(x10)	Magnification of micrographs or SEM images	8	20 m	

ACWS(W)1a-3-bk(1)(x10) is a sample from the ACWS Project, collected during the Winter from Zone 1, Transect 1 at a depth of 1m: the bulk sample was photographed at a magnification of X10.

2.3 Field Work

The field work program involved many different facets and environments, e.g. diving and boat-work, beach sampling, drainage basin sampling (Figure 2.4), so a number of different protocols and forms were designed to enable these activities to remain efficiently co-ordinated and recorded. These are presented in Appendix A. They included the following: submission of excursion form, coordination with field team, confirmation with Captain of *Hero,* confirmation of dive buddy/technical assistant, equipment needed, transport and Log book entries. Field protocol documents were prepared and adhered to, other than under exceptional conditions, e.g. weather conditions (Appendix A).

Figure 2.3 Photograph of one of the dredges manufactured for PPM 1 Sediment Budget study. The dredge was ~20 L in volume and had a gape of ~ 15 cm. Once deployed, it immediately dug into any sediments on the sea-floor. Movement of the boat by wave action enabled collection of sufficient sediment within <2 minutes, whereupon the dredge was retrieved. *Posidonia* blade for scale.

2.3.1 Weather

The vagaries of the weather in and adjacent to the Southern Ocean often cause disruptions to planned boat work, and this was the case in more than half of the planned days, especially towards the latter part of the winter sampling program. The nature of the seafloor also necessitated slight re-positioning of some of the proposed transects and/or sample sites. These included such factors as (i) the sea-floor substrate was covered in rocks, (ii) the beach was a rock platform, (iii) the sea-state was such that the Captain considered it necessary to adjust the position. Consequently, the PPM 1 Sample Sites Map was re-drawn to the positions at which the samples were collected.

2.4 Laboratory Work

Standard laboratory techniques were used. See Appendix B for protocols.

2.4.1 Sample preparation

See Appendix B for protocols on initial washing of sediment.

2.4.2 Selection of representative sub-sample (quartering)

Use standard quartering technique on wet sediment to produce homogenous samples from a heterogeneous original sample, i.e. make a cone-shaped pile and quarter it with a ruler. If more than 4 sub-samples are needed, then continue to do this with one or more of the quarters. Allow to dry. When dry, place the subdivided samples into labelled plastic bags, with additional paper label inside bag, i.e. archive (1/4), bulk (1/2) (to be used for sieving), other for use for specialist work (1/4). Place quarter separated for specialist work in the freezer.

2.4.3 Grain size analysis

Sieving

Weigh the dry bulk sample and record weight on 'Sample Description' pro forma.
Wet sieve it through a bank of sieves;

>2mm	gravel - coarse sand
2mm - 0.25mm	medium sand
0.25mm - 0.063mm	fine sand
<0.06 (in collection pan)	very fine sand including silt and clay

Tip any collected water from collection pan into a plastic bucket and allow to settle for 3 days. Once settled, decant water and dry fraction. Place each fraction on labelled paper. Determine which is the dominant fraction (if two fractions are within 10% of one another, then process both as sub-sets) and quarter (wet) until 2 x 1cc of sample is separated for microscope analysis and carbonate digestion. Allow samples to dry. When dry, record on the top of the Sample Description pro forma, the weight and volume (graduated measuring cylinder) of each fraction (include 2 x 1cc splits).
Place each fraction in a labelled plastic bag.

Grain sorting

For this step, use 1cc of the dominant fraction from the sample separated during the sieving step. By eye, estimate the percentage of biogenic material within the sample. Hint:- a hand lens may prove useful. Under the microscope identify, count, separate and record the following:-

- unidentified biogenics
- typical quartz grains
- typical relict grains - orange, black, grey, brown and
- heavy minerals.

Prepare quartz and heavy mineral components for SEM to investigate origin of quartz (Permian chatter mark trails) and EDAX to identify heavy minerals. Record all findings on the Microscope Analysis pro forma.

2.4.4 Mineralogy analysis of grains

Identification of the percentage of quartz, carbonate, organic material and "other" minerals in each sample was undertaken. "Other" minerals expected included various silicates such as clays, mica, feldspar, garnet and staurolite, oxides such as ilmenite, magnetite and hematite and other minerals such as barite and glauconite.

Petrographic identification
Quarter the bulk sample, using the standard quartering technique. Take 1 cc and count the individual grains under a binocular microscope, allocating each grain to a mineral species. Separate out any problematic grains by either individual picking or by use of the Franz Magnetic Separator. Some grains need special techniques such as X-ray diffraction (XRD) for confident identification, e.g. the different clay species, or Scanning Electron Microscopy (SEM) in the case of ilmenite, garnet, feldspar species and a number of others. Statistically calculate the percentage of each mineral.

Franz Magnetic Separator
This technique allows the concentration of the heavier minerals, i.e. most of those in the group "other". This concentrate can then be scanned under the SEM. Weigh a 1 cc sample, pass through the Franz Magnetic Separator and then weigh the concentrate. Calculate the percentage, but note that this is only a qualitative figure, not a quantitative one, as the separation is only approximate.

Scanning electron microscope
Mount sub-sets of the selected "other" minerals on SEM stubs, coat with Au, and view under the SEM. Take images of grains to record any surface features, as these can be diagnostic of various erosion processes that have occurred, e.g. collision of grains due to the wind causes quartz grains to become frosted whereas collision in water causes quartz grains to become polished. Identify elements present in the minerals grains by scanning under EDAX, recording the resultant spectrum. The position of each peaks is specific to the elements present, representing the different orbitals in the atom. The height of the peaks of the different elements present allows a qualitative estimate of the concentration of the element. So, the identification of the mineral presupposes an understanding of the formula of the mineral, both the elements present and how much of each is in the unit cell.

X-ray diffraction
There may still be some minerals remaining unidentified. These can be analysed under XRD and their spectra matched to International Records. This technique is also needed for complex clays and for non-crystalline silica species such as Opal-A or Opal-CT.

2.4.5 Biogenic component analysis

Prepare a table on which to score the biota that have been observed as being in sufficient density to warrant inclusion as a separate taxon. Quarter the bulk sample, using the standard quartering technique, until a single layer of the sample covers a counting tray. Place sample under a binocular microscope and methodically score each grain, until 300 grains have been counted. Calculate the percentages of each taxon.

There are a number of dilemmas concerning the technique used in this biogenic analysis. If there are fragments of a recognisable organism, are these considered to all belong to the same individual and therefore only counted as "1" or is each fragment scored as "1"? In other words, how do you tell whether you are dealing with one individual, or with many that are similar, e.g. the cockle *Katelesia* sp. – which is usually disarticulated rapidly after death at the very least. If the organism is a "colonial" one, and the colony disarticulates after death due to the decay of individual nodal points, e.g. articulated zooidal bryozoans (See Section 3.4) that disarticulate into individual zooids, articulated coralline algae that break into small branches, what do you count?

Does one large, robust, complete organism, e.g. *Turbo* sp. only have the same score as a fragment of a foraminifer? Whichever choice is made, there is a bias. These dilemmas remain unresolved amongst taxonomic paleontologists, so that it is important that the choice is stated clearly in the methodology. The choice of scoring in this project was that each individual particle was counted as "1".

An additional dilemma concerns the technique for the collection of the sample. It was considered important to include infaunal biota as well as epifaunal biota, as both are contributing to the sediment budget. Consequently, the dredge used was constructed and deployed in a manner that insured that it dug into the sediment, to a depth of about 5 cm, if such a veneer was present (Figure 2.3). All beach samples were taken so that a representative sample of the top 10 cm was made.

2.4.6 Sources of sediment grains

The same methods were used as delineated in the section on grain size, so they are not repeated here. Any discrepancies are noted in the individual discussions.

2.5 Photography

2.5.1 Field photography

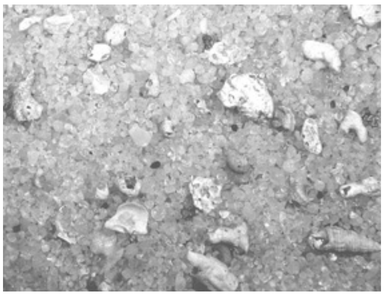
Photographs were taken “on the beach” to illustrate the nature of each locale (Appendix C). A few sites of the sea-floor were photographed to illustrate the various environments, selected after perusal of all the samples (Appendix D). The diving company, Divers Delight ®, St Peters, SA, was hired to take underwater photos with time and weather factors interfering once again. Photographs were also taken By Divers Delight from the boat looking shorewards to the entry point of the transect. (See Appendix E).

2.5.2 Laboratory photography

Two types of photography were used in the laboratory:

- Petrography: The various size fractions of the dried samples were photographed under a binocular microscope.
- Scanning electron microscopy: This technique was used where the grains were small necessitating the use of very high magnification or the preparation of a thin section. This included: (i) grains where the surface marking on the grains provided diagnostic features in the identification of the source of grains and (ii) grains where the mineralogy was uncertain and so crystal form was needed. Graphs of EDAX analyses were made of all samples analysed.

Photographs of selected samples are shown in Figure 2.4. The photos of the samples are representative of the particular sample, i.e. the samples were not high-graded in any way to bias any aspect. The explanation of the labelling is given in Figure 2.2. A complete album of all sample site photographs can be found in Appendix D.



A

B

Figure 2.4A&B These two photographs show two samples, featuring differences in grain size, mineralogy and biota and are from different water depths.

ACWS 2i-5(bulk) x10
Zone 2, Transect i (Henley Beach) depth 5 m, bulk fraction. The sediments from this site, just north of the Torrens Outlet, are fine grained and dominated by quartz.

ACWS 1a-1(medium) x10
Zone 1,Transect a (Port Gawler), medium-grained fraction. Sediments are mainly modern molluscs and much coarser than the previous sample.

The photographs can be compared to the field observations by referring to the appropriate data tables in Appendix F and G and to the laboratory analyses in Tables 2.2 and 2.3.

3 RESULTS

3.1 Field Data

Tables that give complete field data are presented in Appendix G. These tables record the following information about each site on each Transect:- date collected; time; sample site and number; depth; co-ordinates; temperature; weather; sea-state; weather previous day; volume of sediment collected; colour of sediment; living biota in sediment; other biota in sediment; general description of sediment.

3.2 Grain Size Analysis

The numerical results of the laboratory grain size analyses are shown in two tables, which give the Summer and Winter results, (Appendix G). The results for the Zone 1, Transect A and Zone 4,Transect z Summer samples are shown in Table 3.1 as examples.

Table 3.1 Grain size analysis of the Summer samples from **A**. Zone 1, Transect a and **B**. Zone 4, Transect z.

Transect	No.	Sample wt gm	Coarse wt gm	Medium wt gm	Fine wt gm	V fine wt gm	Coarse %	Medium %	Fine %	V Fine %
Port	1a-1	364.14	38.39	232.51	87.44	5.80	10.54	63.85	24.01	1.59
Gawler	1a-1	154.19	27.32	45.64	73.06	8.17	17.72	29.60	47.38	5.30
North	1a-2	232.76	122.78	86.49	21.16	2.33	52.75	37.16	9.09	1.00
	1a-3	184.44	97.19	77.02	8.11	2.12	52.69	41.76	4.40	1.15
	1a-4	132.66	13.31	51.16	54.60	13.59	10.03	38.56	41.16	10.24
	1a-5	267.55	3.23	180.00	76.61	7.71	1.21	67.28	28.63	2.88
	1a-6	-	-	-	-	-	-	-	-	
	1a-7	276.18	18.28	145.49	99.53	12.88	6.62	52.68	36.04	4.66
	1a-8	152.50	3.48	41.03	56.52	51.47	2.28	26.90	37.06	33.75

A

Sellicks	4z-1	450.23	100.99	259.16	87.92	2.16	22.43	57.56	19.53	0.48
Beach	4z-2	428.95	35.43	294.35	93.28	5.89	8.26	68.62	21.75	1.37
	4z-3	352.93	22.41	261.77	63.73	5.02	6.35	74.17	18.06	1.42
	4z-4	357.07	0.30	248.08	103.05	5.64	0.08	69.48	28.86	1.58
	4z-5	368.36	0.07	5.21	361.30	1.78	0.02	1.41	98.08	0.48
	4z-6	357.41	0.09	3.49	352.35	1.48	0.03	0.98	98.58	0.41
	4z-7	-	-	-	-	-	-	-	-	
	4z-8	318.29	0.16	7.30	289.31	21.52	0.05	2.29	90.90	6.76

B

The data from Appendix G were plotted on to pie diagrams to show the distribution of the different grain size fractions along each transect, for both Summer and Winter. This enables rapid comparisons to be made as one goes from the beach seawards at the different seasons. These pie diagrams also feature the mineralogy of the grains and the biota present, but these are referred to in other sub-projects. All the pie diagrams are shown in Appendix H.

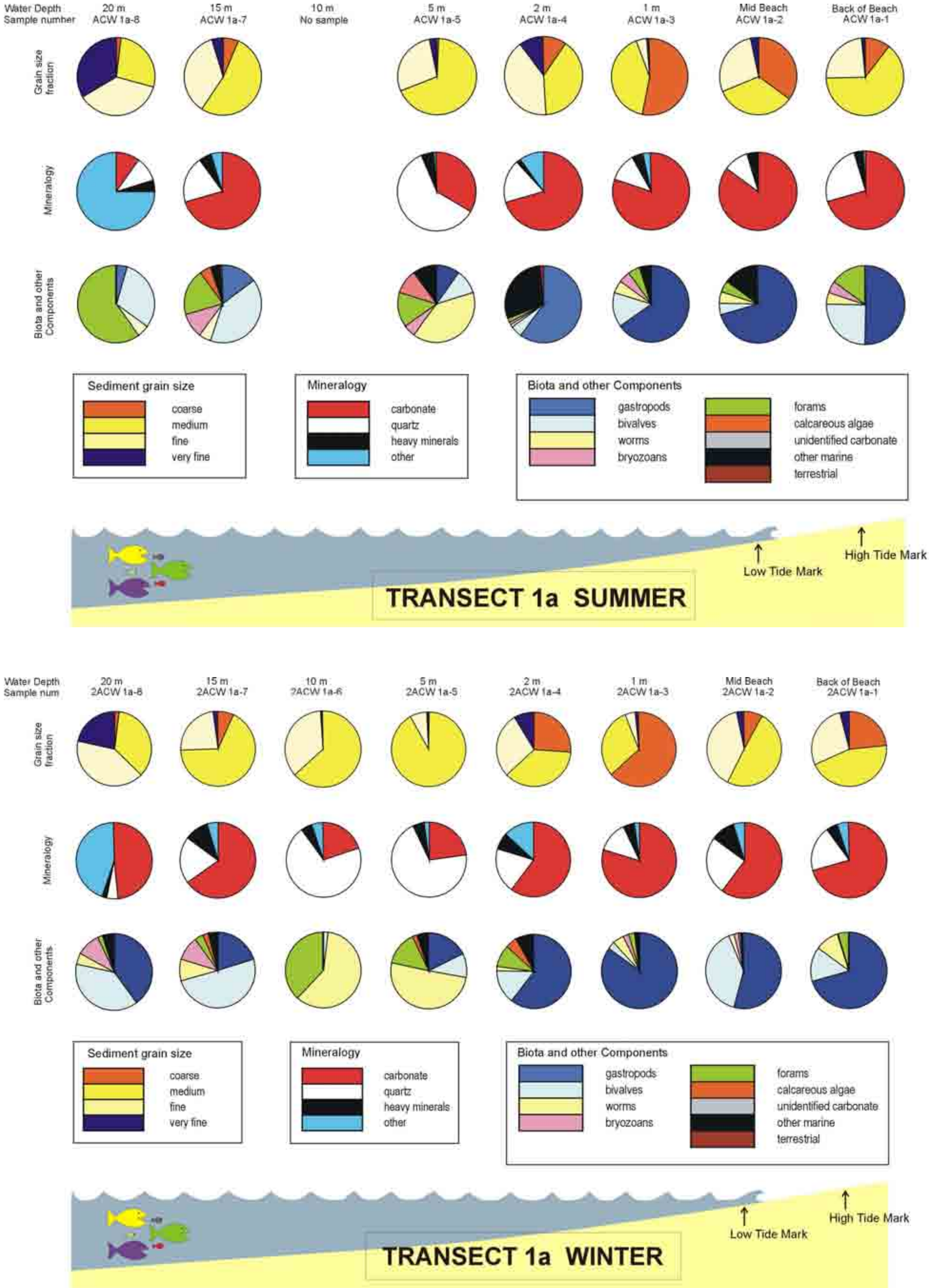


Figure 3.1 Pie diagrams showing sediment grain size, mineralogy and biogenic and other components Zone 1, Transect a; Summer and Winter.

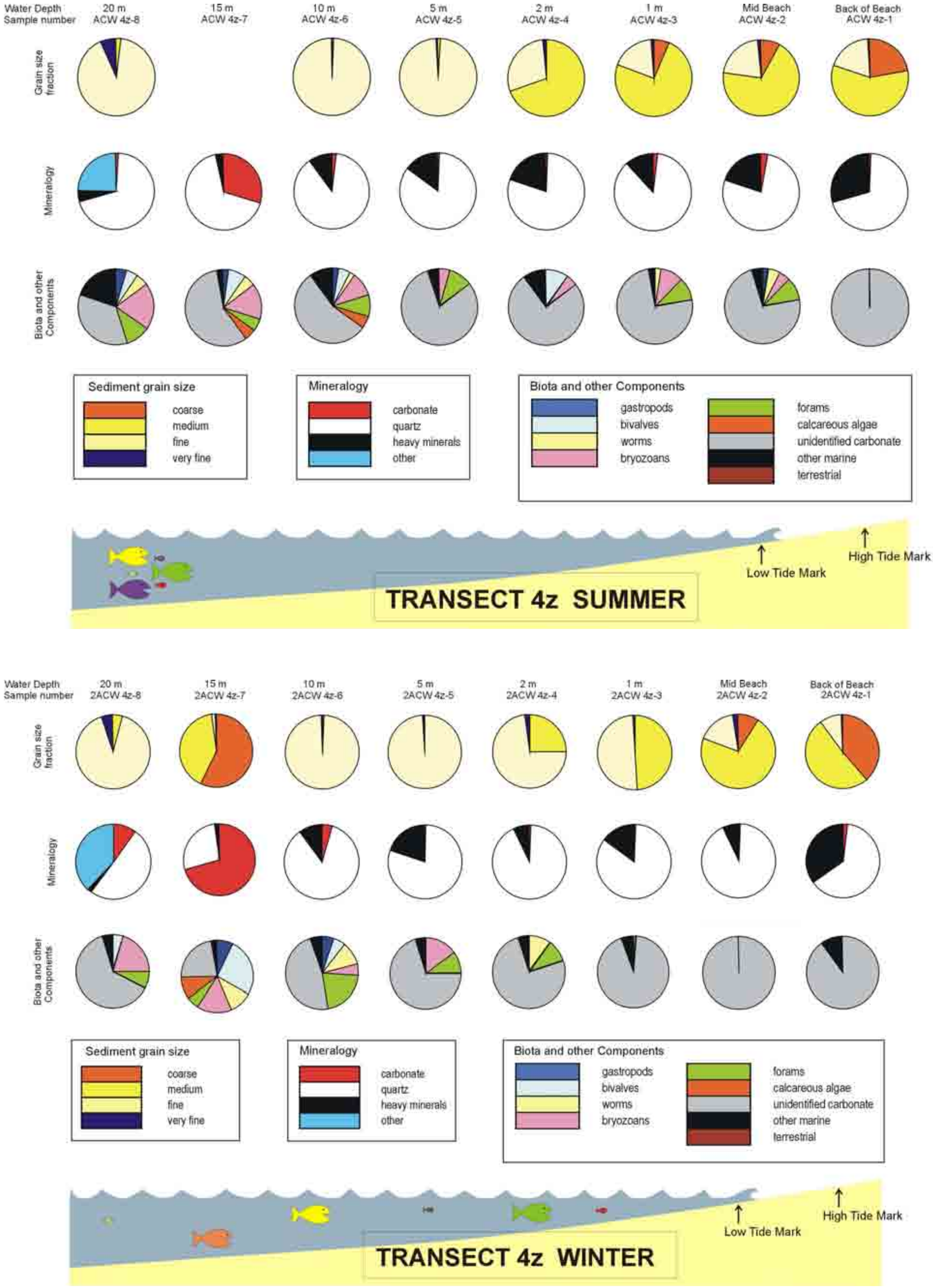
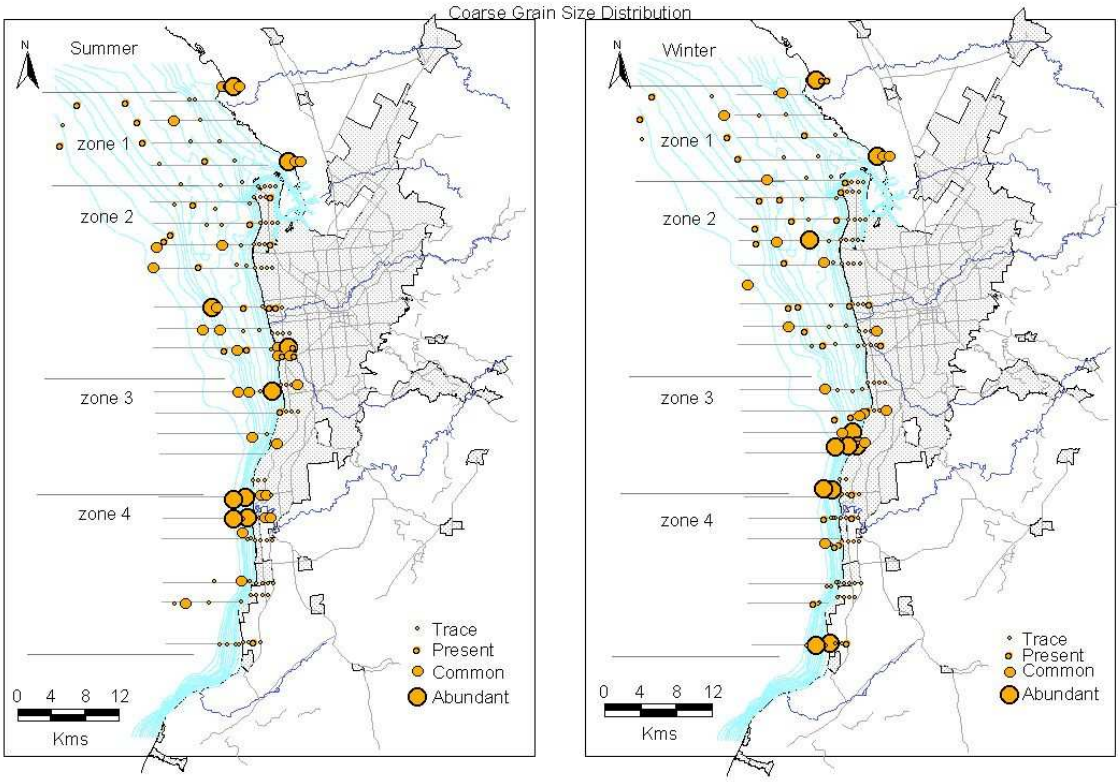
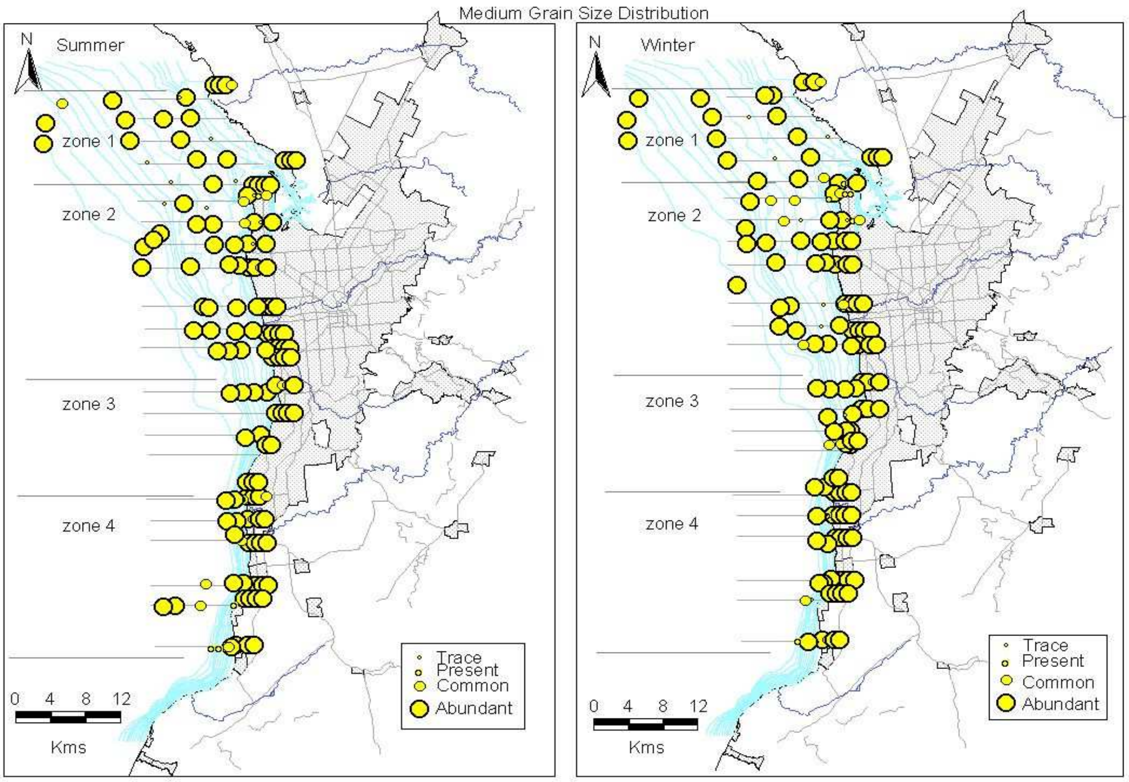


Figure 3.2 Pie diagrams showing sediment grain size, mineralogy and biogenic and other components Zone 4, Transect z; Summer and Winter. The data from Appendix H were also plotted on to the Field Sampling Maps (Figures 3.3, 3.4, 3.5 and 3.6) to enable immediate visualisation of the distribution of the different size fractions throughout the ACWS area.



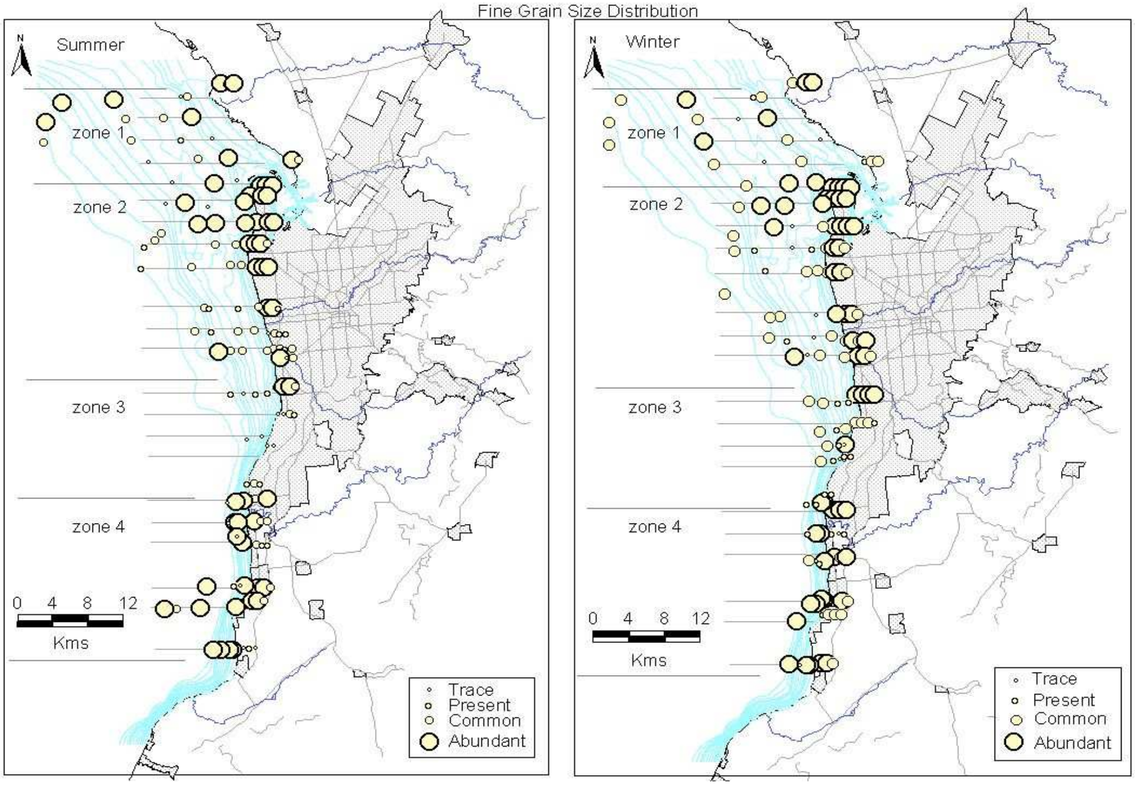
A **B**

Figure 3.3 Distribution of the coarse fraction of the sediment samples throughout the ACWS area - **A.** Summer and **B.** Winter



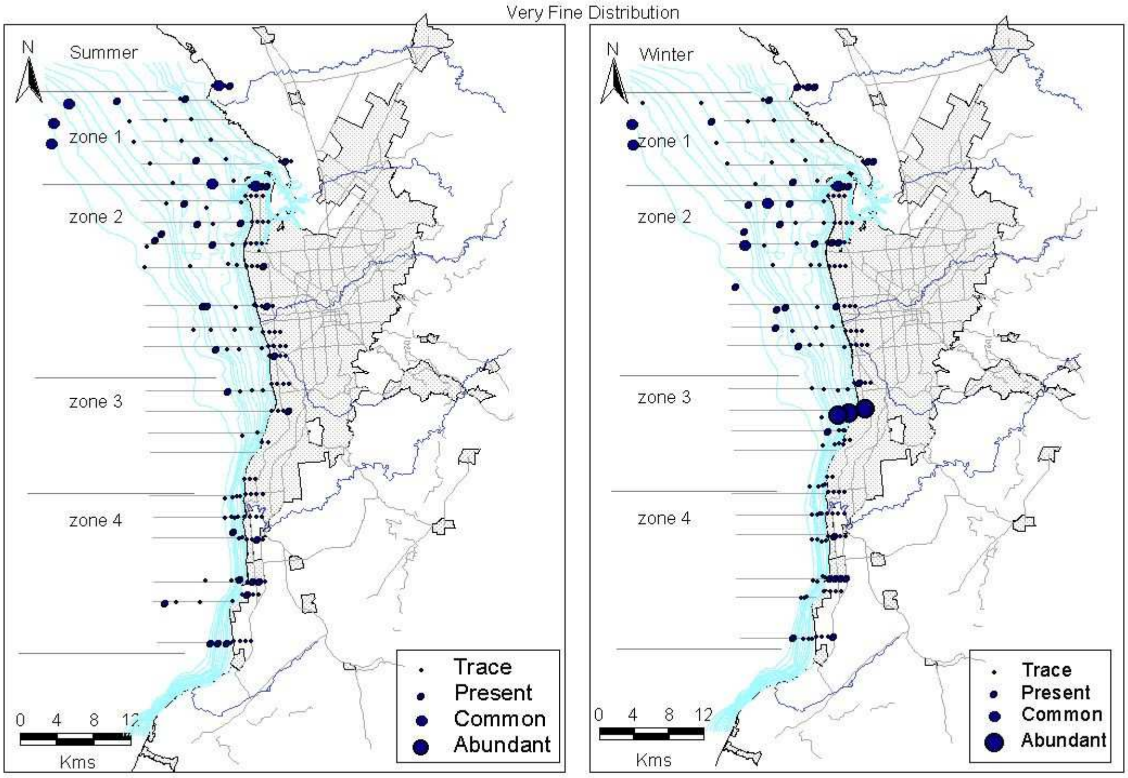
A **B**

Figure 3.4 Distribution of the medium fraction of the sediment samples throughout the ACWS area - **A.** Summer and **B.** Winter.



A **B**

Figure 3.5 Distribution of the fine fraction of the sediment samples throughout the ACWS area - **A.** Summer and **B**. Winter.



A **B**

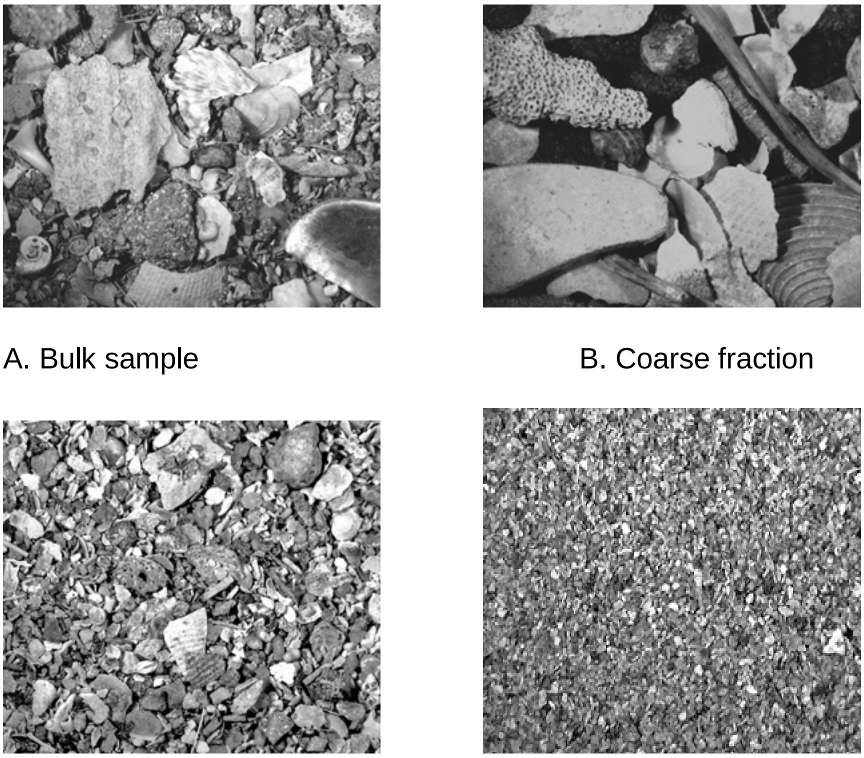
Figure 3.6 Distribution of the very fine fraction of the sediment samples throughout the ACWS area - **A.** Summer and **B.** Winter.

The calculated percentages were converted into quantitative terminology according to the density of the distribution (Table 3.2).

Table 3.2 Conversion of percent of sediment present into qualitative terminology.

Term	Percentage Present
Abundant	35 – 100
Common	10 – 34
Present	2 – 9
Trace	0 – 1.9

All of the size fractions from each of the samples were photographed, with multiple exposures where necessary (Appendix D). A selection is presented here in black and white (Figure 3.7). The photos of the samples are representative of the particular sample, in the case of photos labelled bulk (bk) or of the particular fraction labelled, i.e. coarse (cs), medium (md) or fine (fn). The samples were not high-graded in any way to bias any aspect.



A. Bulk sample B. Coarse fraction

C. Medium fraction D. Fine fraction

Figure 3.7 Sample ACWS1a-7, showing the components of the different size fractions. All photos are x10.

A complete set is presented in colour in the Appendix D. Refer to the Sample numbering system in the Methodology Section Figure 2.2.

Underwater photographs of 14 sample sites (Appendices D and E) show aspects of the sea-floor and its veneer of sediments. Parameters such as colour (wet), relative grain size, variability, e.g. sorting, rocks and biota present, geomorphic features of the sea-floor are all accurately recorded by such methods, as is the effectiveness of the collecting methods. *NB: An important caveat to add at this point is that these results do not differentiate between the naturally-occurring sediments, which include those debouching on to the sea-floor, from man-made drainage features, and those artificially dumped or pumped into the area from the beach replenishment scheme.

3.3 Mineralogy

The complete results are shown in Appendix I. The results for the Zone 1, Transect a and Zone 4,Transect z Summer samples are shown in Table 3.3 as examples.

Table 3.3 Mineralogy of the Summer samples from **A.** Zone 1, Transect a and **B.** Zone 4, Transect z.

Transect	Sample No.	Sample wt gm	Carbonate wt gm	Organic wt gm	Other wt gm	Carbonate %	Organic %	Inorganic %
Port	1a-1	4.4920	3.5583	0.0048	0.9289	79.21	0.11	20.68
Gawler	1a-2.1	3.0126	1.6165	0.0525	1.3436	53.66	1.74	44.60
North	1a-2.2	3.2058	2.1987	0.0287	0.9784	68.59	0.90	30.52
	1a-3	2.4271	1.9635	0.0165	0.4471	80.90	0.68	18.42
	1a-4	2.7194	1.6438	0.1402	0.9354	60.45	5.16	34.40
	1a-5	3.6326	0.6696	0.0564	2.9066	18.43	1.55	80.01
	1a-6	-	-	-	-	-	-	-
	1a-7	3.6386	2.3184	0.0619	1.2583	63.72	1.70	34.58
	1a-8	2.8107	2.3377	0.0949	0.3781	83.17	3.38	13.45

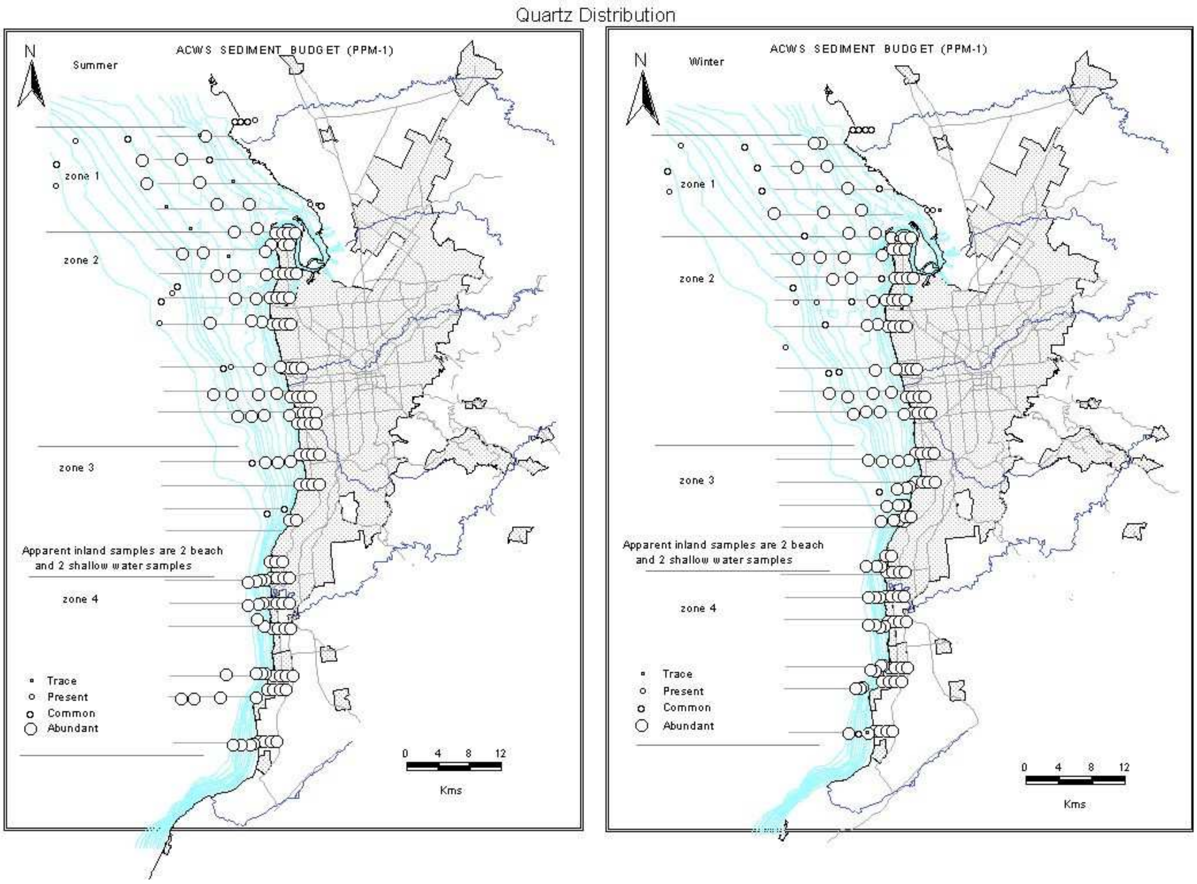
A

Sellicks	4z-1	2.3583	0.1251	0.0055	2.2277	5.30	0.23	94.46
Beach	4z-2	2.3658	0.2662	0.0936	2.0060	11.25	3.96	84.79
	4z-3	2.6085	0.2431	0.053	2.3124	9.32	2.03	88.65
	4z-4	3.4716	0.3305	0.7981	2.3430	9.52	22.99	67.49
	4z-5	2.4057	0.2708	0.0303	2.1046	11.26	1.26	87.48
	4z-6	2.6962	0.4238	0.0201	2.2523	15.72	0.75	83.54
	4z-7	2.2551	0.9947	0.0261	1.2343	44.11	1.16	54.73
	4z-8	2.6639	0.6020	0.0423	2.0196	22.60	1.59	75.81

B

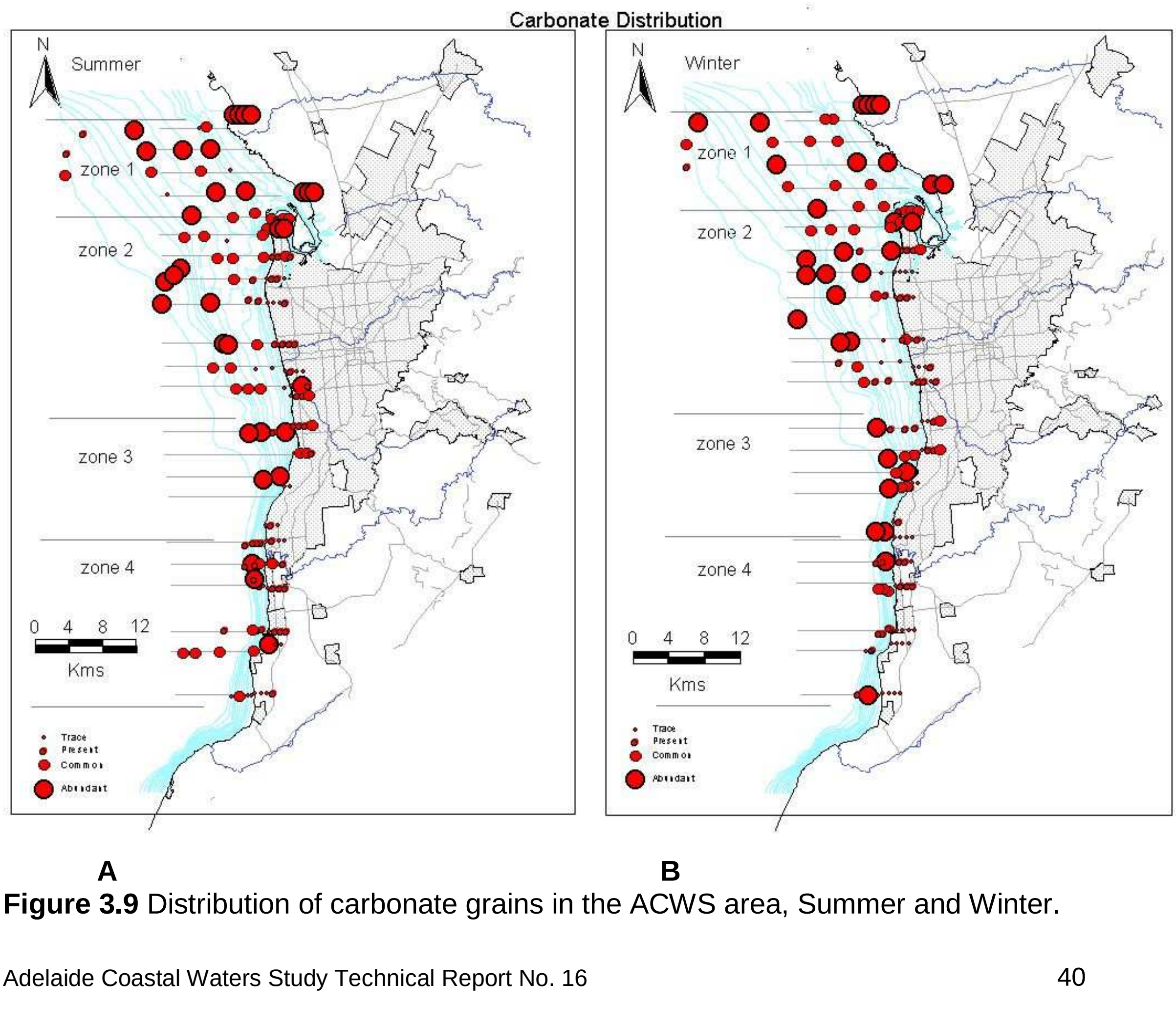
The results were plotted on to pie diagrams, which are shown in Appendix H and in Figures 3.1 and 3.2.

The results were also plotted as distribution maps (Figures 3.8, 3.9, 3.10 and 3.11).



A B

Figure 3.8 Distribution of quartz grains in the ACWS area - **A**. Summer and **B.** Winter.



A B

Figure 3.9 Distribution of carbonate grains in the ACWS area, Summer and Winter.

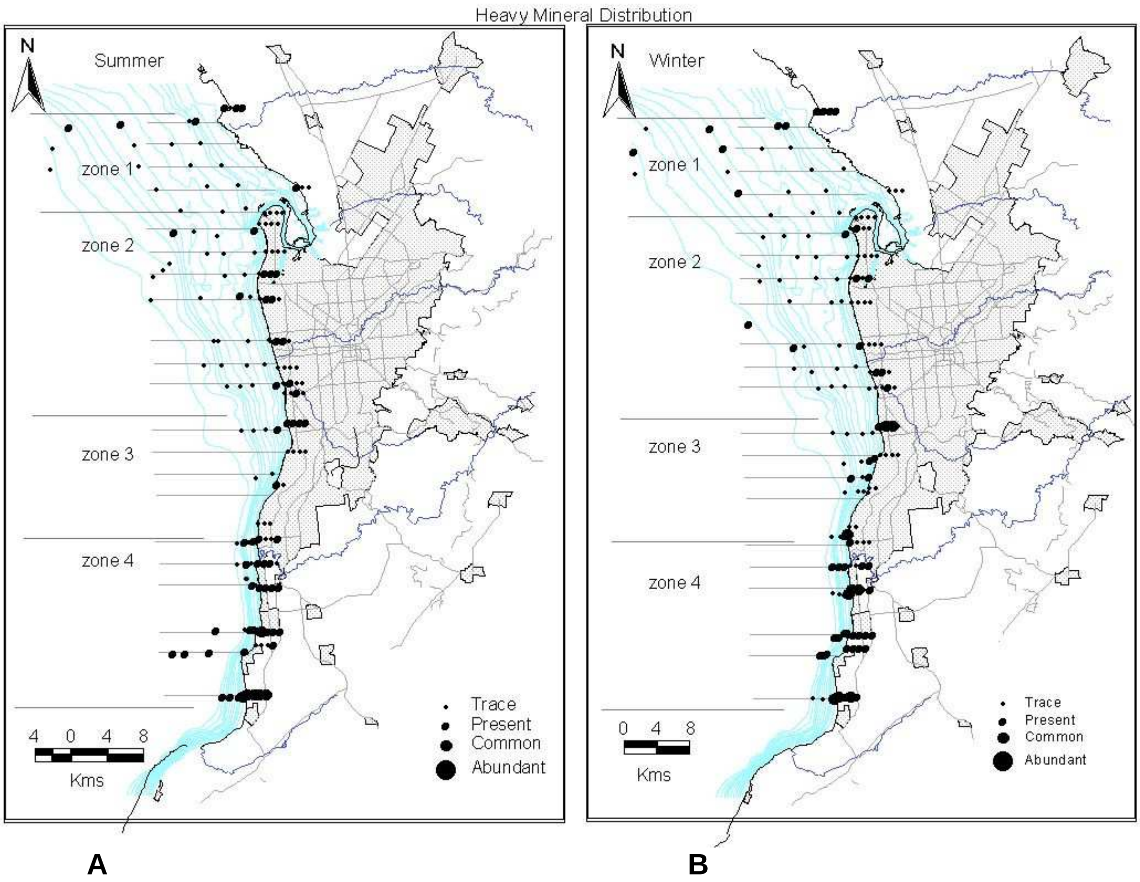


Figure 3.10 Distribution of heavy mineral grains in the ACWS area - **A** Summer and **B** Winter.

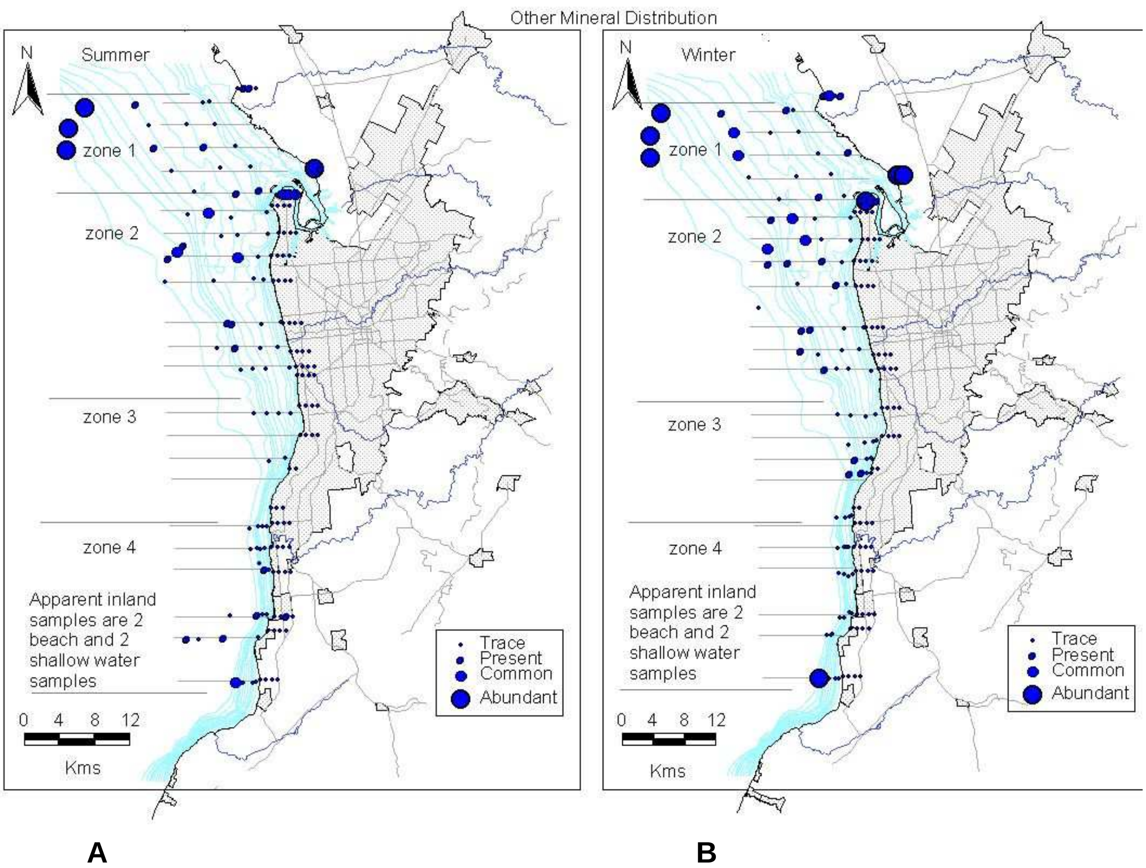


Figure 3.11 Distribution of other mineral grains in the ACWS area - **A** Summer and **B** Winter.

3.4 Biogenic Components

The complete results of the analyses of the biogenic grains present in each sample are shown in Appendix J. The results for Zone 1, Transect a and Zone 4, Transect z Summer samples are given in Table 3.4 as examples.

Table 3.4 Biogenic grains as a percentage of total biota of the Summer samples from **A.** Zone 1, Transect a and **B.** Zone 4 Transect z.

Zone	gastropods	bivalves	calcareous worms	bryozoans	foraminifers	calcareous algae	unID CO_3	other CO_3 marine
	%	%	%	%	%	0	%	%
1a-1	50	25	5	5	15	0	0	0
1a-2.1	70	5	5	0	5	0	0	15
1a-3	65	15	5	5	5	0	0	5
1a-4	60	5	1	1	2	0	0	30
1a-5	10	10	40	5	15	10	0	10
1a-6	0	0	0	0	0	0	0	0
1a-7	15	40	5	10	20	5	0	4
1a-8	5	30	5	0	60	0	0	0

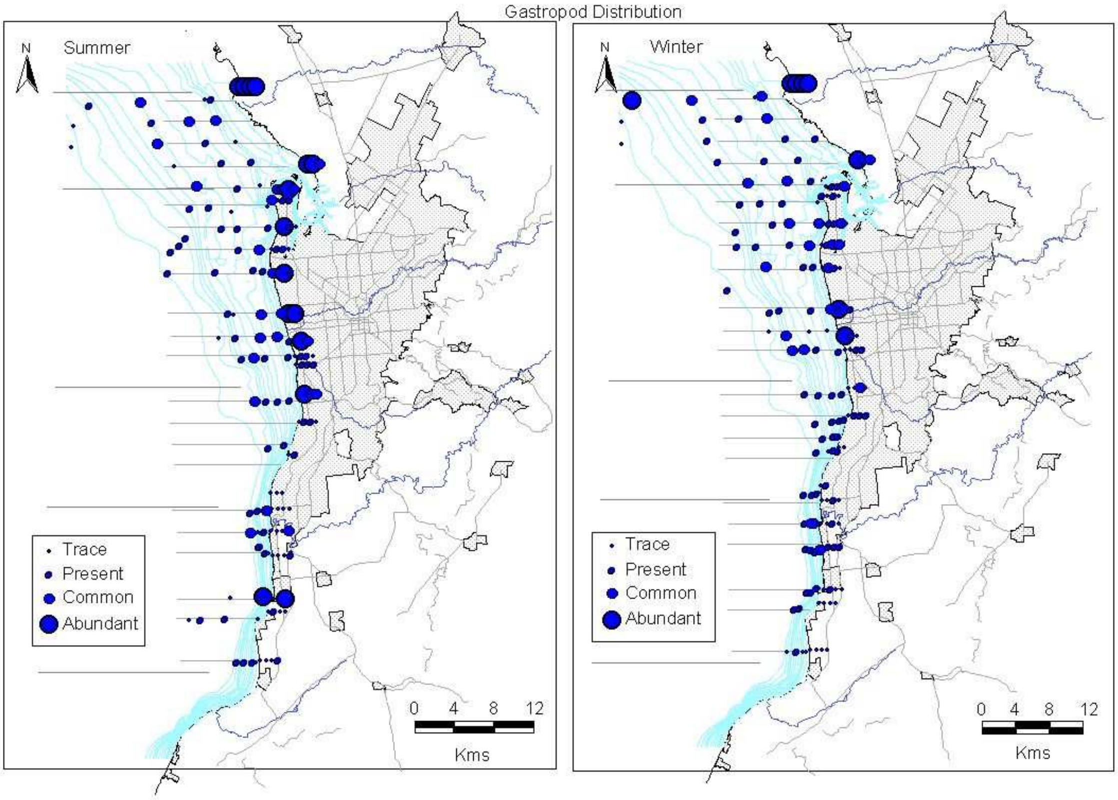
A

4z-1	0	0	0	0	0	0	100	0
4z-2	2.5	0	5	5	10	0	73	5
4z-3	0	0	2.5	10	10	5	75	2.5
4z-4	0	10	0	5	0	0	75	10
4z-5	0	0	0	5	10	0	80	5
4z-6	2.5	5	2.5	10	10	5	55	10
4z-7	2.5	7.5	5	15	5	5	58	2.5
4z-8	5	5	5	20	10	0	35	20

B

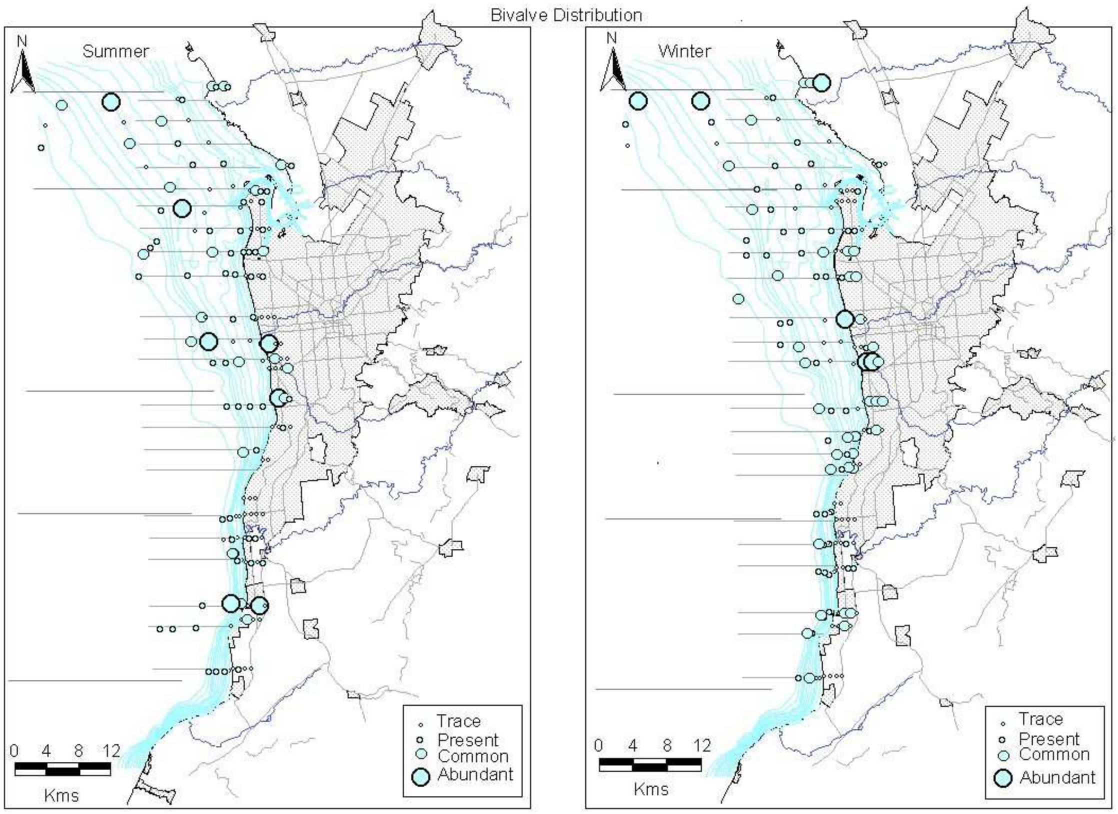
The following maps (Figures 3.12, 3.13, 3.14, 3.15, 3.16, 3.17 and 3.18) show the distribution of the calcareous biota throughout the ACWS area. The maps are based on the individual taxon, which has been re-calculated to a percentage from the number present at a site compared to the total individual identified organisms at that same site.

On each distribution map the beach samples are apparently plotted well inland, but this is an artefact caused by the scale used.



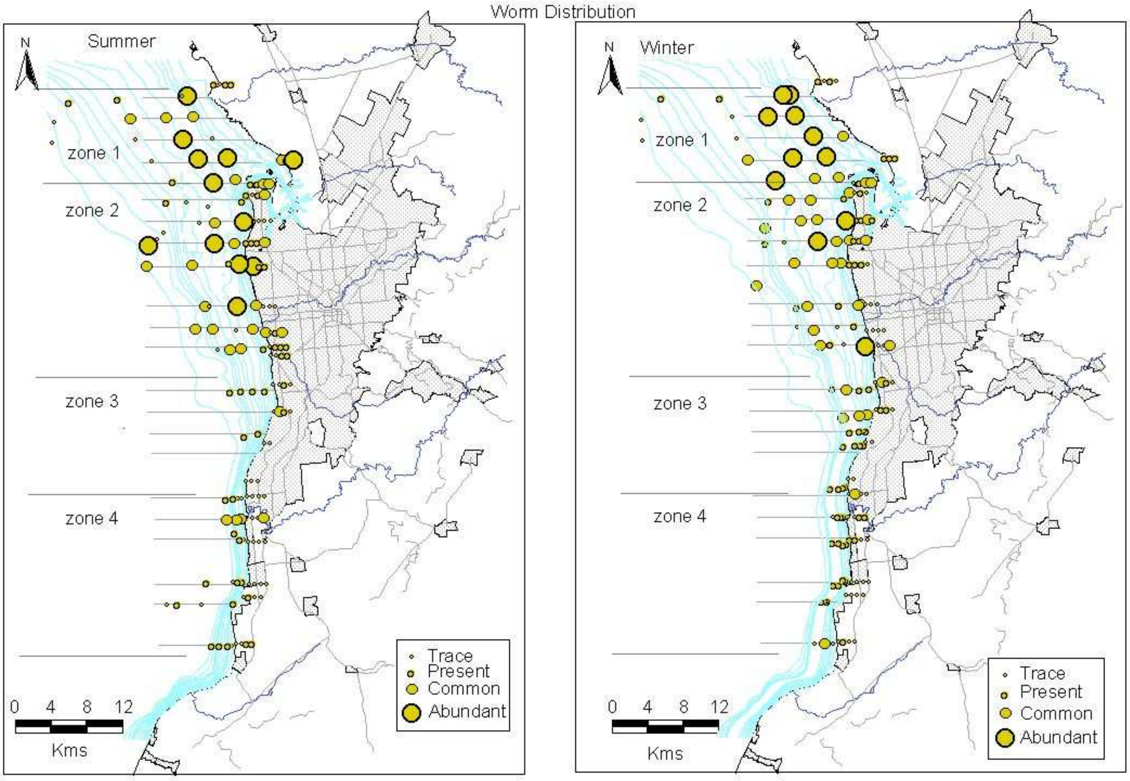
A **B**

Figure 3.12 Distribution of gastropods in the ACWS area - **A.** Summer and **B.** Winter.



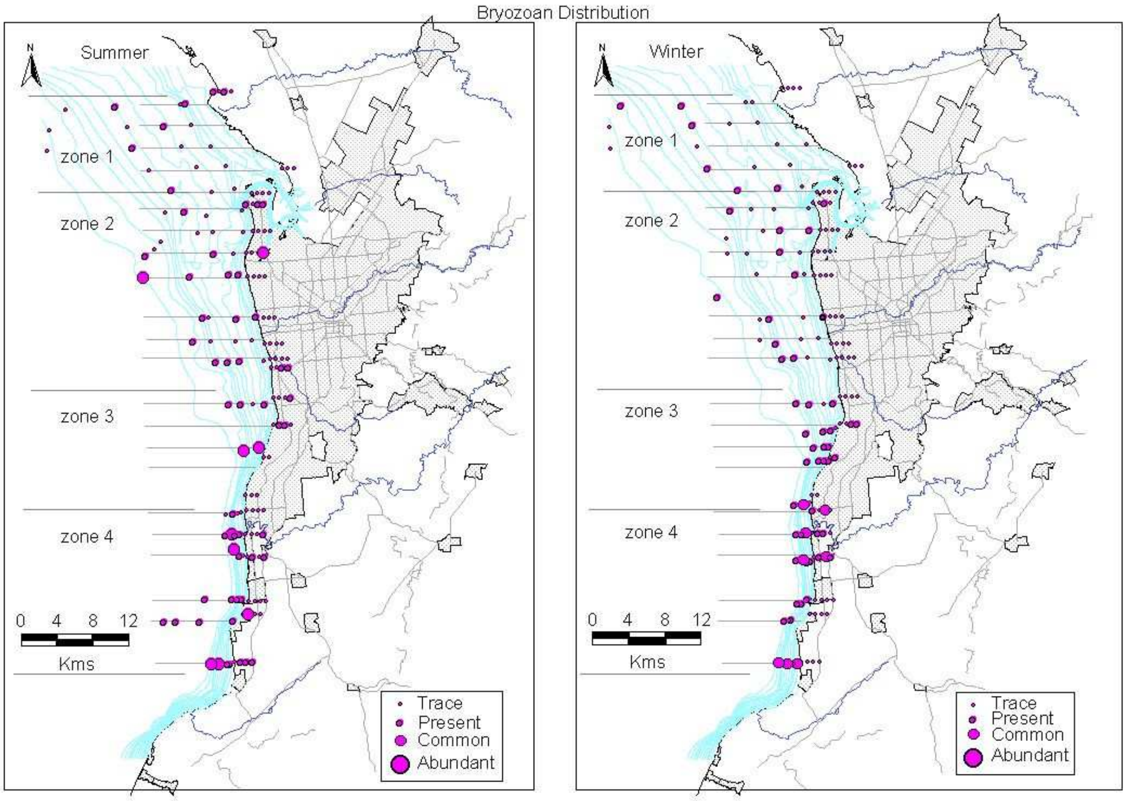
A **B**

Figure 3.13 Distribution of bivalves in the ACWS area - **A.** Summer and **B.** Winter.



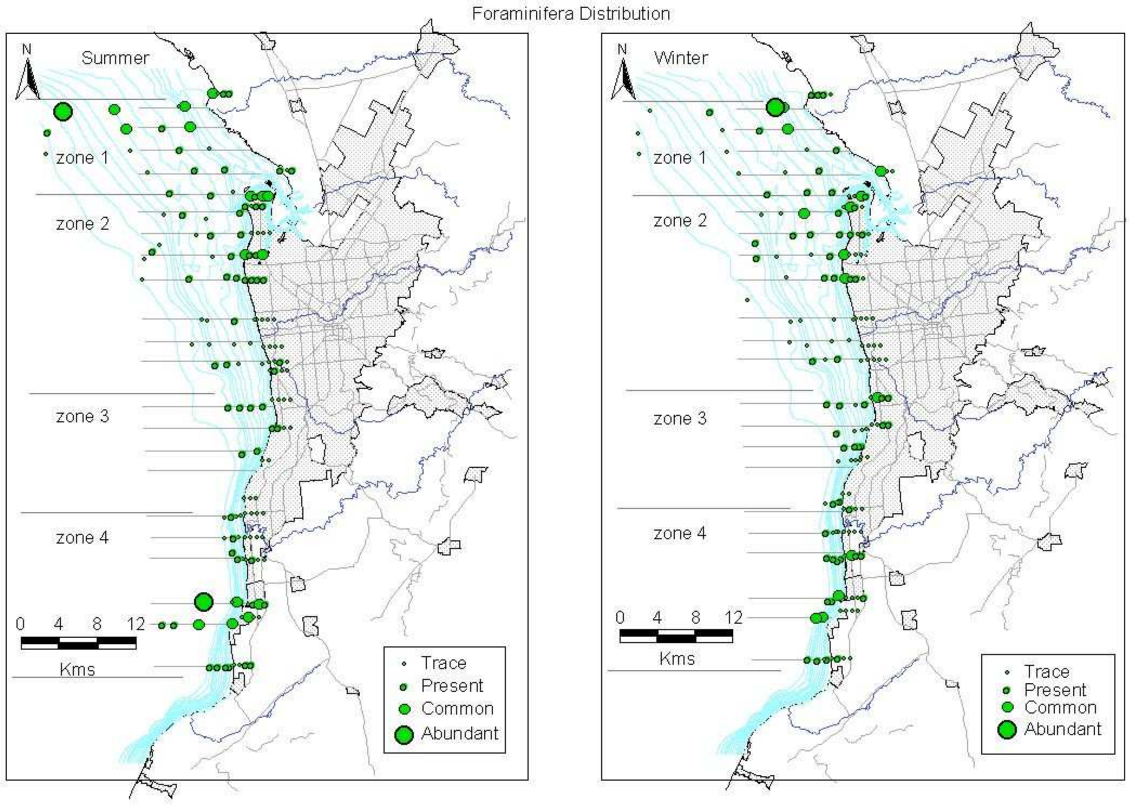
A B

Figure 3.14 Distribution of calcareous worms in the ACWS area - **A.** Summer and **B.** Winter.



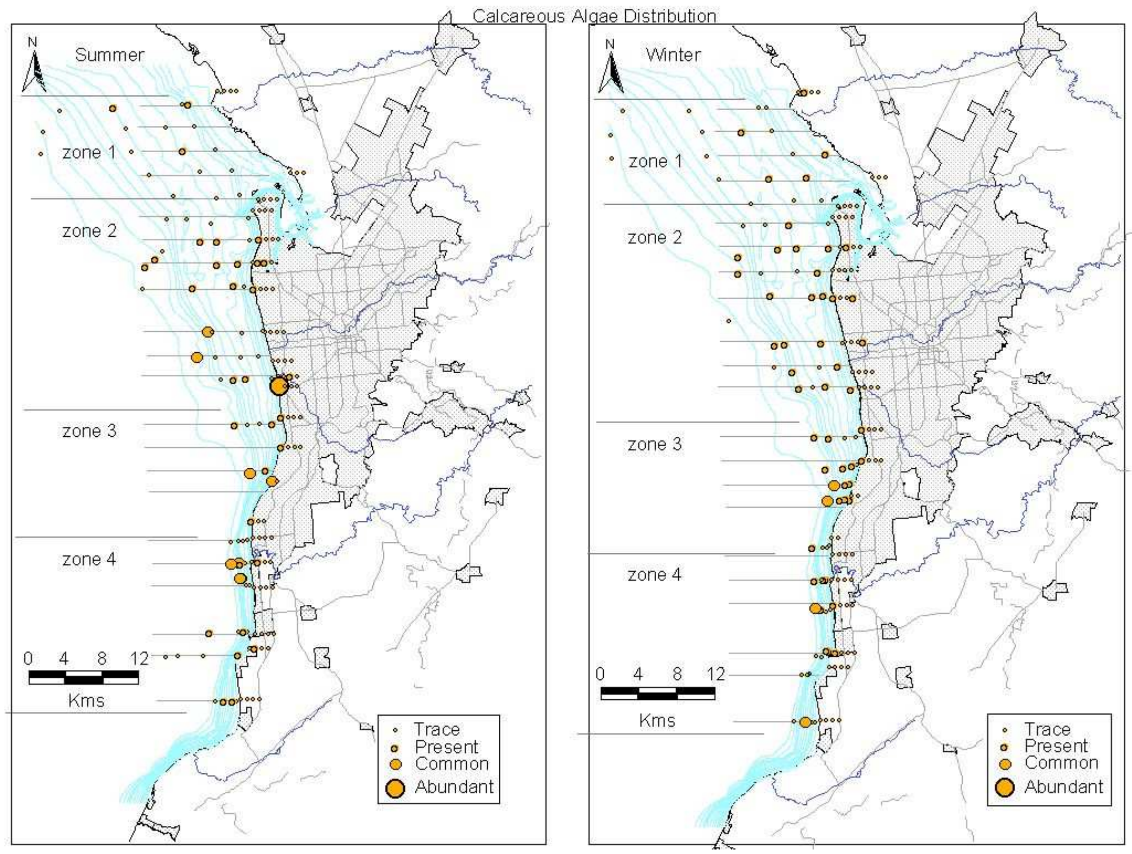
A B

Figure 3.15 Distribution of bryozoans in the ACWS area - **A.** Summer and **B.** Winter.



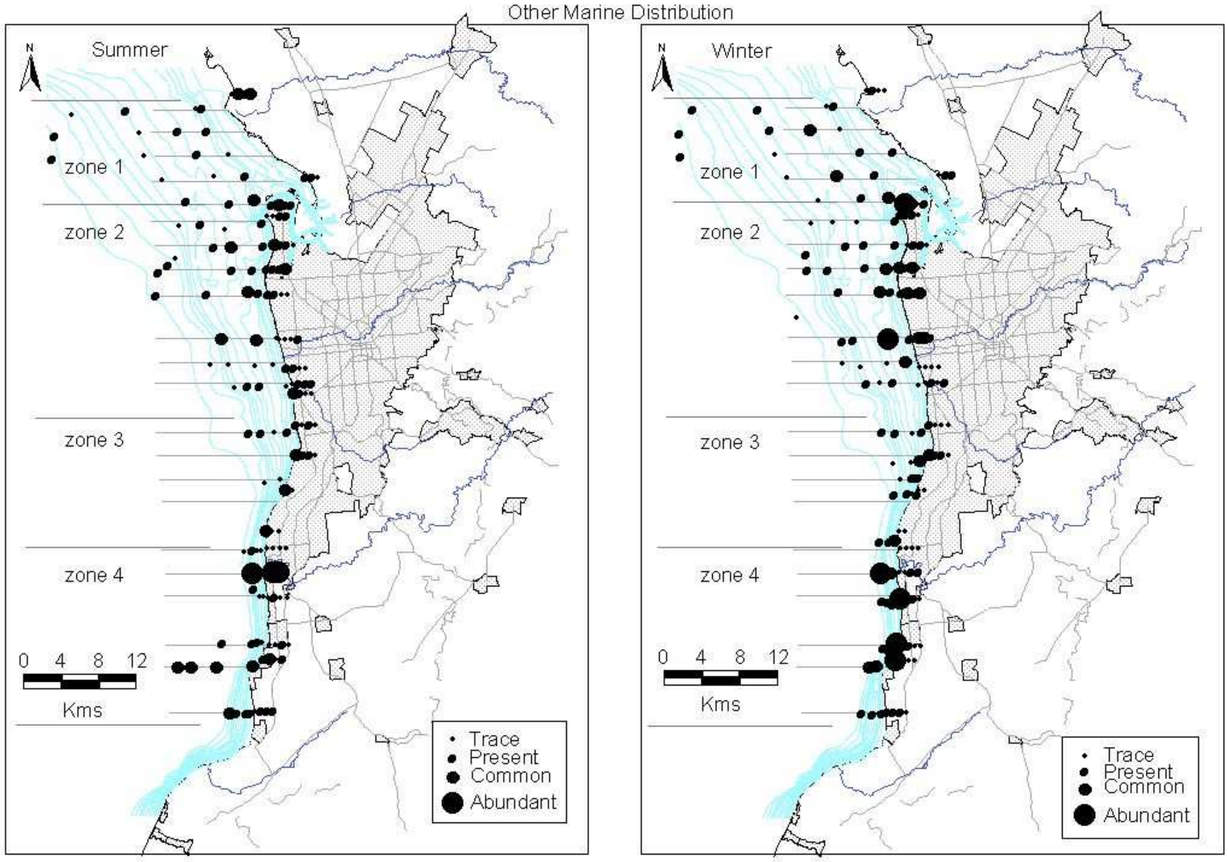
A **B**

Figure 3.16 Distribution of foraminifera in the ACWS area - **A** Summer and **B** Winter.



A **B**

Figure 3.17 Distribution of calcareous algae in the ACWS area - **A** Summer and **B** Winter.



A **B**

Figure 3.18 Distribution of other marine carbonate biota in the ACWS area - **A.** Summer and **B.** Winter.

The set of pie diagrams (Appendix H and Figures 3.1 and 3.2) for each transect for Summer and Winter also show the distribution of the calcareous biota, and give an overview compared to the other biota present at that site and also on that transect. They also show the relationship of the biota to the grain size of the sediments and to the mineralogy of those grains.

3.5 Relict Grains

Not all the sediment samples contained relict grains, especially those from the beach itself. The percentage of relict grains present in the sediment samples is shown in Appendix K. The results for Zone 1, Transect a and Zone 4, Transect z are shown here as examples. Relict grains are readily seen in Figure 5.3 and in many of the colour photos of the sediment grains which are in Appendices C, D and E.

Table 3.5 Relict grains in the samples from Zone 1, Transect a and Zone 4, Transect z - Summer and Winter.

SUMMER			WINTER		
sample no	**% relict**	**% other**	**sample no**	**% relict**	**% other**
1a-1	2.00	98.00	1a-1	1.00	99.00
1a-4	2.00	98.00	1a-4	2.00	98.00
1a-3	1.00	99.00	1a-3	2.00	98.00
1a-2.1	0.00	100.00	1a-2	1.00	99.00
1a-5	1.00	99.00	1a-5	10.00	90.00
1a-6	0.00	0.00	1a-6	15.00	85.00
1a-7	27.00	73.00	1a-7	50.00	50.00
1a-8	0.00	100.00	1a-8	1.00	99.00
4z-1	5.00	95.00	4z-1	5.00	95.00
4z-4	7.00	93.00	4z-4	12.00	88.00
4z-3	7.00	93.00	4z-3	7.00	93.00
4z-2	7.00	93.00	4z-2	7.00	93.00
4z-6	7.00	93.00	4z-6	75.00	25.00
4z-7	40.00	60.00	4z-7	5.00	95.00
4z-8	5.00	95.00	4z-8	5.00	95.00

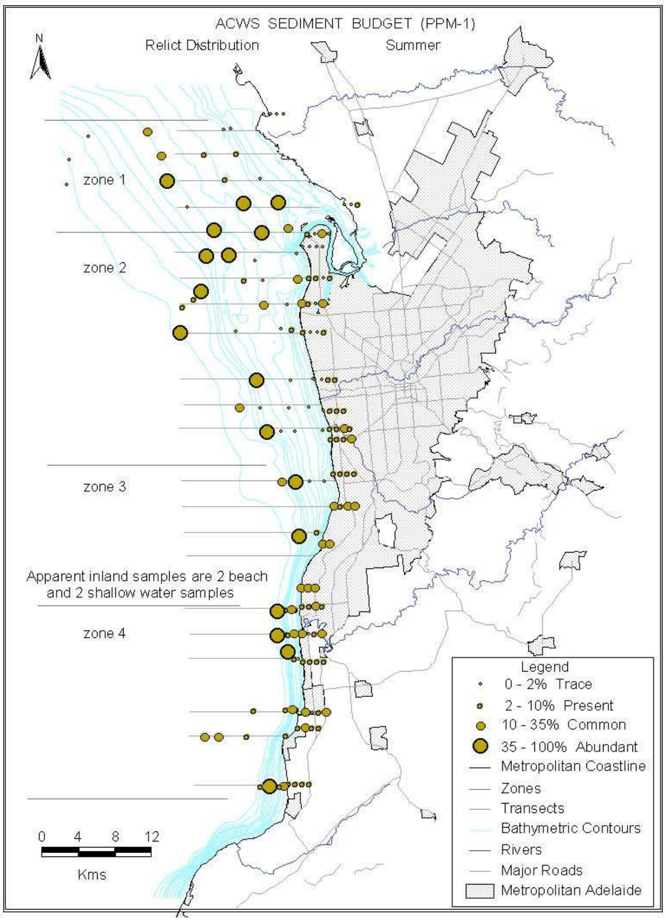


Figure 3.19 Distribution of relict grains in the ACWS area - Summer

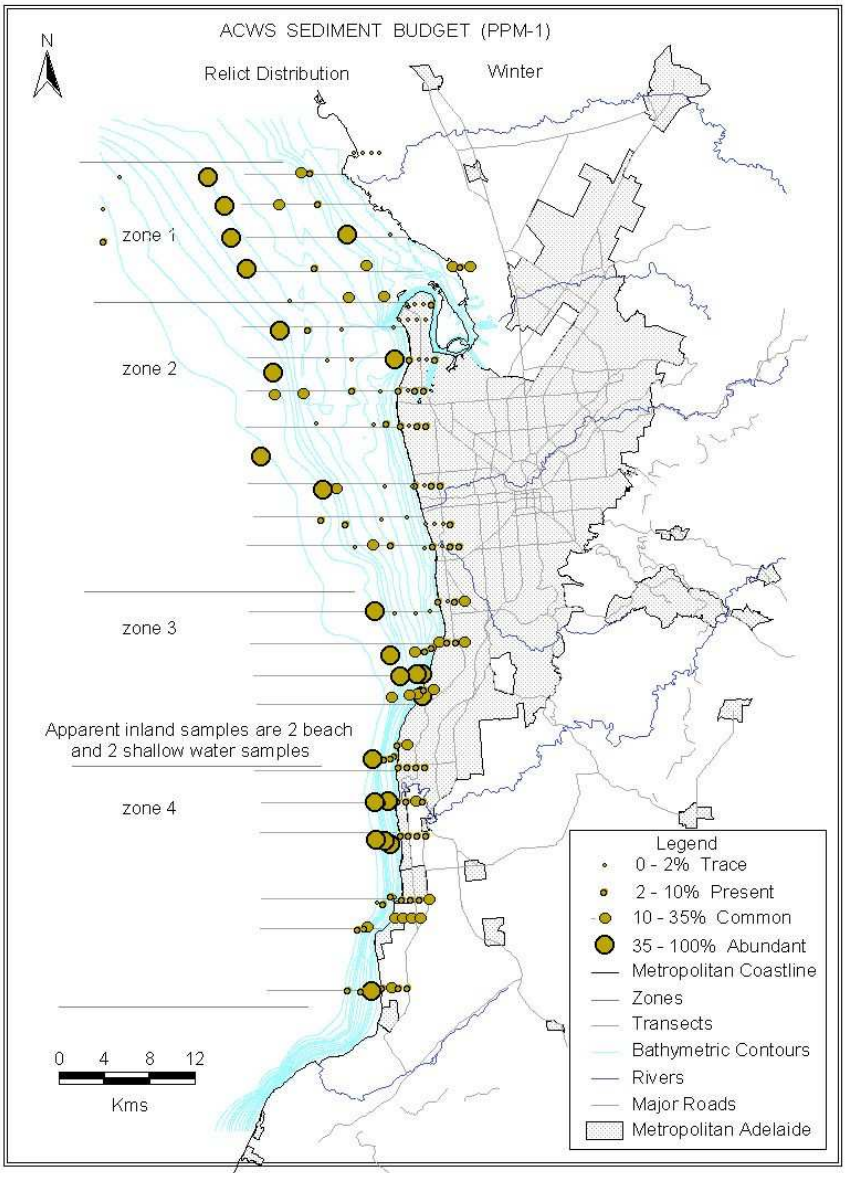
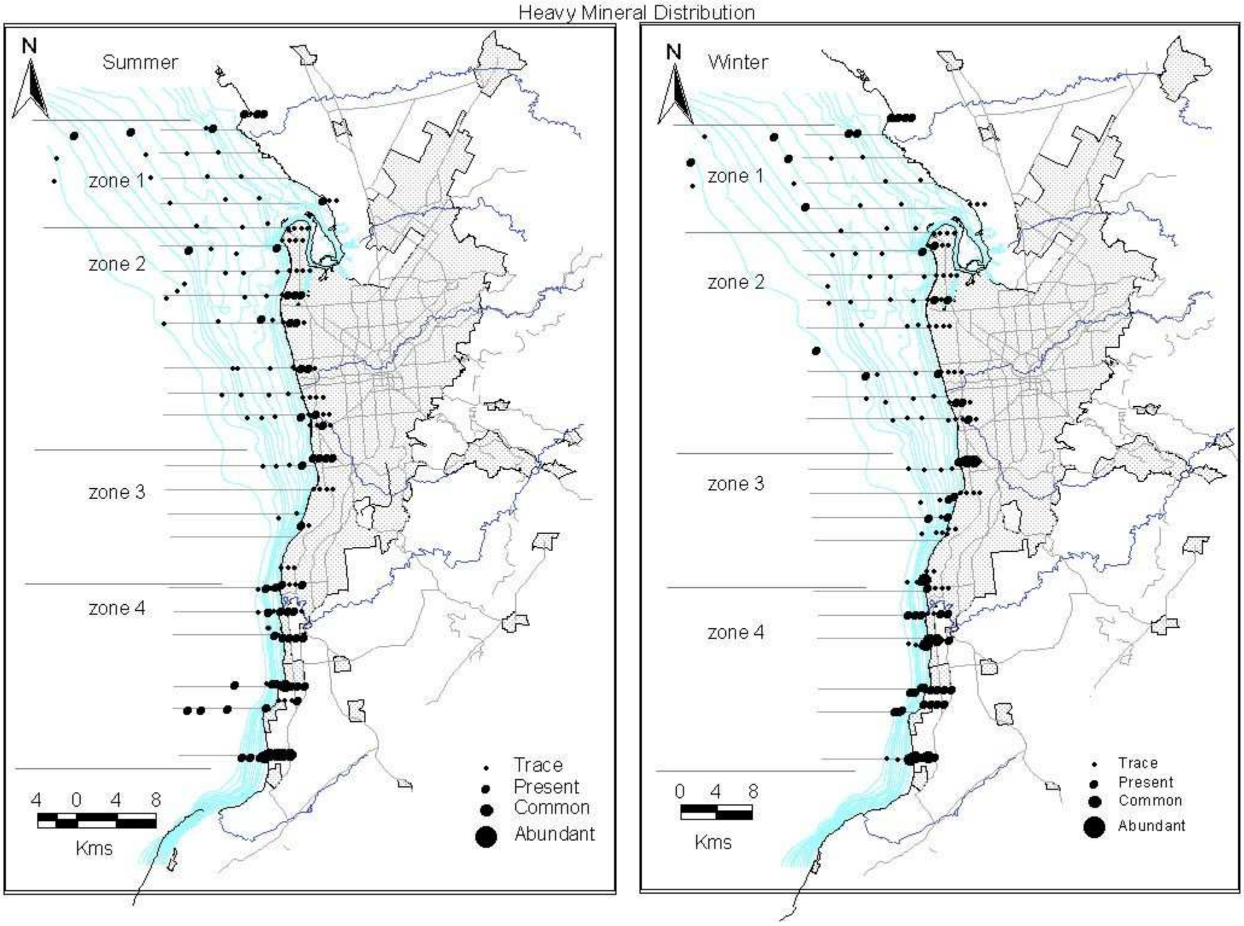


Figure 3.20 Distribution of relict grains in the ACWS area - Winter

3.6 Heavy Minerals

The main heavy mineral in the ACWS area is the black Fe-Ti oxide, ilmenite (Figure 3.20). Garnet, amphiboles, pyroxenes and magnetite also occur.

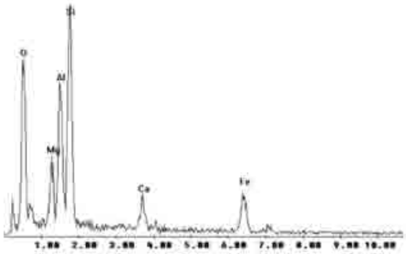
Figure 3.21 Heavy mineral sands (ilmenite) deposited by the Onkaparinga River in the Onkaparinga Estuary. These heavy grains are only transported during high-energy flow. The grains are only half the size of the co-existing quartz grains. Walking stick leaning against bank for scale.



A **B**

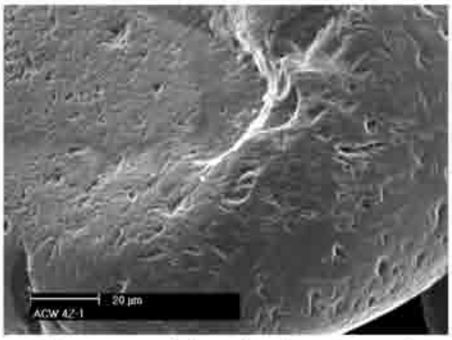
Figure 3.22 Distribution maps of heavy minerals in the ACWS area **A** during the Summer and **B** during the Winter.

The Franz Magnetic Separator was used to concentrate the heavy minerals, which were then photographed under SEM and also analysed using the EDAX attachment. The results are shown in Figures 3.23A and 3.23B.

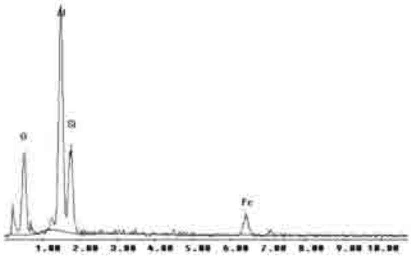


Elemental analysis of a garnet grain, using a Philips XL20 SEM, incorporating an Energy Dispersive Spectrometer (EDAX) [elemental composition (Mn, Fe,Ca)3 (Al, Fe)2 (Si,04)3]. Grain taken from sample ACWS(S) 4z-1

Garnet grain with poorly developed cleavage, from samlpe ACWS(S) 4z-1, taken from the back of the beach region.

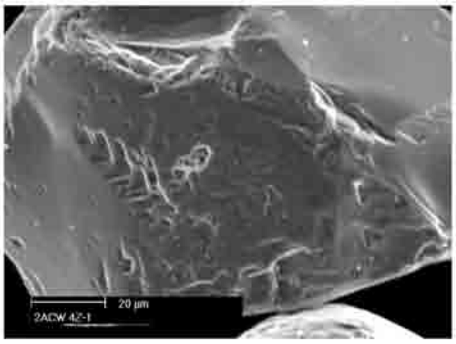


Close up of the pitted grain surface, showing signs of glacial transport.



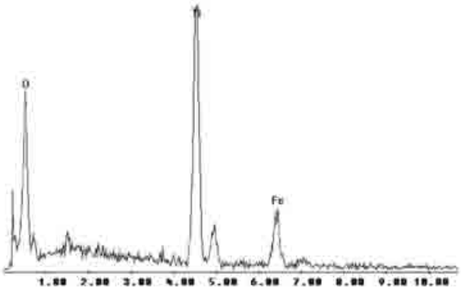
Elemental analysis of a staurolite grain, using a Philips XL20 SEM, incorporating an Energy Dispersive Spectrometer (EDAX) [elemental composition (Fe,Mg, Zn)2 Al9 (Si,Al)4 O22(OH)2]. Grain taken from sample ACWS(W) 4z-1

Cleaved, staurolite grain from sample ACWS(W) 4z-1, from the back of beach region.



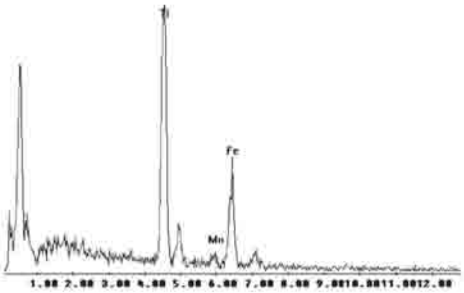
Close up of the pitted grain surface, showing signs of glacial transport.

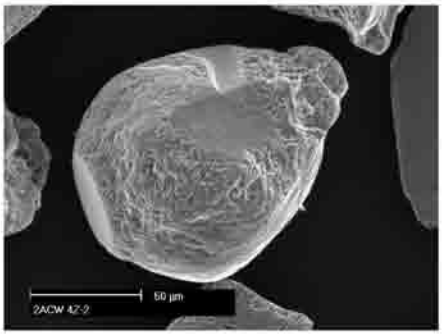
Figure 3.23A SEM images and spectra of heavy minerals from selected beach sand samples from the ACWS area - garnet and staurolite.



Elemental analysis of an ilmenite grain, using a Philips XL20 SEM, incorporating an Energy Dispersive Spectrometer (EDAX) [elemental composition Fe TiO3].
Grain taken from sample ACWS(W) 4z-2

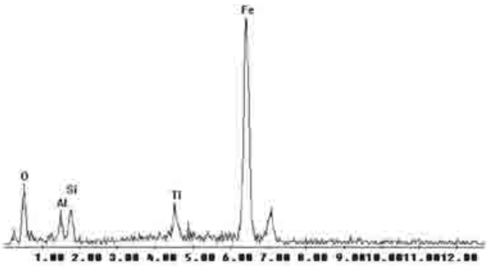
Ilmenite grain from sample ACWS(W) 4z-2, taken from the back of the beach region.





Elemental analysis of an ilmenite grain, using a Philips XL20 SEM, incorporating an Energy Dispersive Spectrometer (EDAX) [elemental composition Fe TiO3].
Grain taken from sample ACWS(W) 4z-2

Ilmenite grain from sample ACWS(W) 4z-2, taken from the back of the beach region.



Elemental analysis of an titanoheamatite grain, using a Philips XL20 SEM, incorporating an Energy Dispersive Spectrometer (EDAX) [elemental composition α-Fe2O3, where α =Ti].
Grain taken from sample ACWS(W) 4z-2

Titanohematite grain from sample ACWS(W) 4z-2, taken from the back of the beach region.

Figure 3.23B SEM images and spectra of heavy minerals from selected beach sand samples from the ACWS area - ilmenite and titanohematite.

3.7 Input from Rivers, Creeks and Storm Drains

There was no ongoing study of the sediments derived from surface transport across the Adelaide Plains so PPM 1, after their program was completed, did a cursory field and laboratory program of Patawalonga Creek and all other outlets to the north and of creeks in the southern part of the ACWS area. The results are shown in Tables 3.6 and 3.7 and Figures 3.24 A and B.

End of cemented channel of Brownhill Creek, Watson Avenue, Netley

Where Brownhill and Keswick Creeks merge (Brownhill Creek in fore ground, Keswick Creek in back ground), corner Watson and Baroda Avenues.

Patawalonga Creek Sites 1 and 2, opposite Stanley Street, Glenelg North

Patawalonga Creek Site 3, Beach Road, West Beach

Onkaparinga River Estuary, Site 1, Weatherald Terrace 100m northeast of footbridge.

Onkaparinga River (site 2) corner of Patapinda Road and Hall Cresecent, away from estuarine sea water influence.

Figure 3.24A Some of the rivers and creeks sampled to assess their contribution to the sediment budget.

Maslin Creek, looking east from beach

Willunga Creek, looking east towards William Street, Port Willunga

Looking landwards up Aldinga Creek, at end of Button Road, Aldinga Beach

View seawards of Aldinga Creek, Button Road, Aldinga Beach

View inland up Sellicks Creek, end of Sellicks Beach Road, Sellicks Beach

View seaward of Sellicks Creek, Sellicks Beach Road, Sellicks Beach

Figure 3.24B Creeks in the southern part of the ACWS area - Maslins Creek, Willunga Creek, Aldinga Creek and Sellicks Creek. The gentle slopes of the Adelaide Hills in this region have led to the formation of alluvial fans which are dissected by gullies in the Sellicks beach area, thereby supplying a continuous heavy load of silt to cobble sized material to the sea.

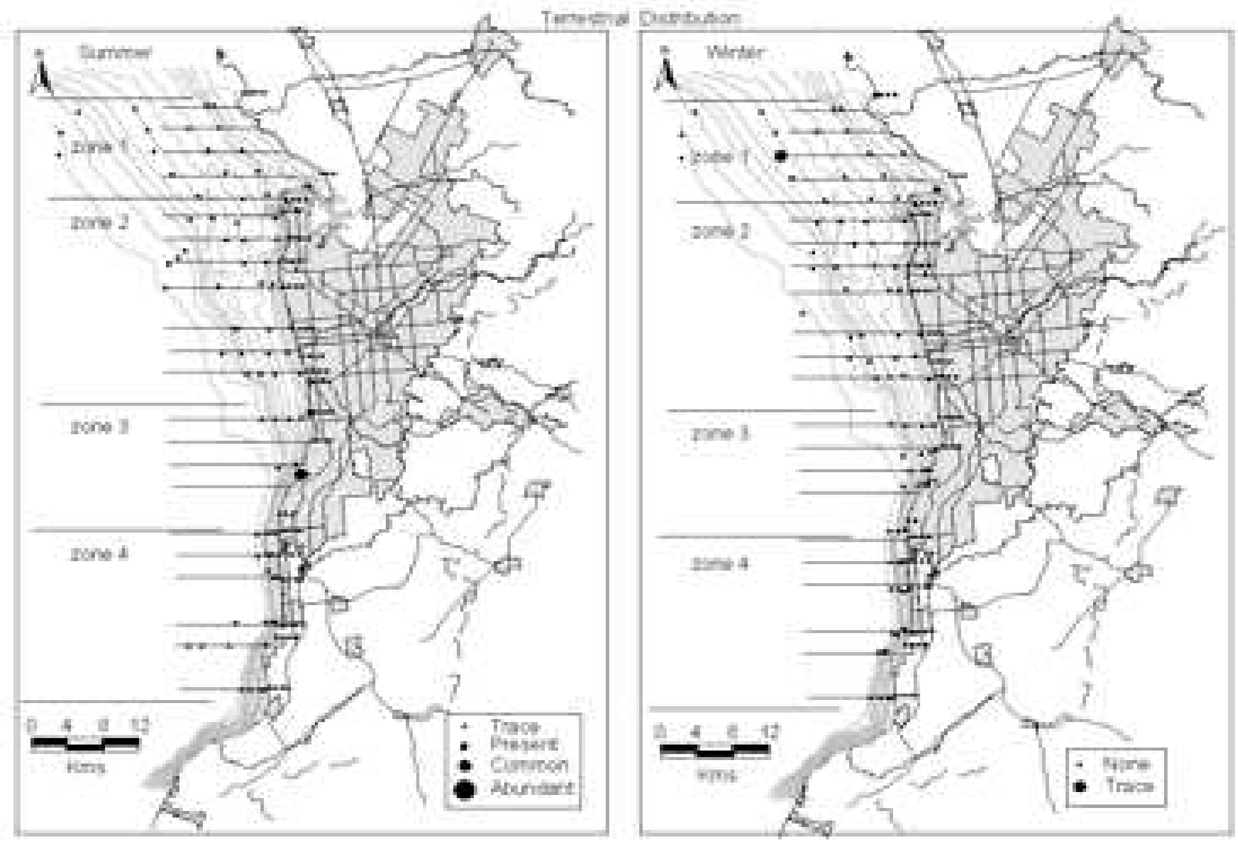
Table 3.6 Grain Size analyses of the load delivered by rivers and creeks in the ACWS area (Data from J. Wilkinson IS 1).

	Sample wt (g)	Coarse wt (g)	Medium wt (g)	Fine wt (g)	V.Fine wt (g)	Suspend sed(t/yr)	Ss Cse (t/yr)	Ss Med. (t/yr)	Ss Fine (t/yr)	Ss Vfine (t/yr)
Brownhill Ck	183.9	63.11	52.66	42.86	25.22	-	-	-	-	-
Keswick Ck	153.1	12.00	16.57	38.70	85.80	-	-	-	-	-
Patawalonga Ck 1	333.2	4.47	219.50	101.92	7.32	**690.50**	9.25	454.83	211.22	15.19
Pat. Ck 2	233.9	107.06	61.84	62.38	2.65	**690.50**	316.04	182.57	184.16	7.80
Pat. Ck 3	43.00	24.13	11.71	3.22	3.94	**690.50**	387.51	188.02	51.72	63.25
Torrens R. 1	218.2	1.03	140.60	71.74	4.79	**630.60**	2.96	406.42	207.34	13.87
Torrens R. 2	96.76	3.74	10.09	41.87	41.06	**630.60**	24.40	65.77	272.86	267.56
Sturt River	too sm to use		-	-	-	-	-	-	-	-
Thompson Ck	239.2	27.60	81.68	51.11	78.76					
Gawler River	221.2	10.60	80.60	86.24	43.75	**1912.44**	91.61	696.89	745.66	378.28
Peddler Ck	too sm to use		-	-	-	24.97	-	-	-	-
Christies Ck	105.7	3.26	64.98	20.02	17.39	**225.60**	6.97	138.74	42.75	37.13
Field River	106.8	6.09	42.98	26.13	31.61	**251.30**	14.32	101.12	61.47	75.26
Aldinga Ck	**711.1**	**180.91**	**283.99**	**242.24**	**3.94**	**15.10**	**3.84**	**6.03**	**5.14**	**0.08**
Maslin Creek	**380**	**0.00**	**360.23**	**18.78**	**0.94**	**10.79**	**0.00**	**10.23**	**0.53**	**0.03**
Onkaparinga1	**224.3**	**6.45**	**64.59**	**95.87**	**57.42**	**210.00**	**5.25**	**52.54**	**77.99**	**74.21**
Onkaparinga2	**147.8**	**0.85**	**13.86**	**45.97**	**87.14**	**210.00**	**1.22**	**19.70**	**65.31**	**123.80**
Sellicks Ck	**363.1**	**36.67**	**18.03**	**16.56**	**291.8**	**5.87**	**0.59**	**0.29**	**0.27**	**4.72**
Willunga Ck	**100.8**	**4.21**	**6.65**	**16.53**	**73.42**	**16.50**	**0.69**	**1.09**	**2.71**	**12.02**

Table 3.7 Mineralogy of sediment collected from bed-load of rivers and creeks flowing to the sea across the Adelaide Plains.

Creek/ River	carbonate	White quartz	Black heavy mins	Blue other
Brownhill Creek	0.00	55.00	3.00	42.00
Keswick Creek	0.00	40.00	1.00	59.00
Patawalonga Creek #1	10.00	83.00	2.00	5.00
Patawalonga Creek #2	5.00	89.00	5.00	1.00
Patawalonga Creek #3	15.00	0.00	0.00	85.00
Torrens River #1	3.00	92.00	4.00	1.00
Torrens River #2	0.00	30.00	0.00	70.00
Sturt River	0.00	0.00	0.00	100.00
Thompson Creek	0.00	40.00	1.00	59.00
Gawler River	3.00	66.00	1.00	30.00
Pedler Creek	0.00	80.00	10.00	10.00
Christies Creek	2.00	82.00	1.00	15.00
Field River	10.00	81.00	2.00	7.00
Aldinga Creek	5.00	85.00	10.00	0.00
Maslin Creek	0.00	80.00	0.00	20.00
Onkaparinga # 1	10.00	86.00	1.00	3.00
Onkaparinga #2	0.00	85.00	0.00	15.00
Sellicks Creek	25.00	73.00	1.00	1.00
Willunga Creek	0.00	35.00	4.00	61.00

All values are percentages ;heavy minerals are mainly ilmenite clay minerals and organic



A B

Figure 3.25 Distribution of organic material in the ACWS area **A** during the Summer and **B** the Winter. (Data from J. Wilkinson, pers. comm.)

Pie diagrams showing the mineralogy of sediments collected from the bed load of rivers and creeks draining the Adelaide Plains are shown in Appendix L. The results of this limited study showed that the silt fraction is considerable. The volume of water in Willunga Creek varies seasonally (Figure 3.26).

Figure 3.26 Willunga Creek outlet to the sea, photographed in summer.

In winter, the creek flows rapidly, discharging sediment from the surrounding agricultural properties.

3.8 Input from Glaciated Areas

South Australia was covered by continental glaciation during the Permian, some 270 Mya. Sediment (and rocks – "erratics") from this glaciation is preserved at many locations throughout the state, with exceptionally well-preserved examples at Hallett Cove. It is less well-known that these Permian glacial sediments also occur today as part of the sediment budget on the sea-floor in the southern half of the ACWS area (Figure 3.27). The erratics are eroding over time and releasing their individual mineral grains.

Figure 3.27 Sample of beach sand from Sellicks Beach (ACWS 4Z-1(bulk) x25) showing garnets derived from erratics of Kanmantoo Schist.

Observation of the mineral grains under SEM reveals chattermark trails on the surface of hard minerals that were entrained in the base of the glacier, either as individual grains or as grains on the outer surface of entrained rocks (Figure 3.28). There is no alternative explanation for the production of these delicate chattermark trails on such small surfaces (Bone 1978). Soft minerals, such as the carbonates, lack the strength to survive glacial transport.

These glacially-derived grains are a significant component of the sediment in Zone 4, particularly in the Sellicks Beach area (Figure 3.27). They are also present further north into Zone 3 but were not present in Zones 1 and 2.

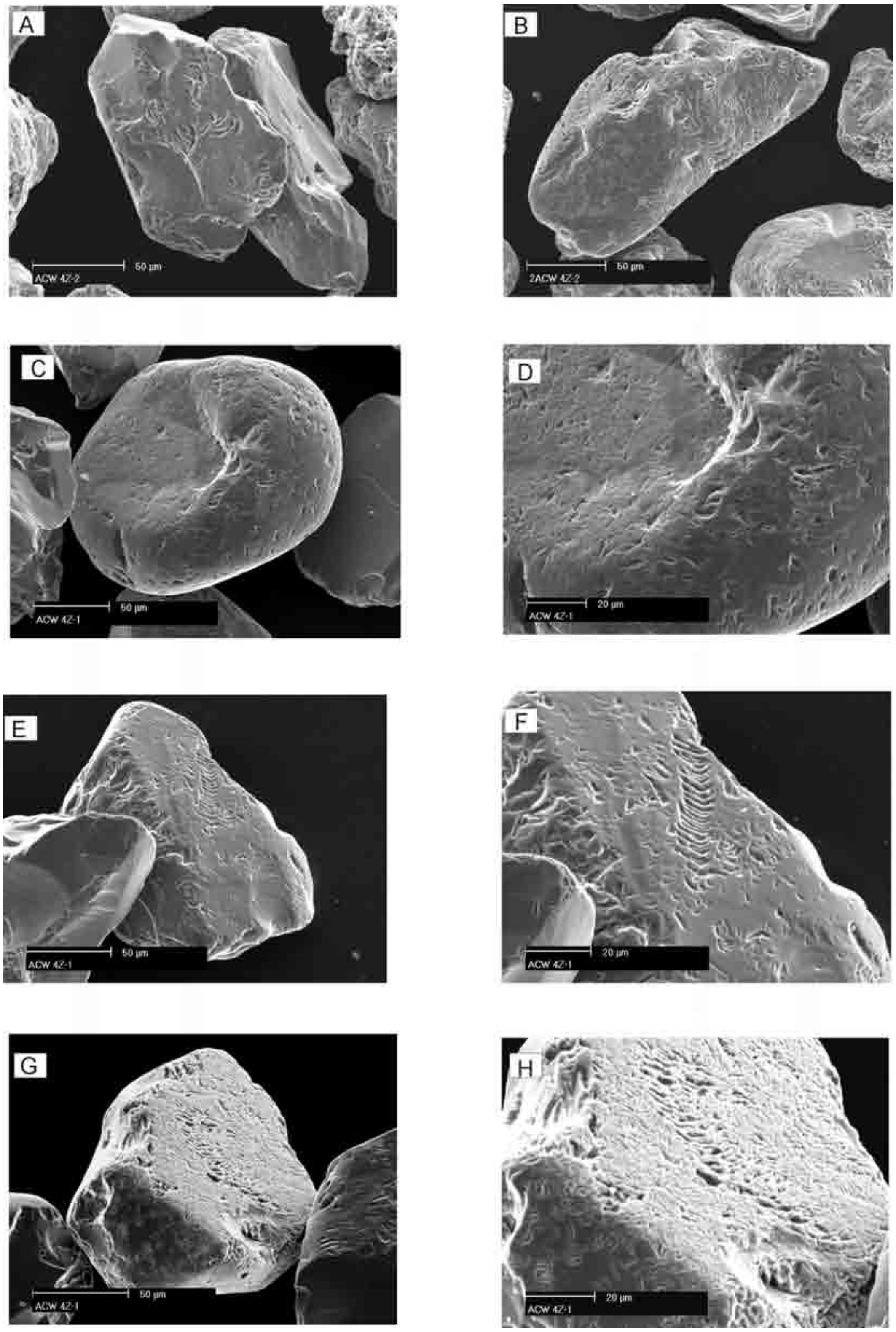


Figure 3.28 SEM images of chattermark trails on the surface of garnet grains collected from Sellicks Beach. **A** and **B** ACWS(S)4z-2; **C** ACWS(S)4z-1; **D** Closeup of C; **E** ACWS(S)4z-1; **F** Closeup of E; **G** Curved chattermark from ACWS(S)4z-1; **H** Closeup of G.

3.9 Anthropogenic Inputs

3.9.1 Sand replenishment

No analytical work was performed on the introduced sand grains. This work is under the auspices of the Coast Protection Board.

3.9.2 Industrial waste

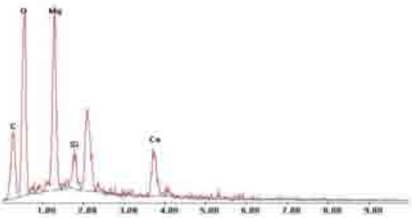
The South Australian EPA requested some samples from the dumping of spoil at Outer Harbour from Penrice be identified, and information provided on their anticipated longevity and pollution potential. Five samples were supplied and analysed by the EDAX attachment of the Phillips SEM at the University of Adelaide. The results are shown in the Table 3.8.

Table 3.8 SEM EDAX analyses of samples from Penrice spoil grounds, Outer Harbour. Two analyses from each of the five samples are shown.

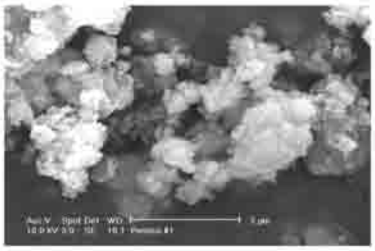
PENRICE 1					PENRICE 1				
Element	Wt %	At %	K-Ratio		Element	Wt %	At %	K-Ratio	
C K	11.80	19.49	0.05		C K	9.12	15.77	0.06	
O K	38.48	47.72	0.19		O K	46.24	60.03	0.18	
MgK	21.52	17.57	0.18		MgK	3.17	2.71	0.03	
SiK	5.99	4.23	0.05		SiK	0.00	0.00	0.00	
CaK	22.22	11.00	0.21		CaK	41.47	21.49	0.39	
Total	100.00	100.00			Total	100.00	100.00		
Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B	Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B
C K	10.48	0.43	3.70	24.52	C K	17.03	0.29	3.80	58.75
O K	28.76	1.10	2.23	26.06	O K	39.69	0.31	2.48	126.38
MgK	26.54	2.37	2.38	11.19	MgK	5.24	3.12	8.57	1.68
SiK	6.12	2.76	5.72	2.22	SiK	0.00	3.09	0.00	0.00
CaK	9.26	1.10	4.08	8.39	CaK	24.78	1.28	3.20	19.36
PENRICE 2					PENRICE 2				
Element	Wt %	At %	K-Ratio		Element	Wt %	At %	K-Ratio	
C K	10.25	17.29	0.07		C K	11.20	18.42	0.08	
O K	46.64	59.06	0.19		O K	50.16	61.90	0.21	
MgK	5.09	4.25	0.04		MgK	1.42	1.15	0.01	
SiK	0.82	0.59	0.01		SiK	0.95	0.67	0.01	
CaK	37.19	18.80	0.35		CaK	36.27	17.87	0.34	
Total	100.00	100.00			Total	100.00	100.00		
Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B	Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B
C K	19.36	0.54	2.77	36.11	C K	24.82	0.93	3.24	26.70
O K	44.57	1.32	1.83	33.79	O K	54.10	2.16	2.20	25.03
MgK	9.00	3.38	4.71	2.67	MgK	2.76	2.39	13.02	1.16
SiK	1.30	2.43	17.85	0.54	SiK	1.68	1.53	16.89	1.10
CaK	23.52	1.16	2.54	20.29	CaK	25.45	0.80	3.19	31.66
PENRICE 3					PENRICE 3				
Element	Wt %	At %	K-Ratio	Z	Element	Wt %	At %	K-Ratio	

C K	19.68	28.64	0.10	1.04	C K	21.52	32.12	0.12	
O K	46.00	50.25	0.26	1.02	O K	41.19	46.16	0.20	
MgK	20.37	14.65	0.17	0.96	MgK	15.24	11.24	0.13	
SiK	2.07	1.29	0.02	0.96	SiK	3.25	2.07	0.03	
CaK	11.87	5.18	0.11	0.92	CaK	18.81	8.41	0.17	
Total	100.00	100.00			Total	100.00	100.00		
Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B	Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B
C K	23.86	0.71	3.05	33.55	C K	29.81	0.82	2.43	36.15
O K	47.97	1.87	2.16	25.59	O K	40.72	2.53	2.12	16.12
MgK	30.13	3.92	2.84	7.68	MgK	24.42	2.71	2.80	8.99
SiK	2.54	2.41	12.85	1.05	SiK	4.42	2.16	7.61	2.04
CaK	5.93	1.29	6.66	4.58	CaK	10.26	0.76	4.24	13.57
PENRICE 4					PENRICE 4				
Element	Wt %	At %	K-Ratio	Z	Element	Wt %	At %	K-Ratio	
C K	8.39	14.08	0.05	1.06	C K	17.38	26.17	0.09	
O K	48.98	61.73	0.21	1.03	O K	46.44	52.50	0.24	
MgK	7.70	6.39	0.06	0.98	MgK	15.36	11.43	0.13	
SiK	1.06	0.76	0.01	0.97	SiK	2.64	1.70	0.02	
CaK	33.88	17.04	0.32	0.93	CaK	18.18	8.20	0.17	
Total	100.00	100.00			Total	100.00	100.00		
Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B	Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B
C K	15.57	0.63	3.82	24.59	C K	27.54	0.82	2.31	33.72
O K	51.46	1.51	2.09	34.16	O K	55.40	2.31	1.64	24.02
MgK	14.13	3.01	4.33	4.69	MgK	27.97	3.50	2.40	8.00
SiK	1.72	2.49	17.59	0.69	SiK	4.10	2.88	7.72	1.42
CaK	22.14	1.27	3.23	17.48	CaK	11.35	0.69	3.66	16.50
PENRICE 5					PENRICE 5				
Element	Wt %	At %	K-Ratio	Z	Element	Wt %	At %	K-Ratio	
C K	10.25	16.72	0.06	1.05	C K	13.32	21.38	0.04	
O K	46.49	56.96	0.22	1.03	O K	36.08	43.47	0.22	
MgK	14.78	11.92	0.12	0.98	MgK	1.67	1.33	0.01	
SiK	2.30	1.61	0.02	0.97	AlK	24.65	17.61	0.22	
CaK	26.18	12.80	0.24	0.93	SiK	22.10	15.17	0.19	
Total	100.00	100.00			CaK	2.17	1.05	0.02	
					Total	100.00	100.00		
Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B					
C K	14.46	0.65	3.56	22.27	C K	12.43	0.51	2.89	24.45
O K	45.98	1.72	1.99	26.74	O K	55.01	1.56	1.37	35.37
MgK	23.84	2.70	2.86	8.82	MgK	3.53	3.37	7.43	1.05
SiK	3.19	2.70	10.07	1.18	AlK	48.26	3.12	1.48	15.46
CaK	14.68	1.32	3.61	11.16	SiK	36.38	2.73	1.72	13.32
					CaK	1.46	0.64	9.93	2.28

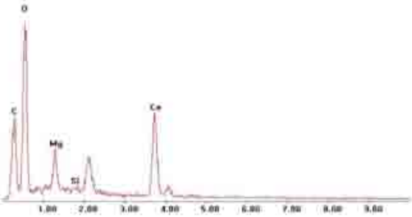
SEM photographs were also taken, and these are illustrated in Figure 3.29, along with the spectra obtained from the analyses given in the Table 3.8.



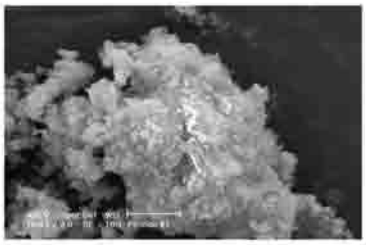
Elemental analysis of a cluster of magnesium calcite grains using a Philips XI30 SEM, incorporating an Energy Dispersive Spectrometer(EDAX).



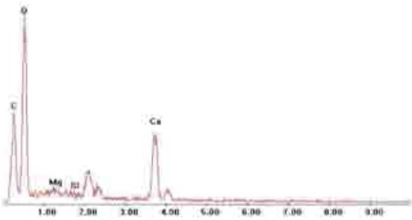
Cluster of rounded mg calcite grains after the addition of a floculating polymer



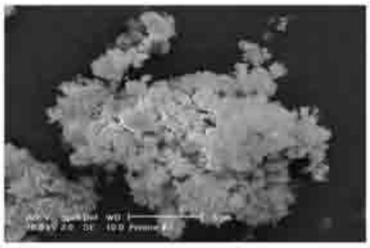
Elemental analysis of a cluster of magnesium calcite grains using a Philips XI30 SEM, incorporating an Energy Dispersive Spectrometer (EDAX).



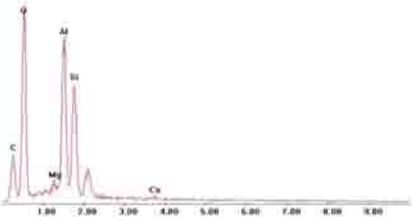
Cluster of rounded mg calcite grains after the addition of a floculating polymer



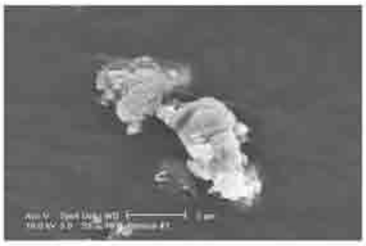
Elemental analysis of a cluster of magnesium calcite grains using a Philips XL30 SEM, incorporating an Energy Dispersive Spectrometer (EDAX).



Cluster of flat, platy mg calcite grains before the addition of a floculating polymer



Elemental analysis of a kaolinite grain using a Philips XI30 SEM, incorporating an Energy Dispersive Spectrometer (EDAX).



Kaolinite grain, with smaller Mg calcite grains adhered to surface

Figure 3.29 Elemental analysis and SEM image of samples of Penrice spoil material.

The spoil material has decomposed to a fine-grained complex carbonate mineral. This increase in fine-grained material is "captured" in the grain size analyses, which also illustrates that the material has remained *in situ*. It is expected that it will have no deleterious effect on the overall grain size distribution, but effects on other features, e.g. sea-weed, were not assessed by PPM 1.

4 DISCUSSION

4.1 Introduction

4.1.1 General characteristics of sediment

The physical characteristics of the sediments veneering the sea-floor in the ACWS area did not reveal any major surprises. They are typical of cool water (temperate) environments (James & Clarke 1995 and references therein), such as those found across the southern margin of Australia (James et al. 1992, 1994, 1997, James & Bone 2000, Fuller et al. 1994). The sediments are mixed carbonate and siliciclastic sand, with varying amounts of mud and gravel. The carbonate grains are autochthonous and biogenic in origin and quartz grains dominate the siliciclastics.

4.1.2 Deposition and accumulation

These two parameters are quite different, although they are often loosely used indiscriminately as the same as one another. Deposition involves the emplacement of a grain in a fixed position. It is not necessarily permanent. Indeed, permanence tends to be the exception. Accumulation implies a permanent emplacement, be it the sea-floor or the beach, following transport of the grains by tidal/storm transport, longshore drift or passive transport as attached grains, such as in the case of calcareous epiphytes on other biota, particularly seagrasses.

If all deposited grains remained *in situ,* the sea-floor height would rapidly accrete, thereby causing a sea-level fall. This rarely happens in the geological short term in areas that are not altered anthropogenically. A case where sea-level is locally altered occurs where there is progradation of the sediment, i.e. the beach builds sea-wards due to the high production of calcareous sediment outstripping the transport of the grains to a new accumulation site. Even here, though, there is movement of the grains by ebb-tides due to the unsorted nature of the sediment, allowing the infiltration of the sea-water into the unconsolidated deposit. The establishment of tidal channels in these usually flat-lying regions sees the incoming tide distribute water shallowly over the area, followed by an increasingly higher velocity (=high-energy) outflow of water following high tide. This transports large volumes of mixed (including quite large gastropods) sediment sea-wards, gradually building a wedge of sediment seawards. This process is well illustrated in the northern two thirds of Zone 1 (Figure 4.1). It is a process that occurs relatively rapidly (Gostin et al. 1984). If the high biota production in the intertidal area is decreased, this progradation will cease.

4.2 Grain Size and Mineralogy

4.2.1 General

The variability in the grain size is mainly a function of the carbonate material (Figure 3.8), as the size of the fragments that persist in the sediment are dependent upon the architecture of the original biota, e.g. large robust gastropods (e.g. *Turbo* Figure *2.8)* will be resistant to physical erosion for a long period of time, not diminishing in size until waters cause dissolution of their metastable aragonitic shell whereas a large colony of the articulated zooidal cheilsotome bryozoan (e.g. *Orthoscuticella)* will rapidly disintegrate into hundreds of individual zooids following the death of the colony. This latter organism is delicate and the thin walls are easily broken in a high-energy environment. However, in quiet environments, it will persist, especially as its skeleton is made from stable calcite (LMC).

On the other hand, the allocthonous inorganic quartz grains tend to be uniform in size (Figure 2.6A), this is because of their original terrestrial source, where they are often already uniform in size, e.g. the Precambrian Aldgate Sandstone weathered from the Adelaide Hills and then transported many tens of kms down the Onkaparinga River drainage system. During this transportation phase, which itself may be episodic, physical erosion abrades the chemically-resistant grains to a relatively uniform size. Flood events will cause the debouchment of a gravel bedload of an atypical size, which then becomes an anomalous deposit on the beach, e.g. beach north of the mouth of the Onkaparinga River Figure 4.3.

Figure 4.1 Pt Gawler: (clockwise from upper left) A - Looking seawards across intertidal area at low tide. B - Tidal channel cut into beach alongside mangroves. These channels act as high-energy sluices during outgoing tides and as gentler inlets during incoming tides, spreading water over the swamps and samphire flats behind the beach barrier. C - Lag of coarse molluscs in bottom of tidal channel are much larger than beach sediment grains. D - Water drains rapidly from swamp/samphire area at back of beach during outgoing tide via the tidal channels, leaving intertidal area exposed.

In contrast, the siliciclastic rocks of similar age that form the cobbles on the rocky beach and shore platform at Marino Rocks are weathered to produce smaller "grains", but these cobbles have not been transported long distances, and hence it is only the smaller cobbles that become rounded, with the larger cobbles often having a flat, smooth upper surface due to abrasion by the diurnal action of tidal flow. These cobbles are often overturned during storm events so that the obverse side then becomes smoothly planed off, resulting in strandlines of oblate cobbles. However, similar cobble beaches are produced, at locations like Sellicks

Beach, by the gullying of the nearby slopes of ancient outwash fans. Outwash fans contain a bimodal distribution of rounded or oblate pebbles in a fine clay/quartz matrix, so that the cobbles are not carried out to sea, but remain in the supratidal area, where they form long linear strandlines.

So, a generalisation is that the modern carbonate fraction is dominated by poorly- sorted, poorly-rounded grains with a range of sizes, in contrast to the quartz (terrigenous - siliciclastics) fraction, which is dominated by well-sorted, well-rounded grains that are fairly uniform in size. The dilemma is that in a temperate environment, such as the ACWS area, where there is a paucity of large rivers continually carrying large loads of terrigenous material to the sea-floor and beach, it is inevitable that a mixed sediment, in every aspect, is the norm.

Any management scenario has to consider this maxim – managers are dealing with mixed sediments that contain two main populations of grains with vastly different physical and chemical characteristics. Figures 3.2 to 3.5 show the comparison between grain size distribution during Summer and Winter. Does this mean that water depth is a controlling parameter when dealing with grain size? The answer is that it is an indirect parameter. The coarse size component, particularly, reflects the influence of the aforementioned two populations, with the quartz fraction tending to be concentrated inshore and the carbonate fraction in the offshore regions. Once again, this leads to areas that are mixes, e.g. the muddy flats of the northern region, where the environment is favourable to huge populations of smaller molluscs. This is not a "new" scenario, as evidenced by the extensive shell-grit cheniers that blanket the low-lying adjacent area (Flaxman 2003). Similarly, the wide intertidal area of the Semaphore – Largs Bay area, the depocentre of the finer fraction resulting from long-shore drift, is a favourable environment for foraminifers, which then contribute their fine to very fine-sized tests to the sediment budget. Their tests are extremely fragile and are unlikely to survive transport by pipeline to the southern beaches in a slurry mix. On the other hand, this will result in the material that is "imported" being sent back to whence it came. But, the alkalinity (often referred to as pH, with alkaline >7, neutral 0 and acidic <7**)** will be quite different to the original state, and so the local biota will either have to adapt, or die out, or be replaced by a new biota assemblage. The local biota, hopefully, has as one of its major components, seagrass(es), even though the seagrass itself does not end up as components of the sediment.

Unfortunately there was no scope in this study for determining the thickness of the sediments on the sea-floor. However, a "hint" can be obtained by looking at the complete field data set in Appendices A and I, where one column records the volume of sediment that was collected at each sample site, and any other observations related to, or causing, this.

Overall colour of the sediment package is also recorded in the complete field data set, giving an indication of the redox state of the environment. However, this use of colour is not straightforward, as relict grains (see Section 4.6) are colourful, ranging from bright orange to brown, gray and black, many biofragments still contain a vestige of their original natural colour (e.g. scallops, rhodoliths) and heavy mineral grains occur as the typical colour of the mineral (e.g. ilmenite is always black).

The comparison between Summer and Winter samples indicated that seasonal variation was minor, consisting of some changes in the distribution of some of the biogenic carbonate material, and distribution of grain size due to the effects of longshore drift.

4.2.2 Mineralogy and hydrodynamics

There is less seasonal change in the distribution of the mineral grains than there is in the grain size. There are explanations for this difference, with the most important one being the fact that the two most common minerals, quartz and carbonate species, have a similar specific gravity. This would result in their exhibiting similar hydrodynamic activity and thus separating out into similar-sized grains for any given environment. The architecture of the two grains, however, frequently does vary considerably, e.g. quartz grains are usually compact and round whereas carbonate grains initially reflect the morphology of their biogenic precursor. This can result in buoyancy that is not a function of specific gravity and which seemingly defies hydrodynamic processes, in the same way that an iron ship does. So, the exoskeletons of many marine invertebrates are easily transported elsewhere even although their specific gravity is 2.5 times that of seawater.

4.2.3 Physical erosion and mineralogy

The mineral quartz is a very hard mineral (7 on Moh's Hardness Scale, where talc is 1 and diamond is 10), and needs a high impact in order to shatter into smaller pieces. The lack of cleavage also impedes the progress of a fracture once an initial parting is produced. The presence of a layer of the fluid, water, around all individual grains on the sea-floor also diminishes the strength of any impact between grains. The lattice of the quartz unit cell also imparts a considerable strength to quartz.

In contrast, marine carbonates are relatively soft minerals (3 on Moh's Hardness Scale) and so are easily shattered when impacted by other objects. The bonds that make up the lattice of the unit cell in a carbonate are such that there are rhombohedral cleavage planes along which parting readily occurs. Thus, an impact that would have no effect on a quartz grain will readily shatter a carbonate grain.

4.2.4 Chemical re-activity, biological interactions and mineralogy

Quartz is considered a comparatively inert mineral, with a long residence time in any environment. It can be transported by fluvial processes many hundreds of kilometres with little change other than a slight reduction in grain size. Once quartz grains become part of the sea-floor sediment veneer, there is little change other than minimal dissolution, particularly if the alkalinity of the sea-water increases. Dissolution can, and does, occur in microenvironments, but is more related to the amorphous silica species, opal-A and opal-CT.

Carbonate grains, on the other hand, have a much shorter residence time due to the highly re-active behaviour of CO_3 in an aqueous environment where the pH < 7. Consequently, grains do not survive transport more than a few tens of kilometres.

Many organisms that incorporate carbonate into their skeletal elements extract the CO_3 from pre-existing (both living and dead) organisms by using an acidic secretion to simply dissolve what they need. This has the effect of either reducing the size of the carbonate grains or even completely removing them from the environment. Other organisms extract it from the bicarbonate in the sea-water.

A further cause of change is the effect of temperature on carbonate grains. It has been shown that these grains form a significant fraction of the sediment budget. An aspect of carbonate geochemistry that was not undertaken, but which could become significant, and which is certainly so in localised areas, is the inverse solubility of carbonate species in regard to temperature. There are four common carbonate forms used by calcareous-secreting biota – two are stable: low-Mg calcite (LMC <4 mol%Mg), and intermediate-Mg calcite (IMC 4-12 mol%Mg) and two metastable: high-Mg calcite (HMC >12mol%Mg) and aragonite (no Mg). The first three form in the trigonal crystal form and aragonite in the orthorhombic crystal form.

At temperatures >28°C, aragonite, and HMC to a lesser extent, precipitate inorganically from sea-water (the well-known ooids of the tropics) and as the temperature decreases, they start to dissolve ("uncomfortable" for living biota!). Almost all gastropods use aragonite for their skeletal elements. In shallow areas in the ACWS area it is conceivable that anthropogenic activity, both industrial and recreational, can create localised "hot" areas that cause the precipitation of aragonite, e.g. outlet pipes from stationary vessels or from industrial sites adjacent to the coast. Any precipitate in such a situation should be analysed by X-ray diffraction, the only technique to differentiate between the four carbonate species.

Turnover rates of quartz versus carbonate therefore differentiate in favour of the retention of quartz in the marine environment. As there are similar volumes of quartz and carbonate within the overall ACWS area, it follows that there must be a greater initial production of carbonate, but that its disappearance from the environment decreases this volume substantially. This also explains why beaches are usually quartz-dominated even though the intertidal area may have a significant carbonate component and the offshore area may be dominated by carbonate.

The sediment veneer on the sea-floor is analogous to the soil cover on land. Similarly, plant and algal growth is influenced by parameters such as grain size and pH. The pH of the sea-water that permeates through the sediment is usually in the alkaline range, due to the above-mentioned biogenic and chemical processes, although it can be buffered where there is the availability of a high silica presence and the decay of organic material to produce organic acids. This affects the composition and health of the infaunal biota and any plant and algal material growing in the sediment.

The other minerals present, particularly the heavy minerals, are discussed in the section on sources of mineral grains.

4.4 Biogenic Sediment Grains

4.4.1 Calcareous phyla

Molluscs
Two of the Orders of molluscs are conspicuous throughout the ACWS area – the Gastropods (Figure 4.2) and the Bivalves (Figure 4.3), so they are treated separately.

Gastropods
The gastropods are predominately mobile, epifaunal, aragonitic organisms. They have a wide range of architectures, from thin to robust shells, from flat to high spired forms and from micro- to macro-sizes. They are either herbivorous or carnivorous. Consequently, they have adapted to all environments in the ACWS area, from intertidal, e.g. “periwinkles”; to shallow rocky, e.g. *Turbo* sp.; to mud flats, e.g. the cerithiids (which spend some of their time partially infaunal); to deeper water forms, e.g. “cowries”. They mainly consist of two calcareous parts, the main shell and the operculum. There are exceptions to this, e.g. *Haliotis* sp. does not have an operculum. It is the shell that is commonly preserved in the sediment, although some of the more robust forms also have a robust operculum that is usually preserved as well, e.g. *Turbo* sp. Gastropods often constitute the major part of the coarse fraction of carbonate fragments in a sediment. The weight and architecture of most of the larger gastropods precludes their movement shorewards following death. The smaller and lighter ones are carried shorewards, where they form “shell hash”, frequently mixing with bivalves. Their aragonitic mineralogy enhances their diagenetic destruction, so that they are under-represented in preserved sediments.

Bivalves
The bivalves (Figure 4.4) are dominated in the ACWS area by mobile infaunal species, i.e. those commonly known as “cockles”. Ubiquitous amongst these are the *Katelysia* spp., with other common genera such as *Donax* spp. and *Ostrea*. In specific environments, sessile epifaunal bivalves occur in densely-packed populations, such as mussels attached to intertidal rocky areas. Others move from the substrate, to the sea-floor and even, for a short

period, into the water column, e.g. some of the *Chlamys*. Yet other sessile genera have their attachment processes within the substrate and their feeding processes protruding into the water column, e.g. *Pinna bicolour*. All of them consist of two valves joined together at a hinge line. These valves usually disarticulate following the death of the individual, thus producing two sediment fragments. If the infaunal ones remain within the substrate, they are usually preserved as complete valves, but if they are exhumed, they, like all the other bivalves, may well be broken into many smaller fragments, depending on the energy regime of the area in which they accumulate. Their architecture enhances their movement shorewards, where they can accumulate as “shell hash”.

Most bivalves are aragonitic, and so they are readily subjected to diagenetic alteration, particularly if they are stranded on the beach. A few are calcitic, e.g. the pectens, and some are an ordered mix of both mineralogies, e.g. *Ostrea* spp. so that their original mineralogy remains pristine and they are preferentially preserved in the sediment. Only one bivalve is epiphytic on seagrasses in the ACWS area.

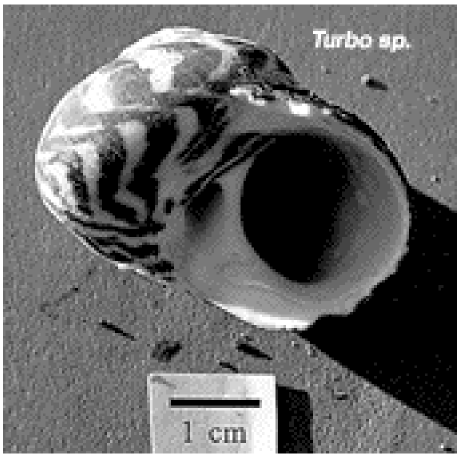


Figure 4.2 The robust intertidal gastropod survives abrasion in high-energy environments, and also survives in polluted areas. Its remains are well represented in the sediment, the operculum <<< than the main skeleton.

Figure 4.3 Bivalves: Pectens are common throughout the ACWS area. The external surfaces of the valves are used as an attachment surface by by various other benthic biota, even whilst the bivalve is still alive.

Annelids
There are a number of different groups of annelids (worms) occurring in the ACWS area, but those of most importance as far as sediment production is concerned are the serpulids (Figure 4.4) and the spirorbids, which secrete calcareous tubes in which the soft-bodied worm is housed. The serpulids, although individuals, tend to eventually aggregate in large groups, whereas the spirorbids maintain an individual habit. They are all sessile. Both tend to remain cemented to their substrate upon death, and are only carried shorewards if that substrate moves shorewards, e.g. a dead abalone. Serpulids often occur on rocks in the intertidal area, within a fairly depth-constrained area, where they compete for substrate space with mussels. Their calcitic mineralogy enhances their preservation in the sediment.

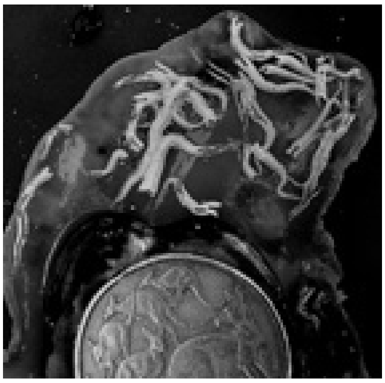


Figure 4.4 Calcareous worms: A dead bivalve encrusted by serpulids. Valves are often encrusted with a variety of biota.

Bryozoans

These colonial organisms (Figures 4.5 and 4.6) are common in cool-water in temperate environments such as pertains in the ACWS area, where they fill the role that corals do in the tropics, but not with the same reef framework construction ability. On the other hand, they are not depth or light controlled, as they do not have a symbiotic relationship with algae. Apart from one group (the free-living forms, such as *Selenaria* sp.), they are sessile. The colonies have various attachment behaviours, from direct encrustation of just about anything to the intrusion of root-like processes into coarse shifting sediments. They can rapidly foul anthropogenic structures, e.g. pipe outlets and inlets, ship hulls, jetty pylons, etc. Their disintegration upon death is covered in methodology, and in Bone and James (1993). Many species rapidly encrust seagrasses, with some restricted to the stems only of *Amphibolis* sp. (Figure 4.6). Their mineralogy ranges from the LMC of the cyclostomes to the IMC or aragonite of the cheilostomes. Due to the range of architectures employed by this phyla, their ultimate accumulation site also varies. However, those that are epiphytic on seagrasses usually accumulate on the beach, where they become an important component of the sediment after the seagrass has decayed.

Figure 4.5 Bryozoans encrusting *Amphibolis* are firmly attached and survive transport to the beach. Scale is 1cm

Figure 4.6 A bryozoan articulated colony removed from a *Posidonia* sp. stem

Coralline algae
All corallines are calcareous. The red algae have a range of habitats, in the ACWS area as their photic requirement is less than the green and brown algae. There are three different architectural forms occurring within the area: platy encrusting, articulated encrusting (Figure 4.7) and rhodoliths (Figure 4.8). The latter are passively mobile, i.e. they can be turned over by water movement or by other foraging biota. The encrusting forms use anything, living, dead or inanimate, as a substrate. They can be short or, in the case of rhodoliths, very long lived. They all use HMC in their cell walls. This facilitates their diagenetic destruction once the alga is dead.

Figure 4.7 Articulated coralline attached to the coral, *Plesiastrea* sp. The algae will disarticulate upon death, forming innumerable fine sediment grains.

Figure 4.8 A rhodolith ("red rock"). These algae are unattached, living on the sea-floor, where they are rolled around by the currents.

The encrusting forms are particularly prevalent as epiphytes on seagrasses (Brown 2005, James et al. *in press*). The articulated corallines, like their architectural counterparts in the bryozoans, disarticulate and produce "hundreds" of individual pieces upon the death of the alga. The platy encrusters are difficult to recognise in the sediment grains without resorting to the cutting of a thin section. Consequently, it is likely that they are well-represented in the group known as UnID.

Foraminifers
This large group of calcareous single-celled heterotrophic protists are ubiquitous in the ACWS area, where they are all benthic forms, both infaunal and epifaunal. They are all fine to very-fine grained individuals, with mainly light tests that are readily transported by water or wind, once dead. Most are unattached, but some are epiphytic on seagrasses, e.g. *Nubecularia* sp., which is particularly common at Semaphore. The foraminifers cover a range of mineralogies, with those that use LMC and IMC preferentially preserved in the sediments.

Other calcareous biota
This group includes a number of common and well-known organisms; they are not sufficiently widespread or common in the ACWS area to warrant detailed individual attention.

Examples include:

- Echinoids: epifaunal echinoids are widely distributed, and are restricted to a few species (<20), such as the herbivorous cidariids (Fig. 4.16), which live on rocky substrates and the *Holopneustes* type which "float" amongst seagrasses and algae. When these mobile biota die, they disintegrate into a number of different sized fragments, thus contributing many grains from just one organism. Their skeletal elements consist of HMC. Infaunal forms are rarely seen.

- Corals: most corals in the area are small solitary types and are insignificant as sediment producers. There are three zooxanthellate reef-building types, although they certainly do not produce reefs in low-temperature waters of the ACWS area. The colonial forms are dominated by *Pleiseastrea* sp. (Fig. 4.13). They too are insignificant as sediment producers.

- Brachiopods: there is only one species that occurs commonly in the ACWS area – *Magellania flavescens.* This LMC brachiopod is an attached form. It is occasionally washed up on the beach from Moana southwards.

- Chitons: chitons are occasionally found attached to the Precambrian rocks in the intertidal zone in Zone 3. Their individual plates make a minor contribution to the sediment. Their teeth, however, consist of magnetite, a heavy mineral.

- Hydroids: the volume of carbonate (aragonite) in the thin skeletons of hydroids is so insignificant that it is not even visible under SEM imaging of any of the sediments.

- Ascidian spicules: these bizarre mace-shaped spicules occur in the organic mass of both compound and solitary ascidians. They are released when the organic material decays, so that they become a ready source of carbonate cement, due to their aragonitic mineralogy and their high surface area/volume.

- Cuttlefish "bones": cuttlefish are the prey of many fish in Gulf St Vincent, particularly dolphins, all of which find their internal skeleton unpalatable. These are often transported on to the beach, especially from Marino Rocks southwards. The porous chalky part is comprised of aragonite. This is readily dissolved in meteoric waters, becoming a component in early diagenetic fluids. So, although it is not seen as an individual grain, it has been instrumental in the earliest loose cohesion of sediment grains.

- Mobile crustaceans: mobile: crabs are the major contributors of carbonate to the sediment package from this group, although their skeletons are a mix of two mineralogies – carbonate and apatite (Ca-phosphate). They can be widely distributed on the beaches throughout the ACWS area, especially in the northernmost part of Zone 1.

- Sessile crustaceans: barnacles are found in the intertidal zone, cemented to rocks in Zone 3. Their disaggregated plates can be found in the pockets of sand on the adjacent beaches, but only in small quantities.

Figure 4.9 An epifaunal echinoid, showing its many spines. These will detach as the organic material decays, releasing many large grains into the sediment, along with the large test itself.

The distribution of the calcareous biota (Figures 3.12 to 3.18) is controlled by the suitability of the habitat. Their adaptability to polluted or contaminated environments varies across the assemblage, e.g. the robust gastropod *Turbo* sp. will overwhelm nearshore, stormwater polluted areas whereas many of the delicate, sessile filter feeders will be eliminated, e.g. the bryozoan *Crisia* sp. Thus the entire ecosystem becomes skewed towards senescence (i.e. towards a monoculture), with the concomitant destruction of the production of a mixed carbonate sediment component. This change will carry over into the capacity of the sediment to support a flourishing flora.

Many excellent references can be found in the three-part series of *Marine Invertebrates of Southern Australia,* edited by Shepherd and Thomas (1982).

Siliceous Biota

Diatoms

This group of ubiquitous autotrophic protists are found throughout the ACWS area, but their extremely small size makes them “unappreciated” in their contribution to the sediment budget. They are comprised of opal-A, an amorphous form of silica, and they play an important role in the Si-budget of sea-water.

Sponge Spicules

Many sponges use opal-A to manufacture their skeletal elements - a mesh-work of spicules. Upon disintegration of the sponge following its death, these spicules are released into the sediment. They may remain as individual grains (Figure 4.10), or in high pH environments, i.e. where the sediment is mainly composed of carbonate grains, they may diagenetically alter to opal-C (chert).

Not all sponges used silica for their spicules. One common group are the “sponges” found washed up on beaches, which use spongin. A small group use carbonate, but these are rare in the ACWS area.

Figure 4.10 Silica spicules from a sponge collected at 5 m water depth at Blanche Pt., Maslins Beach. The spicules are composed of opal-A (amorphous silica) and remain as very fine sediment grains once the sponge decomposes. Similar spicules occur in the Eocene (>40 Mya) rocks in the cliffs at this site. Field of view - 3 mm. (Photo N.P. James).

4.5 Sources of Sediment Grains

4.5.1 Sediments from localised sources

The main thrust of this section is to present information that has not been covered elsewhere, and yet is of sufficient significance to warrant its inclusion.

There are many unexpected sediment types significant in localised areas, e.g. heavy mineral sands in the Sellicks Beach area, derived from the Cambrian age Kanmantoo Schist, transported to the site by Permian glacial ice and the barytes grains in the Moana area, derived from an old barytes quarry situated in the upper reaches of Pedler Creek. These two examples are indicative of the complexity of answers to the subsidiary aims of a) assessing the continuing viability of areas as future sources of sediments, and b) flagging those either already unavailable or under threat of becoming unavailable. In the case of the glacial source, the transport ceased over 200 Ma, but many of the rocks that were transported then are still eroding to produce more of their component grains but at a diminishing rate. In the barytes example, as long as the quarry is part of the local drainage system, and as long as the deposit itself is not eroded away completely, barytes grains will continue to be transported to the coastal area.

4.5.2 Sediments from drainage basins

Some of the rivers and creeks of the Adelaide Plains are still in their natural state, e.g. Willunga Creek, others have been totally altered, e.g. Sturt Creek, whilst others have been “modified” e.g. River Torrens (Figures 3.23A and 3.23B). All of them deliver a load of sediment to the coastal area. Storm drains are anthropogenic additions to the drainage pattern, with those that drain onto the beach relevant to this section.

All of these drainages carry a suspended load and also a bed-load that is dragged and saltated along the floor of the channel. Regardless of the material, it is all dumped onto the sea-floor. The sediment can include large boulders, tree branches, a vast array of anthropogenic trash, and a large volume of silt and fine sand, particularly during storm events. This material becomes part of the sediment budget once it reaches the sea-floor.

4.5.3 Sediments from the land-sea interface area

The land-sea interface area may consist of rocky shore platforms and cliffs that are continually eroding into smaller particles. Eventually these particles become grains of a size that are carried on to the sea-floor. Alternatively, the interface area may consist of friable, unconsolidated material abutting the beach. This is more rapidly eroded because of simple gravity – it falls down (Figure 4.11 and 4.12).

Figure 4.11 The cliffs at Trig Point are cemented Oligocene limestones at the base, overlain by many metres of unconsolidated clays, grading upwards into calcrete.

Figure 4.12 The Onkaparinga River estuary at Pt Noarlunga cuts into Eocene and Oligocene marls and calcarenites at its mouth. These are overlain by Pleistocene mottled clays. The road built on the cliff edge has accelerated the rate of erosion caused by run-off.

The interface area is perhaps the largest autochthonous contributor of all sediment to the sea-floor, especially in areas where the cliffs consist of loosely-consolidated limestones, e.g. the Pliocene Burnham Limestone at Pt Willunga/Aldinga and the Glanville Formation north of Pt Adelaide, or the terrigenous glacial till at Hallett Cove.

4.6 Relict Grains and Stranded Beach Ridges

4.6.1 Relict, stranded and palimpsest grains

The distribution of the relict grains is a function of the ongoing oceanographic hydrodynamics and sea-level changes, particularly over the last 125 Ka. This was a time of rapidly occurring glacial and inter-glacial events. These concomitantly caused sea-level “highs and lows” due to part of the global water budget being frozen and then the ice thawing. The timing of these events has been well-established by O^{18} geochemistry (Kennett & Stott 1991).

Skeletal calcareous grains and other grains that accumulated on the sea-floor during the high-stand stages during this time that were not lithified before the next glacial period were left stranded in a shallow or exposed environment. These became extensively “attacked” by Fe-oxidising bacteria, such as *Siderocapsis* sp. When the bacteria die, their orange-brown external capsule is left encrusting the grain. This process can be long-lived or can occur rapidly.

During the next transgression and high-stand, more skeletal grains are deposited. Not all of these, however, are engulfed by bacteria, but may become extensively abraded. Quartz grains become well-sorted, polished, clear and rounded whilst calcareous grains have a slightly rounded and white appearance. These grains are referred to as "stranded" to distinguish them from the relict grains with which they are now mixed.

Finally, the transgression, high-stand and minor regression of the last 6 Ka occurs. During this period, more unsorted, angular and rounded quartz grains accumulate along with a mix of calcareous skeletal fragments of recently dead biota. This mix of grains is referred to as a palimpsest sediment **(**James et. al. 1992). It is universal in coastal margins in cool-water temperate environments (James 1997). The distribution of the three types (relict, stranded and palimpsest) of grains in any sea-floor location is partially dependent on the hydrodynamics of the slightly heavier specific gravity of the relict grains due to the addition of the Fe-oxides. Dating of the three calcareous groups of palimpsest grains by C^{14} confirms the timing of these pulses back to 40 Ka, the reliable limit of the technique (Rivers et al. *in press).* Dating is expensive and not part of this study, but the above discussion validates the qualitative method of observation of the grains to predict their relatively recent history.
Only the Recent fraction will be an ongoing contributor to the sediment budget, so that the relict fraction (Table 3.5) must be subtracted when determining future supplies of carbonate grains to the sediment budget.

4.6.2 Timing of stranded beach ridges

One of the best non-analytical methods of timing of the sediments on the sea-floor is simple observation and photography. One excellent example of this is the presence of a distinctive N-S trending, linear ridge of rounded pebbles, seen on the sea-floor at a depth of 15 m, from the southern boundary of the ACWS area to just north of Christies Beach (Figure 1.8). This geomorphic form is a stranded beach ridge, formed at the back of the beach, probably during the 11 Ka glacial period. The pebbles (lithoclasts of Precambrian terrigenous rocks and limestones) have been colonised by Fe-oxidising bacteria. The presence of such ridges was predicted decades ago by Sprigg (1952), long before the development of simple underwater photography.

All of the packages of grains delivered, allochthonously or autochthonously, to the sea-floor, could be qualitatively timed by this and similar techniques, but this was beyond the brief of PPM 1.

4.7 Heavy Mineral Sands

"Heavy minerals" is the general term for grains within an accumulation within which all the other grains are at least twice their size. The mix of grains has been transported to the deposition site by water or wind, so that they have been hydrodynamically sorted during the process, providing there has been sufficient time, which can equate to distance in many cases. They are deposited when the energy level of the transporting agent is insufficient to move them further. The major limiting factor is the weight of the grains, i.e. the specific gravity of the minerals of which the grains are composed. If there is a high concentration of heavy minerals, the heavy minerals are referred to as a placer deposit. Common heavy minerals of economic significance include gold, tin, rutile, ilmenite, magnetite and monzonite. Other heavy minerals that are often mixed with these include garnet, various Fe-oxides, staurolite, amphiboles and pyroxenes.

Where the allochthonous load includes any of these heavy minerals, they can be concentrated into pockets of, or lenses, of “heavy minerals”. If they are thrown on to the beach during storm events, the energy level of average backwash is insufficient to return them to the sea-floor, and a linear heavy mineral sand layer is formed (Figure 3.20). These can be of economic importance, but those in the ACWS area are not of ore value at the present.

4.8 Authigenic minerals

These are new minerals that form mainly by inorganic processes *in situ.* There were only rare traces of these throughout the entire area, so they are not discussed further.

4.9 Input from glaciated areas

Glaciers moving across a landscape generate frictional heat at their base, thereby thawing the ice at the interface. This active layer of water then re-freezes, enclosing any loose material on the land surface, from dust to huge boulders. This sold material becomes part of the glacial load, and is moved away from its point of origin. If the glacier calves off into the sea, the lower surface starts to melt and the solid load is shed into the water column, where it behaves the same as any sediment in a column of fluid, settling according to its physical properties and the hydrodynamics acting upon it (See Section 3.8). Continental glaciation occurs on a larger scale than individual glaciers, but the results, although extensive and widespread, follow the same pattern. They are a non-renewable source.

4.10 General Discussion

The sediments veneering the sea-floor in the ACWS are markedly heterogeneous. This applies particularly to the grain size of the sediments. There is no one factor that causes this heterogeneity. Rather it is a complex web of interacting processes such as hydrodynamics (refer to the work of PPM 2), vigour of the seagrass beds, which has a binding/baffling effect on the sediment grains, particularly when the seagrass is in a healthy state (EP 1), the intrusion of anthropogenic activity, e.g. all types of boat and human activity, particularly in the intertidal zone, and structures, particularly those that impede the natural movement of sediment grains, e.g. the marinas at O’Sullivans Beach, Glenelg and North Haven. Anthropogenic activity has also changed the natural drainage pattern and the geomorphology of the coastal area so that there is now an episodic debouchment of sediment grains on to the beach and intertidal area, often catastrophic, rather than the historical gentle ongoing flow.

5 MANAGEMENT STRATEGIES

5.1 Grain Size

It is inevitable that the sediment produced in the ACWS area, a temperate environment, the modern carbonate fraction is dominated by poorly- sorted, poorly-rounded grains with a range of sizes, in contrast to the quartz (terrigenous - siliciclastics) fraction, which is dominated by well-sorted, well-rounded grains that are moderately uniform in size. Temperate environments invariably produce this type of sediment package, particularly if there is a paucity of large rivers continually carrying large loads of terrigenous material to the sea-floor and beach.

Any management scenario has to consider this maxim – the managers are dealing with mixed sediments that contain two main populations of grains with vastly different physical and chemical characteristics. Figures 3.2 – 3.5 show the comparison between grain size distribution during Summer and Winter. Does this mean that water depth is a controlling parameter when dealing with grain size? The answer is that it is an indirect parameter. The coarse size component, particularly, reflects the influence of the aforementioned two populations, with the quartz fraction tending to be concentrated inshore and the carbonate fraction in the offshore regions. Once again, this leads to areas that are mixes, e.g. the muddy flats of the northern region, where the environment is favourable to huge populations of smaller molluscs. This is not a “new” scenario, as evidenced by the extensive shell-grit cheniers that blanket the low-lying adjacent area (Flaxman 2003). Similarly, the wide intertidal area of the Semaphore – Largs Bay area, the depocentre of the finer fraction resulting from long-shore drift, is a favourable environment for foraminifers, which then contribute their fine to very fine-sized tests to the sediment budget.

5.2 Mineralogy

One major finding from this Task was that primary carbonate production is greater than quartz input and accumulation. Later chemical reactions involving these minerals are responsible for the pH of the marine ecosystem. In order to maintain a healthy marine fauna and flora, any addition (contamination) made to the environment needs to ensure that this pH is not changed in any way.

Similarly, all proposed and existing discharges into the marine environment should have checks made to insure that no further chemical reactions will occur as a result, e.g. carbonate grains could be suspended in a flow-through chamber of the proposed discharge material. Temperature of any discharges should be monitored, especially at the exit location.

5.3 Biogenic Components

The current level of production of calcareous biota needs to be strictly maintained. Any decrease in production will lead to a decrease in sediment grains, which will have a domino effect on the entire area. Activities that may affect marine biota include the following:

- dredging - alters the sea-bed level locally and changes the nature of the substrate.
- removal of living biota (non-selective) - decreases the reproductive capacity of the local assemblage to a lower density.

- removal of targeted biota - decreases the ongoing reproduction of the target, thereby altering the composition of the assemblage, with disequilibrium likely to follow, and normal succession disrupted.
- introduction of exotic species - as above.
- introduction of contaminants and pollutants - must not have deleterious effect on any member of the biota assemblage.
- sea-floor disturbance - determine depth of disturbance of sea-floor sediments by anthropogenic activities, e.g. recreation vessels of all types, large commercial vessels, etc.
- commercial harvesting of beach products - e.g. “seaweed” is an erosion barrier against wind, has carbonate grains attached, provides nutrients for beach infaunal biota, provides necessary nutrients back to the sea via sediment pumping.
- forward assessment of the effect of new anthropogenic activity outside the current ACWS area - development of ferry terminals, marinas - e.g. Pt Wakefield, aquaculture areas, expanded salt fields, near-coastal housing developments, freeways, and many others.

5.4 Sources of Sediment Grains

5.4.1 Localised sources

In the case of glacial sources, transport ceased over 200 Ma during the Permian, but many of the rocks that were transported then are still eroding to produce more of their component grains, but at a diminishing rate. In the case of localised barytes grains, as long as the old quarry is part of the local drainage system, and as long as the deposit itself is not eroded away completely, barytes grains will continue to be transported to the coastal area.

The value of these two examples is that these grains can assist in identifying the source of the material on the sea floor. It is not necessary to maintain a supply of grains with chattermark trails, rather to maintain a supply of like material - siliciclastic allochthonous grains, predominantly quartz.

Neither are the barytes grains in themselves necessary. However, a management strategy should endeavour to consider the possibility of future mines (or alterations to the present drainage basins that might allow drainage from other mines) contributing harmful material to the sea.

5.4.2 Drainage basins rivers, creeks and drains

The aims of the PPM 1 Task were to determine the nature of the sediments on the sea floor and, from this, to determine the sediment sources and the probability of an ongoing supply.

On completion of the major part of PPM 1 work, this Task undertook a cursory field and laboratory program of creeks in the ACWS area. The results are shown in Tables 3.6 and 3.7 and Figures 3.24A and B. In addition, a cursory analysis was made of the material from the Penrice Spoil material.

No task undertook a complete study of the nature and amount of sediment transported to the sea in rivers, creeks and drains. This needs to be quantified.
It is too late to estimate the effect of past modifications to rivers and creeks that drain the Adelaide Plains, since the preliminary data is not available. However, it should be part of the management strategy to consider, and plan for, the effects of any future drainage modifications, including drains. This should include the bed load and

material in saltation, suspension and solution over sufficient time periods to include major storms. In addition, a study is necessary of the anthropogenic inputs, especially from drains, but also by way of rivers and creeks, including rubbish and chemicals (as suggested by the Penrice study).
A reduction, or preferably a complete removal, of harmful anthropogenic inputs should be a major management strategy.

The sand replacement scheme, whether by trucking or by pumping of a slurry, should be closely monitored. At present the effect on the seafloor of this material is unknown. In order to preserve the natural system, the following questions should be addressed:

- does the sand contain heavy minerals, and if it does, what are they?
- does the grain size match that of the dump site?
- does the dominant mineralogy match that of the dump site?
- is the northward movement of this exotic material the same as that of the local material?
- are complete records kept of all activity in this regard?
- is every truck load analysed?

The net result of sand replacement should be to maintain as near as practically possible, the natural grain size, mineral composition and availability for transport by waves and currents.

5.5 Use of Pie Diagrams

The following scenario is presented to illustrate how the pie diagrams can be interpreted to assist management and decision making. The managers of a controlled boat ramp at Christies Beach need to install marker buoys as guides for users, at the -20m, -15, -10, -5 and -2 positions. They also need to know whether there will be significant seasonal differences, whether there are likely to be environmental concerns and whether there are nearby major differences that may impinge on their route selection. The most cost effective route is for a transect at right angles to their ramp entrance.

The managers have two options:

(1) they can look at the pie diagrams for Summer and Winter for Transect 4t, the northernmost transect in Zone 4, with cliffs of Tertiary limestones and Precambrian silicates immediately to the north at O'Sullivans Beach.

(a) This shows them that the grain size is a mix of medium and coarse sand at 20 m and 10 m in the Summer, but at 15 m and 5m and 2 m there is a significant grains size change, to fine sand dominant. The Winter pattern is similar but the coarse sand is present at 20 m and 15 m and then the fine-grained sand is dominant shorewards. There are a series of gravel stranded beach ridges at approx.15 m depth in the southern region (Section 4.5), so these are contributing relict cobbles to the sediment sample. It would be advisable to check these by SCUBA diving.

(b) There is a marked difference in the mineralogy between Summer and Winter, with the Summer dominated by quartz throughout, reflecting the bed-load from Christies Creek (local drainage basin is in Precambrian siliciclastic rocks), which is transported a short distance south, counter to the normal northwards longshore drift pattern. There is a dominance of carbonate in the deeper water in the Winter, reflecting a higher production of skeletal biofragments. There is a minor heavy mineral component at all depths, which becomes significant at 5 m water depth during the Winter. These grains are sourced from the Precambrian Aldgate Sandstone in the

Adelaide Hills, and are released during transport of the Onkaparinga River bedload as it flows seawards to Port Noarlunga. Longshore drift carries the grains northwards during the Winter, when energy levels are highest. The higher specific gravity of the heavy minerals would result in grains half the size of the quartz grains in the same environment, leading to a dramatic skew to fine grain material at -5 m, which is exactly what is seen in the grain size pie diagrams.
Any plans to change the debouchment of the quartz grains from the Christies Creek bed load on to the sea-floor need to be checked, as this would markedly alter the pattern of grain size and mineralogy.

(c) The biota changes across the transect, with the highest diversity in Winter, especially in the deeper water. The assemblage changes dramatically at 5 m water depth, with a change to mainly infaunal biota, including foraminifers, the same depth at which, during the Summer, the only living biota are gastropods. This change correlates with the grain size change, and indeed, the foraminifers are adding to the fine grain-size fraction.

The heterogeneity of the distribution and diversity along this single transect suggests a high degree of stress, particularly amongst the filter feeders. This is particularly noticeable around 5m water depth.

(2) the managers can look at the ACWS distribution maps and refer to the three nearest sample site on the transects to the North (Transect 3s in the Precambrian siliciclastic rocks of Zone 3) and to the South (Transect 4u immediately north of the Onkaparinga River at Port Noarlunga, also in Zone 4), and to the adjacent two on Transect 3t. This is a little more complex, as there are now more pages to look at for each assessment.

(a) This confirms that the grain size changes orthogonally to the beach, with the coarser material in the deeper water throughout the year, but with medium sand closer inshore in the Summer than in the Winter. There is coarser material to the north in the Winter, which may move southwards with storm activity, whilst the opposite occurs in the Summer, with more coarse material in the Onkaparinga Estuary area. This apparent anomalous Summer influx of coarser material is a result of the time-lag from Winter erosion of the source area in the Adelaide Hills and then lengthy transport to the deposition site via the Onkaparinga River. A similar scenario occurs north of the River Torrens, whereas rivers that drain only the Adelaide Plains do not experience this time lag to the same extent, some of which is likely to be taken northwards during longshore drift. This has been greatly enhanced with the excavation associated with the building of the Freeway and the widespread ongoing housing development. Minor gravel bars may result.

(b) The mineralogy appears to be dominated by quartz in all directions. This is partially because of the ranking of this graphic with >35% as the highest amount, so that it is possible to have almost three equally-distributed mineralogies. However, viewing the other maps, this is not the case here. Carbonate is high off-shore in the Winter and only present or in trace amounts in the Summer, with slightly more to the south. Heavy minerals are common in mid-depths in the Winter, but insignificant in the Summer. The Winter material has come from the south, from the Onkaparinga River bedload.

(c) The biota distribution maps of individual taxa show that gastropods and bivalves are present throughout, with a slight increase in the inshore gastropods in the Winter, with more molluscs overall to the south. Calcareous algae are present but insignificant except at the deepest site in the Winter, but with a sharp increase in the south in the Summer. Foraminifers are present overall, with an increase in the inshore Winter sites. Bryozoans are common in the Winter both here and even more so in the south, but not in the north whilst calcareous worms are common in the south. Overall, the assemblage and density of the biota across Transect 4t indicates a distinct difference from the transects to the south. As this boundary coincides with a Zone boundary, this supports the Zone divisions.

The question to be addressed is whether the paucity of biota is significant or is it simply reflecting the higher fine fraction of grains that become re-suspended and clog the feeding processes of benthic filter and suspension feeders? Once again, the Christies Creek outflow, coupled with that from the Sewage Plant, may also be detrimental to the health of the biota. Further monitoring and consultation on this matter would be advisable.

So, the managers would have two interpretations for their questions regarding a portion of one transect in this Christies Beach scenario. If necessary, they could return to the data tables to resolve any significant differences.

If they seek information on the entire ACWS area for another reason, they would be advised to go straight to the maps and get an overall impression by visually clumping (akin to contouring) the different parameters presented for whichever area is of interest. Users who, not-withstanding the above, prefer more statistically-precise interpretations, can go to the Appendices and access the data tables and copy and convert the data into whatever statistical package best suits their needs. Others may be better served by looking at the hundreds of photos of the different sediment fractions for each sample and at the underwater photos of the sea floor. This way, when used in conjunction with the other Task Reports, a complete picture of the ACWS sea-floor is obtainable.

6 CONCLUSIONS

6.1 Grain Size

The sediment grains are a mixture of sizes, i.e. the sediment budget in the ACWS area is heterogeneous in terms of grain size. This has been the case for at least the last 125Ka.

Mineralogy
The major minerals comprising the sediment grains in the ACWS area are Ca-carbonate and quartz.

The initial deposition rates of quartz and Ca-carbonate grains are similar, with carbonate slightly exceeding quartz

Accumulation rates of carbonate < quartz grains because of the chemically inert nature of quartz and its hardness in contrast to the softness and chemically-reactive nature of carbonate grains.

Sandy beaches are dominated by quartz grains although carbonate production is much higher than the influx of quartz grains in the offshore area.

6.2 Biogenic Components

Diversity, density and distribution of biota in the marine realm are driven by a number of parameters, such as the chemical (e.g. the presence of sufficient necessary nutrients, salinity), and physical (e.g. temperature, depth, photic zone depth, hydrodynamic system) characteristics of the water column. The most critical parameter, however, is the sea-floor and its veneer of sediment.

The ongoing production of sediment grains by calcareous-secreting biota is dependent on the maintenance of a "healthy" sediment substrate. It is this substrate that is the lynch pin for all biotic activity that occurs within, on and above it. In the nearshore coastal ACWS area, seagrasses are the most visible biota. These seagrass meadows need a healthy substrate in which to, firstly, become established, and then to maintain healthy growth. The interaction between sediment, plants and fauna is a complex, interdependent web. The cyclicity of this web can only be maintained by attention to the ongoing stability of all members of the web. To view and treat the sediment as of secondary importance due to its inanimate nature is to risk breaking the cycle of a healthy coastal environment.

6.3 Sources of Sediment Grains

Carbonate grains are produced primarily by the metabolic processes of marine fauna and flora. The hard parts (skeletal and cell wall elements) are retained as Ca-carbonate grains, unless some erosive process causes their destruction.

Quartz grains are derived primarily from outside the ACWS area, reaching the sea-floor by various transport means such as erosion of siliciclastic cliffs and drainage processes. Occasionally, exposed siliciclastic bedrock on the sea-floor contributes weathered grains to the sediment budget.

Relict grains are a significant fraction of the sediment components, but they are not renewable.

Heavy minerals occur as two entirely different groups:

(a) ilmenite grains sourced from the Neoproterozoic Aldgate Sandstone and transported to the coast mainly by the Onkaparinga River. A renewable source.

(b) a heavy mineral suite sourced from the physical erosion of Cambrian Kanmantoo Group rocks from the Encounter Bay area that were transported as erratics by the Permian glaciation. A non-renewable group.

Both groups are concentrated locally, but overall are not significant.

Rivers, creeks and stormwater drains episodically debouch large volumes of sediment into the intertidal area. The fine fraction is environmentally significant as it precludes normal metabolic processes from occurring in the marine biota. The drainages are the source of most of the quartz fraction that forms a major component of the sediment budget. The source areas are widespread, but many are steadily becoming sterilised by new urban development, after an initial dramatic increase as the development is initiated. This will lead to depletion of the quartz grains in the fine to coarse size fractions from renewing “sandy” beaches.

6.4 Antropogenic Activity

Industrial sources of “sediment grains” are mainly an unknown factor, emanating from a myriad of different industries. Environmentally-concerned industries ask to have their waste monitored, e.g. Penrice. This practice should be publicised to encourage other industries to do likewise.

Beach and marine activities carelessly contribute an array of unsightly material into the area. The quantity is unknown, but little of it appears to become part of the sediment budget.

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