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The Geomorphology and Sediments of Cockburn Sound

Darren Skene, David Ryan, Brendan Brooke, Jodie Smith and Lynda Radke

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by

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1. Cooperative Research Centre – Coastal Zone, Estuary and Waterway Management, c/- Geoscience Australia GPO Box 378 Canberra ACT 2601

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Executive Summary

Cockburn Sound is a large, low-energy coastal waterway located on a moderate to high-energy coast near Fremantle, Western Australia. It has formed in an elongate depression in the lee of a remnant Pleistocene shore-parallel dune ridge. This study, undertaken as part of the Coastal CRC Project at Geoscience Australia, examined the geomorphology of the sea bed, the spatial distribution of the various sediment types and the geomorphic evolution of Cockburn Sound. Sediment grab samples and 3–6 m long vibracores were collected. Samples dominantly comprise biogenic carbonates, with sandy mud and mud in the large relatively deep (15–20 m) central basin; the marginal banks (2–10 m) are composed of carbonate sand; and there is mixed carbonate and quartz sand in the eastern nearshore zone.

The stratigraphic analysis of Cockburn Sound reveals that much of the clay soil that formed on the original calcarenite land surface prior to the Holocene rise in sea level is preserved below the marine carbonate mud that has been deposited in the central basin. The central basin is partially infilled and considerable accommodation space remains for the further accumulation of muddy sediment. Up to four distinct lithostratigraphic units comprise the sediment fill identified in vibracores. The spatial extent of these units will be better defined with future acoustic sub-bottom profiling of the sound.

Submarine groundwater discharge in the central and northeastern sections of Cockburn Sound is suggested by surface sediment geochemical data and the presence of water-filled cavities within a vibracore that penetrated the Tamala Limestone that underlies the central basin sediments.

A higher proportion of fine terrestrial sediment with elevated levels of some trace metals was identified in surface sediments from the eastern side of the sound. Previously reported background metal concentrations in surface sediments are consistently higher than pre-industrial background values which have been determined from the new down-core geochemical data. Metal contamination in surface sediments, therefore, may have been greater than previously reported but there is evidence for recently improved conditions at some sites; mainly due to large reductions in discharges from industry. Importantly, the spatial distributions of trace metals in the surface sediments identified in this study need to be compared to maps of changes in the extent of benthic habitats in the sound to help identify any long-term ecological impacts of the sediment contamination, as well as their impacts on benthic habitat composition.

Our maps of surface sediment types and their characteristics provide new insights into the physical controls on the distribution of benthic habitats in the sound. These maps can now also be compared with maps of acoustic backscatter to help explain patterns in the acoustic data that has been collected as part of the Coastal CRC Coastal Water Habitat Mapping Project.

Introduction

Cockburn Sound is a key study site for the Coastal CRC Coastal Water Habitat Mapping (CWHM) Project. At this site, benthic habitats have been mapped at a range of scales and levels of detail using a suite of acoustic and video techniques. The focus of the Coastal Geomorphology subproject in Cockburn Sound is to examine the geomorphology of the sea bed, the spatial distribution of the various sediment types and the geomorphic evolution of this basin. These new geological data will be used to ground-truth acoustic data collected in Cockburn Sound, such as the multibeam backscatter data collected using the Coastal CRC's Reson 8125 Seabat system. This study will also provide a better understanding of the physical controls on the distribution of benthic habitats in the sound and substrate data that can be incorporated into a benthic habitat classification scheme.

Several environmental surveys on the carbonate sand resources of Parmelia and Success Banks have been conducted over the last two decades. However, relatively little attention has been paid to the broader nature of the sediments and stratigraphy of Cockburn Sound, particularly in the deeper central basin. Therefore, another focus of this study is to provide a more detailed level of knowledge of the benthic environments and sediment fill in the deeper reaches of the sound, and a linkage of these to more thoroughly studied shallow habitats.

AIMS

This report examines the geomorphology and sediments of Cockburn Sound through the analysis of a suite of sediment grab samples and vibracores as well as existing data in published reports and scientific papers. The specific aims of this study are to: 1) Characterise the surface and sub-surface sediments and geochemistry of Cockburn Sound from a representative set of sediment grab samples and vibracores; and 2) Develop a conceptual model of the recent evolution of Cockburn Sound (spanning the Late Pleistocene and Holocene), based on the new and existing data. Importantly, these geological data are required to enable better interpretation of acoustic sub-bottom profiles and multibeam sonar datasets that have or will be collected in Cockburn Sound as part of the Coastal CRC's CHWM Project.

STUDY PARTICIPANTS AND COLLABORATION

The field survey and sample analysis was undertaken by Darren Skene, David Ryan and Brendan Brooke (Geoscience Australia (GA)). Assistance in the field was provided by the crew of the vessel *FP Response*, Jamie Strickland (Fremantle Ports) and Mark Small (Fremantle Ports), Lee Woolhouse (hydrographic surveyor, Fremantle Ports) and Rob McCauley (Curtin University of Technology). Lynda Radke (GA) undertook the analysis of the surface sediment geochemical data and Jodie Smith (GA) interpreted the vibracore geochemical data and completed the editing and formatting of the report. Helen Bostock (GA) assisted with editing the report. Laboratory analyses at GA were undertaken by Alex McLachlan, Neal Ramsey and Richard Brown (sedimentology) and Bill Pappas, John Pike and Liz Webber (geochemistry).

REGIONAL SETTING

Cockburn Sound is an elongate, shallow, partially enclosed coastal basin with an area of approximately 124 km^2, located immediately south of Fremantle, Western Australia (Fig. 1). The sound is approximately 22 km long and ranges from 15 km wide in the north to 9 km wide in the south and sits between the mainland and a remnant Pleistocene dune ridge that forms Garden Island. This relatively quiescent coastal water body has contrasting shoreline environments with heavy industry along much of its eastern coast whereas the western shoreline of Garden Island, apart from the naval base at Careening Bay, is largely undeveloped.

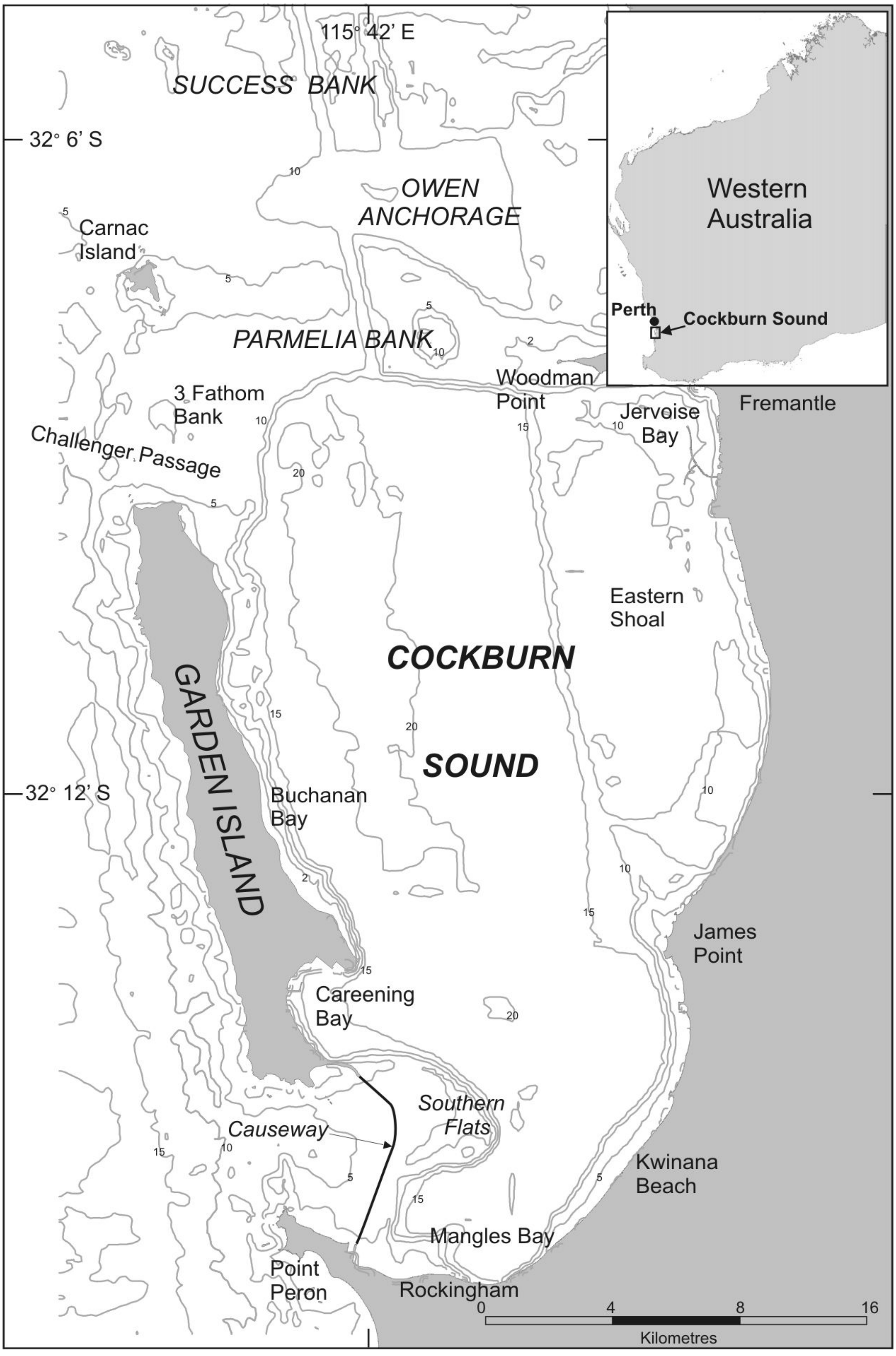


Figure 1: *The location and bathymetry of Cockburn Sound. Depths are shown in metres.*

CLIMATE AND OCEANOGRAPHY

Cockburn Sound forms part of the coastal margin of the Rottnest Shelf which is characterised by a high energy swell-wave regime and subtropical waters (water temperatures range between 16 to 20°C) that are influenced by the warm, low-nutrient waters of the Leeuwin Current (Collins, 1988). The wind regime for the region varies seasonally with the dominant onshore winds from the southwest operating in summer (October to April), whereas winter winds are more variable and lower in strength. However, storms during winter and spring generate strong north westerly to south westerly winds, producing large waves (6-7 m), and enhanced tides. Swell waves are generated by the extreme fetch of the Southern Ocean (known as the 'Roaring Forties') throughout the year. Wave data for outside Cockburn Sound between 1970 to 1976 indicated a maximum significant wave height of 5.1 m, with a maximum peak wave height of 8.5 m. Offshore wave conditions are more severe and variable during winter and spring, due to the passage of fronts and associated high and low pressure systems, while in Careening Bay (Fig. 1) wave conditions may be more severe and variable during spring and summer due to prevailing southerly winds. In contrast, within Cockburn Sound waves consist primarily of low amplitude 'wind chop' with a maximum recorded wave height in the order of 1 m (Department of Construction, 1977). Tides in Cockburn Sound, like the open coast of southwest Australia, are micro-tidal and mainly diurnal, with a maximum spring tide in the order of 0.9 m (Hearn, 1991).

Complex circulation patterns occur within the semi-enclosed waters of Cockburn Sound due to horizontal wind-pressure gradients, tides, waves, atmospheric pressure, changes in water density, and continental shelf waves (Pattiaratchi *et al*., 1995; DAL, 2002). Due to combinations of these effects, three seasonal hydrodynamic regimes have been identified (Department of Environmental Protection, 1996). In summer the circulation is primarily wind-driven, during autumn the wind subsides and circulation is determined by atmospheric pressure gradients, while in winter and spring the circulation is driven primarily by pressure gradients with infrequent periods of wind-driven circulation due to storms. The exchange of water between Cockburn Sound and the open ocean is restricted by Parmelia Bank to the north and a narrow southern channel. As a consequence, flushing times are slow and estimates of the period required for 63% of the water body to be flushed range from 22 days in winter to 44 days in summer (Department of Environmental Protection, 1996; DAL, 2002).

BATHYMETRY

Cockburn Sound comprises a large, low gradient basin area confined by shallow banks to the north and south (Fig. 1). The broad and relatively deep central basin, which gently slopes from the 17 m isobath to a maximum depth of 22 m, is flanked by the relatively steep slopes of the surrounding banks, shoals and shoreline to the north, south and Garden Island to the west, and a lower gradient bank to the east (Fig. 1). The Eastern Shoal is a relatively planar feature with an average water depth of approximately 8 m. Isolated limestone reefs (approximately 4 m water depth) outcrop along the western margin from James Point to Woodman Point. Cockburn Sound is bounded in the north by Parmelia Bank, a large, shallow (average water depth 5 m) sand bank extending from Carnac Island to Woodman Point. A north–south navigation channel has been dredged across Parmelia Bank to provide access for large vessels to the sound (Fig. 1). Challenger Passage provides access to the ocean for smaller vessels on the northwest margin of the sound. At the southern end of the sound there is a narrow inlet to the open ocean between Cape Peron and Garden Island. The inlet is flanked by an extensive sand bank, the Southern Flats, where water depths are only a few metres. The southeastern (south of James Point) and western margins (bordering Garden Island) of the sound are characterised by quite narrow sand banks less than 500 m wide where the water depth shoals rapidly to a couple of metres.

GEOLOGY AND GEOMORPHOLOGY

The Quaternary geological units for the inner Rottnest Shelf have been described by several researchers (Searle and Semeniuk, 1985; Semeniuk and Searle, 1985; Semeniuk and Searle, 1987; Searle *et al*., 1988) and the published lithostratigraphic classification is summarised in Table 1. Cockburn Sound has developed within an elongate depression that forms a margin between the Swan Coastal Plain and the Rottnest Shelf, known as the Cockburn-Warnbro Depression (Fig. 2). The deeper sections of this depression were likely formed by the solutional (karst) weathering of the Tamala Limestone during periods of low sea level. Cockburn Sound contains a variety of terrestrial and marine deposits and Pleistocene dune ridges (Fig. 2; Fairbridge, 1948; Playford *et al*., 1976; Collins, 1988; Searle and Semeniuk, 1988; Searle *et al*., 1988; Kelletat, 1991). The relict dunes, which form part of the Tamala Limestone Formation, were emplaced as coastal sand barrier deposits during or shortly after the last interglacial period approximately 120,000 to 80,000 years ago (Price *et al*., 2001). As sea level fell below the present-day shelf during the last glacial period, the carbonate-rich sand dunes were subjected to weathering, soil formation, and subsequent cementation.

Following the last glacial maximum (~18,000 years ago), sea level began to rise and flooded the Rottnest Shelf, reaching its current level around 6,500 years ago. During the post-glacial marine transgression, a phase of rapidly rising sea level in the early to middle Holocene, the limestone ridges were significantly eroded by wave action and now form the current line of remnant islands and submerged reef that extends from Point Peron to Rottnest Island (Fig. 2).

Since sea level became relatively stable in the middle Holocene, large volumes of sediment have been transported across the shallow shelf and thick sand accumulations such as Success and Parmelia Banks began to develop (France, 1977; Coastal and Marine Geosciences, 1998a, b). The extensive series of beach ridges immediately south of Point Peron also began to build out from the coast at this time (Woods and Searle, 1983; Searle *et al*, 1988). Although carbonate sediment has been accumulating in Cockburn Sound during the last 7,000 years, the sheltering effect of Garden Island has restricted the ingress of carbonate sand that has piled up in sand banks on the northern and southern margins of the sound (Semeniuk and Searle, 1987; Searle and Semeniuk, 1988).

Table 1: Stratigraphic column detailing the main Quaternary sequences found in the vicinity of Cockburn Sound

	LITHOSTRATIGRAPHIC UNIT	SEDIMENT DESCRIPTION
HOLOCENE	Lacustrine and swamp sediments	Peaty clay and sandy silt
	Safety Bay Sand	Beach ridges and dunes composed of calcareous quartz sand
	Becher Sand	Grey quartzo-skeletal muddy sand with seagrasses (Semeniuk and Searle, 1985)
	Bridport Calcilutite (Early Holocene to Present)	Grey primarily carbonate mud (Semeniuk and Searle, 1987)
	Ridge Apron Facies	Eroded Pleistocene aeolianite derived from the Tamala limestone
PLEISTOCENE	Tamala Limestone	Cemented aeolianite and shallow-marine carbonate sequences

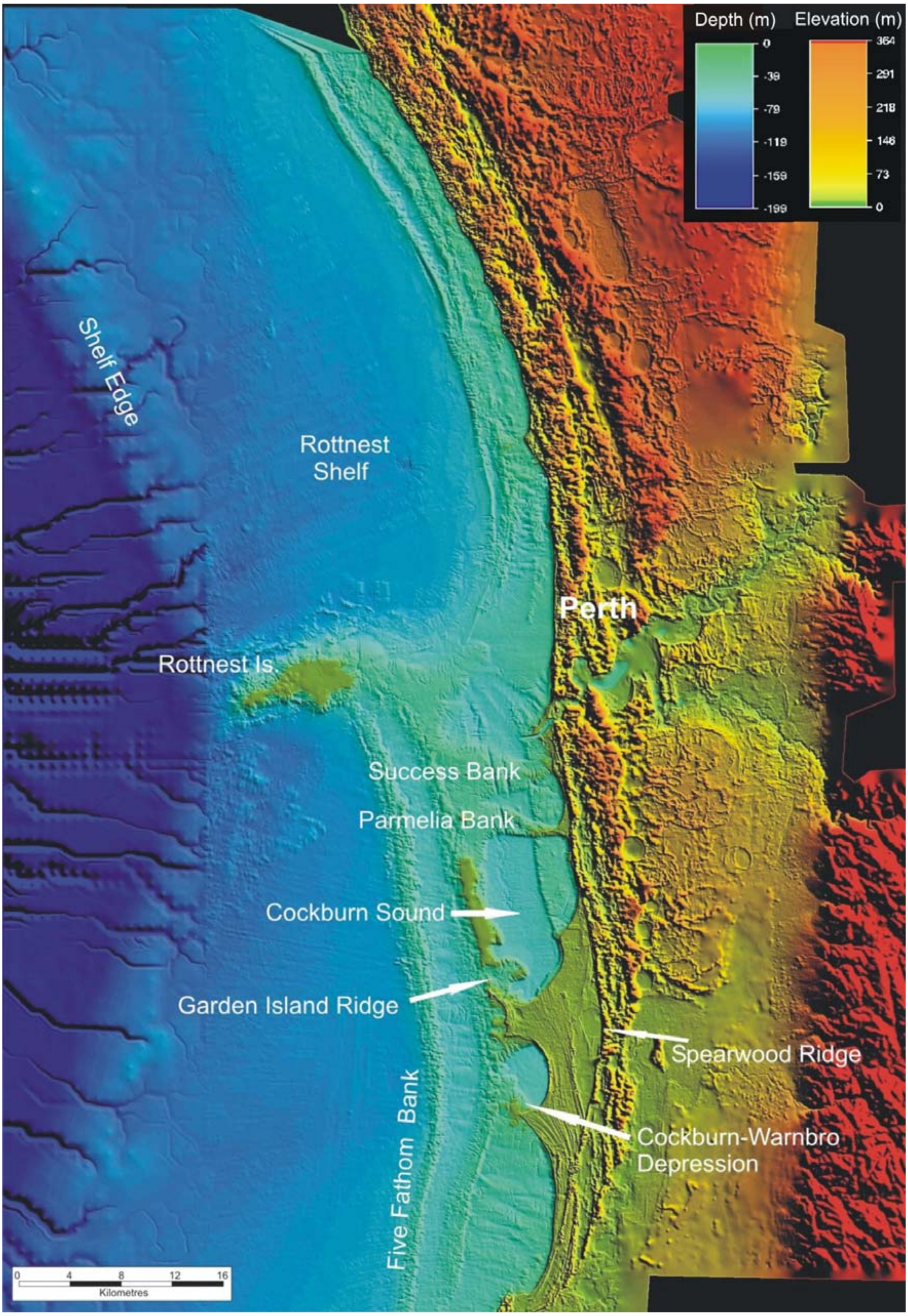


Figure 2: *A Digital Elevation Model of the Rottnest Shelf and Perth Coastal Plain showing the major geomorphic features of Cockburn Sound and the adjacent coast.*

ANTHROPOGENIC CHANGES

Considerable human alteration of Cockburn Sound has occurred since European settlement of the area during the 1800s. This includes industrial development and building of ship loading facilities on the mainland coast, dredging for shipping channels within Parmelia Bank and the Eastern Shoal, and construction of a causeway across the southern opening between the mainland and Garden Island (Fig. 1). Extensive industrial development in Cockburn Sound began in 1954 with the construction of an oil refinery on its eastern shore. Subsequent development has been rapid and the area now includes iron, steel, alumina and nickel refineries and processing plants, chemical and fertilizer plants, a wastewater treatment plant, electricity station and a bulk grain terminal (Department of Environment, 2005).

Industrial discharge of pollutants along the east coast has included the metals Cd, Cu, Fe, Pb and Zn (Murphy, 1979; Rosman *et al.*, 1980), organic compounds (pesticides and petroleum products) and nutrients, most notably nitrogen. Tributyltin, from anti-fouling paint, is also an issue in the southern section of the bay (DAL, 2001). These industrial waste discharges into Cockburn Sound were made on the incorrect assumption that the waters of the sound are regularly flushed. Efforts were made to reduce pollution in industrial discharges that were identified in studies conducted in the 1970's (Department of Conservation and Environment, 1979) and by the early 1980's water quality had significantly improved (Department of Environment, 2005). However, water quality again declined in the late 1980's and it was subsequently found that up to 70% of the total nitrogen load to the sound was entering the bay through the groundwater system (Department of Environmental Protection, 1996). Contamination of the groundwater by nitrogen is a significant environmental issue, with N concentrations up to 220 mg L^{-1} in shoreline sediment pore water and up to 130 mg L^{-1} in offshore bottom sediment pore water (Smith *et al*., 2003). Groundwater N loads to the sound have recently been estimated as 234 ± 88 t yr^{-1} (Smith *et al*., 2003).

Groundwater flows into Cockburn Sound from the east through Quaternary and recent sediments that form the regional unconfined aquifer. Discharge occurs both along the shoreline and at several offshore sites. Significant discharge has been measured in a narrow zone along the eastern shore, while submarine discharge points have been inferred from echosounder profiles of the water column and bottom sediment pore water chemistry (Smith *et al.*, 2003). However, the offshore sites of discharge have not been directly identified on the seabed. Possibly, they are related to solutional features in the Tamala Limestone, the porous limestone bedrock (Smith *et al*., 2003).

Large quantities of metal contaminants have been discharged into Cockburn Sound from heavy industry on the eastern shoreline. These discharges impact the water quality and can settle out of the water column or bind with the fine fraction of surficial sediments. Analysis of sediments, compared to water monitoring, provides a longer-term assessment of the state of the marine environment. When compared with sediment quality guidelines that have been produced by the Australian and New Zealand Environment and Conservation Council (ANZECC, 2000), this also provides a tool for the assessment of environmental health.

The 1976-1979 Cockburn Sound Environmental Study found widespread metal contamination of sediments in the sound (Department of Conservation and Environment, 1979). Talbot and Chegwidden (1983) also examined the build up of several heavy metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn) in sediments within Owen Anchorage, Cockburn Sound and Warnbro Sound. Anomalous and background values were estimated for each metal measured within Cockburn Sound and Owen Anchorage, and more than half of the metals in sediments from Cockburn Sound were above background levels. The contamination was found to be related to industrial discharge from Woodman Point (metropolitan sewage discharge) and James Point (steel mill, oil refinery and superphosphate plant). Subsequent sediment studies within the sound in 1994 (Department of Environmental Protection, 1996) found that contamination levels had decreased significantly when compared with results reported in the 1976 to 1979 study due to large reductions in wastewater discharges. The 1994 study found metal levels in Cockburn Sound were below Department of Environmental Protection draft guidelines except for arsenic and mercury in some areas near industries or harbours (DAL, 2001). The 1999 study found that levels of all metals were well below the national ‘Interim Sediment Quality Guidelines’ (ISQG; ANZECC, 2000) for the protection of marine ecosystems. Attempts were also made in the 1999 survey to determine the natural levels of metals (Cr, Cu, Pb, Ni and Zn). Based on these values, it was indicated that there was lead contamination near areas of shipping and widespread zinc contamination throughout the sound.

At the southern end of Cockburn Sound, a causeway links the mainland at Point Peron to the southern end of Garden Island. It was completed in 1973 to provide vehicular access to the naval base at Careening Bay. Two openings were built into the causeway to maintain some water exchange, however, the southern channel has been reduced from 2 km wide prior to construction of the causeway to two separate channels that are 305 m and 610 m wide (DAL, 2002). The causeway has significantly reduced exchange between Cockburn Sound and the ocean, especially for the southern area. The exchange through the southern opening has been restricted by approximately 40%, and the overall flushing of the sound has been reduced by 30 to 50% (Department of Environmental Protection, 1996). However, water quality was a problem in Cockburn Sound prior to construction of the causeway, as noted above. Extensive areas of seagrass were lost due to poor water quality between 1954 to 1978 and approximately 260 ha were lost in Mangles Bay and Southern Flats, and 440 ha between Rockingham Beach and James Point (Fig. 1; Cambridge, 1979).

Methods

FIELD APPROACH

A total of 63 surface sediment grabs and 12 vibracores were collected throughout Cockburn Sound during a field survey in March 2004 (Figs. 3 and 4). The field work was conducted from the vessel *FP Response* hired from Fremantle Ports and the sediment sample sites were loaded into the vessel's differential global positioning system (DGPS), allowing the ships master to subsequently position the vessel accurately over the sample site. The majority of the surface sampling was conducted using a small (0.5 L) stainless steel Van Veen grab (Fig. 5) which was loaned from Quaternary Resources Pty Ltd. The grab was deployed and recovered by hand. Because of the small capacity, two grabs were collected at the majority of sites to ensure that there would be a large enough sample for the analyses. Several grabs per site were necessary where there were extensive seagrass beds because of limited sediment recovery at these sites. The remaining grabs were collected using a larger (8 L) Van Veen grab.

The drilling was carried out using a vibracoring system hired from Quaternary Resources Pty Ltd. The method uses a submersible, electrically driven, vibrating head to drive a disposable aluminium core barrel (80 mm OD, 76 mm ID) into the seabed (Fig. 5). Up to 6 m of core were collected at some sites. At each location the water depth, time and GPS position of the vibracorer off the stern of the vessel was recorded. Once the core barrel was removed from the vibracorer, the length of sediment recovered in the barrel was logged. The grab samples and vibracores were transported to GA where they were stored in a cool-room until examined. Underwater video traverses were also collected for representative sections of the various benthic environments of Cockburn Sound during March 2004 (Fig. 3). This survey was undertaken by project members from the University of Western Australia using a towed underwater video system (Fig. 5).

SAMPLE ANALYSIS

Surface sediment samples were described lithologically and then subsampled for measurements of grain size and calcium carbonate ($CaCO_3$) content in the Sedimentology Laboratory at GA. Subsamples were also collected for the measurement of trace and major elements by X-Ray Fluorescence (XRF) and Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) in the Geochemistry Laboratory at GA. Vibracore barrels were split longitudinally to expose the core sediments, photographed and logged prior to sampling. Logging included visual estimation of colour, texture and composition of the various lithologic units, along with notes on any major stratigraphic changes. Samples of the various lithological units were collected from half of each core for grain size and $CaCO_3$ content and XRF-ICPMS (cores CSV03, CSV04, CSV05, CSV06, CSV07 and CSV09 only) and the other half was retained and archived.

Samples were analysed for sediment grain size using standard sieves and by laser diffraction using a Malvern Mastersizer 2000 (Malvern Instruments Ltd, Worcestershire, UK). Laser diffraction measures particle assemblages in the 0.02-2000 μM size range as volume percentages. The percentage of calcium carbonate (of the combined sand and mud fraction only) was determined using the 'carbonate bomb' method (Muller and Gastner, 1971). Briefly, 20% orthophosphoric acid was warmed to 50^{o}C and placed in a warm (35^{o}C) Perspex chamber. The dried and crushed sediment samples, weighing 0.9 g, were introduced to the chambers. Pressure gauges were screwed onto the top of the chambers forming a seal. The chambers were agitated until all the carbonate dissolved, producing CO_2 gas. The mass of carbonate was determined by a calibration curve of CO_2 gas pressure as a function of carbonate content. The accuracy of the method is ±0.5% (Muller and Gastner, 1971).

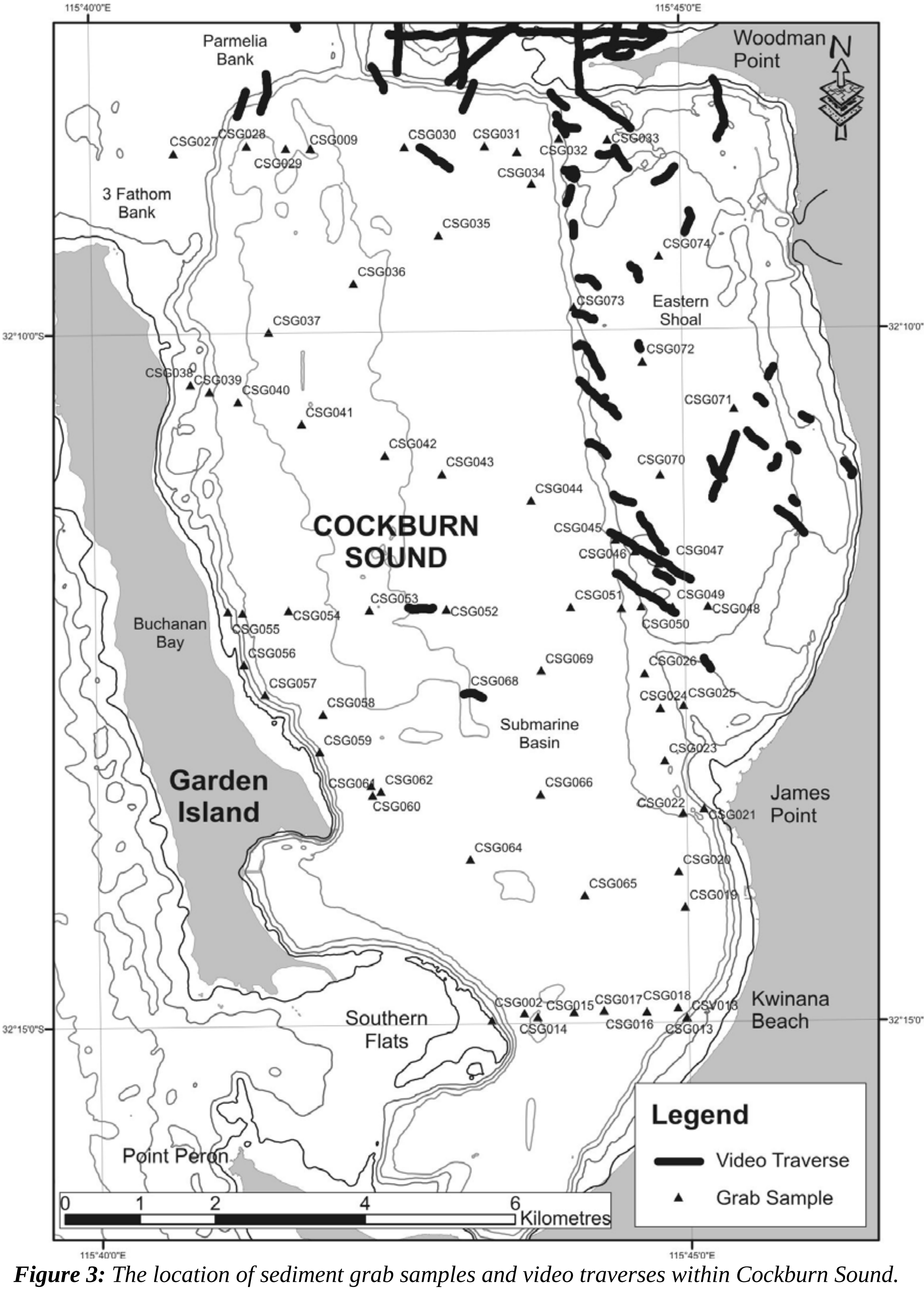


Figure 3: *The location of sediment grab samples and video traverses within Cockburn Sound.*

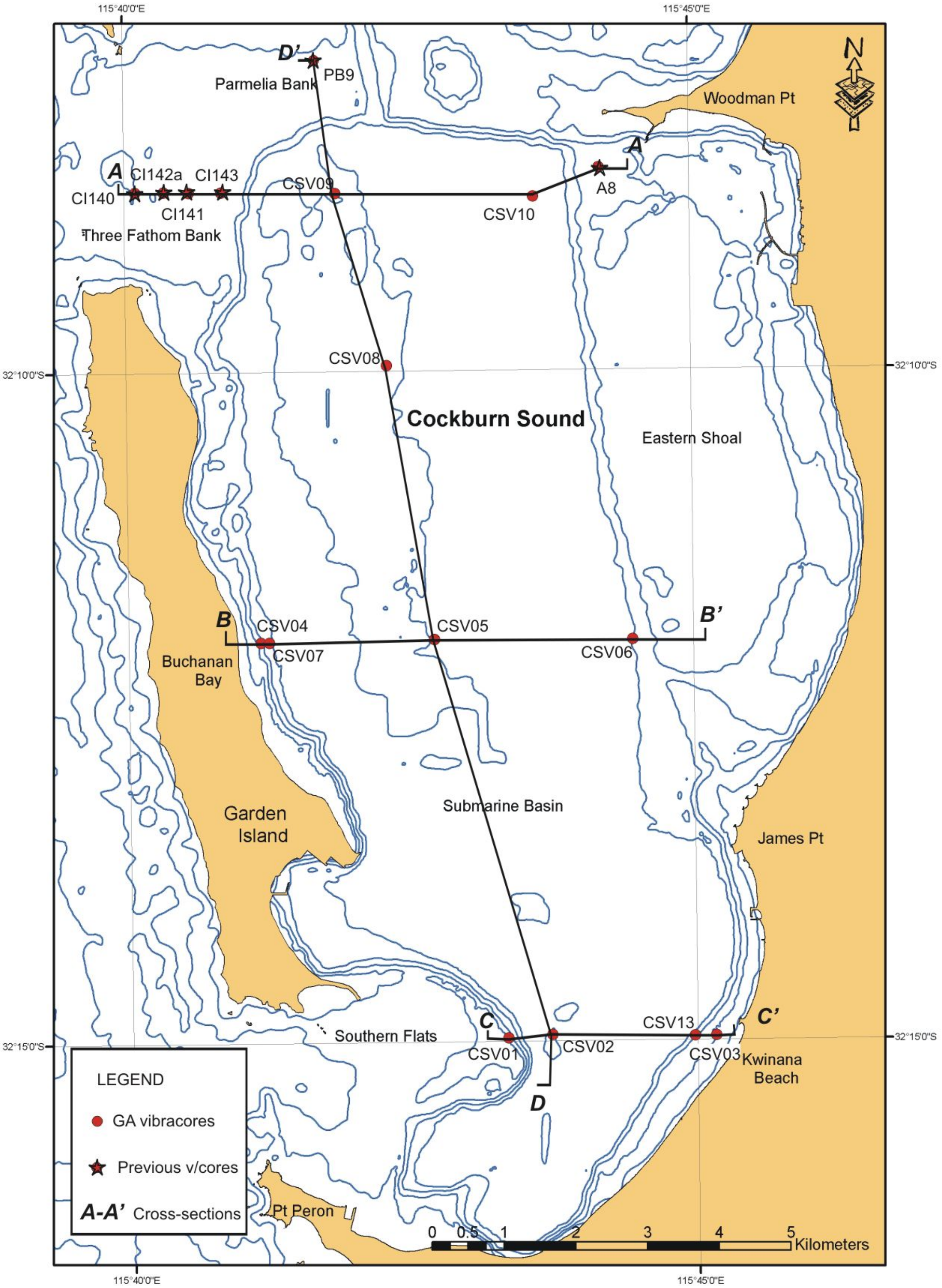


Figure 4: *The location of vibracores and stratigraphic cross sections within Cockburn Sound (CSV12 is located in Owen Anchorage to the north of the map area).*

***Figure 5:** Sediment sampling and underwater video equipment used in this study. A) Van-veen type grab sampler; B) Submersible vibracorer; C) Towed underwater video camera used by the CWHM team from University of Western Australia.*

GEOCHEMICAL ANALYSIS

Sub-samples were wet sieved using a 63 µm nylon sieve and deionised water to separate the fine (<63 µm) fraction from the bulk sample. Major element concentrations as oxides were determined by XRF using a modified version of the Norris and Hutton (1969) method whereby no heavy absorber was added to the flux. The instrumentation used was a Philips PW2404 4kW sequential spectrometer. A full description of the XRF method is given in Radke *et al.* (2004). Trace elements (including rare earth elements) were determined by ICP-MS at Geoscience Australia using a Perkin Elmer Elan 6000. The analysed XRF fusion discs were shattered and approximately 0.1 g of sample was weighed into Savillex teflon vessels. 5 ml of internal standard, 1 ml of distilled HF and 5 ml of distilled HNO_3 was added and the vessels sealed and heated for 12 hours at 120^{o}C on a timed hotplate. The cooled samples were diluted with distilled water and analysed by ICP-MS. The instrument was calibrated against Australian Soil and Plant Analysis Council (ASPAC) standards, and a range of United States Geological Survey (USGS) and South African Reference Material (SARM) standards.

DATA ANALYSIS

Various sedimentological and geochemical parameters and sample site PCA scores were plotted on a map of Cockburn Sound using *ArcGIS 8.3* software. The ESRI application *ArcGIS Spatial Analyst* was utilised to interpolate measured parameters employing an inverse-distance weighted contouring algorithm. Principal Components Analysis (PCA) was performed on the combined geochemical and sedimentological data using *Statistica 6* to investigate spatial patterns in, and significant relationships between, the physical and chemical composition of sediment samples from the bed of Cockburn Sound. The input variables included major element oxides and trace elements (<63 µm fraction only), proportion of $CaCO_3$ and the following grain size parameters: modal grain size, percentages of sand, mud and gravel, clay:silt ratio, skewness, kurtosis and a sediment sorting index (*i.e.* the standard deviation of the grain size/mean grain size). One sample (CSG027) was excluded from the PCA because the sample contained insufficient mud for an accurate measurement of this fraction. The grain size parameters were based on bulk sediment samples. The major element oxide and trace element datasets were log-transformed prior to analysis to improve the normality of their distributions.

Nd/Sr and K_2O/Al_2O_3 ratios (log transformed) were also integrated into the analysis. The Nd/Sr ratio is used to help trace the plume of terrestrially derived sediment into Cockburn Sound. Neodymium (Nd) is almost exclusively derived from terrestrial sources (McCulloch *et al*., 2003), whereas Sr is abundant in seawater (~8 mg kg^{-1}) and found in appreciable concentrations in marine carbonates. In comparison, the K_2O/Al_2O_3 ratio has been successfully used as an index of chemical weathering in estuaries in southwest Western Australia (Radke *et al*., 2004).

Results

SURFICIAL SEDIMENTS OF COCKBURN SOUND

Surface sediment grain size characteristics for Cockburn Sound are presented in maps of mean grain size (Fig. 6), relative sediment grain sorting as defined by grain size standard deviation normalised to mean grain size (Fig. 7), and pie charts showing relative percentages of gravel, sand and mud for each sample site (Fig. 8). The results of all sedimentological analyses are provided in Appendix I (Table A1.1, A1.2).

Sediments within the central basin are dominantly fine with the mud content increasing in the south and southwest of the sound (Figs. 6 and 8). Coarser, mainly sandy sediments are confined to the sand banks and shoals as well as the margins of the sound. Samples from Parmelia and Three Fathom Banks in the north and Southern Flats to the south are almost exclusively sand with a low proportion or absence of mud (Figs. 6 and 8). Gravel deposits are confined to the Eastern Shoal and the western margin of the sound, adjacent to Garden Island (Fig. 8). Figure 7 indicates that the coarser sediments located on Three Fathom Bank, Eastern Shoal and the Southern Flats tend to be better sorted whereas the central basin sediments show a greater range in grain size.

Calcium Carbonate

The highest proportions of calcium carbonate ($CaCO_3$) occur on the banks at the northern and southwestern margins of Cockburn Sound, typically 80 to 90% $CaCO_3$ (Fig. 9). The proportion of $CaCO_3$ in the sediment samples appears to be related to mean sediment grain size (Figs. 6 and 9). $CaCO_3$ concentration in the muddy sand ranges between 77 and 87% (average 82%). Lower percentages, from 60 to 66%, were found in a number of sand samples collected on the Eastern Shoal and may be due to the mixing of the carbonate sand with quartz sand derived from the erosion of the underlying Tamala Limestone or the reworking of relict sand deposits. The lowest proportion (53%) is associated with gravely sand collected in the southeastern section of the sound, offshore from Kwinana Beach.

Sediment Composition and Underwater Video

On the shallow northern banks and southern flats of Cockburn Sound the seabed consists of light grey, relatively uniform, moderately sorted, fine to coarse grained sand with varying proportions of shell gravel (fragments and whole shell), seagrass fiber and decaying seagrass fragments. Video footage from Parmelia Bank shows these sediments form the substrate of extensive seagrass meadows and patches of seagrass which alternates with bare sand flats, some covered with decaying seagrass debris.

The seabed of the Eastern Shoal comprises grey, very poorly sorted, very fine to very coarse grained muddy sand with scattered carbonate gravel (0 to 18% shell and foraminifera) and occasional blackened seagrass fragments. Gravels include *in situ* mollusc shells usually associated with seagrass and eroded fragments of limestone reefs that form talus slopes. Video footage across parts of the Eastern Shoal reveals patches of exposed limestone reef, especially along the western edge of the shoal. The adjoining slope that grades down to the central basin is strewn with calcarenite gravel in places.

The central basin is characterised by fine grained sediment in water depths greater than approximately 15 m. These deposits are cohesive, greenish-grey, poorly sorted, very fine grained, sandy carbonate muds (clayey silt) with varying proportions of shell fragments and whole shell. Localised high proportions of gravel in the central basin are typically related to isolated shell deposits. Video transects of the floor of the central basin show a relatively flat, bioturbated seabed with patches of unidentified vegetation (e.g. macroalgae). Scattered large shells and carbonate encrustations are also evident.

Sediment Facies

Four distinct sediment types were identified based upon the sedimentological analyses of the samples of surface sediment (Fig. 10).

Nearshore Quartz Sand (Gravelly shelly mixed carbonate/quartz sand): This unit comprises light greyish brown, fine to coarse grained (mean: 0.43 mm; standard deviation: 0.36 mm), poorly sorted, gravelly sand with a low fine material (<63 um) content of <5%. The total calcium carbonate content is >55% and comprises mainly broken fragments of molluscan shells, some gastropods, echinoids and bryozoa and abundant whole foraminifera (to 8 mm diameter). The carbonate fraction is platy while the quartz fraction is composed of rounded to well rounded, medium to very coarse grains.

Carbonate Banks (carbonate sand): This unit features a high carbonate content (typically ~90%), and an average mean grain size of 0.34 mm (range: 0.25-0.43 mm; standard deviation: 0.17 mm). The total amount of fine material is <5%. This unit was encountered at Parmelia Bank and Southern Flats, at the northern and southern margins of Cockburn Sound respectively; on the eastern shore of Garden Island; and to the north of Garden Island as a sheet blanketing the Three Fathom Bank (Fig. 10).

Eastern Shoal Sediments (Carbonate muddy sand): This unit features an average mean grain size of 0.29 mm (range: 0.12 - 0.43 mm; standard deviation: 0.28 mm). The calcium carbonate component typically exceeds 80% and the fines (<0.063 mm) range from 11 to 50% (average 27%). This facies occurs on the Eastern Shoal and the slopes surrounding the central basin and also mantle the seabed in the northern margin of the central basin (Fig. 10).

Central Basin (Carbonate sandy mud/mud): The average mean grain size of this facies is 0.062 mm (range: 0.023-0.12 mm: standard deviation: 0.11 mm). In this unit the proportion of fines ranges from 56 to 93% (average 76%). The calcium carbonate content averages approximately 80%. The proportion of mud in the central basin increases to the southwest. This pattern appears to be the result of reduced circulation within these regions, allowing suspended sediment to be deposited. This deposit covers the deeper reaches of the sound (Fig. 10).

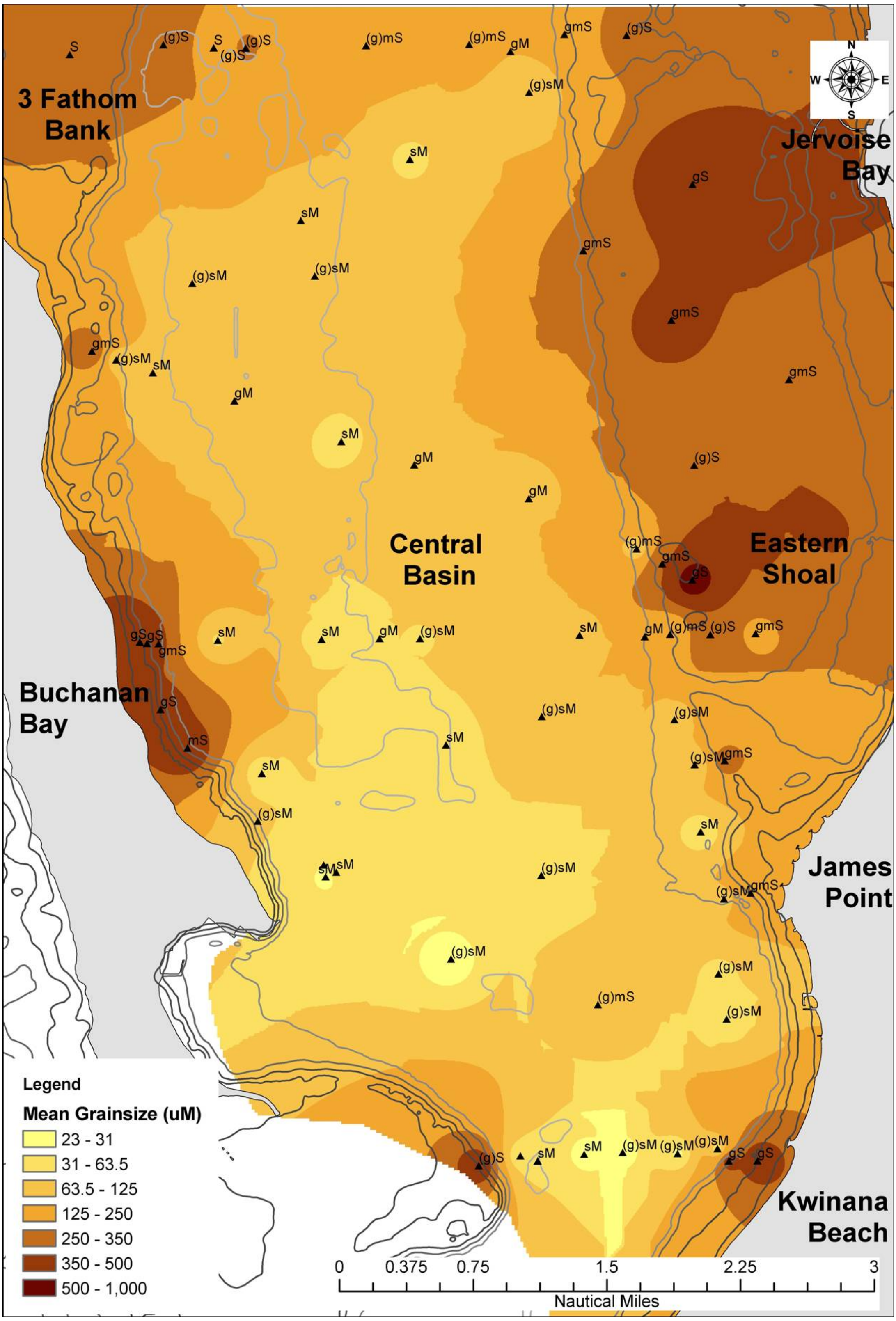


Figure 6: *A map of the mean grain size of the sediment samples collected in Cockburn Sound. Sample sites are coded using grain size descriptors, (g)sM: gravely sandy mud; sM: sandy mud; gM: gravely mud;.mS: muddy sand; gmS: gravely muddy sand; gS: gravely sand.*

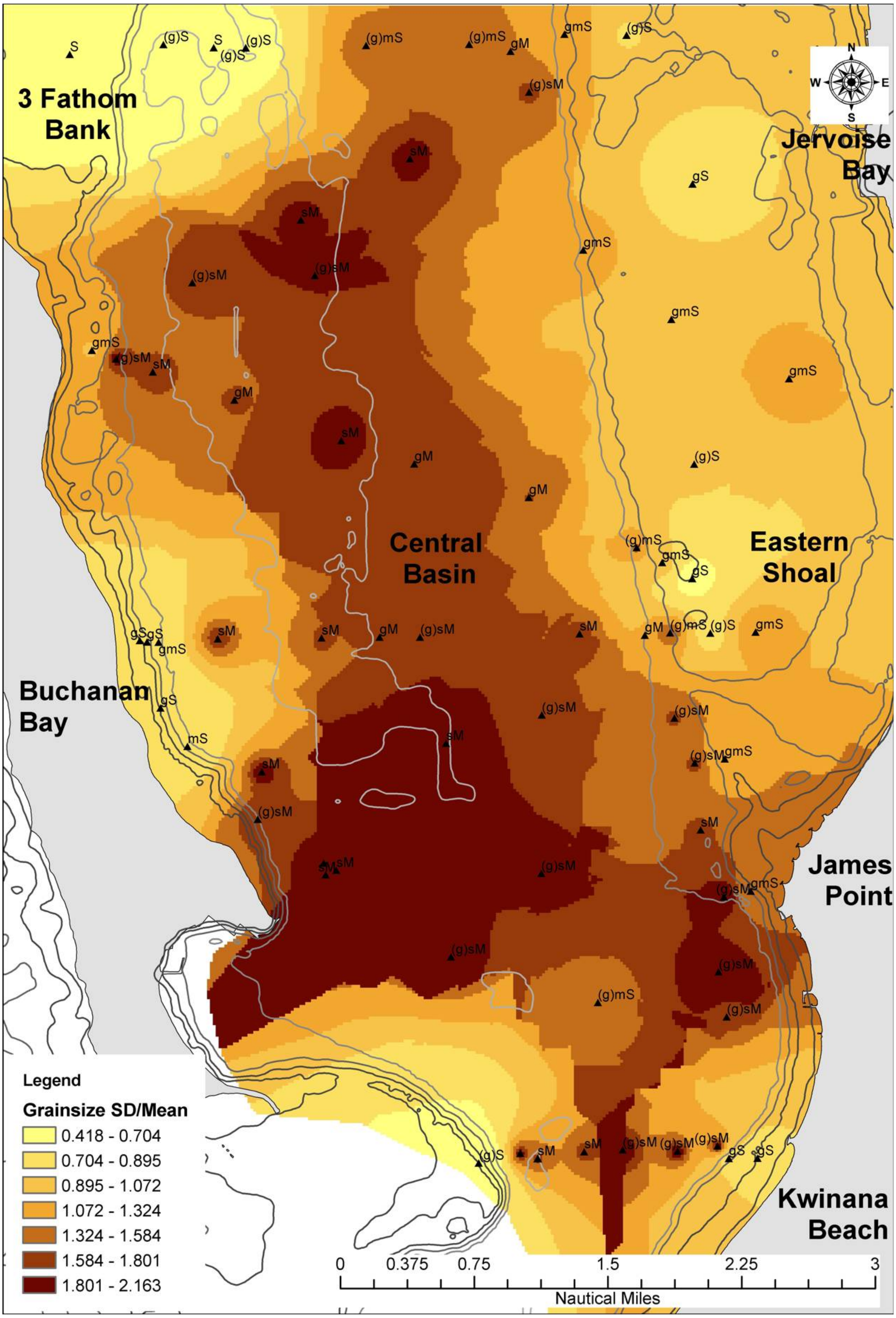


Figure 7: *A map of the degree of sorting in the sediment samples collected in Cockburn Sound as indicated by the standard deviation/mean grain size ratio.*

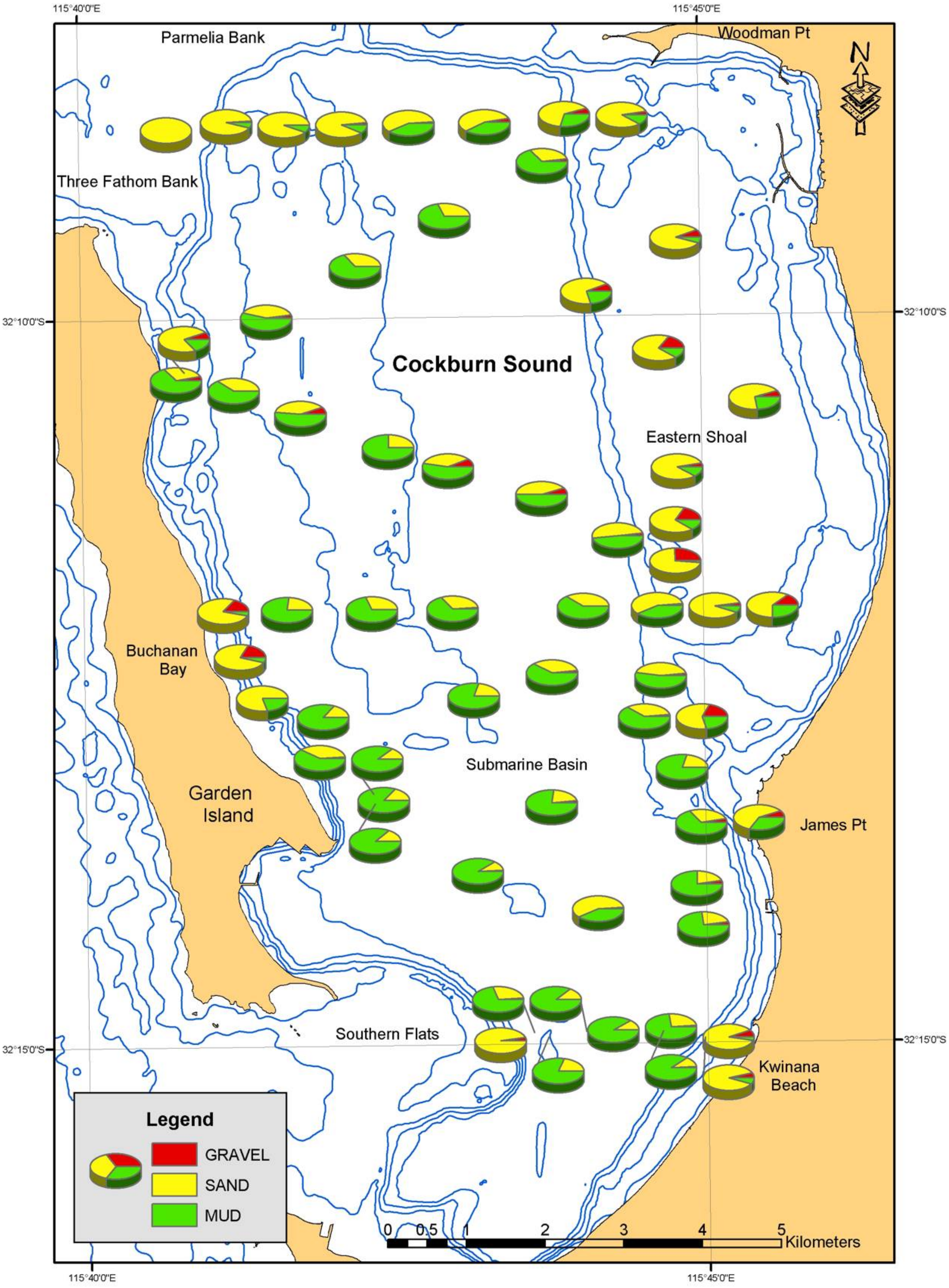


Figure 8: *The proportion of gravel, sand and mud in the sediment samples from Cockburn Sound as determined by sieve measurements.*

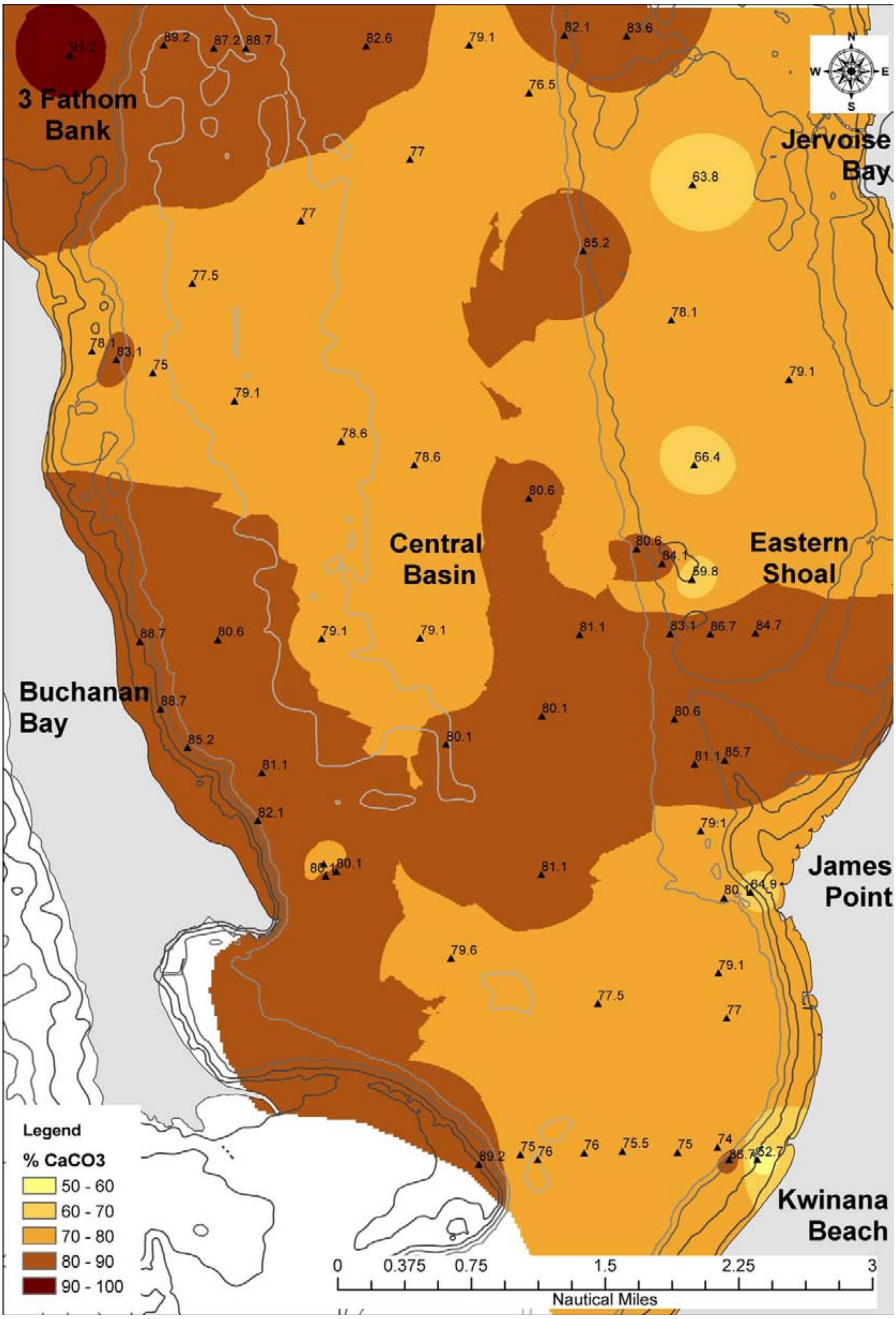


Figure 9: *A map of the proportion of calcium carbonate ($CaCO_3$) in sediment samples from Cockburn Sound.*

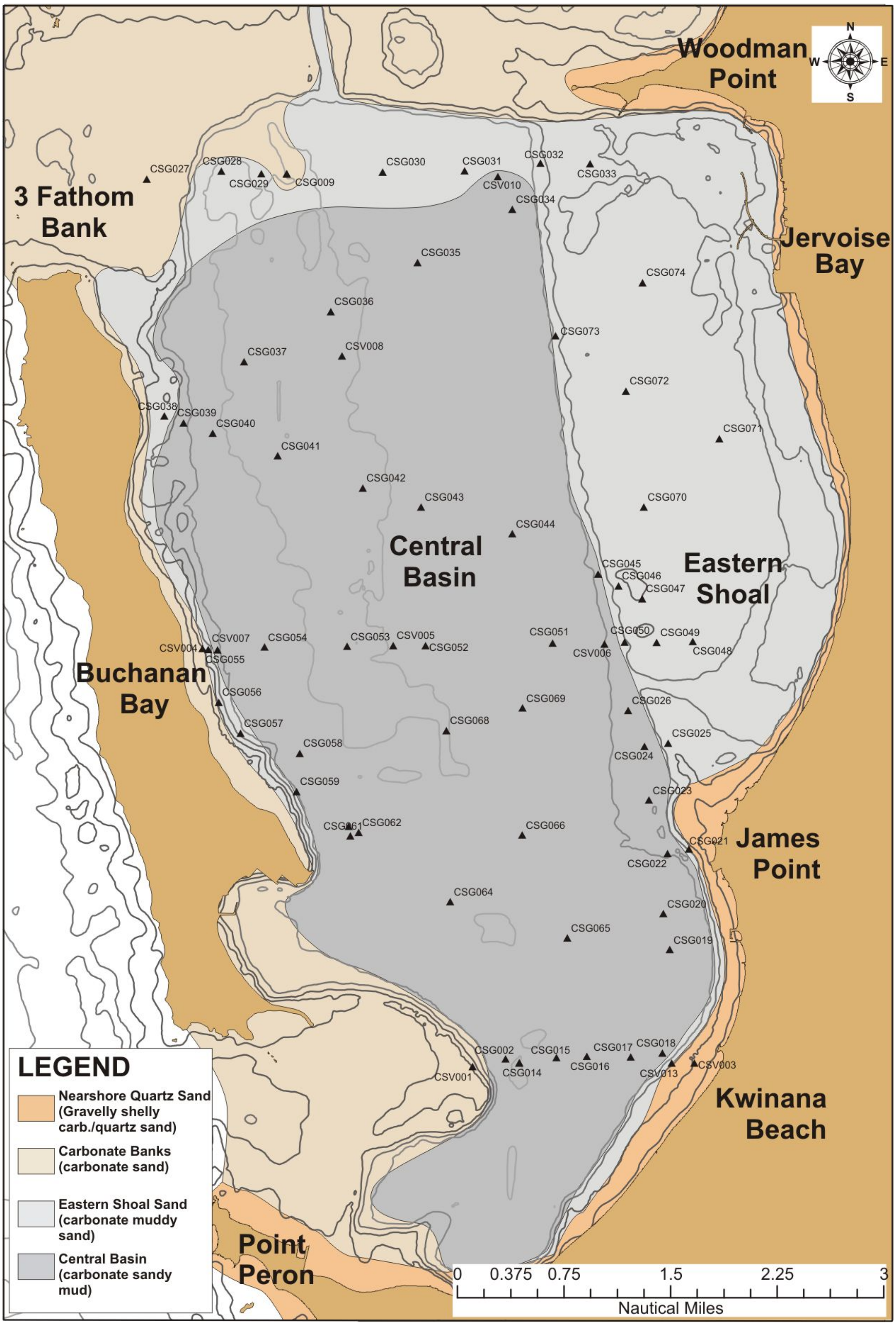


Figure 10: *A map of the distribution of distinctive surface sediment types (facies) identified in Cockburn Sound.*

Principal Components Analysis of Sediment and Geochemical Data

The PCA factor coordinates of the geochemical and sedimentological variables are shown in Table 2 and the complete geochemical data are presented in Appendix II. The first principle component (PC1, Axis 1 of the PCA plot) explains 42.2% of variance in the data. Most trace and major elements and especially the Nd/Sr ratio have strong positive loadings on this axis and are inversely correlated to CaO and Sr and to a lesser extent the K_2O/Al_2O_3 ratio (Table 2). When the sample site scores for Axis 1 (Table 3) are plotted on the map of Cockburn Sound (Fig. 11a), the scores appear to define the source areas of trace metal contamination and to indicate likely sediment transport pathways from these sites. On this map, Kwinana Beach is a major location of elevated trace and major elements, with other sites on the southwestern margin of the Eastern Shoal near Woodman Point and east of Three Fathom Bank (Fig. 11a). The isolated site of relatively high contamination northeast of Three Fathom Bank (sample site CSG29) does not conform to this pattern and may be a spoil dump. A map of the Nd/Sr ratios confirms the pattern of distribution of fine terrestrial sediment (and contamination) identified by PC1 (Fig. 12). This map clearly indicates a major source of fine terrestrial sediment at Kwinana Beach and on the Eastern Shoal and suggests this sediment is transported in an anticlockwise direction within Cockburn Sound.

Axis 2 of the PCA explains 13.6 % of the variance in the data set. Sediment samples are differentiated along this axis on the basis of the grain size characteristics, from well-sorted sands with strong positive loadings to poorly sorted mud with strong negative loadings (Table 2). These sediment physical characteristics do not vary significantly on the first principle component axis (PC1), which reflects the fact that both sandy and muddy facies in Cockburn Sound can comprise marine-dominated sediment (bioclastic carbonate) and terrestrially-dominated sediment (quartz, feldspars and clay minerals). The map of site scores for Axis 2 (Fig. 11b) shows a good correlation with the map of sample grain size (Fig. 6) due to the strong influence of the proportion of sand and degree of sorting on these scores. Sites with the lowest scores in the southern end of the sound reflect a higher proportion of poorly sorted muds and higher proportions of most elements. This trend is also born out in the moderate degree of negative correlation between terrestrial elements and grain sorting (Table 4).

A further 9.3% of the variance in the dataset is explained by the third principle component, PC3 (Table 2). The SO_3 variable has the strongest (negative) loading on this axis and in association with the relatively strong negative loadings for Na_2O_3 and Cl may indicate a relative lowering of seawater salt assemblage in these samples caused by the submarine discharge of comparably fresh groundwater. When the site scores for Axis 3 (Table 3) are plotted on the map of the sound (Fig. 11c) there is a distinct zonation focused on the northeastern coast and extending westwards into the central basin. This pattern appears to indicate either the source submarine groundwater discharge or the source and pathway of distinctive and relatively clay-rich terrestrial sediment or a combination of both influences.

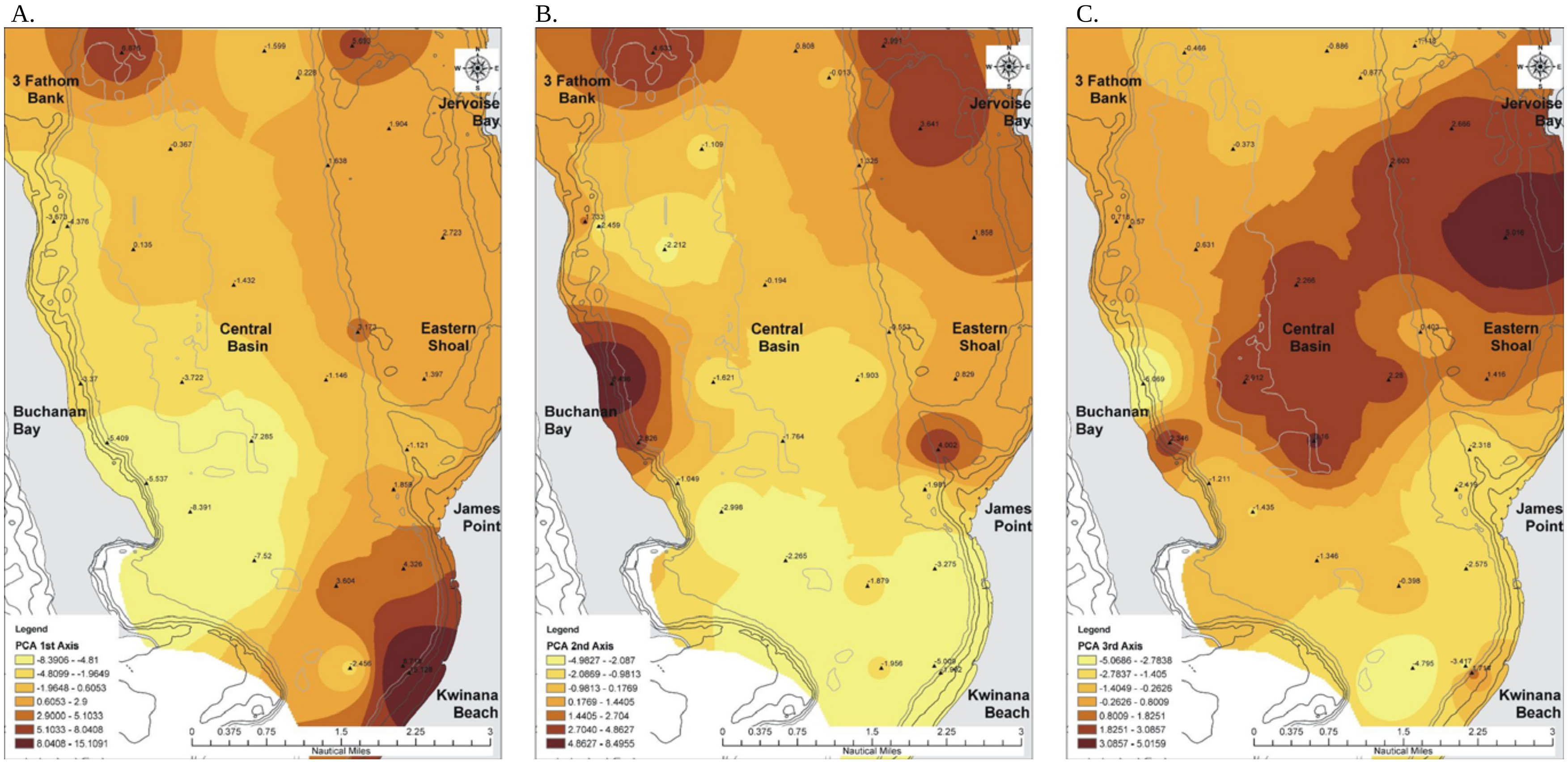


Figure 11: *Maps of the sediment sample sites showing the site scores for the first three principle components of the PCA analysis. A) PC1: The high scores indicate a strong terrestrial sediment signature (Nd/Sr) and relatively high levels of several trace metals. B) PC2: The high scores reflect well sorted sediment. C) PC3: High scores reflect relatively low concentrations of S, Na and Cl that appear to indicate the influence of submarine groundwater discharge and possibly a relatively high proportion of clay-rich fine terrestrial sediment.*

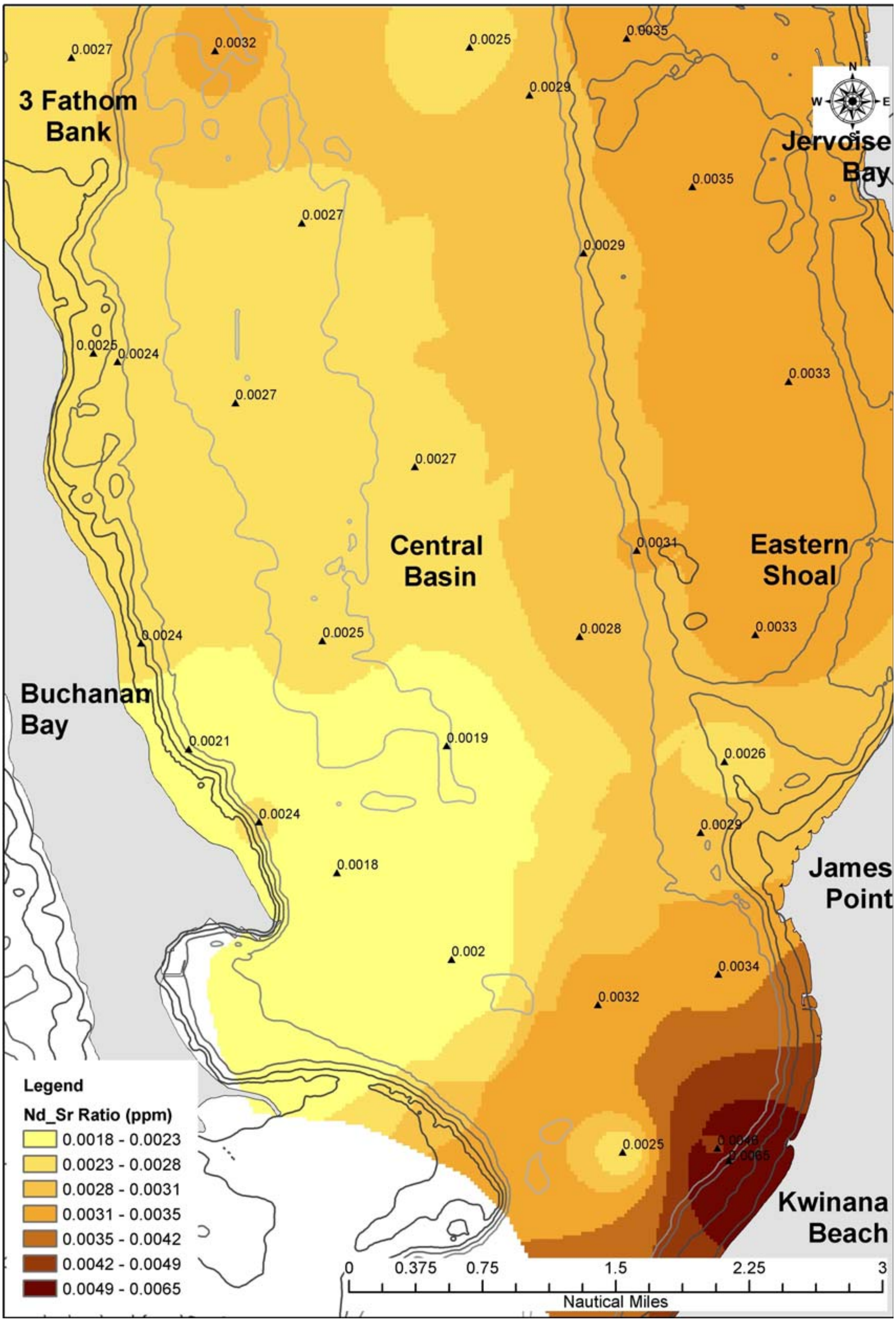


Figure 12: *A map of the Nd/Sr ratios measured in surface sediment samples from Cockburn Sound. Higher ratios indicate a higher proportion of terrestrial sediment in the fine fraction of these samples.*

Table 2: Factor coordinates of variables on Axes 1, 2 and 3 of the PCA. Relatively strong loadings for each axis are shown in bold.

ELEMENT	AXIS 1	AXIS 2	AXIS 3
lCd	**0.54**	-0.24	**-0.53**
lCr	**0.65**	-0.02	-0.23
lCu	0.22	0.38	**-0.53**
lNi	**0.55**	-0.01	-0.49
lPb	**0.77**	0.46	0.01
lZn	**0.83**	0.30	-0.10
lAg	0.18	0.06	0.10
lAl$_2$O$_3$	**0.87**	0.17	0.22
lAs	0.29	0.40	0.37
lBa	0.23	0.02	0.48
lBe	0.45	0.05	-0.27
lBi	**0.60**	-0.13	-0.05
lCaO	**-0.69**	**-0.54**	0.27
lCe	**0.90**	-0.26	0.26
lCl	0.16	**0.66**	**-0.54**
lCs	**0.74**	0.26	-0.33
lDy	**0.91**	-0.27	-0.01
lEr	**0.89**	-0.26	-0.08
lEu	**0.81**	-0.38	-0.26
lFe$_2$O$_3$	**0.87**	-0.11	0.12
lGa	**0.89**	0.16	0.00
lGd	**0.90**	-0.32	-0.03
lGe	**0.59**	0.02	-0.08
lHf	**0.75**	-0.11	0.41
lHo	**0.87**	-0.25	-0.29
lK2O	0.49	**0.59**	-0.28
lLa	**0.93**	-0.22	0.13
lLu	**0.53**	-0.15	**-0.56**
lMgO	-0.07	-0.30	-0.45
lMnO	0.39	0.23	0.00
lMo	**0.54**	-0.08	**-0.52**
lNa$_2$O$_3$	0.12	**0.66**	**-0.52**
lNb	**0.95**	-0.06	0.17
lNd	**0.92**	-0.29	0.11
lP$_2$O$_5$	**0.84**	-0.13	-0.19
lPr	**0.92**	-0.28	0.15
lRb	**0.84**	0.06	0.11
lSb	0.02	0.26	-0.30
lSc	-0.05	-0.15	0.06
lSiO$_2$	**0.84**	0.17	0.02
lSm	**0.80**	-0.32	0.27
lSn	**0.56**	0.07	-0.02
lSO$_3$	0.45	0.20	**-0.68**
lSr	**-0.69**	**-0.58**	0.09
lTa	**0.66**	-0.08	-0.20
lTb	**0.57**	-0.30	-0.32
lTh	**0.81**	-0.07	0.35

ELEMENT	AXIS 1	AXIS 2	AXIS 3
lTiO_2	**0.89**	0.02	0.15
lU	0.45	**-0.53**	-0.23
lV	**0.56**	**0.52**	0.12
lY	**0.87**	-0.29	-0.05
lYb	**0.91**	-0.18	0.00
lZr	**0.71**	-0.09	0.47
%Gravel	0.04	**0.59**	-0.07
%Sand	0.44	**0.77**	0.29
%Mud	-0.41	**-0.80**	-0.26
$CaCO_3$%	0.03	0.34	-0.06
Kurtosis	-0.27	**-0.50**	-0.49
Skew	-0.31	**-0.70**	-0.42
Mode	0.10	**0.80**	0.15
stdev/mean	-0.32	**-0.84**	-0.26
clay:silt	0.35	-0.35	**0.52**
lK_2O/Al_2O_3	**-0.58**	0.35	**-0.52**
lNd/Sr	**0.94**	-0.22	0.11

Table 3: Site scores for the first three Principle Components

SITE	AXIS 1	AXIS 2	AXIS 3
CSG13	15.1280	-1.9025	1.7144
CSG16	-2.4559	-1.9557	-4.7952
CSG18	8.7182	-5.0093	-3.4167
CSG20	4.3262	-3.2755	-2.5750
CSG23	1.8592	-1.9810	-2.4190
CSG25	-1.1208	4.0023	-2.3178
CSG29	6.8759	4.6334	-0.4663
CSG31	-1.5995	0.8076	-0.8863
CSG33	5.6934	3.9905	-1.1176
CSG34	0.2275	-0.0128	-0.8766
CSG36	-0.3668	-1.1087	-0.3731
CSG38	-3.6728	1.7327	0.7182
CSG39	-4.3756	-2.4587	0.5704
CSG41	0.1354	-2.2118	0.6312
CSG43	-1.4318	-0.1939	2.2661
CSG45	3.1727	-0.5530	0.4032
CSG48	1.3969	0.8292	1.4163
CSG51	-1.1461	-1.9032	2.2804
CSG53	-3.7219	-1.6213	2.9120
CSG55	-3.3703	8.4964	-5.0686
CSG57	-5.4087	2.8256	2.3455
CSG59	-5.5366	-1.0486	-1.2112
CSG62	-8.3910	-2.9976	-1.4354
CSG64	-7.5200	-2.2646	-1.3464
CSG65	3.6042	-1.8793	-0.3980
CSG68	-7.2852	-1.7639	3.1598
CSG71	2.7230	1.8576	5.0160
CSG73	1.6381	1.3247	2.6032
CSG74	1.9039	3.6412	2.6664

Table 4: Statistically significant ($p<0.05$) product-moment correlations between the grain sorting variable and various elements in the surface sediment samples from Cockburn Sound.

ELEMENT	CORRELATION WITH GRAIN SORTING
CaO	0.64
V	-0.63
Sr	0.63
Pb	-0.61
As	-0.54
K_2O	-0.48
SiO_2	-0.45
Al_2O_3	-0.43
Ga	-0.43
Zn	-0.42
Cl	-0.40
Na_2O	-0.40
Cs	-0.39

Fine-Fraction Metal Concentrations

A summary of the main trace metal results for surface sediments is presented in Table 5 including the background and anomalous values derived by Talbot and Chegwidden (1983) and the ANZECC (2000) recommended interim sediment quality guidelines (ISQG). The most common trace elements were analysed, however only seven are deemed important anthropogenic contaminants in Cockburn Sound and can be used to compare with results from the previous studies (Table 5). Zn, Cu and Ni concentrations measured in the surface sediments samples in this study are above the background values listed in Table 5. The spatial distribution of these trace metals in Cockburn Sound are displayed in Figures 13, 14, and 15.

Concentrations of Cr measured in this survey are on average higher compared to the results from the 1994 survey (Department of Environmental Protection, 1996). The new data also show that concentrations of As, which fell markedly between the 1994 and 1999 surveys, have on average continued to fall throughout the sound. Although well below the ISQG-low trigger value, 43% of the Zn results are above the anomalous values of Talbot and Chegwidden (1983). Concentrations of Zn are generally higher than both the 1994 and 1999 surveys. There are higher concentrations of Zn in sediments off Kwinana Beach in the southeast of the sound, at Buchanan Bay on the eastern shore of Garden Island, most of Eastern Shoal and on Three Fathom Bank north of Garden Island (Fig. 13). Sample sites with Cu concentrations greater than the ISQG-low trigger value occur near James Point, at Buchanan Bay and on Three Fathom Bank (Fig. 14). Concentrations of Ni greater than the ISQG-low trigger values were recorded in sediments off Kwinana Beach, on Three Fathom Bank and in the northern section of the central basin (Fig. 15).

Table 5: Sediment contaminant levels at Cockburn Sound sample sites. Comparisons are made with background, anomalous and the Interim Sediment Quality Guidelines low and high reference values.

CONTAMINANT	**As** **ICP-MS** ppm[#]	**Cd** **ICP-MS** ppm	**Cr** **XRF** ppm	**Cu** **XRF** ppm	**Ni** **XRF** ppm	**Pb** **ICP-MS** ppm	**Zn** **XRF** ppm
Background values*		0.5	45	14	4.8	37	27
Anomalous values*		0.7	50	16.5	5.5		30
ISQG-Low (Trigger Value)**	20	1.5	80	65	21	50	200
ISQG-High**	70	10	370	270	52	220	410
Sample ID							
CSG13	3.6	0.55	39	16	49	19.8	60
CSG16	2.5	0.23	30	43	9	11.8	28
CSG18	0.7	0.52	37	20	14	14.8	46
CSG20	0.4	0.32	34	20	6	12.8	34
CSG23	0.4	0.15	39	97	15	14.4	29
CSG25	0.4	0.12	32	34	14	12	29
CSG27	6.8	0.12	32	149	56	20.7	37
CSG29	3.7	0.15	43	28	6	18.2	31
CSG31	1.1	0.14	29	36	5	14.4	27
CSG33	2.6	0.18	40	44	10	18.7	38
CSG34	1.1	0.18	40	11	17	16.8	32
CSG36	0.4	0.05	31	36	23	13.8	27
CSG38	0.4	0.15	34	24	2	12.5	26
CSG39	0.4	0.13	33	8	4	9.6	19
CSG41	0.8	0.18	36	20	1.3	10.4	18
CSG43	2.2	0.05	28	17	1.3	12.1	26
CSG45	0.4	0.11	36	24	12	12.7	32
CSG48	0.4	0.11	32	42	7	13	33
CSG51	2	0.05	25	11	7	11.5	23
CSG53	1.9	0.11	25	9	1.3	10.5	21
CSG55	1.8	0.13	22	73	11	14.5	39
CSG57	1.9	0.11	22	7	1.3	11.7	24
CSG59	0.4	0.15	28	12	5	9.2	17
CSG62	0.4	0.11	23	21	9	8.3	17
CSG64	0.4	0.05	29	15	3	9.1	14
CSG65	0.4	0.24	26	13	12	10.6	27
CSG68	1.6	0.05	14	9	1.3	8.8	17
CSG71	3.9	0.05	31	17	2	15	34
CSG73	2.8	0.05	32	11	5	17.2	40
CSG74	2.5	0.05	27	44	8	17.5	32

* - Values from Talbot and Chegwidden 1983

** - Recommended sediment quality guidelines from ANZECC (2000)

\# - ppm - parts per million = mg/kg dry weight

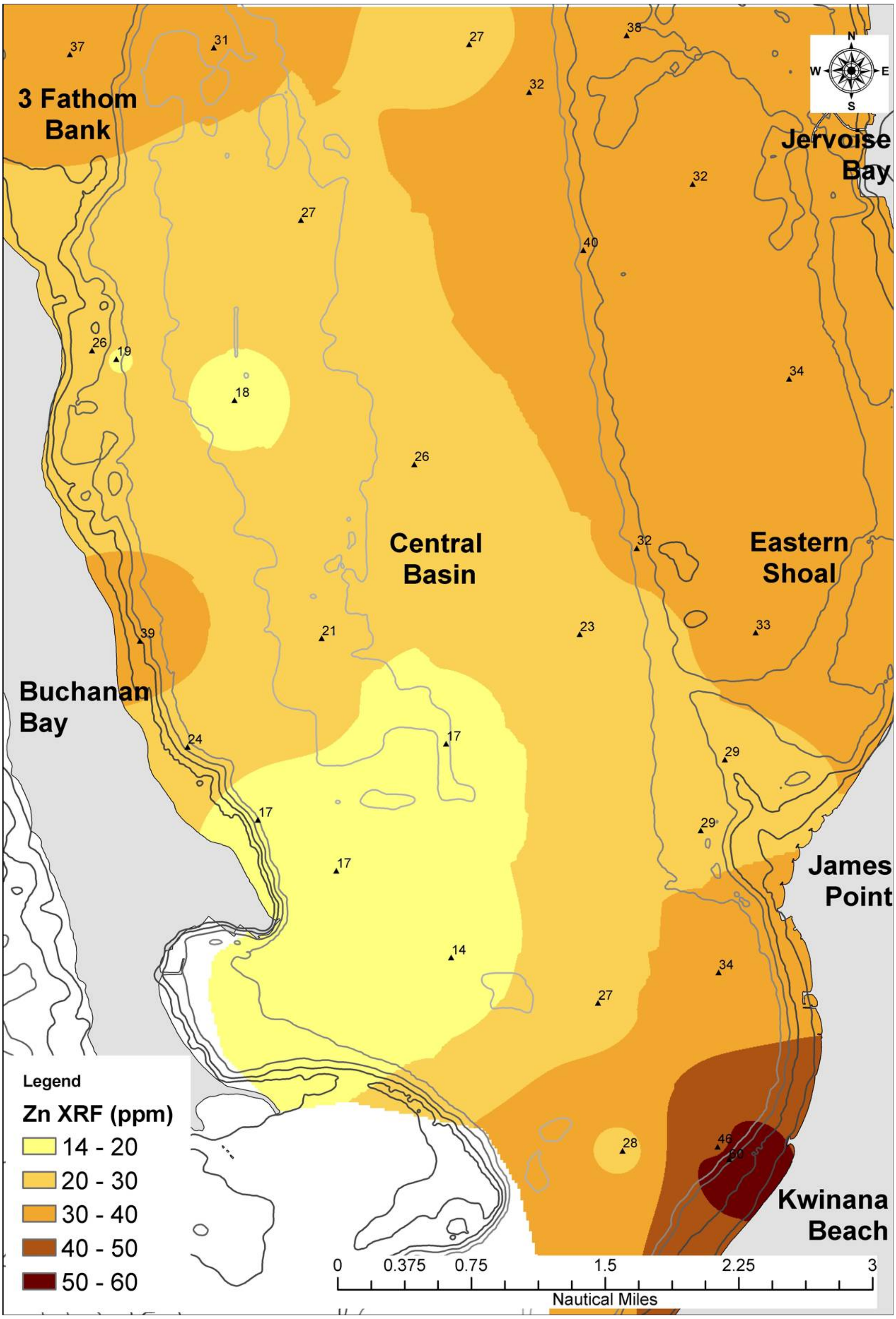


Figure 13: *A map of the concentration of Zn in surface sediment samples from Cockburn Sound.*

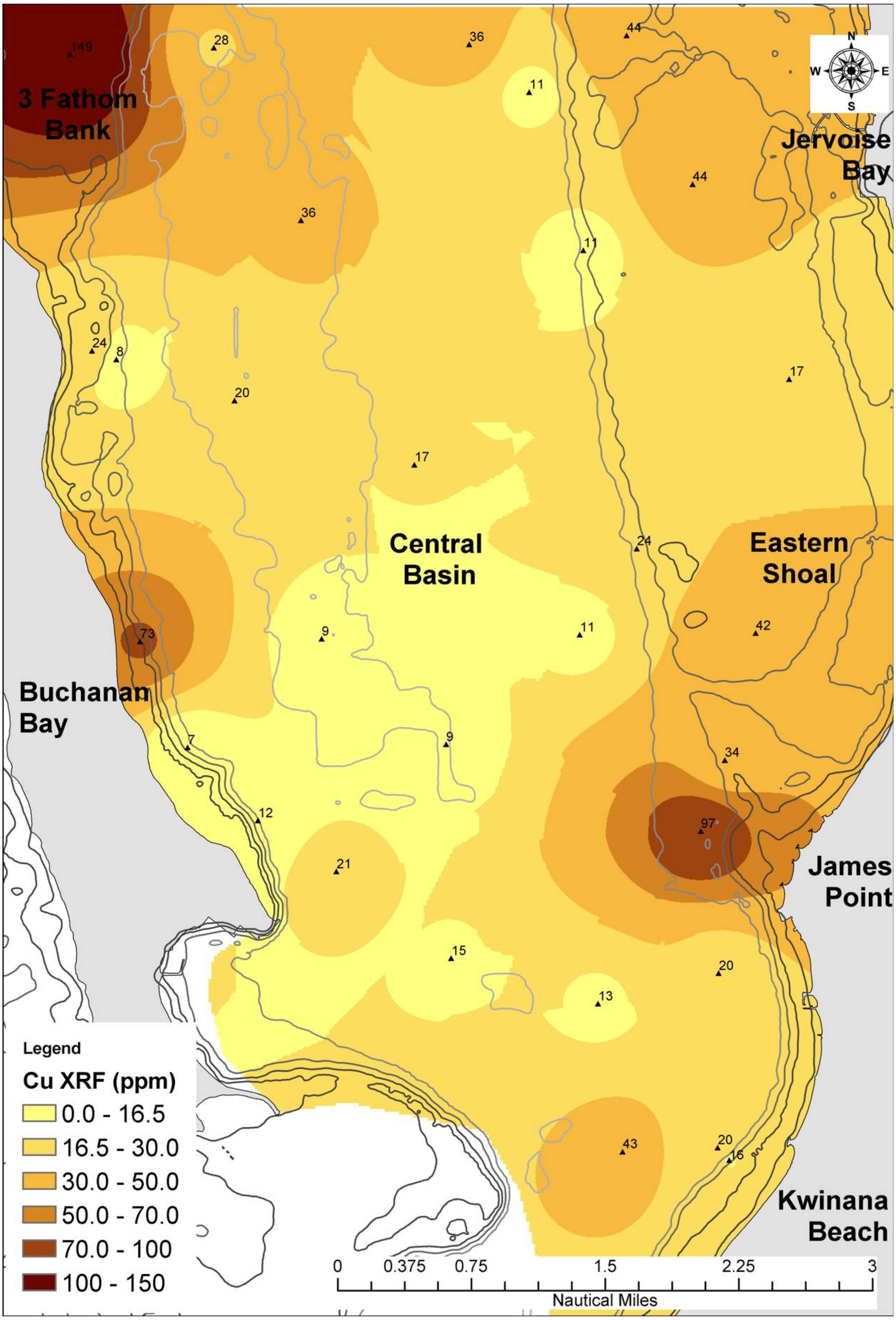


Figure 14: *A map of the concentration of Cu in surface sediment samples from Cockburn Sound.*

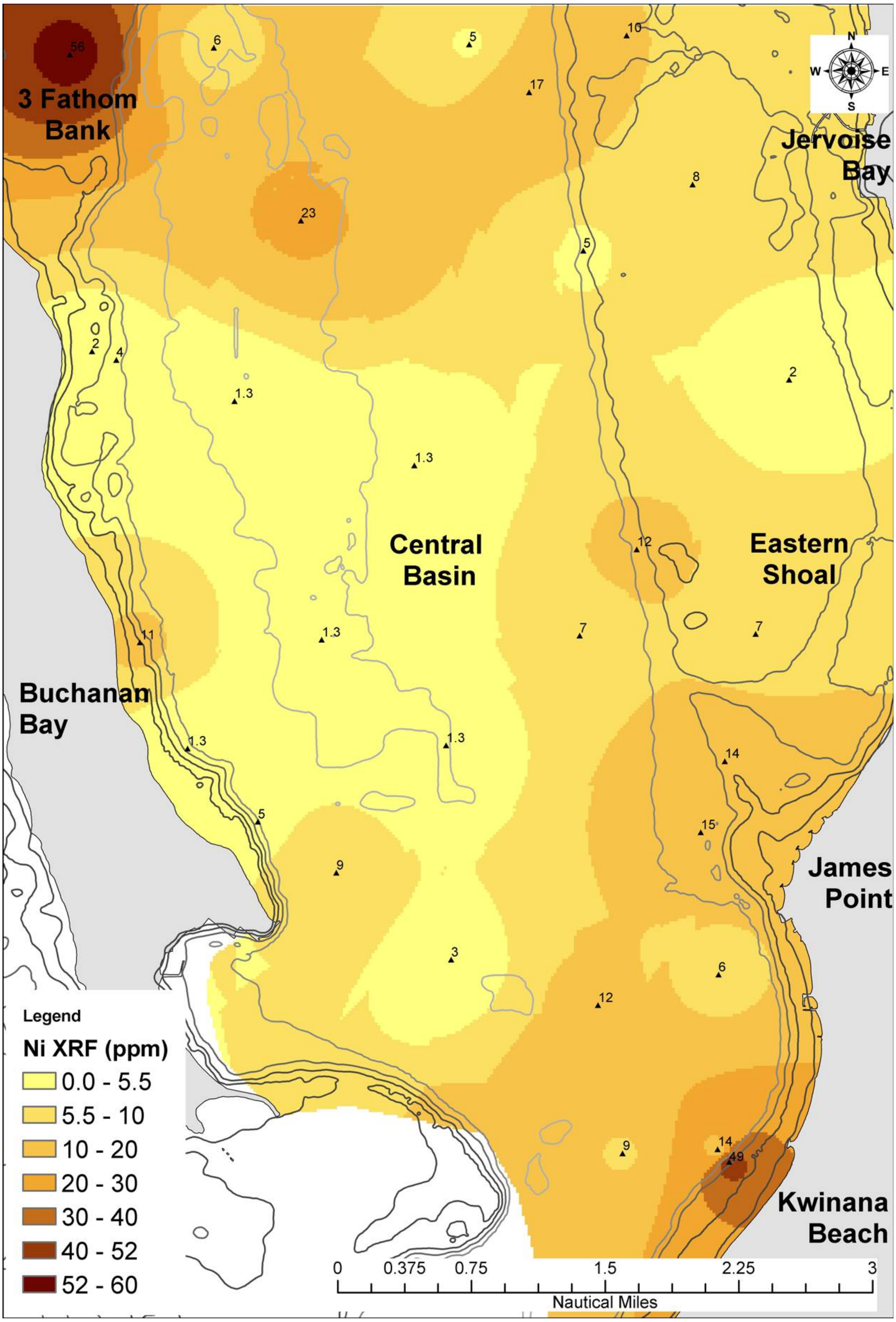


Figure 15: *A map of the concentration of Ni in surface sediment samples from Cockburn Sound.*

SUB-SURFACE SEDIMENTS

Twelve vibracores ranging from 0.45 m to 6.10 m long were obtained from Cockburn Sound. Table 6 summarises the results of the vibracoring survey and simplified logs of the cores are provided in Figure 16. Photographs for selected downcore sedimentary units are provided in Figure 17 and detailed core logs and photographs are included in Appendix III. Appendix III also includes sample grain size data (sieve and laser measurements: Tables A3.1 and A3.2), $CaCO_3$ composition (Table A3.1) and XRF-ICPMS data (Table A3.3).

Table 6: Field data for the vibracores collected in Cockburn Sound.

CORE ID	NORTHING (M, ZN. 50)	EASTING (M, ZN. 50)	WATER DEPTH (m)	DATE/TIME	RECOVERY (m)	COMMENTS
CSV001	6431182	379613	13.4	11-MAR-04 04:34	2.73	Eastern edge of Southern Flats
CSV002	6431231	380226	20.2	11-MAR-04 03:57	6.10	Southern Central Basin
CSV003	6431230	382509	5.0	11-MAR-04 03:03	0.45	Offshore Kwinana Beach
CSV004	6436613	376165	9.1	10-MAR-04 05:38	2.49	Buchanan Bay, east Garden Island
CSV005	6436663	378581	21.0	10-MAR-04 07:05	5.53	Central Basin
CSV006	6436682	381337	15.6	10-MAR-04 07:48	2.32	Southern edge of Eastern Shoal
CSV007	6436610	376285	15.4	10-MAR-04 06:14	2.26	Buchanan Bay, east Garden Island
CSV008	6440433	377909	20.6	11-MAR-04 01:43	2.17	Central Basin
CSV009	6442802	377191	19.7	11-MAR-04 01:02	3.00	Northern Central Basin
CSV010	6442768	379943	17.6	11-MAR-04 00:30	2.40	North eastern Central Basin
CSV011	6446911	378496	14.5	10-MAR-04 04:10	Core lost	No Recovery
CSV012	6447172	376321	11.1	10-MAR-04 03:17	2.63	North of Parmelia Bank/Owen Anchorage
CSV013	6431229	382212	8.6	11-MAR-04 06:45	2.90	Offshore Kwinana Beach

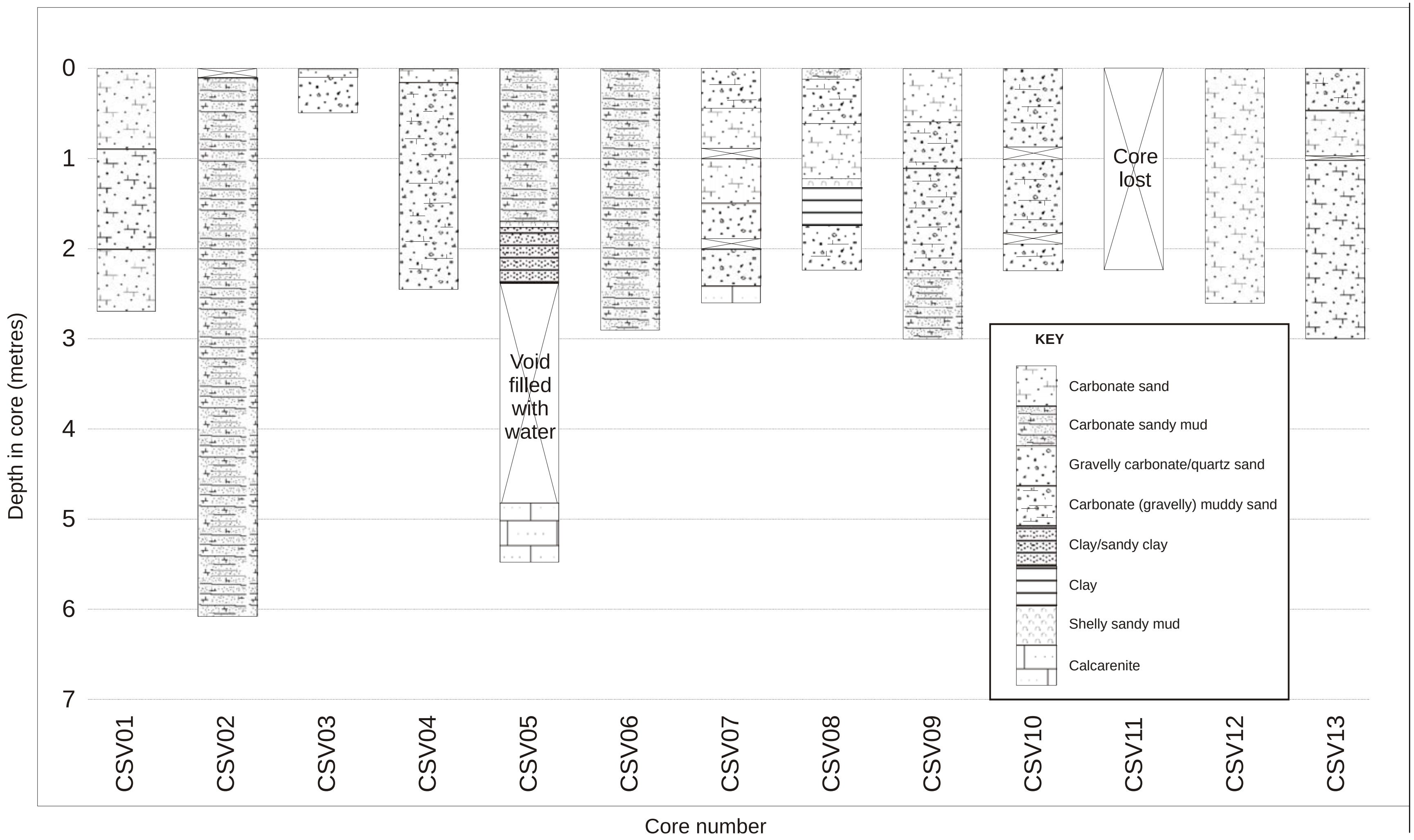
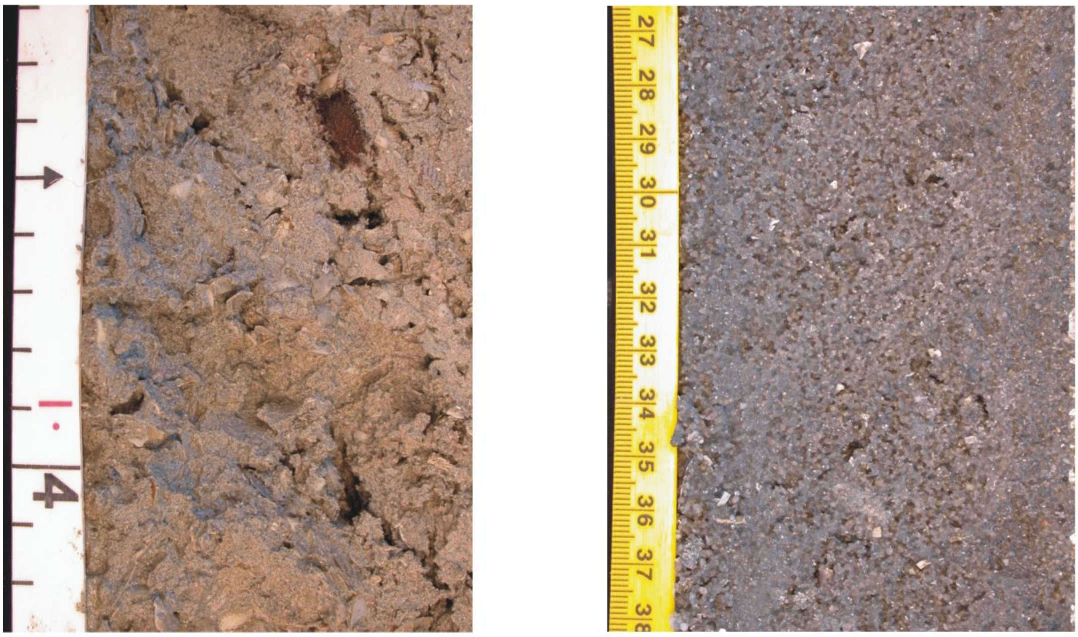


Figure 16: *Lithological logs of the vibracores collected in Cockburn Sound. More detailed logs are included in Appendix III.*

A) Shelly Carbonate/Quartz Sand - Core CSV03. Note platy nature of carbonate fraction.

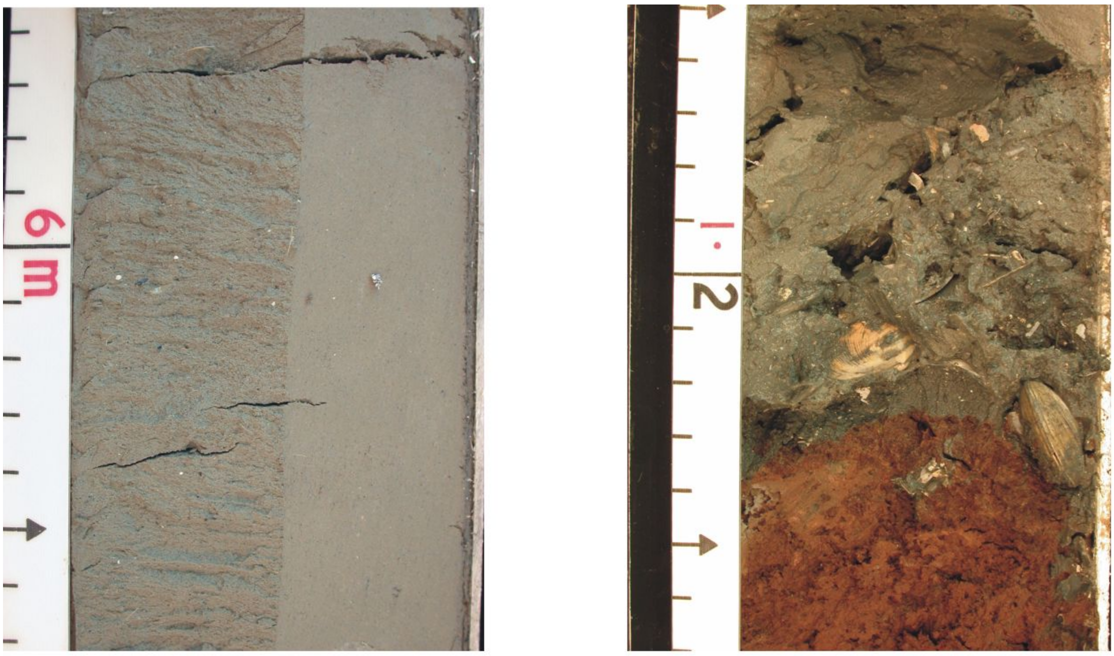
B) Carbonate Sand - Core CSV01. Note dense matt of seagrass fibre within uniform shellsand sequence.



C) Carbonate Muddy Sand - CSV06.

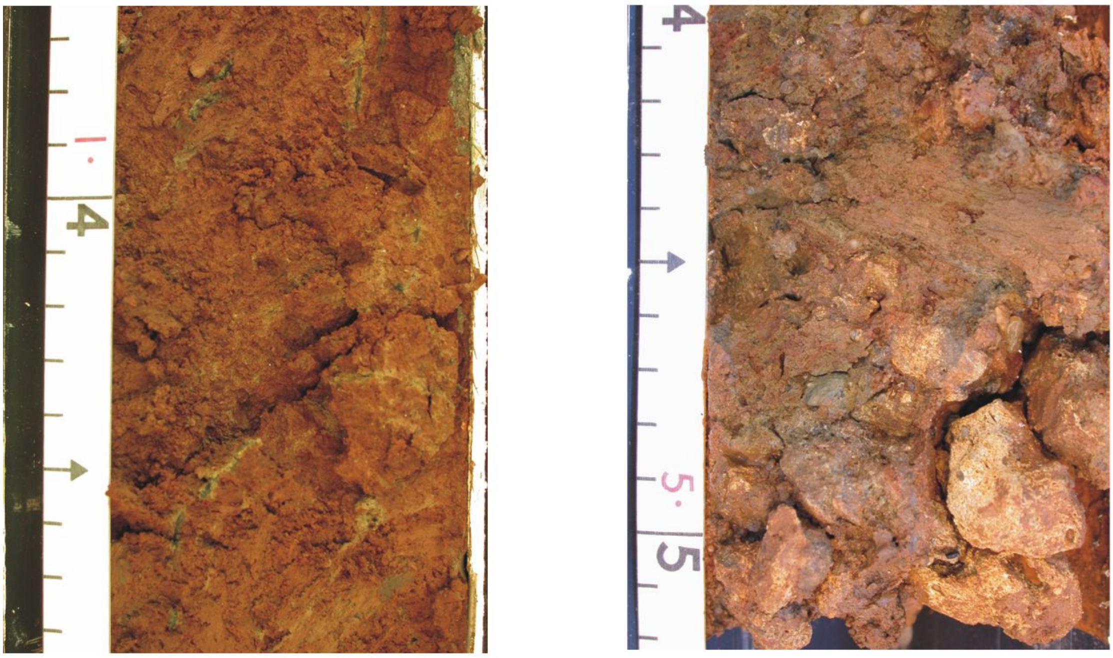
D) Muddy Quartz Sand - Core CSV07. Note scattered shell fragments within coarse grained, well rounded quartz unit.

Figure 17: *Photographs of the various lithological units evident in the vibracores from Cockburn Sound.*



E) Basin Sandy Mud/Mud - CSV02. Uniform, cohesive sandy mud 6.0m below seabed in southern part of central mud basin.

F) Gravelly Shelly Mud - CSV05. Note sharp, unconformable contact with underlying clay unit.



G) Clay/Sandy Clay - CSV08. Stiff, mottled clay unit, may contain some organics.

H) Coastal Limestone/Calcarenite Gravel - CSV05. Gravel in a sandy mud matrix.

Figure 17: *continued*

Lithostratigraphic Units

Six distinct sub-surface units were identified in the cores and are described below in their stratigraphic order based upon the visual logs and the results of the sediment analyses (Figs. 16 and 17). Additionally, in core CSV05 (Fig. 16; Appendix III), water-filled sub-surface cavities were observed in the basal limestone unit.

1) Gravely shelly carbonate/quartz sand. This unit varies in colour from light grey-brown, pink-grey to green-grey (Fig. 17a) and is poorly sorted with fine to very coarse grained sand (mean grain size: 0.48 mm; standard deviation: 0.39 mm). The deposit includes scattered to abundant carbonate gravel that contains fragments of bivalve shells, some gastropods, echinoids and bryozoan, and abundant whole foraminifera. Calcium carbonate within the combined sand and mud fraction ranges from 40 to 60%. This unit was encountered in the southeastern margin of the sound near Kwinana Beach and likely extends to the shoreline.

2) Carbonate Sand to Muddy Sand. These sediments are light grey to grey, moderately to very poorly sorted, very fine to very coarse grained sand and muddy sand with varying proportions of carbonate gravel (fragments and whole shell, diatoms), plant fibers and decaying seagrass fragments (Fig. 17b). There was no evidence of any depositional structures in this unit. Total carbonate content for the sand is approximately 90% but is less for the more muddy sand (~80%). The sand facies is confined to the banks at the northern and southern margins of Cockburn Sound, the eastern shore of Garden Island and a sheet that covers the area immediately north of Garden Island. The unit becomes conformably muddier with depth (Fig. 17c), and the muddy sand is exposed on the bank slopes around the perimeter of the central basin.

3) Muddy Quartz Sand. This deposit comprises grey, loose, muddy (silt), moderately sorted, medium to very coarse grained, sub-rounded to rounded, quartz sand with scattered shell fragments (Fig. 17d). This facies was only encountered in one core (CSV07; Appendix III) and is less than 1 m thick. Calcium carbonate averages 17% in the top of the unit, but decreases abruptly to 5% below a depth of 2 m. The proportion of mud also decreases below 2 m, from 30% to less than 10%, while the mean grain size (0.4-0.65 mm) increases with depth. The unit also includes interbedded lenses of dark grey to reddish brown plant material and fine organic fibers. This deposit appears to be filling a depression within the basal limestone (Cross section B-B’, Fig. 18).

4) Basin Mud and Sandy Mud. This deposit consists of cohesive, greenish-grey, structureless, poorly sorted, very fine grained, sandy carbonate muds (clayey silt), gravelly in places with fine, hair-like fibres and coarse grained shell fragments scattered throughout (Fig. 17e). There are occasional large (up to 5cm) whole bivalves and smaller (up to 1 cm) gastropods. In two cores (CSV05 and CSV08) the bottom 10 cm of this unit is composed of dark grey, cohesive, sandy mud with abundant whole shells (some articulated) and shell fragments (Fig. 17f). This deposit forms the majority of the central basin sediment fill.

5) Sandy Clay. This unit comprises oxidised, yellowish red with brown mottles (Fig. 17f, g), very fined grained (average mean grain size: 0.04 mm; standard deviation: 0.11 mm) firm to stiff sandy clay with remnant organic material, most likely roots. The sediment becomes sandier with depth (Core CSV05), and contains sparse pieces of organic material (possibly fossil rootlets). It forms a cap on the Pleistocene limestone that underlies the central basin muds.

6) Calcarenite Limestone Gravel: This deposit is light grey with irregular pieces of calcarenite gravel in a matrix of greenish grey, very poorly sorted sandy mud (Fig. 17h). The sand is very fine to very coarse grained calcareous quartzose sand. The limestone forms the bedrock of the study area, and has been described as calcreted aeolianite limestone that is part of the Tamala Limestone Formation (Playford *et al*., 1976).

Downcore Geochemical Data

The predominance of marine or terrestrial sediments is also indicated by a number of other parameters, including Al_2O_3, CaO, Fe_2O_3, K_2O, MgO, Na_2O, SiO_2 and $CaCO_3$ (Figs. 18B-I). Al_2O_3, Fe_2O_3, K_2O and SiO_2 all show identical trends to the Nd/Sr ratio suggesting that these parameters are mainly associated with the input of terrestrial sediments. The predominance of $CaCO_3$ (of varying magnesium content) is a defining characteristic of marine-derived sediment in Cockburn Sound. Consequently, CaO, MgO and $CaCO_3$ contents show trends that are the reverse of that of the Nd/Sr ratio. The down-core profile of Na_2O is also the reverse of that of the Nd/Sr ratio. In the surface of core CSV07, several parameters (including Al_2O_3, Fe_2O_3, K_2O and SiO_2) all show a slight increase and indicate the recent input of terrestrial sediment at this site. Concentrations of various metals (As, Cd, Cr, Cu, Ni, Pb and Zn; Fig. 19A-G.) also increase with depth in cores CSV05 and CS07 as a consequence of an increase in the proportion of fine-grained terrestrial sediment. Cores CSV04, CSV06 and CSV09 all have similar and lower concentrations at depth.

The most significant geochemical variations, both down-core and between cores, are a result of the dominance of either marine or terrestrial sediments which have unique geochemical signatures. This is well reflected in the vertical profiles of the Nd/Sr ratio for the cores analysed (Fig.18A.). At the surface, all cores (except CSV06) have a very low Nd/Sr ratio (<0.01), indicating little detectable terrestrial sediment. The Nd/Sr ratio at the surface of CSV06, however, is relatively large (~1.3) and indicates a strong terrestrial sediment input, possibly from a spoil dump. At depth, cores CSV04, CSV06 and CSV09 remain dominated by marine sediments as indicated by the low Nd/Sr ratios (<0.003). In contrast, in core CSV07, below 1.5 m the Nd/Sr ratio gradually increases indicating a higher proportion of terrestrial sediment. In core CSV05 there is a large and marked increase in the Nd/Sr ratio below 1.7 m that indicates a major change to terrestrial sediment. The changes observed in cores CSV05 and CSV07 are consistent with the observed changes in sediment type described in the core logs (Fig. 16 and Appendix III). The upper section of core CSV05 comprises marine carbonate sandy mud overlying a reduced shelly mud layer. At depth there is a change to distinctively terrestrial sediments comprising mottled sandy clay and calcarenite gravel/sandy clay. In core CSV07, the sediments change from marine carbonate muddy sands to terrestrial muddy quartz sand.

Importantly, all cores show recent increases in some metal concentrations in the top half metre. This is particularly true of core CSV03 which has the highest concentrations of Cd, Cu, Pb and Zn at a depth of 0.44-0.45 m. Likewise, core CSV06 has elevated concentrations of As, Cr, Pb and Zn, and to a lesser extent Cu and Ni at 0.1-0.11 m, and core CSV09 has elevated concentrations of Cr, Cu, Ni, Pb, and Zn at 0.3-0.31 m. Cores CSV03, CSV06 and CV09 were collected from near Kwinana Beach, the Eastern Shoal and Three Fathom Bank where the surficial sediments were found to include fine terrestrial sediment with relatively high metal concentrations related to industrial sources (see Fig 11a.). Cores CSV04 and CSV07 also show slight increases in the surface concentrations of Cr, Cu, Pb and Zn. Overall, it appears that elevated levels of trace metals in surface sediment are widespread in Cockburn Sound.

In some cases, the highest concentrations of metals were found below the sediment surface. For example, the Ni concentration in CSV09 (sample depth: 0.3-0.31 m) was 392 ppm compared to nearby surface values of less than 10 ppm (surface sample: CSG29) Also, the Pb concentrations in CSV03 (sample depth: 0.44-0.45 m) and CSV06 (sample depth: 0.1-0.11 m) were 40 and 57 ppm respectively, compared to nearby surface values of less than 20 ppm (surface samples: CSG13 and

CSG45). Likewise, the Cu values in cores CSV03 (sample depth 0.44-0.45 m) and CSV09 (sample depth: 0.3-0.31 m) were 394 and 231 respectively compared to nearby surface values of less than 30 ppm (surface samples: CSG13 and CSG29). These results suggest that sediment quality has improved at sites CSV03, CSV06 and CSV09 in recent years. Interestingly, Nd/Sr ratios are elevated both in the near surface sample of core CSV03 (sample depth 0.44-0.45 m) and in the nearby surface sediment sample (CSG13; Nd/Sr ~ 0.0064). This suggests that there has been a sustained source of terrestrial sediment at this site, despite the observed lowering of metal concentrations between the surface and sub-surface. In core CSV06, the Nd/Sr ratio of the near surface sample (Nd/Sr = 1.28; sample depth 0.1-0.11 m) is significantly larger than the nearby surface sediment samples (~0.003) and suggests there may be a spoil dump at this site. The surface sediments near core CSV09 have also been identified as an isolated site of relatively high contamination despite the low Nd/Sr ratio in the near-surface sediments from the core (Nd/Sr = 0.0025; sample depth: 0.3-0.31 m).

Sediments within vibracores CSV04, CSV06 and CSV09 are relatively uniform with depth (Fig. 16 and Appendix III) and the metal concentrations (As, Cd, Cr, Cu, Ni, Pb and Zn) do not vary significantly with depth (Fig. 19). Interestingly, concentrations of As, Cd, Cr, Ni, Pb and Zn in these cores are lower than the *background* concentrations suggested by Talbot and Chegwidden (1983) based on surface sediment samples collected from across the sound. The background Cu concentration observed in the vibracores is greater than the anomalous values reported by Talbot and Chegwidden (1983) but less than the ISQG low trigger value that is based on overseas biological effects data. On the basis of these results, we suggest that new background values for trace metals in Cockburn Sound should be adopted (Table 5).

The geochemical composition of cores CSV05 and CSV07 also appears to be strongly influenced by iron and sulfate reduction, resulting in iron sulfide formation at depth (see Fig 20A-E). The sulfur concentration increases at a depth of 1.7 m in core CSV05, and below 1.8 m in core CSV07. At these depths, Fe also increases, and as a result the molar Fe:S ratio remains between 1 and 2 which is typical of iron sulfides. Further evidence of iron reduction is seen in the Fe:P ratio. The phosphorus concentration also increases at 1.7 m in core CSV05 and below 1.8 m in core CSV07. Since P is typically bound to iron oxides, iron reduction causes P to be lost from the sediments and while there is an overall increase in the P concentrations at these depths, the molar Fe:P ratio actually increases. At a depth of approximately 1.9 m in core CSV05, the S and P concentrations decrease significantly but the Fe concentration increases causing an overall increase in the molar Fe:S and Fe:P ratios. These distinct changes in CSV05 below 1.9 m are related to the distinct change in sediment facies (Fig. 16 and Appendix III). CSV05 consists of carbonate muddy sands to approximately 1.7 m. Below this depth there is a 0.1 m layer of dark grey, reduced shelly sandy mud which is where iron sulfides have been identified from the geochemical data. The lower part of the core consists of terrestrial sediments, mostly mottled sandy clay, and this is reflected in the marked changes in the sediment geochemistry.

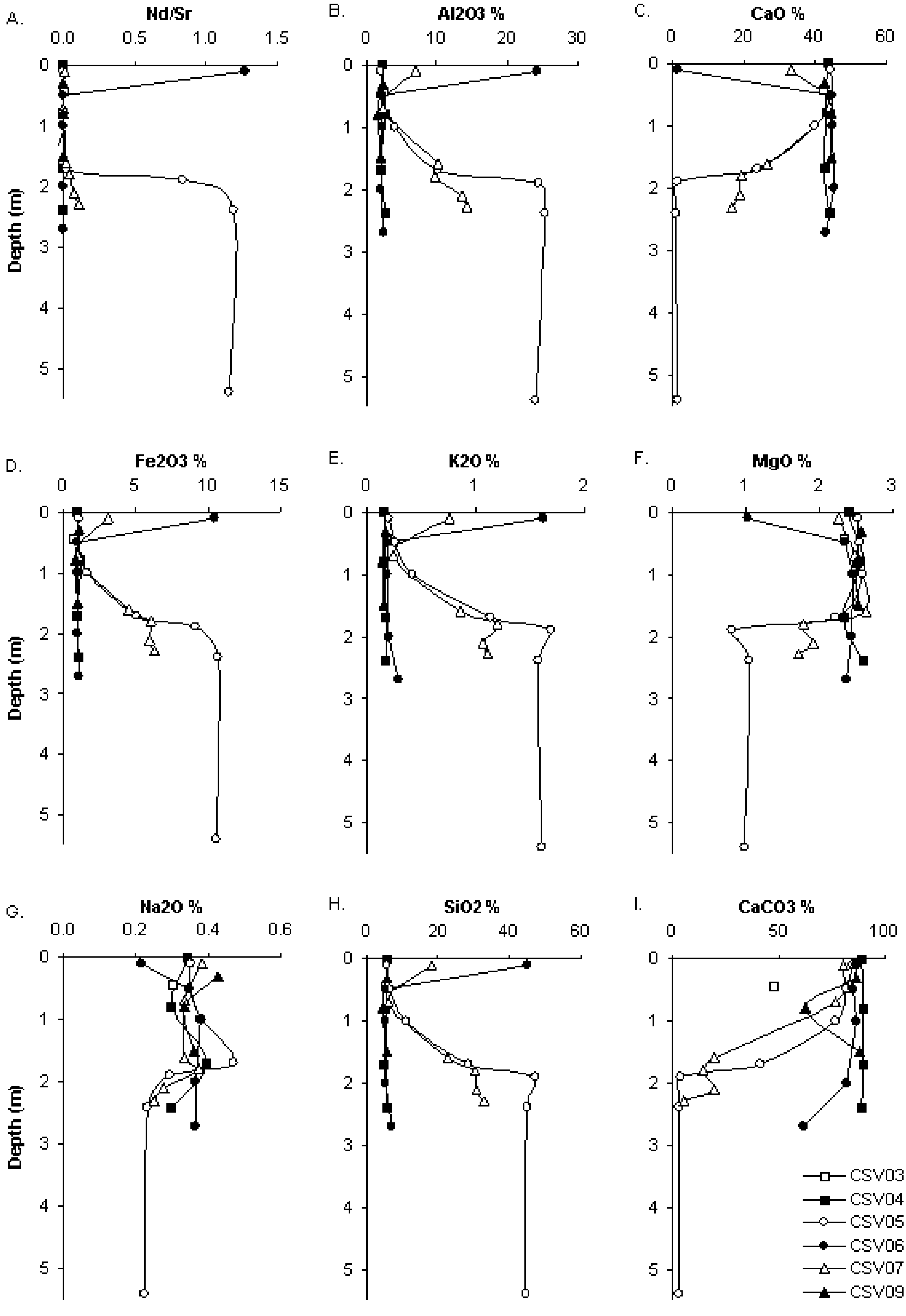


Figure 18: *Vertical profiles of major element geochemical data in vibracores from Cockburn Sound*

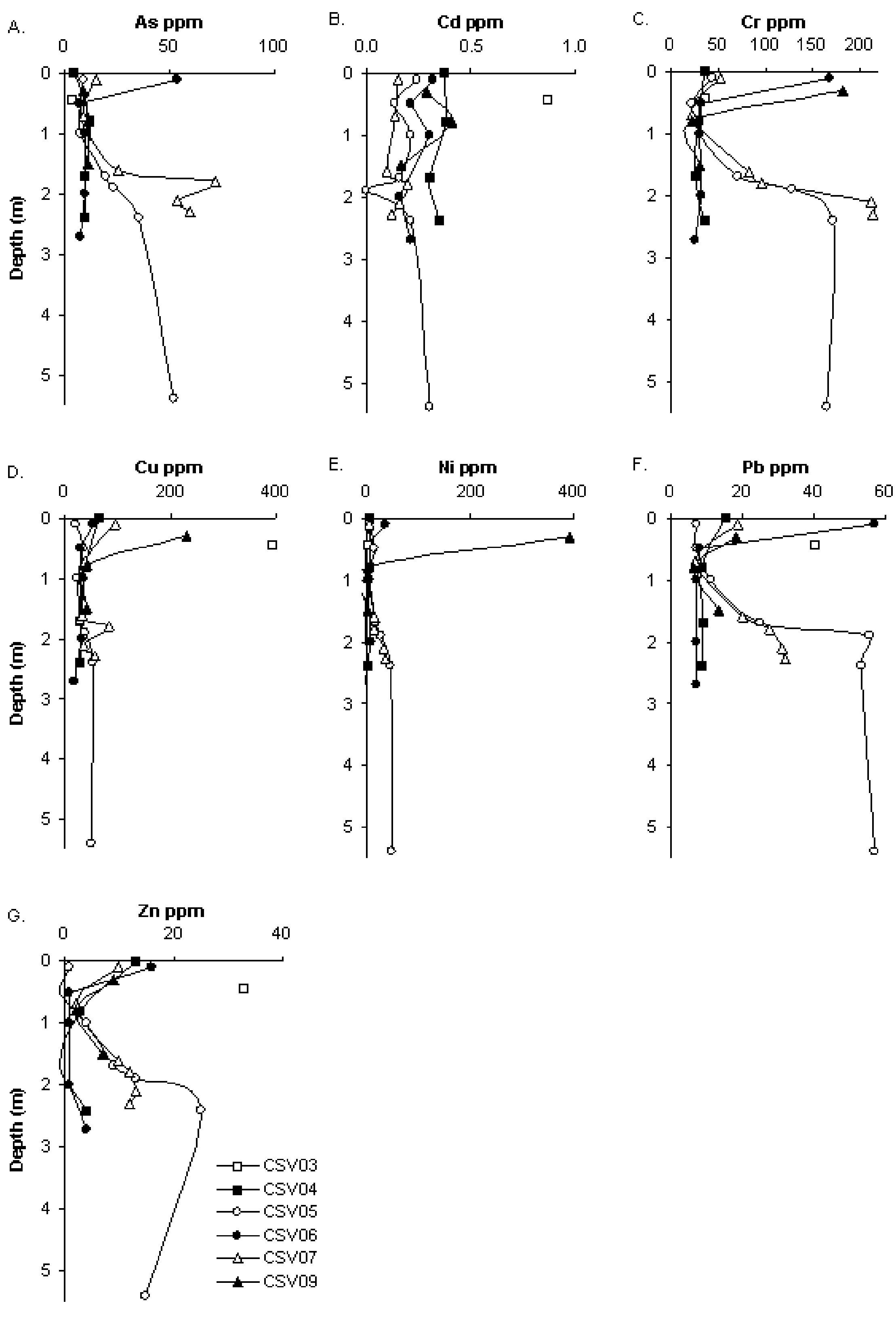


***Figure 19:** Vertical profiles of metal geochemical data in vibracores from Cockburn Sound*

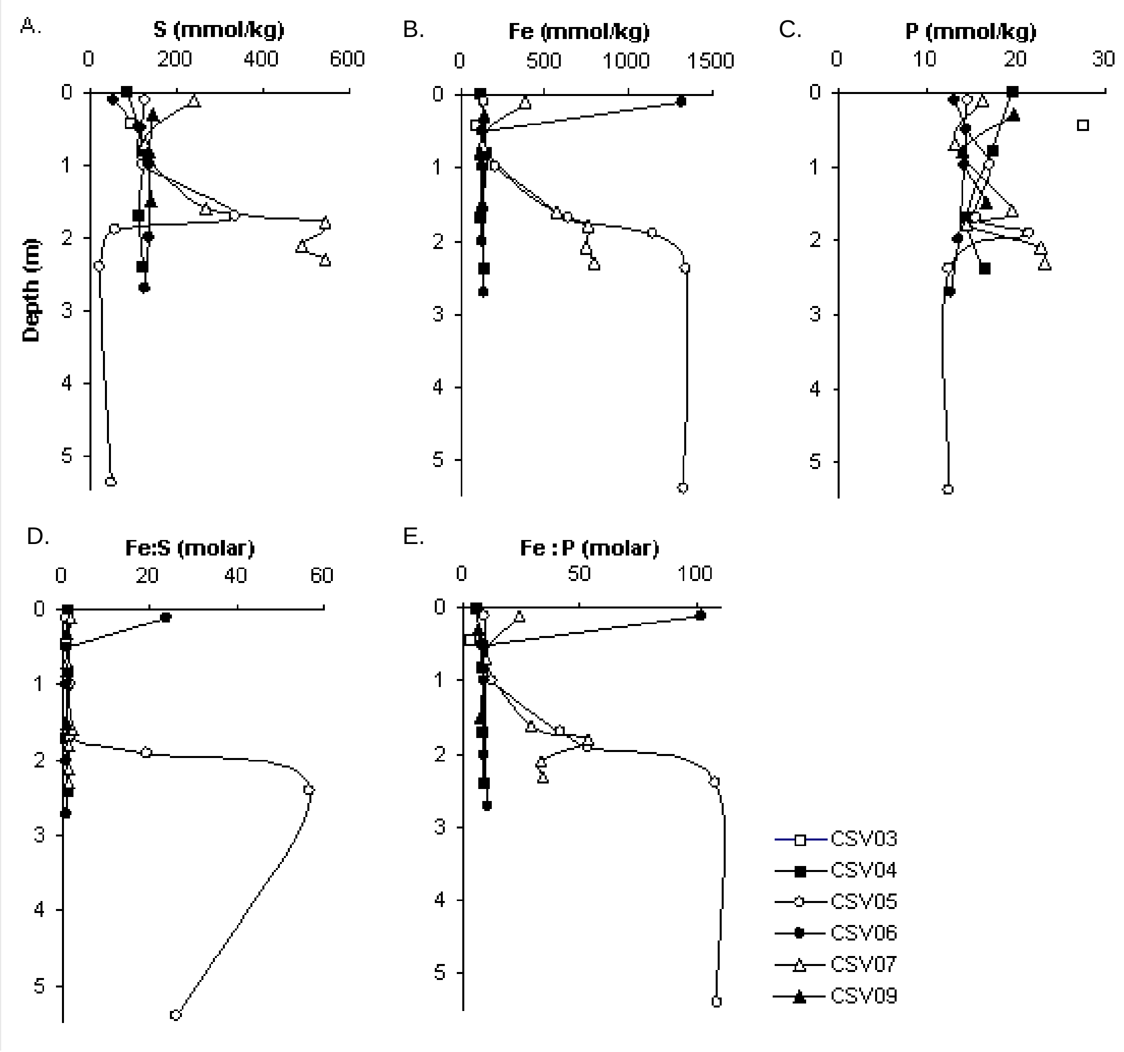


Figure 20: *Vertical profiles of* SO_3*, Fe:S and Fe:P ratios in vibracores from Cockburn Sound*

Discussion

SURFACE SEDIMENT FACIES

Based on the surface sediment laboratory data, field descriptions and video transects of the seabed, four distinct surface facies were identified in Cockburn Sound (Table 7). The areal distribution of these deposits is shown in Figure 10. Because these and the associated sediment data (Figs. 6–11) are georeferenced and incorporated in *ArcInfo* shapefiles they represent reliable maps of surface sediment properties and can now be compared with the acoustic multi-beam backscatter data that was recently collected in the Cockburn Sound. A summary of the various facies characteristics is provided in Table 7.

Table 7: Summary of the physical and chemical characteristic of the surficial sediment types in Cockburn Sound.

FACIES	SEDIMENT COMPOSITION	MEAN GRAIN SIZE & SD (mm)	% CaCO3	FINE FRACTION GEOCHEMISTRY (<63μM)	LITHOSTRATIGRAPHIC UNIT
Eastern Nearshore	Gravelly shelly mixed carbonate quartz sand	0.43 ± 0.36	>55%	High Nd/Sr; High Zn, Ni; Low Cu	Safety Bay Sand
Eastern Shoal	Carbonate Muddy Sand	0.12 - 0.43	>80%	Low Nd/Sr; Mod Zn; Low Cu, Ni	Becher Sand (Semeniuk and Searle, 1985)
Carbonate Banks	Well sorted Carbonate Sand	0.25 - 0.43	~90%	Low to mod Nd/Sr; Mod Zn; High Cu, Ni	Parmelia Bank and Southern Flat Shellsand
Central Basin	Carbonate Sandy Mud	0.023 - 0.12	~80%	Low to mod Nd/Sr; Low Cu, Zn, Ni	Bridport Calcilutite (Semeniuk and Searle, 1987)

The terrigenous component of the Eastern Nearshore quartz sand (gravely shelly mixed carbonate/quartz sand) is probably reworked from older deposits while the carbonate component is composed of the skeletal remnants of contemporary marine carbonate producing organisms. These sediments are part of the beach unit of this region known as the Safety Bay Sand (Passmore, 1970). The exact extent of this sediment type is unknown as it was only recovered in one sample (top of core CSV3) off Kwinana Beach (Fig. 10). Passmore (1970) reported that almost the entire land surface of the Rockingham and Peron Peninsulas, as well as the modern shallow-marine and dune sand of this area, was composed of Safety Bay Sand. A core collected off James Point by France (1977) included a similar sediment unit. Likewise, Semeniuk and Searle (1985) described the occurrence of this unit at Woodman Point, at the northern end of the sound.

The carbonate sand and muddy sand that forms Parmelia and Success Banks, the ‘shellsand’ resource of Cockburn Sound, has long been dredged commercially for the production of quicklime and cement. These Carbonate Banks areas (Fig. 10) are largely covered with seagrass and swept by tidal and wind-induced currents as well as oceanic swells. These currents winnow the fines from the banks, leaving behind the predominantly sand-size carbonate grains.

The distribution of Eastern Shoal sediment (carbonate muddy sand) indicates that the muddy sand is being transported off the northern carbonate banks into Cockburn Sound and is likely also being produced on the Eastern Shoal (Fig. 10). The combined carbonate sand and muddy sand facies mapped in this study are equivalent to the Becher Sand Unit of Semeniuk and Searle (1985). The Becher Sand was formerly part of the Safety Bay Sand which was divided into two distinct lithological units; a beach - beach ridge/dune suite (Safety Bay Sand), and a seagrass bank suite (Becher Sand). Searle *et al*. (1988) further subdivided the Becher Sand into sand wave, seagrass and slope units, which recognised the internal variability of bank sediments related to variations in water depth and the influence of seagrass meadows. The carbonate sand (shellsand) facies and the carbonate muddy sand facies identified in this study correlate with the seagrass and the slope units respectively.

The Central Basin unit (carbonate sandy mud) partially infills the deep, relatively still-water environments of the central basin of Cockburn Sound (Fig. 10). This marine sediment was named the Bridport Calcilutite by Semeniuk and Searle (1987) who suggested that it is sourced from the adjacent seagrass banks where the fine carbonate material is removed from the surrounding bank and sheet units and transported into the central basin by the action of the prevailing currents and waves. The fines are then redeposited from suspension in the deeper more quiescent central basin. This muddy substrate is inhabited by molluscs and their skeletal remains also contributed to the deposit.

Geochemical Relationships

The results of the principal components analysis of the combined sediment and geochemical data provide insights into the character of surficial sediments and their spatial distribution. These findings are useful for i) identifying the source and likely pathway of fine terrestrial sediment; ii) providing maps of variations in the physical character of sediment based on a range of sediment variables; and iii) assessing possible drivers for the loss of benthic biological communities in the sound over the last few decades.

The maps of site scores for PC1 (Fig. 11a) and the Nd/Sr ratios (Fig. 12) show a well-defined pattern of input of fine terrestrial sediment with relatively high metal concentrations from industrial sources at Kwinana Beach, adjacent to the Eastern Shoal, and possibly Jervoise Bay. These maps also indicate a likely anticlockwise transportation pathway of this sediment within the sound. Isolated sites with relatively high loadings for these trace element variables may be spoil dumps. It is possible that analysis of the swath bathymetry for these areas recently collected as part of the CWHM Project may reveal morphological evidence of dump sites.

Site scores for PC2, which has strong loadings for the sediment grain size variables, indicate significant variations in textural features of the surface sediments of Cockburn Sound (Fig. 11b). This data may be useful in understanding patterns of acoustic backscatter in the sound that reflect the influence of sediment texture on the wave-form of the return acoustic signal.

Sites with high scores in PC3 possibly reflect the relatively low concentrations of S, Na and Cl that appear to indicate the influence of submarine groundwater discharge into the sediments of Cockburn Sound (Fig. 11c). Given the high to moderate loadings for trace metals on Axes 1 and 3 (PC1 and PC3), it would be useful to compare maps of these site scores (Fig. 11a, c) with maps of benthic habitat loss in Cockburn Sound to test for any association between this ecological change and sediment contamination. Axis 3 also has moderate loadings for the clay:silt variable, therefore, site scores for PC3 may also help future interpretation of acoustic backscatter patterns.

Sediment Metal Concentrations

Trace metal concentrations of Zn, Cu and Ni are significantly elevated at several sites (Table 5, Figs 13-15). These data suggest that fine contaminated sediment from industrial discharge has accumulated offshore, particularly near Kwinana Beach and James Point, and more broadly across the Eastern Shoal for Zn. Elevated levels were also found in samples from Buchanan Bay and Three Fathom Bank on the western margin of Cockburn Sound. The source of contamination at these sites is not clear, but may be related to spoil dumps. These new data should be useful for the environmental management of the sound, especially if sites of sediment contamination are also areas of benthic habitat loss. As noted above, future analysis of swath coverages of the contaminated sites on the western margin of the sound should prove whether they are related to spoil dumps.

QUATERNARY STRATIGRAPHY

The results of the vibracoring program (Fig. 16 and Appendix III), and logs of cores previously collected to assess the shellsand resource in the northern area of Cockburn Sound (Coastal and Marine Geosciences, 1998b; Dames and Moore, 1979) have been integrated into a series of west-east and south-north stratigraphic cross sections (Fig. 21). These sections provide new insights into the stratigraphy of the sound and will be ground-truthed through future sub-bottom profiling.The cross sections show that four Holocene lithostratigraphic units partially fill the depression in the Pleistocene calcarenite that forms the bedrock of Cockburn Sound. Previous studies of the stratigraphic relationships of coastal units on the Rottnest Shelf have reported a similar assemblage of Holocene deposits (Semeniuk and Searle 1985; Semeniuk and Searle 1987; Searle and Semeniuk 1985; Searle *et al*. 1988; Semeniuk *et al*. 1988). In the following sections, the major units encountered in this study are related to the published regional lithostratigraphy.

Holocene

Gravely shelly carbonate/quartz sand. This facies is part of the Safety Bay Sand, which is a 2 to 6 m thick sequence (tabular deposit) of laminated to structureless sand and shelly sand. It underlies dune deposits of the present coast and overlies the Becher Sand. A carbonate and quartz sand unit (Safety Bay Sand) is restricted to the eastern side of Cockburn Sound. This unit was encountered south of James Point (section C-C'; Fig. 21) where this sediment was emplaced in a beach environment and overlies the muddy sand facies of the Becher Sand.

Carbonate Sand/Muddy Sand. This sand and muddy sand facies is equivalent to the seagrass and slope units of the Becher Sand Unit (Semeniuk *et al*. 1988). The Becher Sand is Holocene in age; all radiocarbon ages for shells obtained from within this unit have are less than 7,000 years BP (Woods and Searle, 1983; Semeniuk and Searle 1985). The unit overlies and interfingers with the basin sandy muds (section C – C', Fig. 21). The Becher Sand is thickest in Parmelia Bank to the north and Southern Flats to the southwest of Cockburn Sound where this carbonate sand and muddy sand is at least 15 m thick. Previous drilling in Parmelia Bank (Coastal and Marine Geosciences, 1998b) shows this unit to be thickest in the centre of the north-south bedrock depression that underlies Cockburn Sound and thins towards the eastern side of the Garden Island Ridge (section A-A', Fig. 21). Cross sections A-A', C-C' and D-D' show that the Becher Sand overlies the basin muds (Fig. 21). Significantly, these results show that the bank sediments are being transported into Cockburn Sound via Parmelia Bank and the Southern Flats and are infilling the northern and southern margins of the central basin.

Muddy Quartz Sand. This facies is less than 1 m thick and appears to be infilling a depression within the limestone that forms the Garden Island Ridge (section B-B', Fig. 21). Possibly, this deposit is reworked sediment that marks the Holocene-Pleistocene unconformity. Alternatively, it may be a relict heavily leached surficial horizon of the Tamala Limestone, or a remnant deposit of Cooloongup Sand (Passmore, 1970).

Basin sandy mud/mud. This deposit represents the Bridport Calcilutite (Semeniuk and Searle, 1987). It is wholly Holocene with reported radiocarbon ages for the unit of less than 7,000 years BP (Semeniuk and Searle, 1987). There is a sharp, unconformable contact with the underlying Pleistocene clay unit (CSV05 and 08, Figs 17e, f). These basin muds occupy former depressions in the underlying Pleistocene topography (Tamala Limestone), represent the basal Holocene marine unit encountered within Cockburn Sound and form most of the contemporary seabed (Fig. 10). The unit appears to have a concave lensoidal shape, being thinner in the middle of the central basin (<1.5m thick, sections B-B’ and D-D’; Fig. 21) and thicker at the eastern and western margins. It also thickens to >6m in the south (section C-C’; Fig. 21). Further south in the Rockingham area this deposit underlies the coastal plain and is up to 10 m thick (Semeniuk and Searle, 1987).

Pleistocene

Clay/sandy clay: This clay overlies calcarenite gravel (possibly calcrete) and appears to be a fossil soil that developed on the calcarenite prior to the Holocene marine transgression. The clay also appears to partly infilling depressions and cavities (possible karst features) within the coastal limestone (sections B-B’ and D-D’, Fig. 21). Vibracore CSV05 intercepted cavities that are filled with groundwater (Fig. 16) and likely form part of the regional shallow aquifer. The groundwater may be discharging into the marine sediments in Cockburn Sound where the clay unit does not form an effective seal between the aquifer and the overlying marine sediment fill, as also suggested by the surface sediment PCA results discussed previously.

Coastal limestone/calcarenite gravel: Tamala Limestone was recovered in the base of cores CSV05 and CSV07 (Fig. 21). The associated quartz sand may be a leached remnant of the calcarenite that infills surficial depressions or vugs in the calcarenite. Alternatively, the quartz sand is related to alluvial or aeolian depositional processes. All of these possible processes of deposition would have occurred during periods of lower sea level.

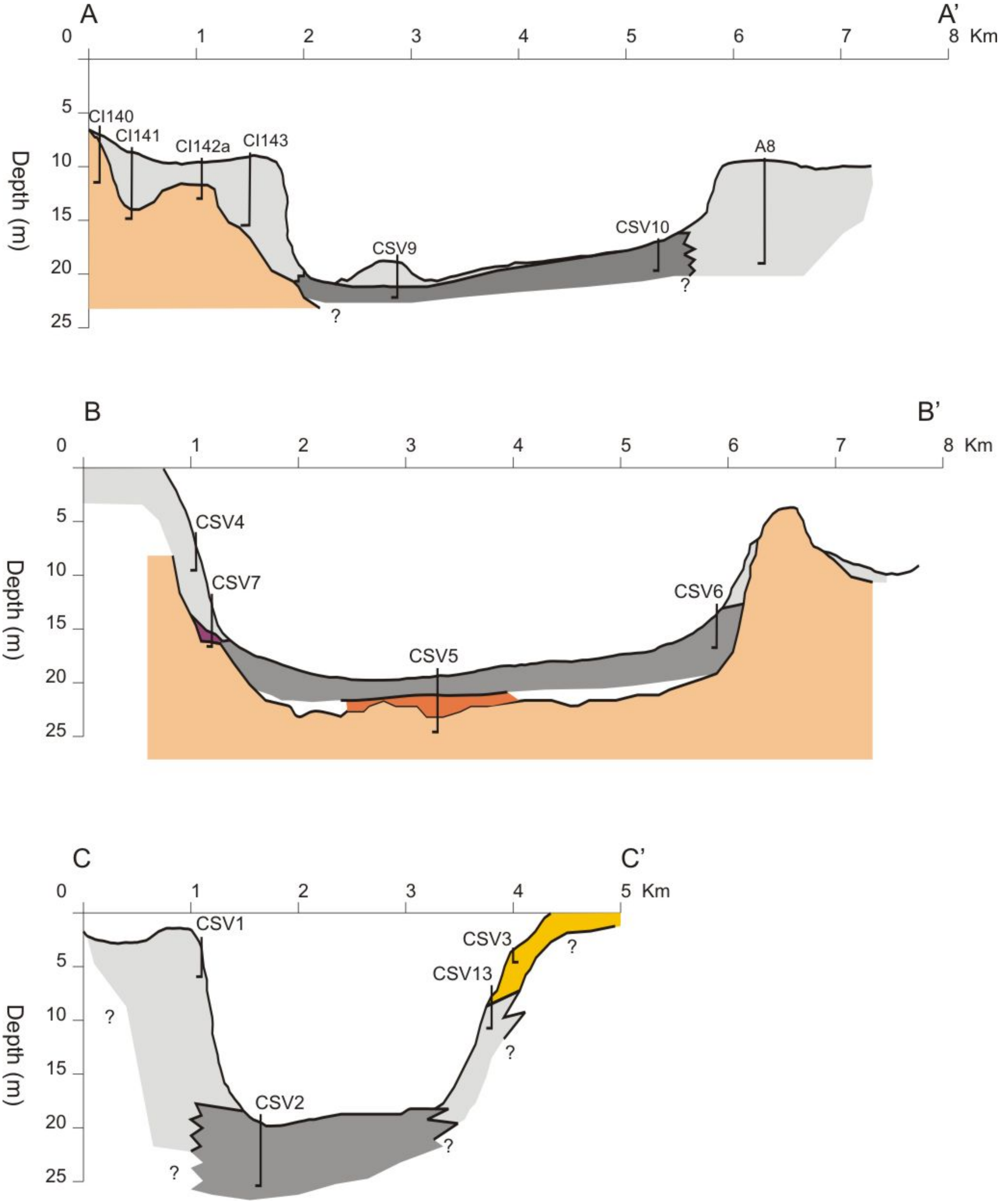


Figure 21: *Stratigraphic cross sections of Cockburn Sound. The sections incorporate data obtained from the vibracores collected in the present study (CSV01-CSV13) and previous studies (cores C1140-C1143; A8; PB9). Locations of the cross sections are shown in Figure 4.*

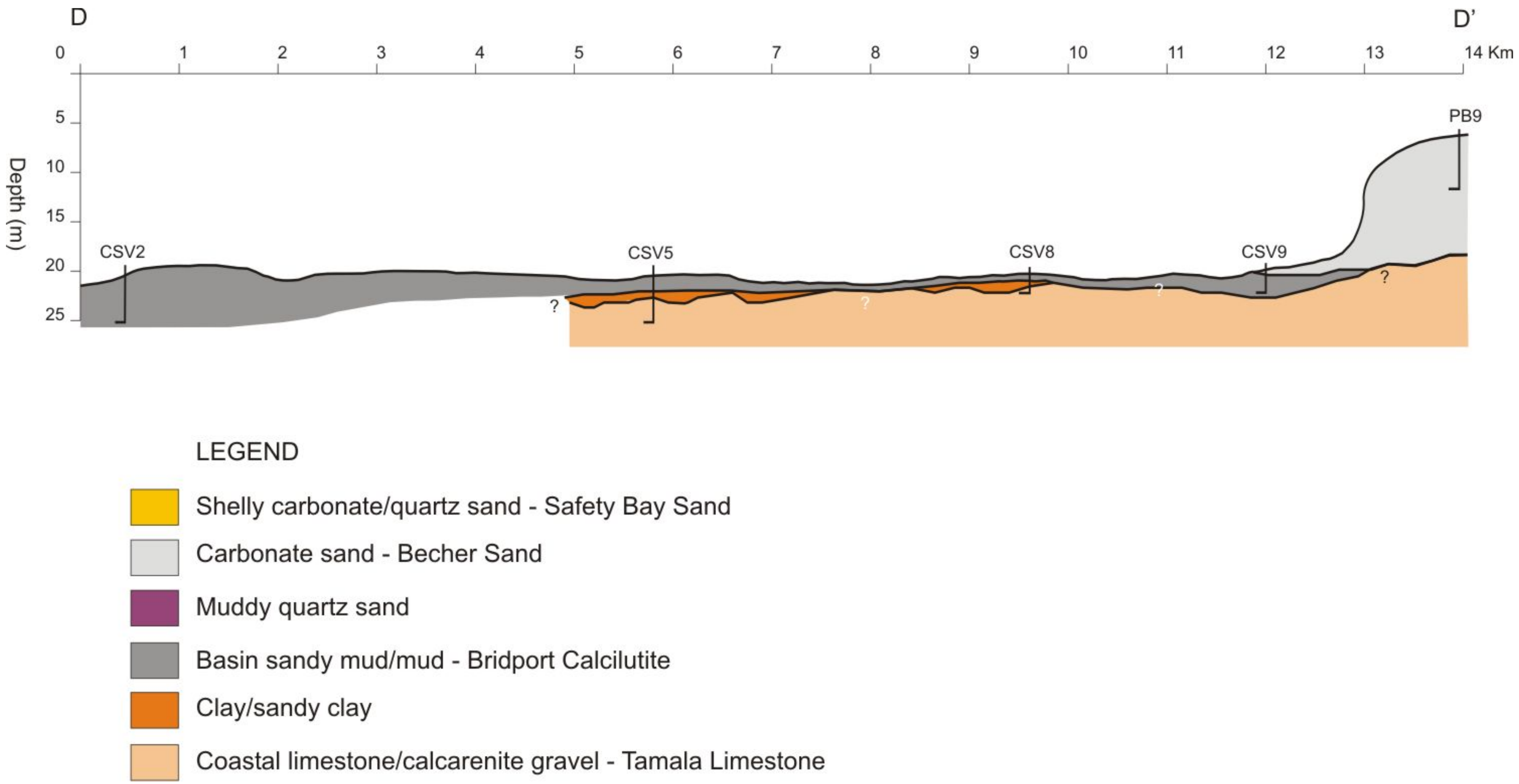


Figure 21: *cont*

Sub-Surface Geochemical Characteristics

The comparison of surface and down-core geochemical data suggests that trace metal concentrations of modern sediment are much higher than pre-industrial levels. However, sediment quality appears to have improved at several sites where the sub-surface metal concentrations are higher than at the surface. This suggests that in the past metal contamination of the surface sediments was greater and these sediments have now been buried by sediment that is significantly less contaminated. The improved conditions at some sites are likely to be due to a lowering of industrial pressure, successful pollution reduction strategies and a change in the contaminant transport path. Since 1955 liquid waste products have been discharged into Cockburn Sound from the heavy industrial area on the eastern foreshore of the sound. The first comprehensive study of Cockburn Sound (1976-1979) identified a large variety of contaminants in industrial discharges to the sound (Department of Conservation and Environment, 1979). The Southern Metropolitan Coastal Waters Study (1991-1994) found that contaminant levels had decreased significantly since the late 1970s, due to large reductions in wastewater discharges from industry (Department of Environment Protection, 1996). This study also found that contaminated groundwater had replaced direct industrial pipeline discharge as the main nutrient input to the sound, which came mainly from the southern part of the Kwinana Industrial Area. Estimated amounts of metals and oil discharged by industry have continued to decrease due to improved waste treatment practices, and are presently about one sixth to one thousandth of those discharged in 1978 (DAL, 2001). In some cases, however, elevated sub-surface metal concentrations may indicate the impact of a point source of pollution such as an old spoil dump.

Previously reported background metal concentrations for Cockburn Sound are consistently higher than pre-industrial background values observed at depth and reflect low levels of contamination themselves. The down-core geochemical data provides information on pre-industrial metal concentrations in sediments of the same type as modern surface sediment. Therefore, it appears that when compared to these new pre-industrial levels, the level of metal contamination in the surface sediments is greater than previously reported.

GEOLOGICAL EVOLUTION OF COCKBURN SOUND

Based on the geomorphic, stratigraphic and sedimentological data presented above, Cockburn Sound has evolved into its present form in the following sequence:

1) With the rise of sea level in the early to middle Holocene the inner Rottnest shelf was flooded and the Cockburn-Warnbro Depression, between the Garden Island and Spearwood Ridges, was inundated. This low lying area is part of a large swale that formed between coastal dune ridges that were emplaced in the Late Pleistocene. The depression had a clay soil cover and possibly some karst landforms.
2) As the depression was filled by the rising sea to form the proto-Cockburn Sound there was some reworking of relict quartz-rich sand. These sediments accumulated on the western margin of the sound as muddy quartz sand and along the eastern shore as shelly carbonate/quartz sand (Safety Bay Sands).
3) Since being flooded, the northern, northeastern, western and southern margins of the sound have rapidly shoaled as large volumes of carbonate muddy sand and sand have been deposited in seagrass meadows (the Becher Sand). At the same time the central basin has been partially filled with carbonate sandy mud and mud (Bridport Calcilutite), a large proportion of which has been winnowed from the surrounding seagrass banks.
4) The fine fraction of surface sediments currently accumulating in much of Cockburn Sound has a terrestrial trace element signature and elevated levels of several trace metals. The spatial pattern of these data suggests major inputs of this sediment from the eastern coast, particularly at Kwinana Beach.

Conclusions

Cockburn Sound is a large, low-energy coastal waterway located on a moderate to high-energy carbonate coast. It has formed in an elongate depression that sits in the lee of a cemented Pleistocene shore-parallel dune ridge. This study provides the following new insights into this coastal depositional environment:

1) Surface sediments in the sound are dominantly biogenic carbonates, with sandy mud and mud in the relatively deep (15–20 m) central basin. The marginal banks (2–10 m) comprise carbonate sand and there is mixed carbonate and quartz sand in the eastern nearshore zone. Maps of the distinctive surface sediment types can be used to ground-truth acoustic backscatter datasets and help explain textural patterns in the acoustic data.
2) Surface sediment Nd/Sr ratios and PCA results indicate that there is a higher proportion of fine terrestrial sediment on the eastern side of the sound and this sediment fraction contains elevated levels of some trace metals. The PCA results and the presence of water-filled cavities within the Tamala Limestone that underlies the central basin sediments suggest there may be submarine discharge of groundwater in a zone that extends from the northeastern coast westwards into the central basin.
3) Maps of surface sediment trace metal concentrations need to be compared with maps of benthic habitat loss, such as seagrass, to indicate whether there is a link between the decline in benthic habitat area and sediment contamination. Cu and Ni levels are higher and exceed trigger values near Kwinana Beach (Ni), Three Fathom Bank (Cu, Ni), northern central basin (Ni), James Point (Cu) and Buchanan Bay (Cu).
4) The most significant geochemical variations, both down-core and between cores, are a result of the dominance of either marine or terrestrial sediments which have unique geochemical signatures.
5) Previously reported background metal concentrations for Cockburn Sound are consistently higher than pre-industrial background values observed at depth and surface metal contamination may be greater than previously reported. However, there is evidence for improved conditions at some sites, mainly due to large reductions in wastewater discharges from industry.
6) The stratigraphy of Cockburn Sound reveals that much of the clay soil that formed on the original calcarenite land surface prior to the Holocene rise in sea level is preserved below the marine carbonate mud that has been deposited in the central basin. The central basin has only partially infilled and there is considerable accommodation space for the continued accumulation of muddy sediment. Up to four distinct lithostratigraphic units were found to comprise the sediment fill and the spatial distribution of these deposits will be better defined in future sub-bottom profiling of the sound.

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APPENDIX I

Table A1.1: Sediment grain size fractions (gravel/sand/mud) and CaCO3 content for the surface sediment samples.

GA SAMPLE #	SAMPLE ID	%GRAVEL	%SAND	%MUD	CACO3 % 0-2 MM FRACTION
1408136	251/CSG002	0.92	19.65	79.43	76.0
1408137	251/CSG009	2.32	89.51	8.17	88.7
1408138	251/CSG011	1.58	70.84	27.58	63.3
1408139	251/CSG013	4.91	89.25	5.84	86.7
1408140	251/CSG014	1.50	28.26	70.24	75.0
1408141	251/CSG015	0.82	12.78	86.40	76.0
1408142	251/CSG016	1.02	10.56	88.42	75.5
1408143	251/CSG017	1.23	10.26	88.51	75.0
1408144	251/CSG018	1.09	25.97	72.94	74.0
1408145	251/CSG019	2.85	23.75	73.40	77.0
1408146	251/CSG020	3.13	21.36	75.50	79.1
1408147	251/CSG021	6.52	60.08	33.40	64.9
1408148	251/CSG022	3.18	31.81	65.01	80.1
1408149	251/CSG023	0.24	21.10	78.66	79.1
1408150	251/CSG024	1.84	37.58	60.57	81.1
1408151	251/CSG025	18.42	60.87	20.71	85.7
1408152	251/CSG026	2.15	45.24	52.62	80.6
1408153	251/CSG027	0.57	98.89	0.54	91.2
1408154	251/CSG028	1.15	93.70	5.15	89.2
1408155	251/CSG029	0.07	92.83	7.10	87.2
1408156	251/CSG030	1.28	57.44	41.29	82.6
1408157	251/CSG031	3.75	55.73	40.51	79.1
1408158	251/CSG032	5.89	65.56	28.54	82.1
1408159	251/CSG033	3.53	86.42	10.05	83.6
1408160	251/CSG034	2.49	32.81	64.69	76.5
1408161	251/CSG035	0.44	30.57	68.99	77.0
1408162	251/CSG036	0.70	34.09	65.21	77.0
1408163	251/CSG037	2.77	42.35	54.88	77.5
1408164	251/CSG038	6.90	77.87	15.23	78.1
1408165	251/CSG039	3.80	31.57	64.63	83.1
1408166	251/CSG040	0.45	38.32	61.23	75.0
1408167	251/CSG041	6.72	41.46	51.82	79.1
1408168	251/CSG042	0.44	24.46	75.10	78.6
1408169	251/CSG043	7.89	38.86	53.25	78.6
1408170	251/CSG044	6.04	43.69	50.27	80.6
1408171	251/CSG045	2.36	49.65	47.99	80.6
1408172	251/CSG046	17.49	71.67	10.84	84.1

GA SAMPLE #	SAMPLE ID	%GRAVEL	%SAND	%MUD	CACO3% 0-2 MM FRACTION
1408173	251/CSG047	25.77	72.82	1.42	59.8
1408174	251/CSG048	12.14	62.46	25.39	84.7
1408175	251/CSG049	2.61	90.86	6.54	86.7
1408176	251/CSG050	1.62	56.74	41.64	83.1
1408177	251/CSG051	0.71	38.74	60.55	81.1
1408178	251/CSG052	1.33	33.34	65.32	79.1
1408179	251/CSG053	0.26	30.43	69.32	79.1
1408180	251/CSG054	0.67	23.19	76.14	80.6
1408181	251/CSG055	15.62	80.81	3.57	88.7
1408182	251/CSG056	18.08	77.13	4.79	88.7
1408183	251/CSG057	0.68	78.80	20.52	85.2
1408184	251/CSG058	0.37	15.57	84.06	81.1
1408185	251/CSG059	1.36	39.30	59.34	82.1
1408186	251/CSG060	0.18	12.29	87.53	79.6
1408187	251/CSG061	0.32	13.45	86.23	80.1
1408188	251/CSG062	0.27	15.08	84.66	80.1
1408189	251/CSG064	1.12	9.77	89.11	79.6
1408190	251/CSG065	1.33	57.21	41.46	77.5
1408191	251/CSG066	2.01	21.36	76.64	81.1
1408192	251/CSG068	0.68	20.83	78.48	80.1
1408193	251/CSG069	2.02	38.44	59.54	80.1
1408194	251/CSG070	3.70	86.41	9.89	66.4
1408195	251/CSG071	6.00	71.30	22.70	79.1
1408196	251/CSG072	16.39	73.08	10.52	78.1
1408197	251/CSG073	7.72	71.21	21.07	85.2
1408198	251/CSG074	7.18	87.33	5.49	63.8

Table A1.2: Average laser grain size data (Malvern Laser Analyser) for the surface sediment samples.

SAMPLE ID	D (0.1)	D (0.5)	D (0.9)	D [4, 3] - VOLUME WEIGHTED MEAN	OBSCURATION	KURTOSIS	SKEW
CSG002	2.568	15.721	70.115	31.209	16.69	37.39	5.265
CSG009	68.925	234.337	459.604	253.029	8.1	0.112	0.551
CSG011	7.197	120.73	434.249	180.4	15.72	4.375	1.923
CSG013	43.763	298.307	873.064	395.659	6.75	1.894	1.376
CSG014	2	13.257	72.659	32.325	29.63	32.87	5.091
CSG015	1.939	12.17	51.993	22.592	19.35	122.57	9.133
CSG016	1.783	11.205	50.908	23.045	25.52	95.57	8.562
CSG017	2.049	11.386	55.847	26.164	29.91	58.4	6.855
CSG018	1.969	12.041	96.854	42.645	24.18	26.796	4.758
CSG019	2.025	17.075	91.482	39.765	33.5	28.446	4.665
CSG020	1.755	16.104	106.653	54.596	33.02	20.657	4.3
CSG021	3.221	67.144	739.269	234.57	23.52	3.162	1.857
CSG022	2.456	21.825	341.372	105.56	24.17	12.156	3.302
CSG023	2.148	16.741	83.68	36.802	25.8	34.29	5.08
CSG024	2.098	30.569	129.536	61.933	20.17	19.485	4.03
CSG025	5.181	168.336	802.546	296.129	12.28	1.887	1.473
CSG026	2.92	44.49	260.677	101.395	24.84	10.188	2.994
CSG027	170.412	296.411	516.557	322.629	3.58	0.241	0.83
CSG028	29.918	271.478	520.675	286.548	8.89	-0.104	0.404
CSG029	15.181	210.934	453.334	230.75	10.04	0.169	0.674
CSG030	5.858	87.272	442.381	166.606	13.48	9.039	2.802
CSG031	4.612	74.299	390.203	145.796	13.53	8.47	2.706
CSG032	4.6	94.796	451.098	169.578	17.54	5.492	2.185
CSG033	16.602	232.511	707.488	310.481	9.47	1.407	1.276
CSG034	2.514	24.402	157.753	63.875	17.55	11.746	3.183
CSG035	1.944	18.771	125.568	56.781	37.67	16.185	3.776
CSG036	2.64	31.93	282.831	100.592	18.57	11.833	3.277
CSG037	2.614	22.729	183.45	68.994	25.8	10.742	3.091
CSG038	7.195	218.894	814.415	325.691	15.47	2.248	1.505
CSG039	2.408	27.655	261.845	92.084	34.72	13.519	3.412
CSG040	2.52	22.15	187.893	66.79	29.46	9.679	2.969
CSG041	2.701	33.081	344.595	107.348	29.57	5.843	2.388
CSG042	2.073	22.646	107.463	54.191	21.29	20.601	4.251
CSG043	2.163	38.911	394.87	120.397	20.17	6.901	2.563
CSG044	2.315	46.123	296.223	104.111	21.85	8.462	2.773
CSG045	2.304	48.008	188.726	81.646	25.83	11.268	2.955
CSG046	8.639	247.374	849.515	352.193	10.4	1.407	1.31
CSG047	182.648	546.005	1125.918	604.239	8.19	0.192	0.683
CSG048	3.809	104.086	679.999	229.873	22.23	3.067	1.829
CSG049	50.526	265.009	745.795	344.468	9.25	2.213	1.442
CSG050	2.959	63.539	311.917	124.077	21.53	9.927	2.97
CSG051	2.245	33.016	213.009	85.024	29.37	10.026	3.043
CSG052	2.132	23.511	142.139	63.169	26.41	13.678	3.48
CSG053	2.445	21.51	122.868	52.655	23.38	14.676	3.47

MODE	STD DEV	RESIDUAL-WEIGHTED	SIZES (μM) % UNDER								
			0.06	0.12	0.24	0.49	0.98	2	3.9	7.8	15.6
22.764	51.474	0.899	0	0	0	0.63	3.37	7.37	16.43	31.29	49.78
257.287	149.341	1.163	0	0	0	0	0.42	1.03	2.31	4.2	6.07
146.629	193.681	0.705	0	0	0	0.33	1.57	3.22	6.25	10.53	15.43
287.319	334.796	1.391	0	0	0	0.09	0.68	1.54	3.09	5.16	7.25
21.416	61.147	0.851	0	0	0	0.97	4.55	10	21.36	37.12	54.16
25.421	38.994	0.982	0	0	0	1	4.80	10.36	21.79	38.41	56.81
14.12	46.872	0.98	0	0	0	1.22	5.47	11.26	22.6	39.84	59.58
6.159	54.027	0.838	0	0	0	1	4.49	9.71	22.05	40.15	58.08
5.908	93.602	0.897	0	0	0	1.06	4.72	10.18	22.32	39.48	56.05
48.183	68.581	0.744	0	0	0	1.15	4.74	9.86	20.72	34.92	48.23
45.766	119.047	0.784	0	0	0	1.48	5.72	11.4	22.21	36.29	49.4
634.893	334.865	0.953	0	0	0	0.63	2.75	5.62	12.5	23.07	32.38
56.836	219.915	0.826	0	0	0	0.8	3.54	7.69	17.58	31.46	44.14
49.999	62.196	0.782	0	0	0	0.97	4.28	9.17	20.38	35.5	48.69
67.546	105.483	0.778	0	0	0	1.15	4.67	9.51	18.58	29.57	39.26
435.633	347.558	1.005	0	0	0	0.3	1.62	3.49	7.5	14.28	22.65
87.479	163.243	0.684	0	0	0	0.71	3.14	6.54	13.57	24.08	35.04
295.08	134.891	1.664	0	0	0	0	0	0	0	0	0
302.111	171.64	1.265	0	0	0	0	0.26	0.78	2.09	4.51	7.33
250.135	161.105	0.997	0	0	0	0.1	0.76	1.69	3.67	6.76	10.14
98.692	237.296	0.603	0	0	0	0.37	1.78	3.58	7.04	12.33	18.41
92.178	207.927	0.653	0	0	0	0.42	2.1	4.32	8.59	14.99	22.32
147.717	217.475	0.663	0	0	0	0.37	1.87	3.92	8.43	15.85	24.28
257.16	274.416	1.384	0	0	0	0.09	0.64	1.44	3.21	6.15	9.68
64.621	104.591	0.786	0	0	0	0.79	3.73	7.79	15.81	27.77	41.25
52.735	108.175	0.72	0	0	0	1.31	5.14	10.29	19.86	32.92	46.4
61.281	189.832	0.749	0	0	0	0.85	3.72	7.49	14.81	25.62	37.26
60.219	118.251	0.747	0	0	0	0.78	3.51	7.3	15.8	28.89	42.78
347.756	342.586	0.8	0	0	0	0.28	1.32	2.51	5.36	10.67	16.08
55.731	177.852	0.69	0	0	0	1.08	4.19	8.17	16.93	29.52	40.63
46.983	113.75	0.747	0	0	0	0.79	3.59	7.61	16.46	29.63	43.18
64.867	170.039	0.727	0	0	0	0.77	3.4	7.09	14.92	26.27	37.76
58.019	102.121	0.8	0	0	0	1.12	4.74	9.64	18.72	31.07	43.39
74.796	199.865	0.841	0	0	0	1.08	4.46	9.22	17.72	27.95	37.04
78.316	165.133	0.739	0	0	0	1.07	4.27	8.62	16.33	25.65	34.03
89.539	112.07	0.686	0	0	0	1.18	4.49	8.76	15.76	23.87	31.96
410.78	341.573	1.27	0	0	0	0.29	1.36	2.83	5.72	9.49	12.79
627.071	370.898	2.713	0	0	0	0	0.12	0.58	1.41	2.61	3.93
107.992	298.713	0.908	0	0	0	0.59	2.39	4.94	10.23	16.97	22.84
266.507	287.187	1.157	0	0	0	0.08	0.55	1.19	2.83	5.35	7.43
92.372	191.76	0.681	0	0	0	0.83	3.31	6.64	12.97	20.64	27.54
73.75	145.214	0.724	0	0	0	1.11	4.4	8.86	17.39	28.7	39.27
58.569	112.94	0.789	0	0	0	1.12	4.58	9.33	18.97	31.67	43.18
61.013	85.073	0.771	0	0	0	0.78	3.61	7.8	17.38	31.24	44.45

31	**37**	**44**	**53**	**62.5**	**74**	**88**	**105**	**125**	**149**	**177**	**210**	**250**
69.88	74.9	79.57	84.18	87.79	90.94	93.55	95.54	96.9	97.75	98.24	98.54	98.77
8.08	8.6	9.04	9.41	9.73	10.27	11.42	13.76	17.81	24.08	32.48	42.74	54.42
20.66	22.35	24.39	27.21	30.4	34.42	39.34	45.08	51.26	57.73	64.05	70.08	75.82
9.33	9.72	10.01	10.24	10.52	11.08	12.25	14.38	17.67	22.3	28.06	34.73	42.18
72.04	76.43	80.47	84.44	87.54	90.27	92.58	94.43	95.77	96.72	97.36	97.82	98.2
76.68	81.67	86.18	90.4	93.44	95.83	97.54	98.62	99.19	99.43	99.51	99.53	99.55
78.7	83.12	87.06	90.74	93.43	95.58	97.17	98.22	98.79	99.05	99.12	99.15	99.2
76.03	80.64	84.9	88.98	92	94.42	96.21	97.38	98.03	98.35	98.49	98.57	98.67
70.96	74.47	77.74	81.05	83.78	86.37	88.78	90.95	92.74	94.17	95.22	95.98	96.57
63.01	67.46	72.04	77.06	81.4	85.54	89.26	92.33	94.57	96.09	97.01	97.57	97.96
63.4	67.54	71.75	76.3	80.19	83.85	87.12	89.8	91.76	93.09	93.92	94.46	94.91
40.82	43.03	45.15	47.34	49.2	51.08	53.06	55.23	57.63	60.34	63.26	66.36	69.61
56.34	59.73	63.21	67.08	70.55	74.04	77.41	80.48	83.03	85.04	86.52	87.62	88.5
63	67.61	72.49	77.95	82.69	87.16	91.04	94.07	96.1	97.3	97.9	98.19	98.37
50.28	54.18	58.64	64.1	69.37	74.92	80.4	85.36	89.32	92.23	94.08	95.17	95.82
30.73	32.71	34.61	36.63	38.38	40.14	41.93	43.8	45.8	48.12	50.85	54.1	58.02
44.21	46.8	49.79	53.69	57.79	62.53	67.73	73.01	77.81	81.94	85.18	87.65	89.59
0	0	0	0	0	0	0	0.06	1.26	4.96	11.8	21.99	35.34
10.16	10.93	11.63	12.22	12.54	12.73	12.97	13.74	15.62	19.36	25.34	33.72	44.42
13.66	14.52	15.29	16.06	16.8	17.82	19.5	22.31	26.61	32.75	40.56	49.75	59.94
24.49	26.7	29.56	33.65	38.25	43.86	50.32	57.22	63.87	69.95	75.05	79.18	82.53
30	32.65	35.85	40.11	44.63	49.87	55.66	61.66	67.33	72.49	76.88	80.58	83.74
31.84	33.74	35.76	38.26	40.91	44.16	48.12	52.75	57.79	63.1	68.3	73.24	77.88
12.83	13.49	14.15	15.01	16.08	17.69	20.1	23.52	27.93	33.34	39.42	45.96	52.9
54.8	58.55	62.46	66.92	71.04	75.3	79.5	83.38	86.65	89.28	91.28	92.83	94.13
60.22	64.17	68.24	72.76	76.75	80.67	84.32	87.49	89.95	91.77	93.02	93.93	94.7
49.4	53.15	57.21	61.93	66.29	70.73	75.01	78.85	81.98	84.46	86.33	87.8	89.11
55.99	59.59	63.33	67.55	71.39	75.29	79.07	82.53	85.41	87.78	89.65	91.21	92.65
20.52	21.66	22.84	24.24	25.67	27.42	29.62	32.36	35.65	39.55	43.93	48.77	54.09
52.24	56.06	60.17	64.87	69.1	73.29	77.23	80.68	83.43	85.58	87.2	88.49	89.69
56.97	60.91	64.92	69.27	73.04	76.67	80.03	83.02	85.51	87.63	89.42	91.04	92.61
48.87	52.01	55.27	58.99	62.39	65.91	69.42	72.79	75.83	78.6	81.08	83.39	85.7
56.41	60.68	65.39	70.92	75.99	81.04	85.69	89.57	92.35	94.14	95.09	95.55	95.83
46.22	49.11	52.31	56.19	59.95	64	68.16	72.17	75.7	78.7	81.12	83.14	84.98
42.53	45.46	48.94	53.41	57.97	63.04	68.35	73.5	77.97	81.66	84.47	86.62	88.41
41.39	44.46	47.99	52.5	57.18	62.58	68.52	74.61	80.21	85.07	88.85	91.64	93.68
16.03	16.9	17.81	18.95	20.2	21.86	24.1	27.05	30.65	34.93	39.68	44.81	50.34
5.07	5.35	5.64	5.96	6.24	6.52	6.79	7.11	7.56	8.33	9.67	11.87	15.34
28.11	29.71	31.62	34.26	37.25	40.96	45.37	50.25	55.12	59.78	63.89	67.5	70.79
9.08	9.43	9.74	10.11	10.6	11.49	13.09	15.75	19.65	24.97	31.48	38.94	47.18
34.92	37.51	40.67	44.92	49.5	54.91	60.97	67.27	73.15	78.31	82.41	85.5	87.83
48.96	52.04	55.61	60.11	64.6	69.5	74.5	79.2	83.12	86.18	88.35	89.89	91.11
55.32	59.25	63.5	68.45	72.97	77.5	81.77	85.49	88.37	90.5	91.97	93.04	93.95
56.71	60.5	64.68	69.65	74.27	78.96	83.41	87.27	90.26	92.47	94.02	95.15	96.09

300	350	420	500	590	710	840	1000	1190	1410	1680	2000
99.02	99.26	99.57	99.85	99.99	100	100	100	100	100	100	100
66.82	76.51	86.15	93.03	97.39	99.81	100	100	100	100	100	100
81.22	85.24	89.33	92.56	95.03	97.15	98.53	99.47	99.95	100	100	100
50.25	57.04	64.77	71.73	77.86	84.06	88.98	93.21	96.42	98.55	99.69	100
98.59	98.92	99.33	99.68	99.92	100	100	100	100	100	100	100
99.58	99.64	99.72	99.82	99.91	99.98	100	100	100	100	100	100
99.29	99.4	99.56	99.72	99.85	99.96	100	100	100	100	100	100
98.85	99.07	99.38	99.67	99.88	99.99	100	100	100	100	100	100
97.1	97.55	98.13	98.72	99.24	99.7	99.92	100	100	100	100	100
98.32	98.65	99.08	99.49	99.81	100	100	100	100	100	100	100
95.43	95.98	96.78	97.64	98.46	99.24	99.73	99.96	100	100	100	100
72.99	75.81	79.14	82.4	85.59	89.22	92.38	95.26	97.49	98.98	99.84	100
89.35	90.14	91.31	92.73	94.31	96.14	97.61	98.75	99.44	99.78	99.94	100
98.59	98.84	99.22	99.59	99.87	100	100	100	100	100	100	100
96.32	96.76	97.43	98.17	98.89	99.56	99.91	100	100	100	100	100
62.68	66.97	72.26	77.37	82.09	87.03	91.03	94.49	97.12	98.85	99.82	100
91.26	92.56	94.07	95.53	96.86	98.18	99.11	99.74	99.97	100	100	100
51.05	64.28	78.14	88.45	95.17	99.27	100	100	100	100	100	100
56.99	67.73	79.31	88.28	94.44	98.69	99.99	100	100	100	100	100
70.59	78.87	87.14	93.12	97.02	99.48	100	100	100	100	100	100
85.32	87.3	89.42	91.35	93.15	95.09	96.69	98.08	99.09	99.71	99.94	100
86.54	88.63	90.89	92.89	94.66	96.45	97.83	98.91	99.62	99.94	100	100
82.21	85.44	88.81	91.61	93.92	96.12	97.71	98.92	99.68	99.96	100	100
60.19	66.24	73.14	79.35	84.77	90.09	94.04	97.1	99.06	99.94	100	100
95.37	96.39	97.56	98.58	99.35	99.87	100	100	100	100	100	100
95.5	96.26	97.23	98.19	99.01	99.68	99.95	100	100	100	100	100
90.43	91.57	93	94.42	95.77	97.19	98.31	99.18	99.75	99.97	100	100
94.09	95.32	96.74	97.99	98.96	99.68	99.95	100	100	100	100	100
59.94	65.01	70.99	76.54	81.53	86.63	90.7	94.22	96.92	98.73	99.65	100
90.95	92.1	93.57	95.05	96.42	97.8	98.78	99.46	99.79	99.94	100	100
94.23	95.57	97.06	98.3	99.21	99.83	100	100	100	100	100	100
88.13	90.21	92.67	94.9	96.78	98.43	99.42	99.93	100	100	100	100
96.19	96.65	97.4	98.24	99	99.67	99.96	100	100	100	100	100
86.88	88.58	90.75	92.93	94.97	97.01	98.45	99.39	99.87	99.99	100	100
90.12	91.58	93.41	95.18	96.78	98.28	99.27	99.83	99.98	100	100	100
95.21	96.24	97.31	98.24	99.01	99.66	99.94	100	100	100	100	100
56.35	61.55	67.78	73.71	79.21	85.01	89.71	93.76	96.82	98.81	99.91	100
20.59	26.45	35.05	44.73	54.77	66.27	76.15	85.04	91.98	96.69	99.44	100
74.03	76.78	80.2	83.69	87.1	90.85	93.93	96.56	98.45	99.57	99.99	100
55.98	63.19	71.12	77.88	83.47	88.76	92.69	95.87	98.13	99.5	99.99	100
89.66	90.96	92.45	93.93	95.38	96.96	98.21	99.18	99.79	99.98	100	100
92.3	93.38	94.81	96.27	97.61	98.87	99.65	99.97	100	100	100	100
94.91	95.79	96.93	98.02	98.94	99.67	99.95	100	100	100	100	100
96.98	97.72	98.58	99.29	99.77	100	100	100	100	100	100	100

SAMPLE ID	D (0.1)	D (0.5)	D (0.9)	D [4, 3] - VOLUME WEIGHTED MEAN	OBSCURATION	KURTOSIS	SKEW
CSG054	2.128	21.902	138.986	58.926	29.27	13.931	3.497
CSG055	17.926	387.73	880.048	432.776	9.49	0.162	0.727
CSG056	37.85	343.731	809.404	399.518	9.41	0.572	0.903
CSG057	6.814	384.181	896.834	412.828	16.81	-0.358	0.607
CSG058	1.523	14.674	80.91	39.375	44.14	23.818	4.543
CSG059	2.483	21.404	170.764	64.029	22.15	13.289	3.344
CSG060	2.136	12.967	63.553	31.459	34.49	39.39	5.797
CSG061	2.2	13.125	62.553	29.913	35.58	45.148	6.115
CSG062	2.245	13.659	63.69	31.941	32.42	37.716	5.688
CSG064	2.176	12.195	59.319	27.506	32.37	49.338	6.297
CSG065	2.886	43.138	318.172	114.947	26.92	7.465	2.492
CSG066	2.192	15.873	87.491	41.356	31.34	18.263	3.999
CSG068	1.795	19.348	104.14	50.934	33.14	18.508	4.047
CSG069	2.264	32.356	279.541	97.571	25.95	9.909	3.027
CSG070	12.772	252.594	808.919	346.3	10.24	1.471	1.298
CSG071	4.229	158.852	723.308	272.643	20.89	3.486	1.801
CSG072	16.972	257.971	899.946	376.358	10.84	1.714	1.396
CSG073	4.846	156.785	659.193	254.157	16.92	3.94	1.864
CSG074	65.945	371.72	1046.699	478.07	8.43	0.84	1.105

MODE	STD DEV	RESIDUAL-WEIGHTED	SIZES (μM) % UNDER								
			0.06	0.12	0.24	0.49	0.98	2	3.9	7.8	15.6
45.484	106.727	0.763	0	0	0	1.15	4.65	9.36	18.77	31.51	43.64
479.41	319.048	1.659	0	0	0	0.09	0.68	1.42	3.03	5.91	9.34
393.448	289.401	1.743	0	0	0	0.08	0.61	1.34	2.83	5.05	7.25
563.732	344.864	1.882	0	0	0	0.26	1.26	2.46	5.55	11.16	16.56
39.156	78.492	0.711	0	0	0	1.96	6.74	12.82	23.96	38.03	51.19
41.407	113.102	0.779	0	0	0	0.83	3.67	7.69	17.07	30.64	43.75
35.533	65.466	0.779	0	0	0	0.99	4.26	9.19	21.51	38.7	54.04
35.918	59.441	0.76	0	0	0	0.97	4.17	8.85	20.9	38.29	53.8
35.829	65.34	0.79	0	0	0	0.93	4.06	8.62	20.3	37.39	52.95
34.709	52.74	0.793	0	0	0	1	4.26	8.96	21.61	39.85	55.35
144.795	168.051	0.71	0	0	0	0.74	3.12	6.44	14.1	25.26	35.72
39.09	76.576	1.066	0	0	0	0.98	4.33	9.01	19.05	33.83	49.6
48.351	97.62	0.761	0	0	0	1.48	5.68	11.09	20.72	33.36	45.94
70.552	173.705	0.73	0	0	0	1.1	4.41	8.82	16.92	27.67	38.46
352.214	320.283	1.286	0	0	0	0.24	1.19	2.52	4.9	7.91	10.85
256.154	321.003	0.951	0	0	0	0.58	2.31	4.77	9.34	14.8	19.56
262.233	359.514	1.135	0	0	0	0.2	0.94	2.02	4.18	7.03	9.69
198.839	293.46	0.809	0	0	0	0.41	1.95	4.14	8.31	13.76	19.09
537.986	390.364	1.736	0	0	0	0.09	0.67	1.53	3.2	5.36	7.17

31	37	44	53	62.5	74	88	105	125	149	177	210	250
57.8	62.38	67.11	72.24	76.57	80.56	84.03	86.85	88.97	90.59	91.85	92.96	94.05
12.43	13.19	13.93	14.7	15.36	16.01	16.67	17.45	18.49	20.07	22.47	25.99	31
9.35	9.93	10.48	11.04	11.51	12.02	12.7	13.78	15.53	18.3	22.29	27.66	34.55
20.74	21.74	22.72	23.8	24.79	25.85	26.96	28.13	29.3	30.57	32.05	34.02	36.92
66.82	71.57	76.29	81.16	85.07	88.48	91.25	93.29	94.63	95.47	95.99	96.39	96.83
58.02	62.1	66.17	70.48	74.15	77.66	80.93	83.88	86.38	88.54	90.36	91.95	93.43
71.26	76.29	81.15	85.99	89.67	92.68	94.92	96.38	97.17	97.54	97.69	97.79	97.93
71.17	76.29	81.26	86.21	89.98	93.07	95.37	96.85	97.65	98.01	98.15	98.22	98.32
70.56	75.77	80.81	85.82	89.61	92.69	94.94	96.38	97.14	97.48	97.61	97.71	97.86
72.72	77.81	82.69	87.48	91.06	93.93	96.02	97.34	98.04	98.34	98.46	98.52	98.62
45.37	47.83	50.28	53.04	55.67	58.63	62.01	65.83	69.89	74.14	78.28	82.17	85.78
66.14	70.72	75.23	79.94	83.79	87.23	90.08	92.24	93.7	94.64	95.28	95.83	96.44
60.25	64.77	69.51	74.72	79.21	83.44	87.15	90.12	92.22	93.6	94.44	95.01	95.53
49.24	52.51	56.11	60.42	64.55	68.94	73.36	77.51	81.04	83.9	86.06	87.74	89.15
13.8	14.56	15.35	16.35	17.5	19.08	21.3	24.32	28.12	32.73	37.91	43.54	49.63
24.29	25.7	27.25	29.18	31.2	33.63	36.58	40.07	43.98	48.33	52.91	57.69	62.68
12.1	12.69	13.35	14.28	15.44	17.15	19.6	22.95	27.09	32	37.36	43.02	48.93
24.13	25.37	26.64	28.2	29.9	32.14	35.09	38.87	43.33	48.44	53.82	59.31	64.85
8.74	9.06	9.32	9.57	9.87	10.39	11.35	13.02	15.56	19.12	23.58	28.83	34.84

300	350	420	500	590	710	840	1000	1190	1410	1680	2000
95.23	96.24	97.42	98.44	99.22	99.79	99.97	100	100	100	100	100
37.86	44.86	54.2	63.65	72.48	81.5	88.37	93.85	97.56	99.69	100	100
43.05	50.95	60.63	69.69	77.66	85.43	91.14	95.59	98.49	99.9	100	100
41.32	46.35	53.87	62.32	70.87	80.17	87.54	93.51	97.53	99.81	100	100
97.38	97.93	98.62	99.25	99.72	100	100	100	100	100	100	100
94.86	96	97.26	98.3	99.1	99.68	99.91	99.99	100	100	100	100
98.19	98.52	98.99	99.46	99.81	100	100	100	100	100	100	100
98.53	98.8	99.2	99.59	99.87	100	100	100	100	100	100	100
98.15	98.5	99	99.48	99.84	100	100	100	100	100	100	100
98.82	99.06	99.42	99.75	99.96	100	100	100	100	100	100	100
89.06	91.42	93.76	95.61	97.06	98.34	99.19	99.75	99.97	100	100	100
97.23	97.99	98.88	99.56	99.94	100	100	100	100	100	100	100
96.16	96.81	97.69	98.56	99.28	99.84	100	100	100	100	100	100
90.54	91.75	93.3	94.87	96.34	97.83	98.9	99.64	99.95	100	100	100
56.22	61.88	68.57	74.84	80.52	86.37	90.96	94.79	97.56	99.26	99.96	100
67.91	72.26	77.22	81.7	85.64	89.63	92.8	95.54	97.65	99	99.71	100
55.14	60.37	66.49	72.29	77.67	83.43	88.22	92.48	95.83	98.15	99.58	100
70.41	74.85	79.73	84.02	87.73	91.41	94.27	96.64	98.36	99.37	99.85	100
41.62	47.61	54.9	62	68.78	76.26	82.68	88.61	93.45	96.91	99.15	100

APPENDIX II: Trace and major element concentrations in the surface sediment samples (XRF and ICP-MS)

SAMPLE NO	**Cd ICP-MS ppm**	**Cr XRF ppm**	**Cu XRF ppm**	**Ni XRF ppm**	**Pb ICP-MS ppm**	**Zn XRF ppm**	**Ag ICP-MS ppm**	**Al2O3 XRF %**	**As ICP-MS ppm**	**Ba ICP-MS ppm**	**Be ICP-MS ppm**	**Bi ICP-MS ppm**	**CaO XRF %**	**Ce ICP-MS ppm**	**Cl XRF %**
CSG13	0.55	39	16	49	19.8	60	0.1	3.196	3.6	54	0.4	0.2	37.585	30.3	5719
CSG16	0.23	30	43	9	11.8	28	0.04	2.333	2.5	42	0.4	0.1	40.841	14.49	12468
CSG18	0.52	37	20	14	14.8	46	0.11	2.947	0.7	51	0.3	0.2	39.964	22.29	11005
CSG20	0.32	34	20	6	12.8	34	0.12	2.768	<0.4	52	0.3	0.1	40.921	18.06	9706
CSG23	0.15	39	97	15	14.4	29	0.16	2.676	<0.4	54	0.3	0.1	41.775	16.94	6348
CSG25	0.12	32	34	14	12	29	0.12	2.379	<0.4	44	0.2	<0.01	41.211	14.24	21023
CSG27	0.12	32	149	56	20.7	37	0.08	2.414	6.8	52	0.2	0.1	27.848	10.95	212123
CSG29	0.15	43	28	6	18.2	31	0.07	3.64	3.7	70	0.4	<0.01	36.359	17.71	11634
CSG31	0.14	29	36	5	14.4	27	0.14	2.327	1.1	55	0.2	0.1	41.563	15.48	11246
CSG33	0.18	40	44	10	18.7	38	0.12	3.074	2.6	54	0.3	0.2	39.098	18.28	19849
CSG34	0.18	40	11	17	16.8	32	0.04	2.624	1.1	53	0.3	0.1	40.827	15.91	8138
CSG36	<0.05	31	36	23	13.8	27	0.07	2.508	<0.4	51	0.2	0.1	41.226	17.11	5267
CSG38	0.15	34	24	2	12.5	26	0.07	2.211	<0.4	44	0.2	<0.01	41.306	15.25	6366
CSG39	0.13	33	8	4	9.6	19	0.05	2.206	<0.4	49	0.2	<0.01	43.059	15.18	3908
CSG41	0.18	36	20	<1.3	10.4	18	0.06	2.623	0.8	51	0.3	<0.01	42.218	17.62	2169
CSG43	<0.05	28	17	<1.3	12.1	26	0.05	2.485	2.2	51	0.3	<0.01	42.064	18.21	7813
CSG45	0.11	36	24	12	12.7	32	0.1	2.938	<0.4	54	0.2	0.1	41.649	18.59	6965
CSG48	0.11	32	42	7	13	33	0.02	2.717	<0.4	48	0.2	<0.01	41.353	18.73	7110
CSG51	<0.05	25	11	7	11.5	23	<0.01	2.455	2	47	0.2	0.1	42.572	18.34	5994
CSG53	0.11	25	9	<1.3	10.5	21	<0.01	2.409	1.9	48	0.2	<0.01	42.685	16.41	3315
CSG55	0.13	22	73	11	14.5	39	0.07	2.162	1.8	43	0.3	<0.01	37.976	12.19	58541
CSG57	0.11	22	7	<1.3	11.7	24	<0.01	2.359	1.9	44	0.2	<0.01	41.714	13.53	8056
CSG59	0.15	28	12	5	9.2	17	0.07	1.939	<0.4	45	0.2	<0.01	42.154	14.66	9255
CSG62	0.11	23	21	9	8.3	17	0.07	1.907	<0.4	43	0.3	<0.01	43.297	12.7	2462
CSG64	<0.05	29	15	3	9.1	14	0.04	2.01	<0.4	45	0.3	<0.01	42.424	13	4837
CSG65	0.24	26	13	12	10.6	27	0.04	2.752	<0.4	66	0.2	<0.01	41.043	18.64	5716
CSG68	<0.05	14	9	<1.3	8.8	17	<0.01	1.993	1.6	99	0.2	<0.01	43.729	13.74	5482
CSG71	<0.05	31	17	2	15	34	<0.01	3.456	3.9	131	0.3	0.1	41.825	17.74	4354
CSG73	<0.05	32	11	5	17.2	40	<0.01	2.933	2.8	51	0.3	0.1	40.634	17.49	4400
CSG74	<0.05	27	44	8	17.5	32	0.05	2.732	2.5	51	0.3	0.2	37.585	30.3	5719

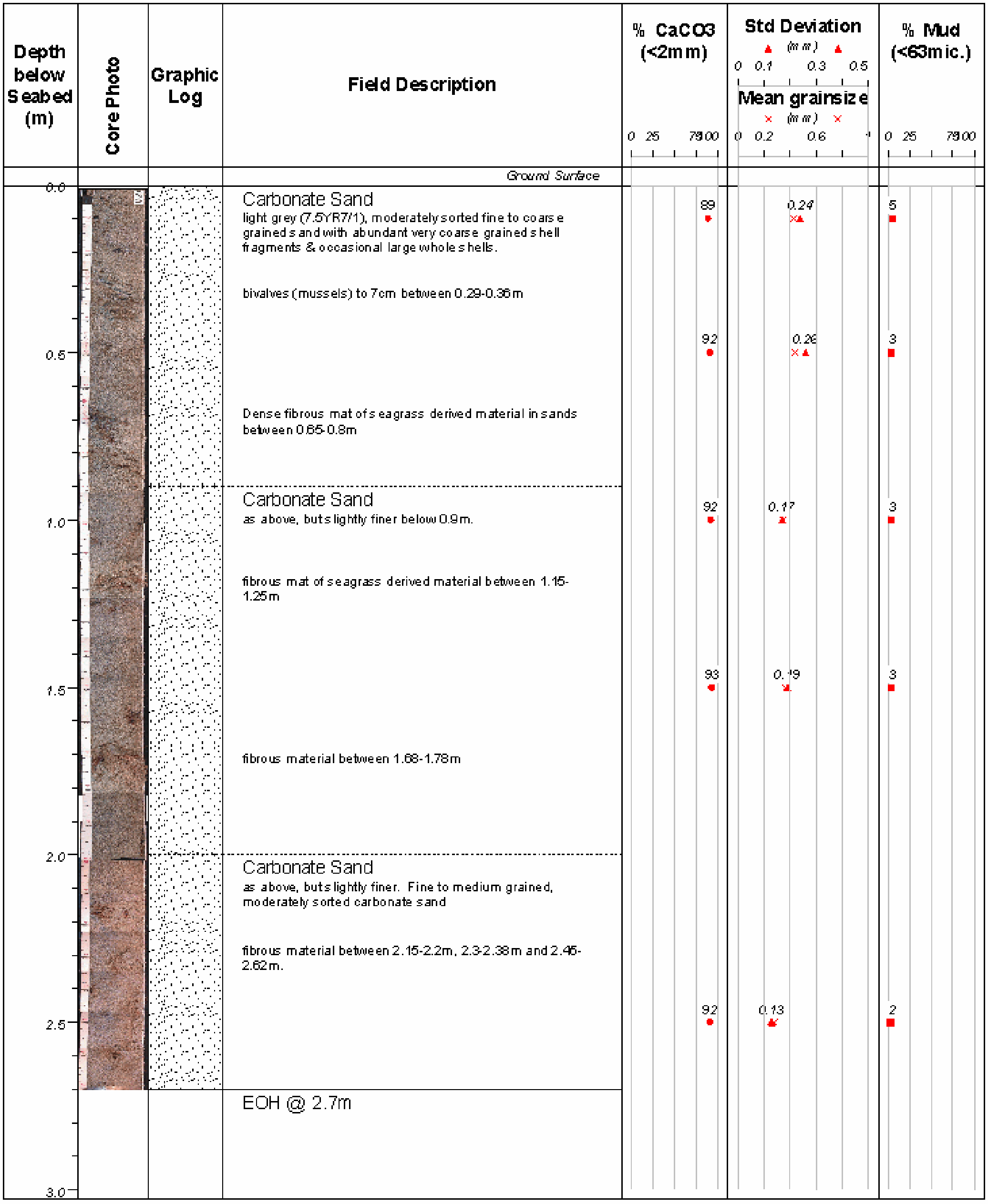
SAMPLE NO	**Cs ICP-MS ppm**	**Dy ICP-MS ppm**	**Er ICP-MS ppm**	**Eu ICP-MS ppb**	**Fe2O3T XRF %**	**Fe ppm**	**Ga ICP-MS ppm**	**Gd ICP-MS ppm**	**Ge ICP-MS ppm**	**Hf ICP-MS ppm**	**Ho ICP-MS ppm**	**K2O XRF %**	**La ICP-MS ppm**	**L ICP-MS ppm**	**MgO XRF %**
CSG13	0.44	2.18	1.3	437	1.403	9813	3.8	2.42	0.3	6	0.41	0.226	17.48	0.13	2.349
CSG16	0.3	0.92	0.59	208	1.131	7910	2.7	1.11	0.2	0.9	0.17	0.25	7.65	0.04	2.437
CSG18	0.41	1.84	1.15	488	1.338	9358	3.5	2	0.6	1.3	0.38	0.249	13.43	0.14	2.426
CSG20	0.42	1.3	0.8	318	1.273	8903	3.1	1.47	0.5	1.4	0.29	0.253	9.94	0.11	2.356
CSG23	0.4	1.24	0.73	276	1.206	8435	3.1	1.18	0.4	1.3	0.25	0.237	8.83	0.09	2.221
CSG25	0.32	1.01	0.62	221	1.017	7113	2.8	0.97	0.4	1.2	0.2	0.262	7.76	0.09	2.248
CSG27	0.41	0.64	0.38	169	1.194	8351	3.1	0.7	0.3	1	0.13	0.738	5.64	0.06	3.207
CSG29	0.58	1.09	0.66	301	1.487	10400	4.6	1.18	0.4	1.5	0.23	0.314	8.98	0.09	2.488
CSG31	0.28	0.95	0.61	212	1.015	7099	2.7	0.96	0.2	1.4	0.2	0.229	7.97	0.08	2.208
CSG33	0.38	1.11	0.77	269	1.199	8386	3.5	1.17	0.2	2	0.26	0.289	9.53	0.11	2.184
CSG34	0.36	0.94	0.56	240	1.071	7491	3	1.02	0.2	1.3	0.19	0.235	8.07	0.08	2.163
CSG36	0.31	0.91	0.62	233	1.08	7554	3	1.05	0.2	1.7	0.2	0.221	8.61	0.08	2.284
CSG38	0.3	0.79	0.48	218	0.929	6497	2.7	0.9	0.2	1	0.17	0.207	7.52	0.06	2.245
CSG39	0.32	0.89	0.55	224	0.974	6812	2.5	1	0.1	1.2	0.19	0.206	7.66	0.08	2.293
CSG41	0.33	0.96	0.64	254	1.205	8428	3.2	1.06	0.2	1.6	0.21	0.224	8.59	0.08	2.395
CSG43	0.31	0.97	0.55	188	1.1	7693	2.7	1.04	0.2	1.8	0.17	0.239	8.83	0.03	2.303
CSG45	0.39	1.16	0.73	276	1.255	8777	3.5	1.16	0.2	2.1	0.24	0.258	9.24	0.09	2.283
CSG48	0.34	1.11	0.61	247	1.167	8162	3.1	1.18	0.1	1.8	0.21	0.227	9.88	0.08	2.127
CSG51	0.32	1.1	0.75	191	1.071	7491	2.6	1.18	0.2	1.7	0.2	0.235	9.25	0.04	2.311
CSG53	0.31	0.99	0.56	196	1.071	7491	2.6	1.04	0.1	1.5	0.16	0.227	8.11	0.03	2.348
CSG55	0.46	0.81	0.55	176	0.89	6225	2.6	0.9	0.1	0.9	0.19	0.331	6.72	0.08	2.37
CSG57	0.29	0.8	0.5	166	0.97	6784	2.7	0.89	0.2	0.8	0.13	0.213	6.81	0.02	2.368
CSG59	0.27	0.86	0.56	192	0.904	6323	2.3	0.9	0.1	1.1	0.19	0.206	7.39	0.08	2.314
CSG62	0.26	0.71	0.46	205	0.901	6302	2.3	0.83	0.1	0.9	0.16	0.183	6.27	0.06	2.429
CSG64	0.29	0.78	0.51	204	0.976	6826	2.3	0.87	<0.02	0.9	0.16	0.203	6.39	0.06	2.305
CSG65	0.39	1.34	0.87	326	1.257	8791	3.2	1.38	0.1	1.7	0.27	0.268	9.96	0.11	2.344
CSG68	0.22	0.83	0.56	207	0.905	6330	2.2	0.88	0.2	1.5	0.15	0.218	6.56	0.04	2.321
CSG71	0.31	1.06	0.63	198	1.43	10001	3.2	1.19	0.2	1.7	0.18	0.269	9.56	0.04	2.018
CSG73	0.32	1	0.64	196	1.189	8316	3.3	1.09	0.2	1.3	0.17	0.22	9.03	0.04	2.171
CSG74	0.33	1.11	0.69	203	1.102	7707	2.8	1.08	0.2	1.9	0.19	0.247	9.42	0.03	2.075

SAMPLE NO	**MLOI Calculate**	**MnO XRF**	**Mn**	**Mo ICP-MS**	**Na2O XRF**	**Nb ICP-MS**	**Nd ICP-MS**	**P2O5 XRF**	**Pr ICP-MS**	**Rb ICP-MS**	**Sb ICP-MS**	**Sc XRF**	**SiO2 XRF**	**Sm ICP-MS**
	%	**%**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**%**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	**ppm**
CSG13	41.962	<0.001	<7.7	1.8	0.832	4.1	13.65	0.46	3.74	12.4	1.6	<1.6	9.96	2.6
CSG16	41.803	<0.001	<7.7	1.9	1.624	2.4	6.09	0.173	1.65	9.5	12.8	<1.6	6.853	1.25
CSG18	40.559	<0.001	<7.7	1.3	1.095	3.1	10.81	0.372	2.92	12.1	3.2	<1.6	8.363	2.13
CSG20	40.505	0.005	39	1.3	1.034	2.8	7.87	0.207	2.15	11.2	0.5	5	8.194	1.4
CSG23	40.96	<0.001	<7.7	1.6	0.811	2.5	6.88	0.16	1.93	11.1	6.6	<1.6	7.916	1.09
CSG25	40.224	0.005	39	1.4	1.648	2.3	5.8	0.168	1.64	9.9	8.7	<1.6	7.416	0.97
CSG27	16.065	0.013	101	2.2	15.159	3.4	4.22	0.204	1.21	11.6	1.1	<1.6	9.237	0.63
CSG29	39.113	0.007	54	1.3	1.127	3.4	7.28	0.208	2.03	15.9	4.1	<1.6	12.615	1.11
CSG31	42.056	<0.001	<7.7	1.2	1.084	2.3	6.08	0.139	1.67	9.9	7.9	<1.6	6.852	0.91
CSG33	40.046	0.005	39	1.8	1.865	2.7	6.94	0.184	2.02	11.9	4.9	<1.6	8.687	1.13
CSG34	42.318	<0.001	<7.7	1.2	0.865	2.3	6.22	0.14	1.74	10.9	0.5	<1.6	7.513	0.97
CSG36	42.45	0.005	39	1.4	0.786	2.4	6.44	0.146	1.85	9.9	3.9	<1.6	7.422	1.04
CSG38	43.057	<0.001	<7.7	0.8	0.778	2.1	6.02	0.147	1.67	9.7	0.4	3	7.139	0.9
CSG39	42.092	<0.001	<7.7	1	0.642	2.2	5.99	0.128	1.65	9.5	0.4	<1.6	6.739	0.96
CSG41	41.402	<0.001	<7.7	1.2	0.535	2.5	6.77	0.137	1.97	10.9	4.3	<1.6	7.655	1.13
CSG43	41.452	<0.001	<7.7	1.2	1.069	2.3	6.59	0.137	1.87	10.7	7.4	<1.6	7.149	1.33
CSG45	40.308	0.005	39	1.2	0.939	2.8	7.1	0.141	2.03	11.4	11.9	<1.6	8.201	1.4
CSG48	41.829	0.005	39	1	0.843	2.7	7.44	0.15	2.14	10	0.5	<1.6	7.525	1.23
CSG51	41.645	<0.001	<7.7	1.1	0.876	2.5	6.93	0.135	1.99	10.4	0.7	3	6.882	1.34
CSG53	41.975	<0.001	<7.7	0.8	0.774	2.3	6.31	0.135	1.78	10.1	0.9	2	6.873	1.29
CSG55	37.777	<0.001	<7.7	1.1	4.152	1.9	4.91	0.155	1.36	8.5	6.7	<1.6	6.771	0.71
CSG57	42.057	<0.001	<7.7	0.7	0.921	2.2	5.3	0.149	1.49	9.3	3.9	2	7.149	1.15
CSG59	42.854	<0.001	<7.7	1.2	0.996	1.9	5.89	0.131	1.63	8.3	4	<1.6	6.243	0.89
CSG62	42.772	<0.001	<7.7	1.2	0.552	1.8	4.95	0.131	1.38	7.8	6.4	2	6.36	0.78
CSG64	43.045	<0.001	<7.7	1.3	0.674	2	5.2	0.133	1.48	8.8	5.6	4	6.584	0.86
CSG65	40.044	0.006	46	1.3	0.727	2.7	7.59	0.214	2.24	11.3	2.7	7	9.28	1.41
CSG68	41.969	<0.001	<7.7	0.7	0.749	2	5.17	0.127	1.48	8.7	0.6	2	6.176	0.92
CSG71	40.108	0.006	46	1	0.657	2.9	7.34	0.166	1.99	10.9	4.7	<1.6	8.278	1.38
CSG73	42.663	<0.001	<7.7	1.3	0.685	2.6	6.69	0.154	1.95	11.8	4.3	<1.6	7.529	1.37
CSG74	42.642	<0.001	<7.7	1.3	1.56	2.6	7.25	0.162	2.05	10.1	5.9	5	7.646	1.46

SAMPLE NO	Sn ICP-MS ppm	SO3 XRF %	Sr ICP-MS ppm	Ta ICP-MS ppm	Tb ICP-MS ppm	Th ICP-MS ppm	TiO2 XRF %	U ICP-MS ppm	V XRF ppm	Y ICP-MS ppm	Yb ICP-MS ppm	Zr ICP-MS ppm
CSG13	1.4	0.895	2110	0.2	0.28	10	0.205	3.8	20	16.4	1.08	246.8
CSG16	1.4	0.975	2464	<0.06	0.09	4.6	0.127	3.5	14	6.8	0.43	31.6
CSG18	0.9	1.06	2333	0.3	0.28	6	0.159	4.42	15	14.3	0.89	46
CSG20	0.9	0.987	2336	0.2	1.06	5.7	0.15	3.79	18	9.4	0.64	52.2
CSG23	1.1	0.839	2353	0.2	0.18	5.2	0.144	3.34	16	7.9	0.62	49.7
CSG25	0.8	0.854	2261	0.1	0.14	5.1	0.121	3.27	21	6.8	0.52	44
CSG27	1.2	2.242	1576	0.3	0.27	4.3	0.163	1.42	27	4.3	0.33	37.1
CSG29	1.3	0.928	2263	0.2	0.17	5.8	0.199	2.59	31	7	0.58	54
CSG31	1.4	0.901	2431	0.1	0.16	5.4	0.131	3.04	13	6.9	0.58	53.6
CSG33	1.2	0.878	1983	0.2	0.18	7.2	0.171	3.08	26	8.6	0.71	79.4
CSG34	1.7	0.914	2180	0.2	0.16	5.6	0.129	3.33	19	6.4	0.49	49.7
CSG36	1.3	0.817	2374	0.2	0.16	5.8	0.141	3.01	14	6.2	0.51	62.4
CSG38	0.8	0.859	2443	0.2	0.1	5.3	0.115	2.78	14	5.7	0.43	38.4
CSG39	0.6	0.757	2470	0.1	0.13	4.6	0.14	3.15	10	6.2	0.47	44.7
CSG41	0.9	0.866	2463	0.2	0.16	6.1	0.146	4.5	15	7	0.58	62.2
CSG43	1.1	0.719	2439	<0.06	0.28	6.6	0.133	2.76	14	6.5	0.52	73
CSG45	1.2	0.797	2308	0.2	0.17	6.3	0.165	3.21	18	7.6	0.61	78.5
CSG48	1	0.832	2231	0.2	0.16	5.7	0.145	2.85	19	6.7	0.51	67.1
CSG51	0.9	0.726	2494	<0.06	0.12	6	0.135	2.9	13	7.8	0.59	66.7
CSG53	0.8	0.665	2497	<0.06	0.1	5.7	0.13	2.69	16	6.3	0.51	57.3
CSG55	0.7	1.064	2084	0.1	0.12	4.3	0.125	2.43	16	5.8	0.46	31.3
CSG57	0.7	0.827	2521	<0.06	0.07	4.7	0.126	3.17	15	6	0.39	32.8
CSG59	0.6	0.857	2490	0.1	0.13	5	0.107	3.14	15	6.1	0.44	43
CSG62	1.1	0.735	2681	<0.06	0.12	4.2	0.111	2.82	10	5.4	0.37	32.5
CSG64	0.6	0.785	2588	0.1	0.12	3.9	0.121	2.91	18	5	0.38	30.1
CSG65	1	0.939	2364	0.2	0.18	5.6	0.167	4.03	16	9	0.69	61.9
CSG68	0.5	0.745	2682	<0.06	0.07	5.2	0.12	2.66	15	6.5	0.49	62.8
CSG71	1.2	0.758	2207	0.2	0.1	5.7	0.166	2.84	22	7	0.5	64.6
CSG73	1.4	0.9	2282	0.1	0.1	5.8	0.146	3.76	19	7.3	0.56	51.5
CSG74	1.1	0.817	2098	<0.06	0.1	5.5	0.136	2.54	25	7.3	0.57	77.9

APPENDIX III: Logs of vibracores from Cockburn Sound

Project: Cockburn Sound
Water Depth (m): 2.4
Vibracore: CSV01
Recovery (m): 2.70
Date: 11/03/2004
Coordinates (WGS84/UTM): 379613 6431182
Time (GMT): 0430



Carbonate Sand
light grey (7.5YR7/1), moderately sorted fine to coarse grained sand with abundant very coarse grained shell fragments & occasional large whole shells.

bivalves (mussels) to 7cm between 0.29-0.36m

Dense fibrous mat of seagrass derived material in sands between 0.65-0.8m

Carbonate Sand
as above, but slightly finer below 0.9m.

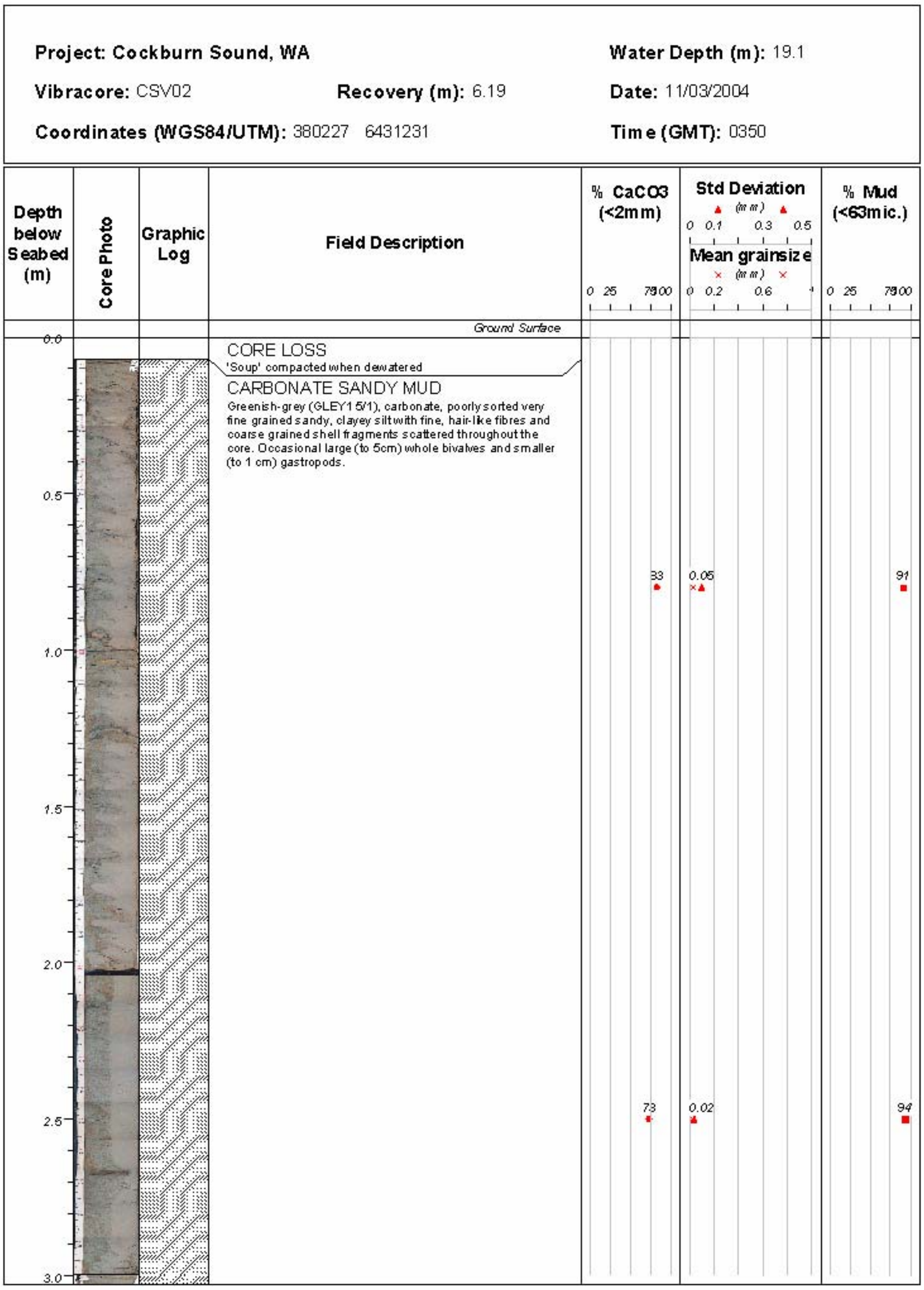
fibrous mat of seagrass derived material between 1.15-1.25m

fibrous material between 1.68-1.78m

Carbonate Sand
as above, but slightly finer. Fine to medium grained, moderately sorted carbonate sand

fibrous material between 2.15-2.2m, 2.3-2.38m and 2.45-2.62m.

EOH @ 2.7m



Project: Cockburn Sound, WA

Water Depth (m): 19.1

Vibracore: CSV02

Recovery (m): 6.19

Date: 11/03/2004

Coordinates (WGS84/UTM): 380227 6431231

Time (GMT): 0350

Field Description

CORE LOSS

'Soup' compacted when dewatered

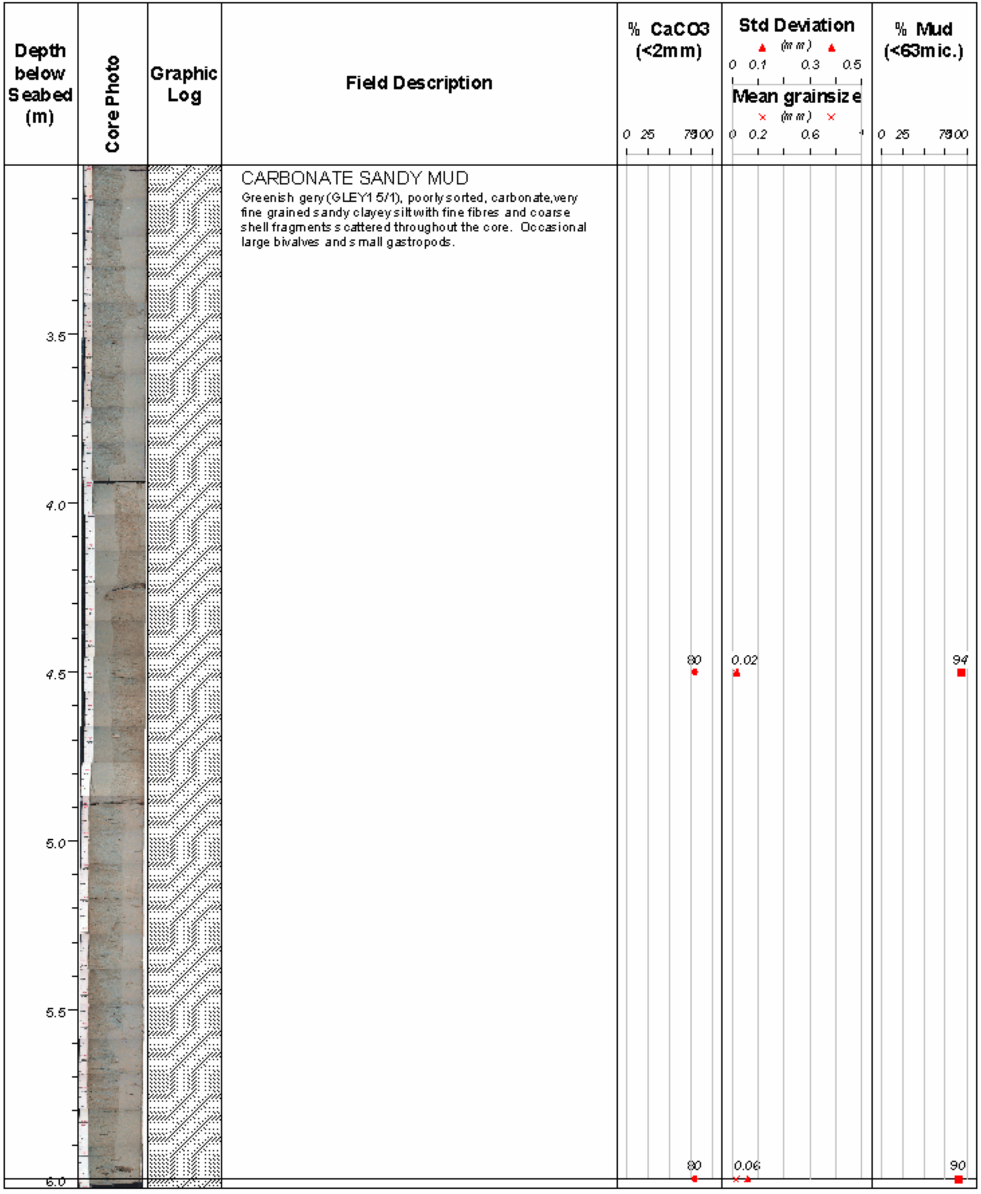
CARBONATE SANDY MUD

Greenish-grey (GLEY1 5/1), carbonate, poorly sorted very fine grained sandy, clayey silt with fine, hair-like fibres and coarse grained shell fragments scattered throughout the core. Occasional large (to 5cm) whole bivalves and smaller (to 1 cm) gastropods.

Project: Cockburn Sound, WA **Water Depth (m):** 19.1

Vibracore: CSV02 **Recovery (m):** 6.19 **Date:** 11/03/2004

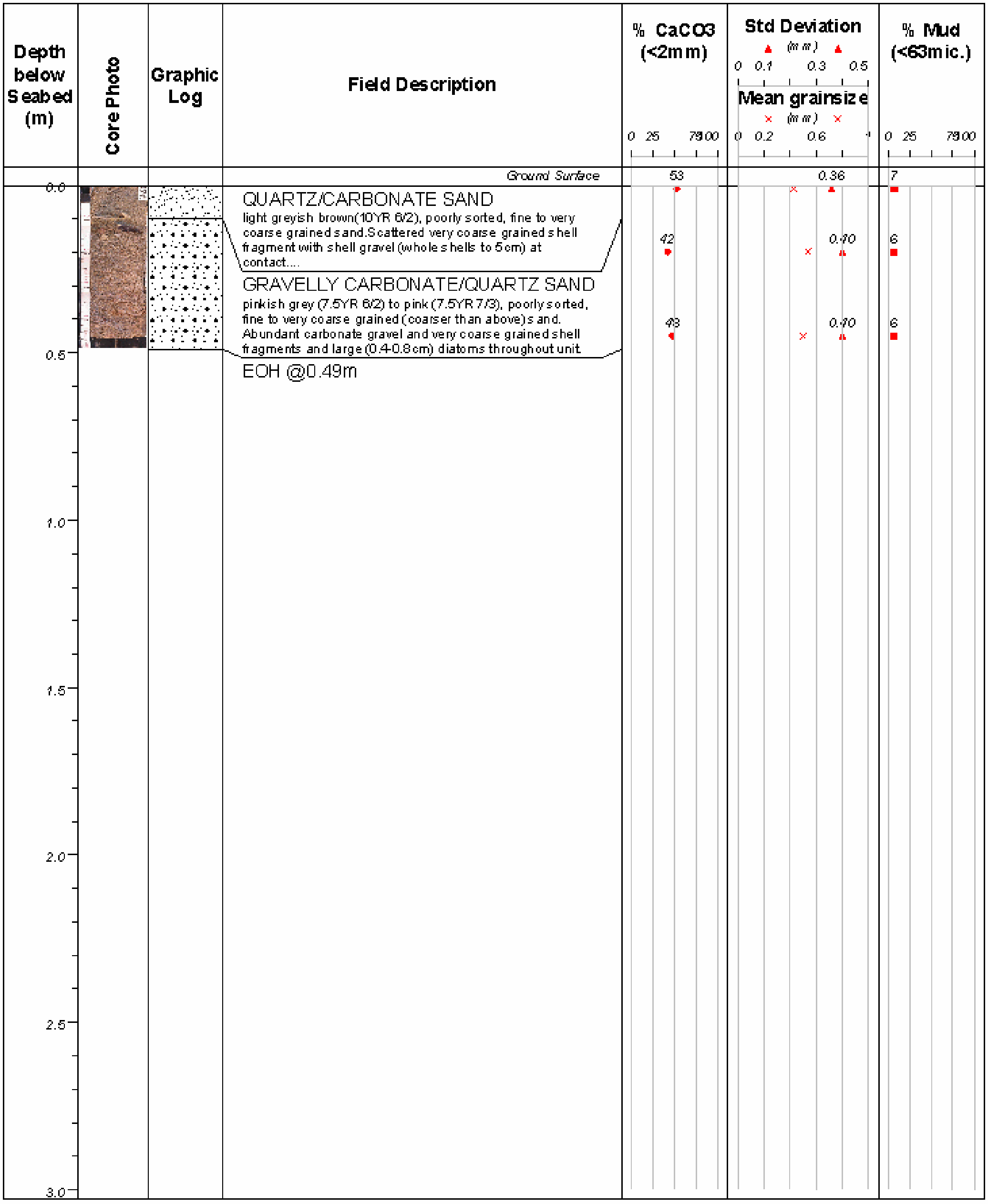
Coordinates (WGS84/UTM): 380227 6431231 **Time (GMT):** 0350



CARBONATE SANDY MUD

Greenish gery (GLEY1 5/1), poorly sorted, carbonate, very fine grained sandy clayey silt with fine fibres and coarse shell fragments scattered throughout the core. Occasional large bivalves and small gastropods.

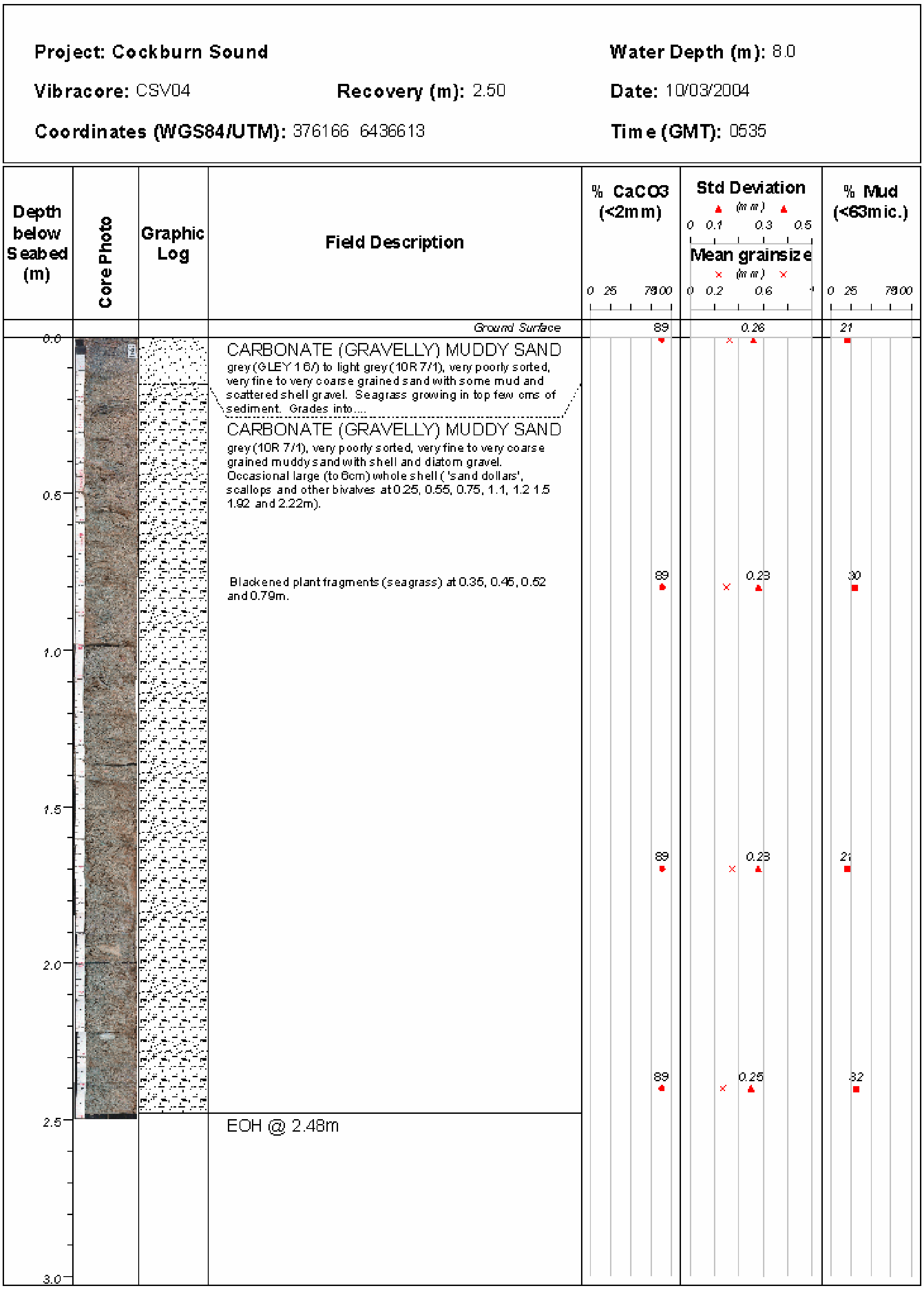
Project: **Cockburn Sound**
Water Depth (m): 3.9
Vibracore: CSV03
Recovery (m): 0.49
Date: 11/03/2004
Coordinates (WGS84/UTM): 382510 6431230
Time (GMT): 0300



QUARTZ/CARBONATE SAND
light greyish brown(10YR 6/2), poorly sorted, fine to very coarse grained sand.Scattered very coarse grained shell fragment with shell gravel (whole shells to 5cm) at contact....

GRAVELLY CARBONATE/QUARTZ SAND
pinkish grey (7.5YR 6/2) to pink (7.5YR 7/3), poorly sorted, fine to very coarse grained (coarser than above) sand. Abundant carbonate gravel and very coarse grained shell fragments and large (0.4-0.8cm) diatoms throughout unit

EOH @0.49m



Project: Cockburn Sound

Water Depth (m): 8.0

Vibracore: CSV04

Recovery (m): 2.50

Date: 10/03/2004

Coordinates (WGS84/UTM): 376166 6436613

Time (GMT): 0535

Field Description

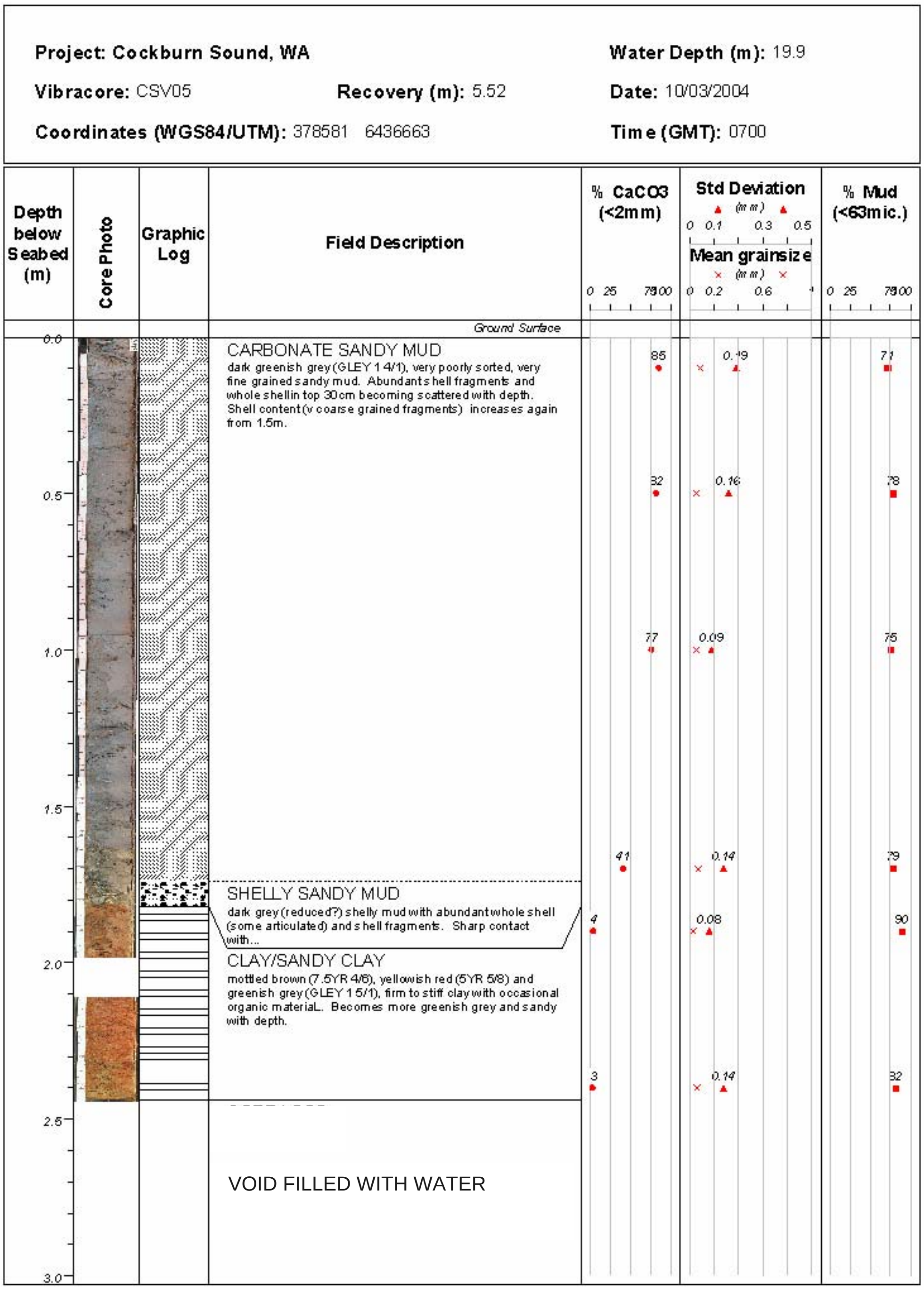
Ground Surface

CARBONATE (GRAVELLY) MUDDY SAND
grey (GLEY 1 6/) to light grey (10R 7/1), very poorly sorted, very fine to very coarse grained sand with some mud and scattered shell gravel. Seagrass growing in top few cms of sediment. Grades into....

CARBONATE (GRAVELLY) MUDDY SAND
grey (10R 7/1), very poorly sorted, very fine to very coarse grained muddy sand with shell and diatom gravel. Occasional large (to 6cm) whole shell ('sand dollars', scallops and other bivalves at 0.25, 0.55, 0.75, 1.1, 1.2 1.5 1.92 and 2.22m).

Blackened plant fragments (seagrass) at 0.35, 0.45, 0.52 and 0.79m.

EOH @ 2.48m



Project: Cockburn Sound, WA

Water Depth (m): 19.9

Vibracore: CSV05

Recovery (m): 5.52

Date: 10/03/2004

Coordinates (WGS84/UTM): 378581 6436663

Time (GMT): 0700

CARBONATE SANDY MUD

dark greenish grey (GLEY 1 4/1), very poorly sorted, very fine grained sandy mud. Abundant shell fragments and whole shell in top 30cm becoming scattered with depth. Shell content (v coarse grained fragments) increases again from 1.5m.

SHELLY SANDY MUD

dark grey (reduced?) shelly mud with abundant whole shell (some articulated) and shell fragments. Sharp contact with...

CLAY/SANDY CLAY

mottled brown (7.5YR 4/6), yellowish red (5YR 5/8) and greenish grey (GLEY 1 5/1), firm to stiff clay with occasional organic materiaL. Becomes more greenish grey and sandy with depth.

VOID FILLED WITH WATER

Project: Cockburn Sound, WA

Water Depth (m): 19.9

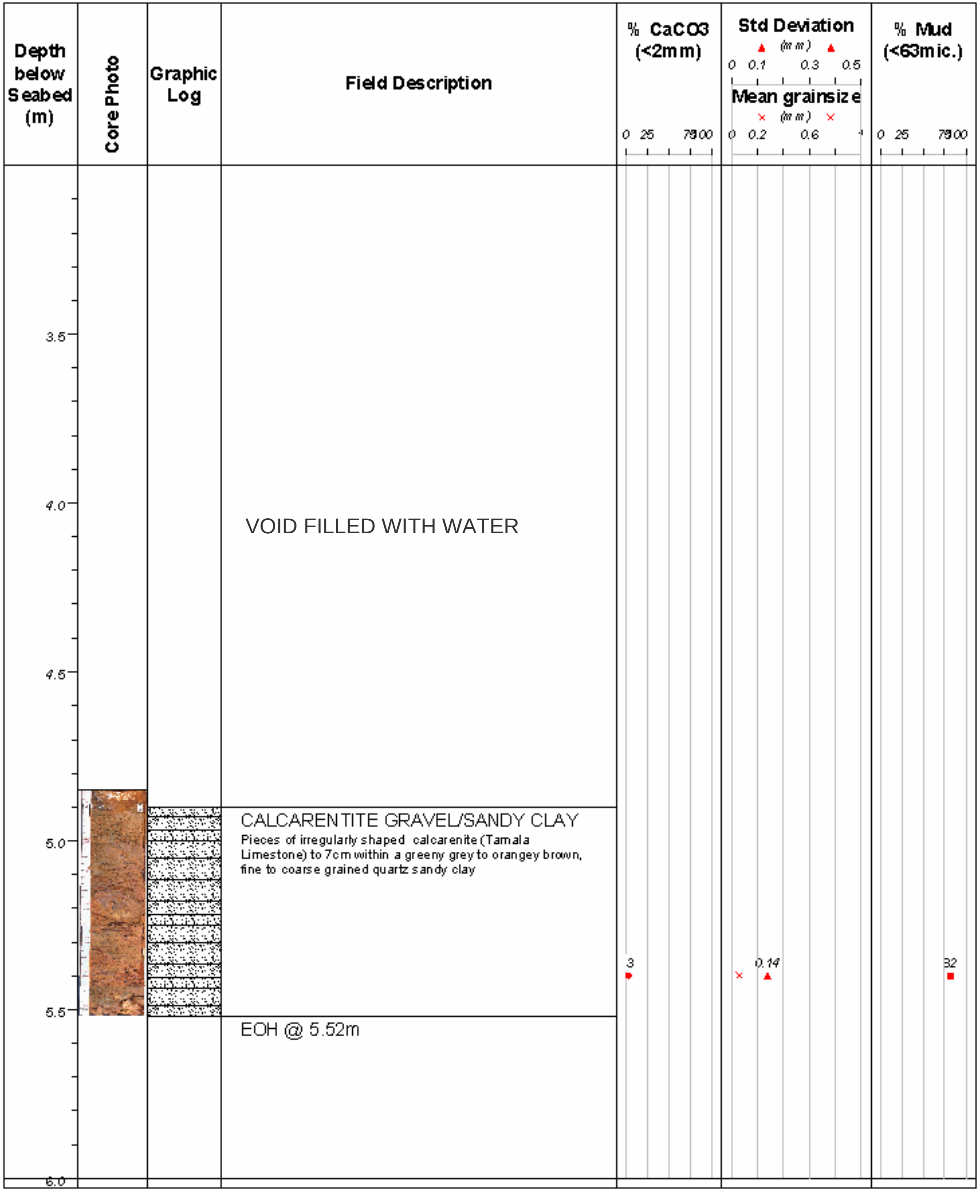
Vibracore: CSV05

Recovery (m): 5.52

Date: 10/03/2004

Coordinates (WGS84/UTM): 378581 6436663

Time (GMT): 0700



VOID FILLED WITH WATER

CALCARENTITE GRAVEL/SANDY CLAY

Pieces of irregularly shaped calcarenite (Tamala Limestone) to 7cm within a greeny grey to orangey brown, fine to coarse grained quartz sandy clay

EOH @ 5.52m

Project: Cockburn Sound

Water Depth (m): 14.5

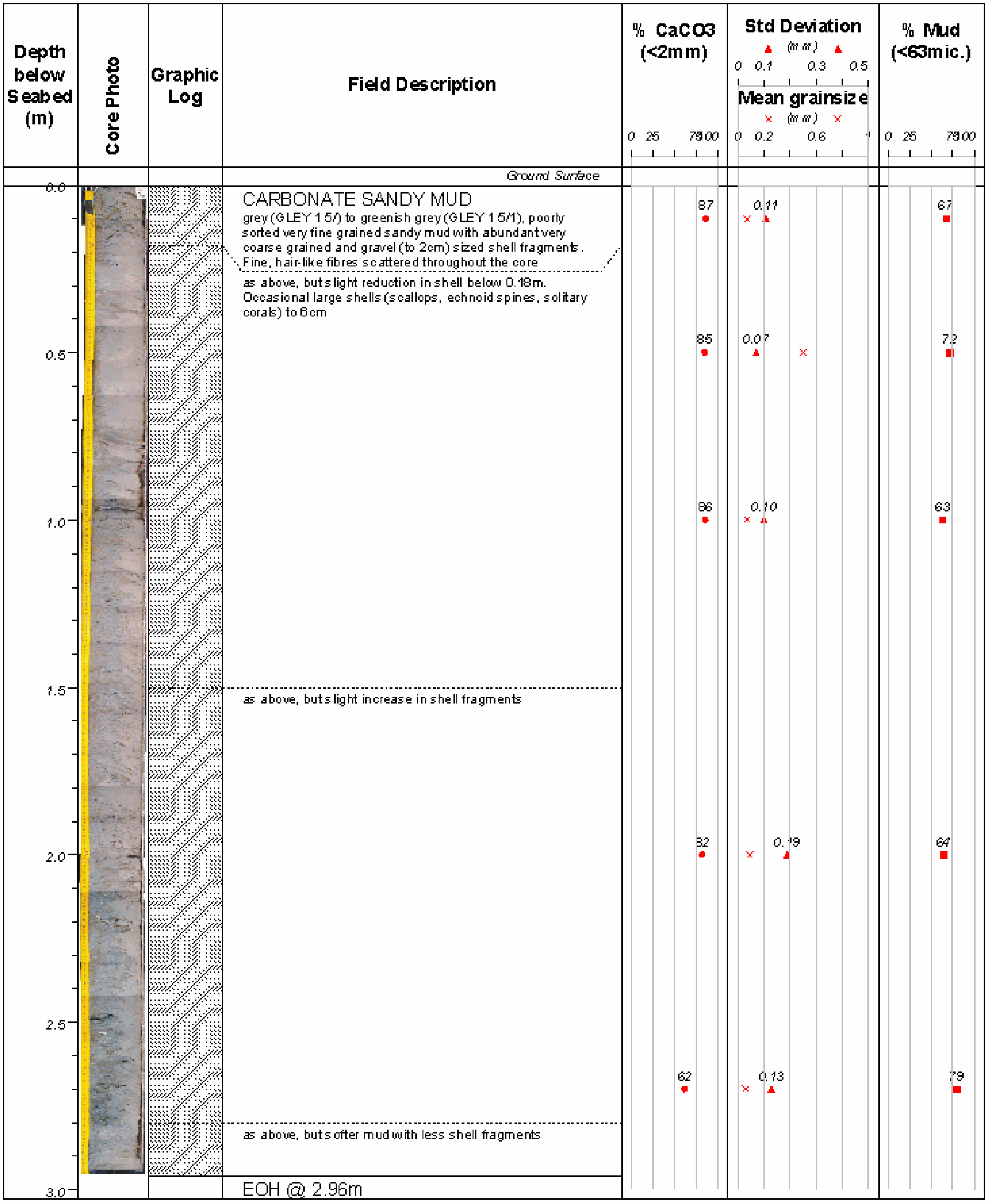
Vibracore: CSV06

Recovery (m): 2.96

Date: 10/03/2004

Coordinates (WGS84/UTM): 381333 6436683

Time (GMT): 0805



CARBONATE SANDY MUD

grey (GLEY 1 5/) to greenish grey (GLEY 1 5/1), poorly sorted very fine grained sandy mud with abundant very coarse grained and gravel (to 2cm) sized shell fragments. Fine, hair-like fibres scattered throughout the core

as above, but slight reduction in shell below 0.18m. Occasional large shells (scallops, echnoid spines, solitary corals) to 6cm

as above, but slight increase in shell fragments

as above, but softer mud with less shell fragments

EOH @ 2.96m

Project: **Cockburn Sound, WA**

Water Depth (m): 14.3

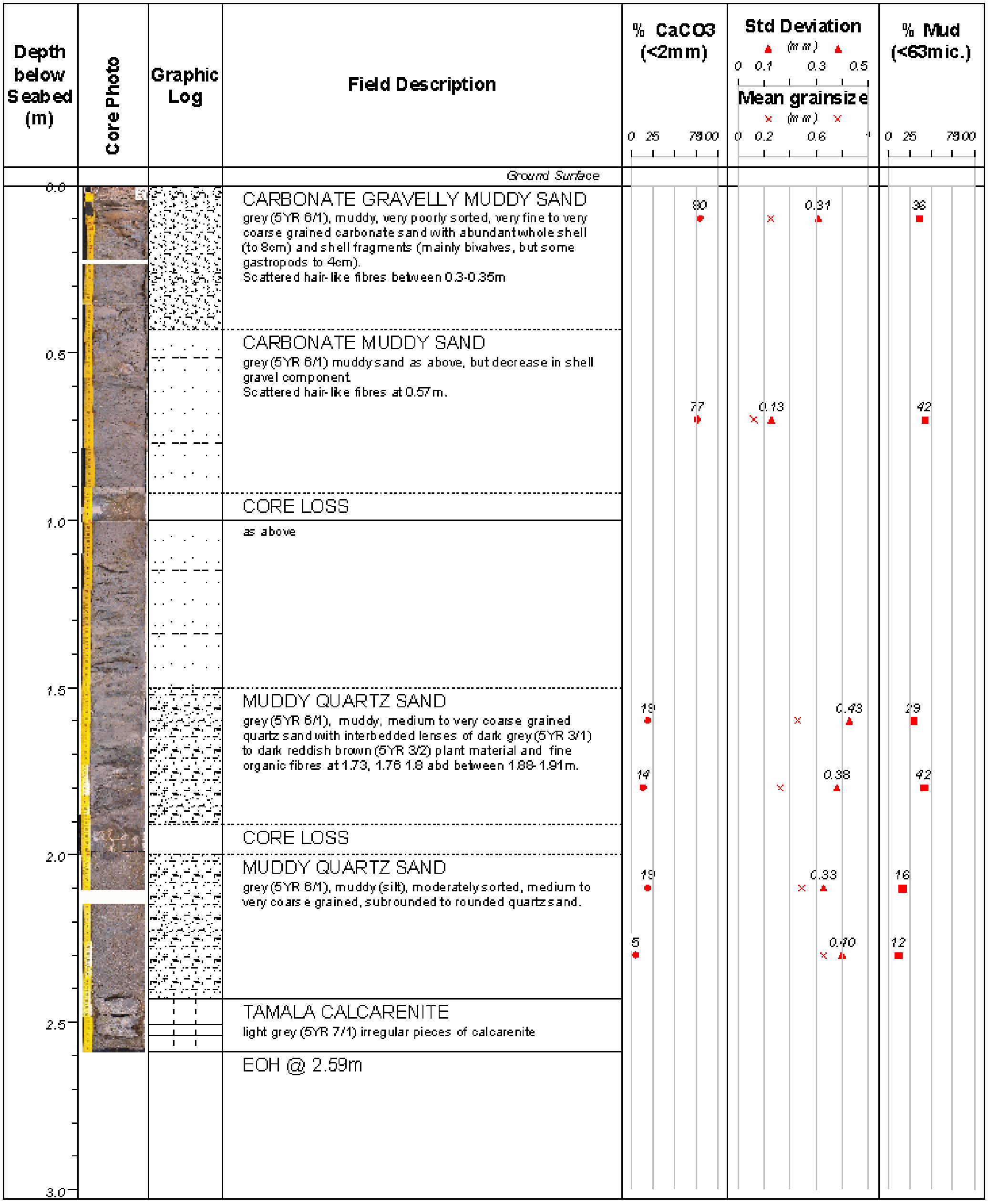
Vibracore: CSV07

Recovery (m): 2.59

Date: 10/03/2004

Coordinates (WGS84/UTM): 376286 6436610

Time (GMT): 0615



CARBONATE GRAVELLY MUDDY SAND

grey (5YR 6/1), muddy, very poorly sorted, very fine to very coarse grained carbonate sand with abundant whole shell (to 8cm) and shell fragments (mainly bivalves, but some gastropods to 4cm).
Scattered hair-like fibres between 0.3-0.35m

CARBONATE MUDDY SAND

grey (5YR 6/1) muddy sand as above, but decrease in shell gravel component
Scattered hair-like fibres at 0.57m.

CORE LOSS

as above

MUDDY QUARTZ SAND

grey (5YR 6/1), muddy, medium to very coarse grained quartz sand with interbedded lenses of dark grey (5YR 3/1) to dark reddish brown (5YR 3/2) plant material and fine organic fibres at 1.73, 1.76 1.8 abd between 1.88-1.91m.

CORE LOSS

MUDDY QUARTZ SAND

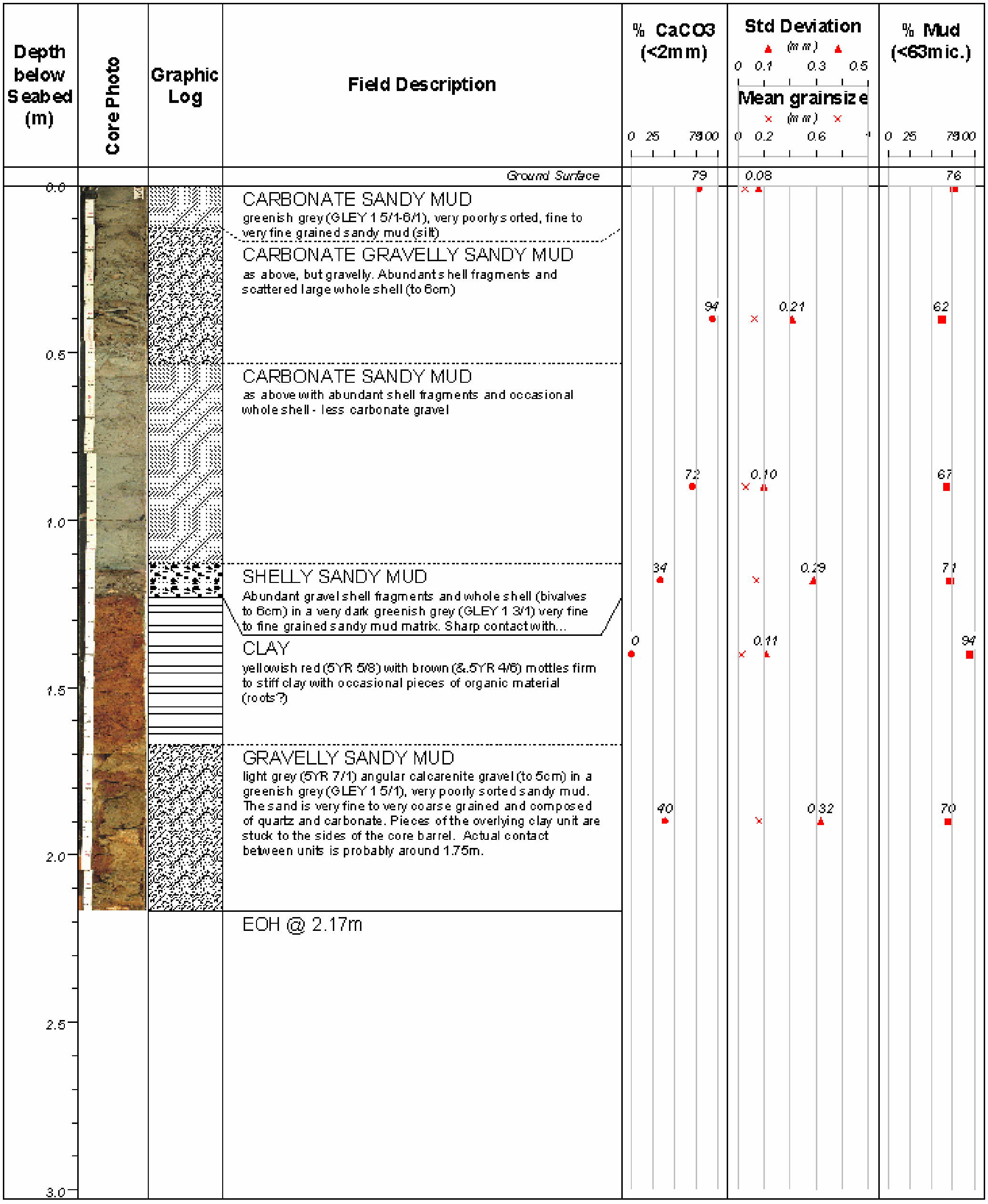
grey (5YR 6/1), muddy (silt), moderately sorted, medium to very coarse grained, subrounded to rounded quartz sand.

TAMALA CALCARENITE

light grey (5YR 7/1) irregular pieces of calcarenite

EOH @ 2.59m

Project: Cockburn Sound, WA
Water Depth (m): 19.5
Vibracore: CSV08
Recovery (m): 2.17
Date: 11/03/2004
Coordinates (WGS84/UTM): 377910 6440432
Time (GMT): 0140



CARBONATE SANDY MUD
greenish grey (GLEY 1 5/1-6/1), very poorly sorted, fine to very fine grained sandy mud (silt)

CARBONATE GRAVELLY SANDY MUD
as above, but gravelly. Abundant shell fragments and scattered large whole shell (to 6cm)

CARBONATE SANDY MUD
as above with abundant shell fragments and occasional whole shell - less carbonate gravel

SHELLY SANDY MUD
Abundant gravel shell fragments and whole shell (bivalves to 6cm) in a very dark greenish grey (GLEY 1 3/1) very fine to fine grained sandy mud matrix. Sharp contact with...

CLAY
yellowish red (5YR 5/8) with brown (&.5YR 4/6) mottles firm to stiff clay with occasional pieces of organic material (roots?)

GRAVELLY SANDY MUD
light grey (5YR 7/1) angular calcarenite gravel (to 5cm) in a greenish grey (GLEY 1 5/1), very poorly sorted sandy mud. The sand is very fine to very coarse grained and composed of quartz and carbonate. Pieces of the overlying clay unit are stuck to the sides of the core barrel. Actual contact between units is probably around 1.75m.

EOH @ 2.17m

Project: **Cockburn Sound, WA**

Water Depth (m): 18.6

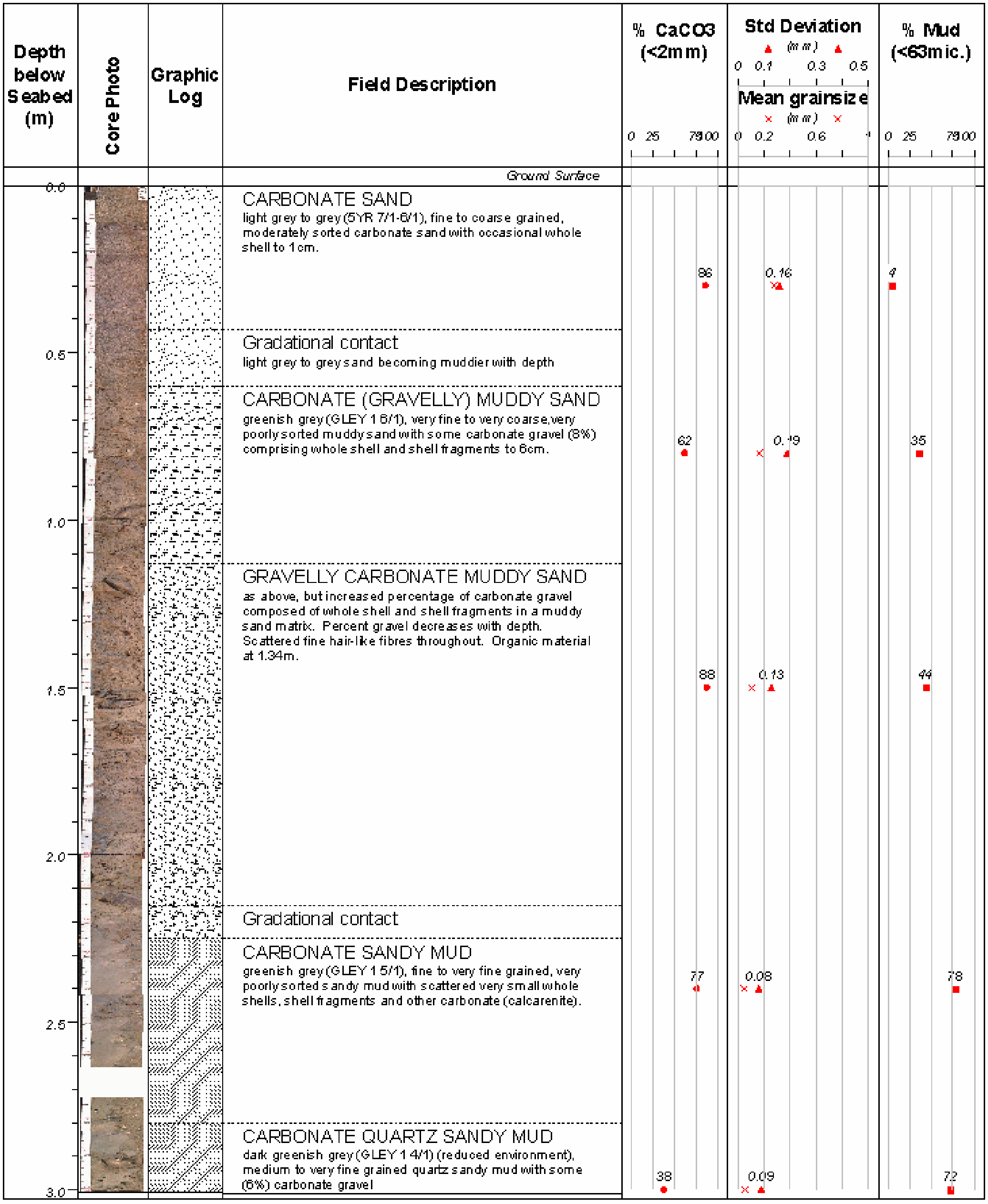
Vibracore: CSV09

Recovery (m): 3.01

Date: 11/03/2004

Coordinates (WGS84/UTM): 377192 6442803

Time (GMT): 0100



CARBONATE SAND

light grey to grey (5YR 7/1-6/1), fine to coarse grained, moderately sorted carbonate sand with occasional whole shell to 1cm.

Gradational contact

light grey to grey sand becoming muddier with depth

CARBONATE (GRAVELLY) MUDDY SAND

greenish grey (GLEY 1 6/1), very fine to very coarse, very poorly sorted muddy sand with some carbonate gravel (8%) comprising whole shell and shell fragments to 6cm.

GRAVELLY CARBONATE MUDDY SAND

as above, but increased percentage of carbonate gravel composed of whole shell and shell fragments in a muddy sand matrix. Percent gravel decreases with depth. Scattered fine hair-like fibres throughout. Organic material at 1.34m.

Gradational contact

CARBONATE SANDY MUD

greenish grey (GLEY 1 5/1), fine to very fine grained, very poorly sorted sandy mud with scattered very small whole shells, shell fragments and other carbonate (calcarenite).

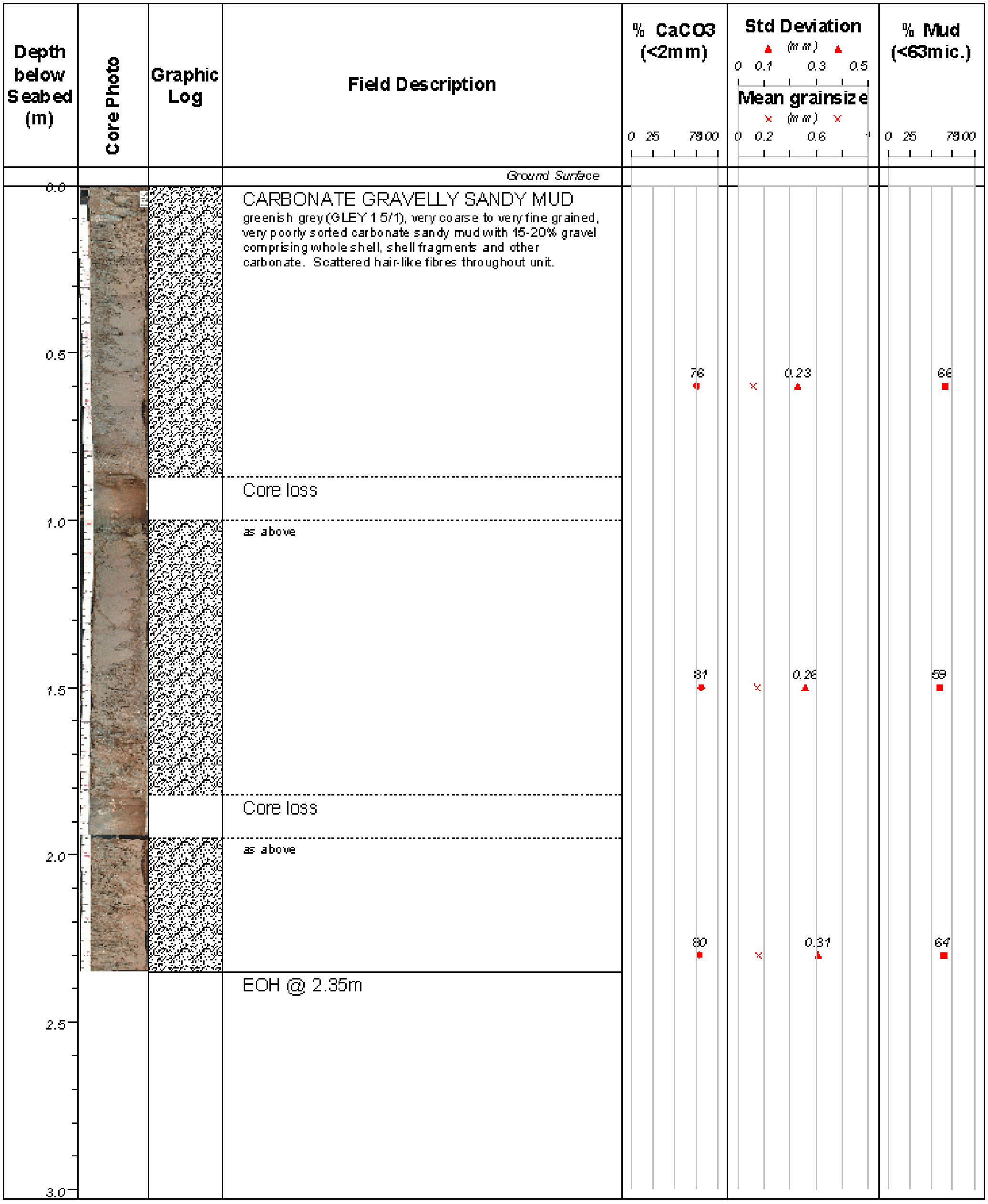
CARBONATE QUARTZ SANDY MUD

dark greenish grey (GLEY 1 4/1) (reduced environment), medium to very fine grained quartz sandy mud with some (6%) carbonate gravel

Project: Cockburn Sound, WA **Water Depth (m):** 16.5

Vibracore: CSV10 **Recovery (m):** 2.35 **Date:** 11/03/2004

Coordinates (WGS84/UTM): 379945 6442769 **Time (GMT):** 0025



CARBONATE GRAVELLY SANDY MUD
greenish grey (GLEY 1 5/1), very coarse to very fine grained, very poorly sorted carbonate sandy mud with 15-20% gravel comprising whole shell, shell fragments and other carbonate. Scattered hair-like fibres throughout unit.

Core loss

as above

Core loss

as above

EOH @ 2.35m

Project: **Cockburn Sound, WA**

Water Depth (m): 10.0

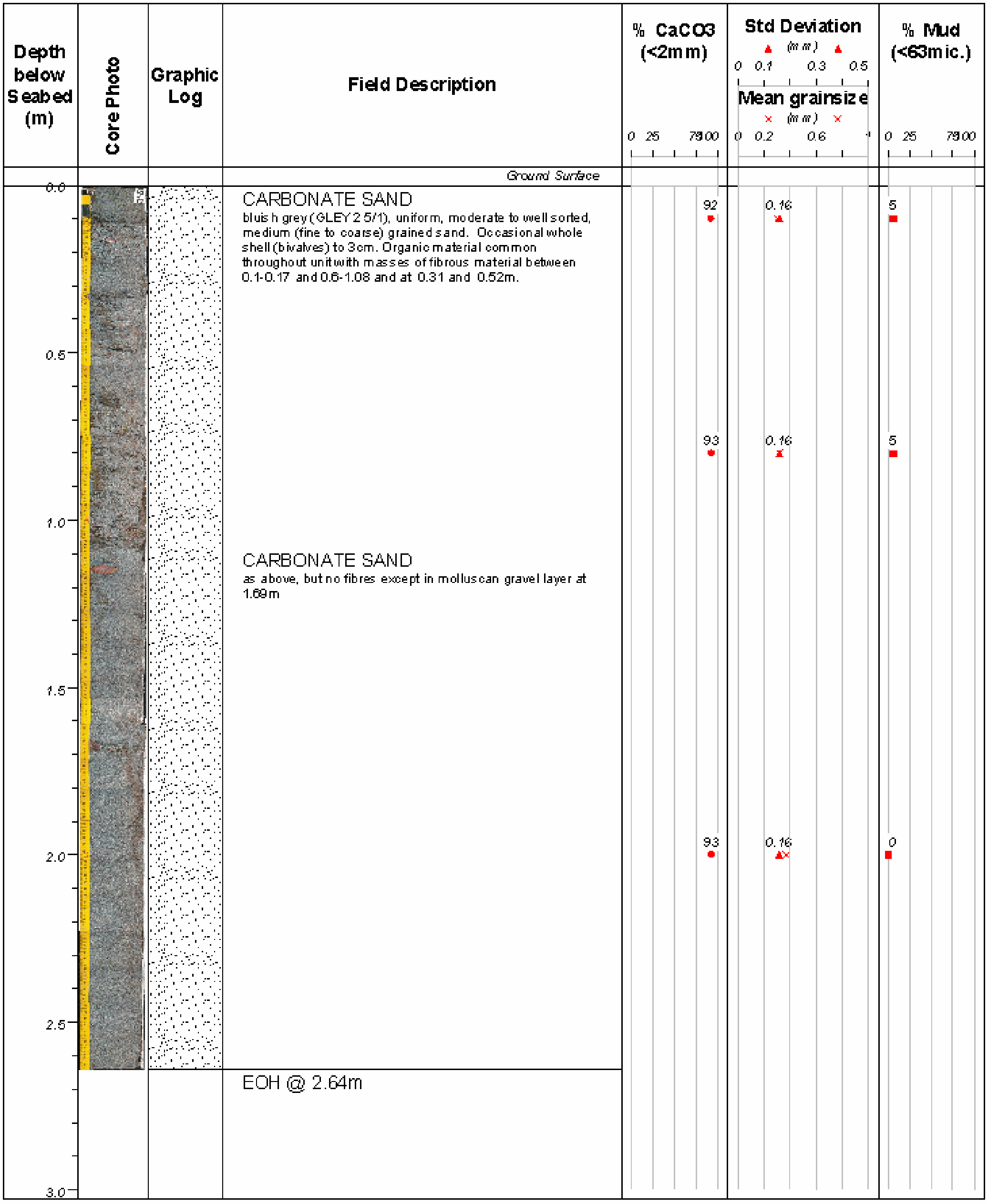
Vibracore: CSV12

Recovery (m): 2.65

Date: 10/03/2004

Coordinates (WGS84/UTM): 376322 6447173

Time (GMT): 0315



CARBONATE SAND

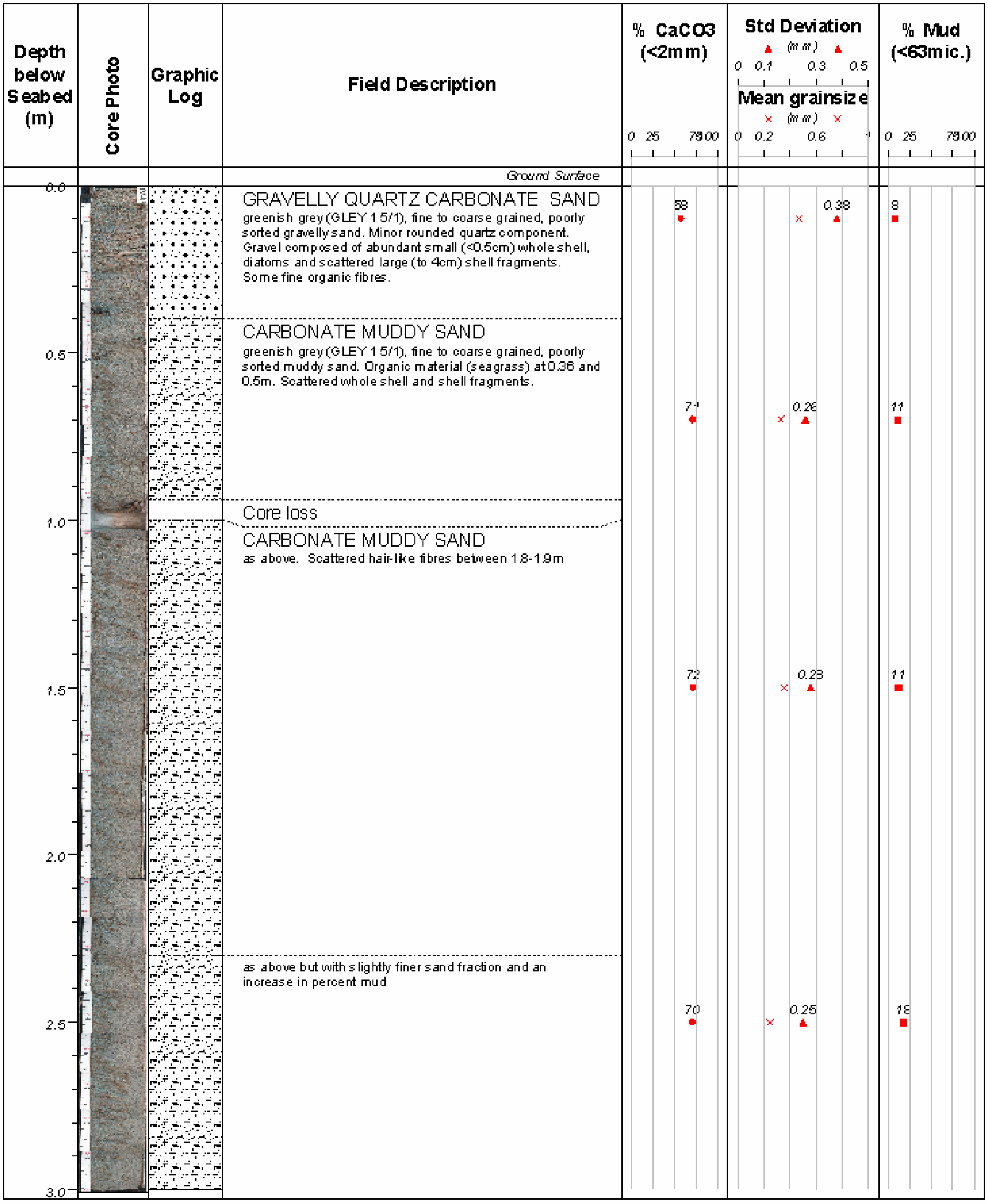
bluish grey (GLEY 2 5/1), uniform, moderate to well sorted, medium (fine to coarse) grained sand. Occasional whole shell (bivalves) to 3cm. Organic material common throughout unit with masses of fibrous material between 0.1-0.17 and 0.6-1.08 and at 0.31 and 0.52m.

CARBONATE SAND

as above, but no fibres except in molluscan gravel layer at 1.69m

EOH @ 2.64m

Project: Cockburn Sound, WA
Water Depth (m): 7.5
Vibracore: CSV13
Recovery (m): 3.00
Date: 11/03/2004
Coordinates (WGS84/UTM): 382213 6431230
Time (GMT): 0645



GRAVELLY QUARTZ CARBONATE SAND
greenish grey (GLEY 1 5/1), fine to coarse grained, poorly sorted gravelly sand. Minor rounded quartz component. Gravel composed of abundant small (<0.5cm) whole shell, diatoms and scattered large (to 4cm) shell fragments. Some fine organic fibres.

CARBONATE MUDDY SAND
greenish grey (GLEY 1 5/1), fine to coarse grained, poorly sorted muddy sand. Organic material (seagrass) at 0.36 and 0.5m. Scattered whole shell and shell fragments.

Core loss

CARBONATE MUDDY SAND
as above. Scattered hair-like fibres between 1.8-1.9m

as above but with slightly finer sand fraction and an increase in percent mud

APPENDIX III

Table A3.1: Grain size data (gravel/sand/mud) for vibracore samples

GA SAMPLE #	SAMPLE ID & DEPTH (m)	%GRAVEL	%SAND	%MUD	COMBINED SAND & MUD CaCO3%
1419971	251/CSV001_0.1-0.11	2.9	96.3	0.8	89.2
1419972	251/CSV001_0.5-0.51	3.8	95.7	0.5	91.8
1419973	251/CSV001_0.99-1	4.0	94.9	1.1	92.3
1419974	251/CSV001_1.5-1.51	0.1	98.6	1.2	93.3
1419975	251/CSV001_2.5-2.51	0.0	99.0	1.0	91.8
1419976	251/CSV002_0.8-0.81	0.4	15.0	84.6	83.1
1419977	251/CSV002_2.5-2.51	0.6	6.7	92.7	73.0
1419978	251/CSV002_4.5-4.51	0.1	4.5	95.4	80.1
1419979	251/CSV002_5.99-6	0.0	9.4	90.6	80.1
1419980	251/CSV003_0-0.01	6.7	90.0	3.2	52.7
1419981	251/CSV003_0.2-0.21	7.6	91.0	1.4	42.0
1419982	251/CSV003_0.44-0.45	23.5	74.8	1.7	47.6
1419983	251/CSV004_0-0.01	6.3	84.6	9.2	88.7
1419984	251/CSV004_0.8-0.81	9.1	79.7	11.2	89.2
1419985	251/CSV004_1.7-1.71	5.9	80.0	14.1	89.2
1419986	251/CSV004_2.4-2.41	4.1	80.7	15.2	88.7
1419987	251/CSV005_0.1-0.11	12.4	23.2	64.4	85.2
1419988	251/CSV005_0.5-0.51	2.2	26.9	70.9	82.1
1419989	251/CSV005_0.99-1	1.1	26.5	72.4	76.5
1419990	251/CSV005_1.7-1.71	6.9	19.7	73.4	41.0
1419991	251/CSV005_1.9-1.91	10.6	15.4	74.0	4.0
1419992	251/CSV005_2.4-2.41	2.5	22.1	75.4	3.0
1419993	251/CSV005_5.4-5.41	27.8	22.9	49.4	3.0
1419994	251/CSV006_0.1-0.11	15.2	36.8	48.0	86.7
1419995	251/CSV006_0.5-0.51	1.4	31.1	67.6	85.2
1419996	251/CSV006_0.99-1	1.7	38.0	60.2	86.2
1419997	251/CSV006_2-2.01	1.6	36.9	61.5	82.1
1419998	251/CSV006_2.7-2.71	8.0	25.3	66.8	61.8
1419999	251/CSV007_0.1-0.11	19.7	53.0	27.3	80.1
1420000	251/CSV007_0.7-0.71	2.7	57.7	39.6	77.0
1420001	251/CSV007_1.6-1.61	1.6	67.8	30.6	19.2
1420002	251/CSV007_1.79-1.8	0.7	76.7	22.6	14.1
1420003	251/CSV007_2.1-2.11	0.4	89.8	9.9	19.2
1420004	251/CSV007_2.3-2.31	1.6	90.9	7.5	5.0
1420005	251/CSV008_0-0.01	2.0	26.2	71.7	78.6
1420006	251/CSV008_0.4-0.41	21.0	29.3	49.7	94.3
1420007	251/CSV008_0.9-0.91	2.1	34.4	63.5	71.5
1420008	251/CSV008_1.18-1.19	10.5	27.8	61.6	33.9
1420009	251/CSV008_1.4-1.41	2.1	8.8	89.1	0.0
1420010	251/CSV008_1.9-1.91	23.0	34.9	42.1	39.5

GA SAMPLE #	SAMPLE ID & DEPTH (m)	%GRAVEL	%SAND	%MUD	COMBINED SAND & MUD CaCO3%
1420011	251/CSV009_0.3-0.31	2.4	95.5	2.1	86.2
1420012	251/CSV009_0.8-0.81	8.7	67.9	23.4	62.3
1420013	251/CSV009_1.5-1.51	27.4	47.7	24.9	88.2
1420014	251/CSV009_2.4-2.41	2.9	22.6	74.5	76.5
1420015	251/CSV009_3-3.01	6.0	29.3	64.6	38.0
1420016	251/CSV010_0.6-0.61	15.1	40.5	44.5	76.0
1420017	251/CSV010_1.5-1.51	20.8	38.7	40.5	81.1
1420018	251/CSV010_2.3-2.31	21.2	36.3	42.4	79.6
1420019	251/CSV012_0.1-0.11	0.3	98.1	1.7	92.3
1420020	251/CSV012_0.8-0.81	0.6	98.7	0.7	92.8
1420021	251/CSV012_2-2.01	0.3	99.3	0.4	92.8
1420022	251/CSV013_0.1-0.11	15.8	79.9	4.3	57.8
1420023	251/CSV013_0.7-0.71	1.4	91.8	6.8	71.0
1420024	251/CSV013_1.5-1.51	1.0	88.6	10.4	72.0
1420025	251/CSV013_2.5-2.51	2.4	84.2	13.4	70.4

Table A3.2: Average laser grain size data (Malvern Laser Analyser) for the vibracore samples

GA SAMPLE #	SAMPLE ID & DEPTH (m)	D (0.1)	D (0.5)	D (0.9)	D [4, 3] - VOLUME WEIGHTED MEAN
1419971	251/CSV001_0.1-0.11	177.557	385.265	765.705	428.9
1419972	251/CSV001_0.5-0.51	171.918	379.36	807.374	438.065
1419973	251/CSV001_0.99-1	166.538	320.595	589.872	349.952
1419974	251/CSV001_1.5-1.51	167.753	341.124	638.672	372.468
1419975	251/CSV001_2.5-2.51	135.703	254.951	468.286	279.572
1419976	251/CSV002_0.8-0.81	1.314	16.439	59.047	28.167
1419977	251/CSV002_2.5-2.51	0.964	13.999	52.16	21.159
1419978	251/CSV002_4.5-4.51	0.963	15.857	52.915	22.133
1419979	251/CSV002_5.99-6	1.081	17.516	61.261	31.611
1419980	251/CSV003_0-0.01	102.591	301.337	960.091	426.228
1419981	251/CSV003_0.2-0.21	123.834	438.978	1114.958	536.27
1419982	251/CSV003_0.44-0.45	109.289	372.281	1093.113	498.713
1419983	251/CSV004_0-0.01	5.605	287.942	699.886	326.856
1419984	251/CSV004_0.8-0.81	3.77	248.3	699.829	299.132
1419985	251/CSV004_1.7-1.71	7.514	313.837	740.883	349.441
1419986	251/CSV004_2.4-2.41	2.822	235.597	637.869	273.984
1419987	251/CSV005_0.1-0.11	1.441	32.786	168.912	88.628
1419988	251/CSV005_0.5-0.51	1.595	32.424	90.367	64.107
1419989	251/CSV005_0.99-1	1.438	33.155	98.904	52.874
1419990	251/CSV005_1.7-1.71	0.932	11.606	234.777	69.193
1419991	251/CSV005_1.9-1.91	0.853	6.785	66.868	31.74
1419992	251/CSV005_2.4-2.41	0.747	3.983	293.48	61.424
1419993	251/CSV005_5.4-5.41	0.713	4.57	287.504	61.465
1419994	251/CSV006_0.1-0.11	1.551	38.384	137.47	70.085
1419995	251/CSV006_0.5-0.51	1.432	34.672	108.203	52.368
1419996	251/CSV006_0.99-1	2.003	43.978	131.431	67.062
1419997	251/CSV006_2-2.01	2.017	42.378	141.42	88.45
1419998	251/CSV006_2.7-2.71	0.866	16.855	120.83	58.633
1419999	251/CSV007_0.1-0.11	2.756	131.191	714.598	245.478
1420000	251/CSV007_0.7-0.71	3.32	87.513	281.774	121.403
1420001	251/CSV007_1.6-1.61	2.641	396.092	1062.528	456.014
1420002	251/CSV007_1.79-1.8	4.928	141.765	892.225	332.746
1420003	251/CSV007_2.1-2.11	8.503	478.017	927.847	487.114
1420004	251/CSV007_2.3-2.31	24.137	632.805	1196.226	656.33
1420005	251/CSV008_0-0.01	1.552	25.893	105.198	50.029
1420006	251/CSV008_0.4-0.41	1.778	40.682	433.783	126.012
1420007	251/CSV008_0.9-0.91	1.556	38.017	133.538	64.702
1420008	251/CSV008_1.18-1.19	1.137	12.897	588.514	143.576
1420009	251/CSV008_1.4-1.41	1.003	7.335	42.687	28.225
1420010	251/CSV008_1.9-1.91	0.856	8.975	633.952	164.078
1420011	251/CSV009_0.3-0.31	116.279	250.142	499.926	281.596
1420012	251/CSV009_0.8-0.81	3.768	111.678	416.563	169.024
1420013	251/CSV009_1.5-1.51	2.633	76.325	258.533	110.401
1420014	251/CSV009_2.4-2.41	0.971	18.126	110.474	47.124
1420015	251/CSV009_3-3.01	0.975	18.207	145.464	53.812
1420016	251/CSV010_0.6-0.61	1.894	30.552	375.768	119.607
1420017	251/CSV010_1.5-1.51	2.221	39.79	513.018	151.51
1420018	251/CSV010_2.3-2.31	1.876	33.559	580.634	162.929
1420019	251/CSV012_0.1-0.11	136.11	287.498	530.331	309.486
1420020	251/CSV012_0.8-0.81	150.312	303.674	543.835	323.932
1420021	251/CSV012_2-2.01	192	342.948	604.977	373.851
1420022	251/CSV013_0.1-0.11	89.631	362.446	1032.77	472.316
1420023	251/CSV013_0.7-0.71	43.755	272.089	698.041	332.589
1420024	251/CSV013_1.5-1.51	37.822	290.793	760.057	358.156
1420025	251/CSV013_2.5-2.51	14.963	173.189	568.013	245.615

SAMPLE ID & DEPTH (m)	OBSCURATION	KURTOSIS	SKEW	MODE	STANDARD DEVIATION	RESIDUAL WEIGHTED MEAN
251/CSV001_0.1-0.11	5.6	0.419	0.749	395.47	238.63	2.37
251/CSV001_0.5-0.51	6.35	0.781	0.981	377.41	258.08	2.15
251/CSV001_0.99-1	6.19	0.392	0.694	325.38	171.24	1.57
251/CSV001_1.5-1.51	6.06	0.234	0.649	353.71	188.42	1.76
251/CSV001_2.5-2.51	7.35	0.545	0.77	256.37	134.49	1.44
251/CSV002_0.8-0.81	17.12	50.249	6.229	28.14	48.71	1.08
251/CSV002_2.5-2.51	17.79	2.891	1.603	27.86	22.51	1.15
251/CSV002_4.5-4.51	14.96	2.332	1.455	29.05	22.30	1.15
251/CSV002_5.99-6	13.57	38.691	5.661	28.20	59.39	1.17
251/CSV003_0-0.01	12.81	1.582	1.371	230.84	360.46	1.77
251/CSV003_0.2-0.21	8.74	0.361	0.935	709.26	398.49	2.51
251/CSV003_0.44-0.45	10.09	0.622	1.083	728.92	401.83	2.01
251/CSV004_0-0.01	18.43	0.178	0.79	396.13	264.67	1.42
251/CSV004_0.8-0.81	22.47	0.111	0.875	432.62	277.53	1.46
251/CSV004_1.7-1.71	18.24	0.01	0.714	436.07	278.38	1.51
251/CSV004_2.4-2.41	19.17	-0.103	0.791	405.78	253.35	1.20
251/CSV005_0.1-0.11	16.9	17.12	3.911	50.31	186.34	0.85
251/CSV005_0.5-0.51	11.82	43.496	6.071	47.10	155.53	0.81
251/CSV005_0.99-1	13.6	32.367	5.139	50.58	89.71	0.82
251/CSV005_1.7-1.71	14	8.256	2.924	3.70	143.97	1.20
251/CSV005_1.9-1.91	20.41	21.409	4.385	13.45	79.02	1.35
251/CSV005_2.4-2.41	19.26	5.305	2.523	2.58	137.10	1.59
251/CSV005_5.4-5.41	17.89	5.338	2.523	2.45	135.35	1.55
251/CSV006_0.1-0.11	13.61	14.238	3.547	63.22	114.35	0.86
251/CSV006_0.5-0.51	12.71	20.98	4.007	59.53	73.54	0.99
251/CSV006_0.99-1	14.52	24.083	4.349	70.21	100.55	0.72
251/CSV006_2-2.01	11.27	29.987	5.089	64.44	189.43	0.72
251/CSV006_2.7-2.71	13.7	16.292	3.864	38.63	125.44	1.13
251/CSV007_0.1-0.11	21.23	3.399	1.878	167.88	314.68	1.05
251/CSV007_0.7-0.71	10.8	4.994	1.832	158.44	126.30	0.69
251/CSV007_1.6-1.61	8.87	-0.091	0.783	685.22	426.00	2.06
251/CSV007_1.79-1.8	8.13	0.236	1.052	641.01	375.74	1.38
251/CSV007_2.1-2.11	13.36	-0.436	0.302	585.36	328.39	3.10
251/CSV007_2.3-2.31	13.81	-0.21	0.307	725.34	400.77	4.30
251/CSV008_0-0.01	12.38	19.825	4.038	52.00	82.79	0.97
251/CSV008_0.4-0.41	16.64	6.386	2.538	54.61	214.66	0.93
251/CSV008_0.9-0.91	11.37	18.648	3.879	63.28	98.64	0.84
251/CSV008_1.18-1.19	17.03	6.6	2.599	5.03	293.40	1.15
251/CSV008_1.4-1.41	14.34	99.917	9.175	13.80	108.53	1.20
251/CSV008_1.9-1.91	18.6	5.729	2.404	2.93	316.55	1.39
251/CSV009_0.3-0.31	6.58	1.378	1.02	256.03	161.66	1.22
251/CSV009_0.8-0.81	12.25	4.919	1.953	162.31	188.81	0.74
251/CSV009_1.5-1.51	15.48	8.272	2.359	118.32	127.28	0.71
251/CSV009_2.4-2.41	18.88	16.97	3.76	55.07	82.15	1.14
251/CSV009_3-3.01	15.66	11.659	3.006	81.25	84.88	0.96
251/CSV010_0.6-0.61	11.68	11.613	3.19	45.08	229.22	0.92
251/CSV010_1.5-1.51	19.21	7.443	2.588	55.42	257.78	0.94
251/CSV010_2.3-2.31	10.8	7.595	2.72	45.09	308.98	0.89
251/CSV012_0.1-0.11	3.32	0.079	0.515	302.80	158.11	1.33
251/CSV012_0.8-0.81	3.21	0.13	0.458	317.61	159.25	1.44
251/CSV012_2-2.01	4.45	0.194	0.813	344.91	160.58	1.79
251/CSV013_0.1-0.11	8.37	0.794	1.107	619.63	383.56	1.83
251/CSV013_0.7-0.71	10.99	0.884	1.066	321.04	255.11	1.22
251/CSV013_1.5-1.51	11.83	0.964	1.093	355.70	281.26	1.27
251/CSV013_2.5-2.51	19.36	4.575	1.984	173.08	245.78	0.93

SAMPLE ID & DEPTH (m)	**SIZES (µM) % UNDER**											
	0.06	**0.12**	**0.24**	**0.49**	**0.98**	**2**	**3.9**	**7.8**	**15.6**	**31**	**37**	**44**
CSV001_0.1-0.11	0	0	0	0.00	0.30	0.96	1.82	2.76	3.51	4.03	4.23	4.43
CSV001_0.5-0.51	0	0	0	0.00	0.00	0.27	0.87	1.63	2.16	2.62	2.79	2.94
CSV001_0.99-1	0	0	0	0.00	0.00	0.08	0.65	1.48	1.98	2.52	2.75	2.95
CSV001_1.5-1.51	0	0	0	0.00	0.00	0.10	0.68	1.50	2.11	2.76	3.01	3.25
CSV001_2.5-2.51	0	0	0	0.00	0.00	0.05	0.67	1.55	1.88	2.13	2.19	2.20
CSV002_0.8-0.81	0	0	0	1.86	7.61	13.89	22.52	33.28	48.51	71.12	77.16	82.58
CSV002_2.5-2.51	0	0	0	2.85	10.18	17.73	26.79	37.68	52.87	74.65	80.41	85.60
CSV002_4.5-4.51	0	0	0	2.91	10.18	17.09	24.86	34.62	49.54	72.74	79.08	84.79
CSV002_5.99-6	0	0	0	2.51	9.12	15.22	22.30	31.63	46.57	69.89	76.15	81.74
CSV003_0-0.01	0	0	0	0.15	0.80	1.64	2.83	4.08	5.18	6.61	6.87	6.90
CSV003_0.2-0.21	0	0	0	0.00	0.31	0.84	1.98	3.59	4.73	5.69	5.88	5.91
CSV003_0.44-0.45	0	0	0	0.00	0.38	0.92	2.15	3.78	4.93	6.14	6.35	6.38
CSV004_0-0.01	0	0	0	0.66	2.29	4.21	7.82	11.65	14.28	17.17	18.00	18.83
CSV004_0.8-0.81	0	0	0	0.97	3.39	6.21	10.21	14.08	18.09	23.77	25.36	26.86
CSV004_1.7-1.71	0	0	0	0.74	2.62	4.75	7.50	10.13	12.92	16.69	17.75	18.77
CSV004_2.4-2.41	0	0	0	1.27	4.33	7.81	12.15	16.19	20.56	26.36	27.93	29.39
CSV005_0.1-0.11	0	0	0	2.06	7.18	12.72	19.34	26.03	34.12	48.40	53.68	59.37
CSV005_0.5-0.51	0	0	0	1.76	6.63	11.71	17.40	23.36	31.17	48.33	55.27	62.79
CSV005_0.99-1	0	0	0	2.10	7.34	12.30	17.59	23.51	31.51	47.71	53.98	60.78
CSV005_1.7-1.71	0	0	0	2.86	10.57	19.41	31.14	43.41	54.96	66.75	69.88	72.95
CSV005_1.9-1.91	0	0	0	2.74	12.20	25.39	39.19	52.86	68.88	82.46	84.79	86.66
CSV005_2.4-2.41	0	0	0	3.80	14.91	31.23	49.46	64.15	73.29	78.09	79.03	79.97
CSV005_5.4-5.41	0	0	0	4.39	15.62	30.65	46.58	60.31	71.73	78.24	79.16	79.96
CSV006_0.1-0.11	0	0	0	1.93	6.81	12.04	18.47	25.10	32.76	44.40	48.95	54.23
CSV006_0.5-0.51	0	0	0	2.17	7.42	12.31	17.74	24.11	32.77	46.77	52.03	57.94
CSV006_0.99-1	0	0	0	1.43	5.39	9.99	15.84	21.74	28.84	40.25	44.73	50.02
CSV006_2-2.01	0	0	0	1.50	5.65	9.95	14.61	19.76	27.27	40.62	45.64	51.28
CSV006_2.7-2.71	0	0	0	3.22	11.45	19.18	27.56	36.78	48.47	63.30	67.42	71.48
CSV007_0.1-0.11	0	0	0	1.15	4.08	7.62	12.93	18.24	23.36	29.79	31.39	32.85
CSV007_0.7-0.71	0	0	0	1.17	4.32	7.41	10.87	14.61	19.53	28.77	31.88	35.07
CSV007_1.6-1.61	0	0	0	1.08	4.24	8.15	12.70	17.04	21.09	25.21	26.22	27.17
CSV007_1.79-1.8	0	0	0	0.29	1.72	4.10	8.24	13.88	22.25	32.71	35.16	37.40
CSV007_2.1-2.11	0	0	0	0.34	1.81	4.06	6.93	9.68	12.23	14.43	14.90	15.35
CSV007_2.3-2.31	0	0	0	0.23	1.31	3.02	5.10	7.11	8.98	10.45	10.71	10.94
CSV008_0-0.01	0	0	0	1.67	6.57	12.29	20.22	29.51	39.94	54.53	59.56	64.96
CSV008_0.4-0.41	0	0	0	1.77	6.06	11.00	18.09	25.09	32.03	43.36	47.55	52.12
CSV008_0.9-0.91	0	0	0	1.85	6.77	11.85	17.27	22.94	30.61	44.22	49.18	54.64
CSV008_1.18-1.19	0	0	0	2.20	8.55	16.29	27.63	41.60	52.61	60.93	63.25	65.71
CSV008_1.4-1.41	0	0	0	1.81	9.67	22.40	36.83	51.38	69.06	84.82	87.85	90.42
CSV008_1.9-1.91	0	0	0	3.16	11.87	23.12	36.05	47.93	57.05	63.72	65.28	66.75
CSV009_0.3-0.31	0	0	0	0.00	0.00	0.27	1.21	2.39	3.05	4.01	4.28	4.44
CSV009_0.8-0.81	0	0	0	0.83	3.19	5.99	10.24	14.98	19.64	25.53	27.44	29.59
CSV009_1.5-1.51	0	0	0	1.11	4.15	7.88	13.47	19.05	24.32	31.45	33.87	36.67
CSV009_2.4-2.41	0	0	0	2.89	10.09	17.05	26.20	36.70	47.43	60.54	64.57	68.75
CSV009_3-3.01	0	0	0	2.75	10.05	18.13	28.12	38.14	47.73	58.45	61.57	64.83
CSV010_0.6-0.61	0	0	0	1.25	5.26	10.52	18.65	27.78	37.50	50.31	54.23	58.20
CSV010_1.5-1.51	0	0	0	1.09	4.46	8.99	16.87	25.65	34.26	45.16	48.55	52.06
CSV010_2.3-2.31	0	0	0	1.39	5.46	10.59	18.50	27.20	36.16	48.31	52.14	56.06
CSV012_0.1-0.11	0	0	0	0.00	0.11	0.54	1.19	2.06	2.87	3.97	4.40	4.79
CSV012_0.8-0.81	0	0	0	0.00	0.04	0.45	1.10	1.97	2.80	3.88	4.31	4.74
CSV012_2-2.01	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CSV013_0.1-0.11	0	0	0	0.12	0.73	1.55	2.75	3.99	5.30	6.88	7.14	7.32
CSV013_0.7-0.71	0	0	0	0.24	1.10	2.18	3.62	5.09	6.84	9.13	9.61	10.01
CSV013_1.5-1.51	0	0	0	0.25	1.13	2.22	3.60	5.02	6.87	9.39	9.94	10.40
CSV013_2.5-2.51	0	0	0	0.50	1.87	3.45	5.44	7.44	10.22	14.27	15.08	15.74

SAMPLE ID & DEPTH (m)	**62.5**	**74**	**88**	**105**	**125**	**149**	**177**	**210**	**250**	**300**
CSV001_0.1-0.11	4.60	4.6	4.6	4.63	5.12	6.71	9.92	15.2	22.92	33.29
CSV001_0.5-0.51	2.95	2.95	2.95	3.21	4.3	6.72	10.83	16.87	25.01	35.28
CSV001_0.99-1	3.01	3.01	3.01	3.16	4.21	6.98	12.13	20.11	31.07	44.74
CSV001_1.5-1.51	3.42	3.42	3.42	3.58	4.62	7.13	11.66	18.6	28.21	40.51
CSV001_2.5-2.51	2.20	2.2	2.36	3.85	7.39	13.78	23.04	34.81	48.43	62.88
CSV002_0.8-0.81	91.13	93.91	95.93	97.26	98.03	98.44	98.63	98.74	98.85	99.03
CSV002_2.5-2.51	93.77	96.38	98.22	99.32	99.85	99.99	100	100	100	100
CSV002_4.5-4.51	93.72	96.49	98.36	99.43	99.9	100	100	100	100	100
CSV002_5.99-6	90.38	93.11	95.04	96.3	97.03	97.44	97.69	97.9	98.14	98.47
CSV003_0-0.01	6.91	7.18	8.17	10.37	14.07	19.45	26.12	33.66	41.67	49.81
CSV003_0.2-0.21	5.91	6.04	6.59	7.88	10.15	13.58	18.01	23.25	29.15	35.64
CSV003_0.44-0.45	6.39	6.64	7.51	9.4	12.54	17.04	22.59	28.82	35.45	42.28
CSV004_0-0.01	20.55	21.49	22.65	24.18	26.25	29.13	32.94	37.85	44.09	51.84
CSV004_0.8-0.81	29.66	30.94	32.31	33.88	35.77	38.21	41.31	45.24	50.21	56.46
CSV004_1.7-1.71	20.74	21.66	22.69	23.96	25.61	27.91	31.04	35.24	40.8	48.01
CSV004_2.4-2.41	32.00	33.11	34.25	35.57	37.24	39.52	42.59	46.65	51.93	58.65
CSV005_0.1-0.11	71.33	76.59	81.22	84.92	87.52	89.21	90.23	90.9	91.49	92.19
CSV005_0.5-0.51	78.06	84.31	89.36	92.92	94.93	95.77	95.81	95.81	95.81	95.86
CSV005_0.99-1	75.11	81.43	86.96	91.32	94.27	96	96.8	97.07	97.14	97.29
CSV005_1.7-1.71	78.83	81.32	83.53	85.36	86.77	87.85	88.7	89.47	90.33	91.46
CSV005_1.9-1.91	89.54	90.65	91.69	92.65	93.52	94.32	95.06	95.79	96.54	97.35
CSV005_2.4-2.41	82.03	83.09	84.17	85.19	86.04	86.71	87.25	87.82	88.71	90.22
CSV005_5.4-5.41	81.68	82.65	83.73	84.83	85.82	86.65	87.31	87.98	88.9	90.42
CSV006_0.1-0.11	66.86	73.2	79.24	84.46	88.39	91.08	92.68	93.59	94.21	94.87
CSV006_0.5-0.51	71.47	78.01	84.11	89.26	93.01	95.43	96.71	97.27	97.51	97.77
CSV006_0.99-1	63.22	70.23	77.25	83.66	88.79	92.5	94.8	96.03	96.62	96.96
CSV006_2-2.01	64.36	70.92	77.31	83.03	87.56	90.84	92.88	94.01	94.58	94.9
CSV006_2.7-2.71	79.37	82.77	85.83	88.39	90.33	91.73	92.67	93.35	93.93	94.59
CSV007_0.1-0.11	35.92	37.88	40.55	44.17	48.63	53.81	59.2	64.43	69.28	73.64
CSV007_0.7-0.71	41.96	45.72	50.15	55.45	61.47	68.13	74.83	81.15	86.78	91.46
CSV007_1.6-1.61	29.04	29.96	30.96	32.08	33.28	34.62	36.09	37.82	40.02	43.1
CSV007_1.79-1.8	41.60	43.53	45.46	47.31	48.95	50.39	51.65	52.94	54.55	56.92
CSV007_2.1-2.11	16.39	16.99	17.64	18.31	18.95	19.61	20.42	21.73	24.1	28.33
CSV007_2.3-2.31	11.46	11.79	12.2	12.64	13.06	13.43	13.77	14.26	15.26	17.45
CSV008_0-0.01	76.43	81.59	86.2	89.97	92.66	94.43	95.47	96.1	96.59	97.14
CSV008_0.4-0.41	62.04	66.64	70.91	74.61	77.53	79.81	81.54	82.99	84.41	86.02
CSV008_0.9-0.91	66.98	73.08	79.03	84.38	88.67	91.85	93.93	95.19	95.96	96.55
CSV008_1.18-1.19	71.03	73.55	75.93	78.02	79.67	80.93	81.84	82.55	83.21	84
CSV008_1.4-1.41	94.38	95.65	96.56	97.13	97.44	97.6	97.7	97.8	97.94	98.13
CSV008_1.9-1.91	69.46	70.6	71.7	72.8	73.91	75.1	76.36	77.72	79.2	80.88
CSV009_0.3-0.31	4.46	4.71	5.63	7.86	11.96	18.44	27.18	37.85	49.96	62.77
CSV009_0.8-0.81	35.22	38.76	43.05	48.1	53.63	59.56	65.5	71.28	76.85	82.15
CSV009_1.5-1.51	44.25	49.04	54.72	61.14	67.77	74.3	80.16	85.17	89.31	92.63
CSV009_2.4-2.41	77.59	81.75	85.68	89.13	91.85	93.83	95.14	95.98	96.6	97.18
CSV009_3-3.01	72.09	75.85	79.78	83.69	87.27	90.39	92.89	94.8	96.25	97.38
CSV010_0.6-0.61	66.17	69.7	72.99	75.95	78.47	80.67	82.57	84.31	86.02	87.79
CSV010_1.5-1.51	59.47	62.98	66.41	69.63	72.5	75.03	77.23	79.2	81.1	83.1
CSV010_2.3-2.31	63.88	67.3	70.44	73.19	75.48	77.42	79.06	80.53	81.96	83.46
CSV012_0.1-0.11	5.22	5.22	5.42	6.23	8.31	12.4	18.92	28.01	39.61	53.25
CSV012_0.8-0.81	5.23	5.23	5.24	5.53	6.77	9.78	15.25	23.6	34.97	49.02
CSV012_2-2.01	0.00	0.00	0.00	0.00	0.38	2.46	6.88	14.25	24.91	38.81
CSV013_0.1-0.11	7.81	8.49	9.81	12.07	15.35	19.68	24.77	30.41	36.5	43.06
CSV013_0.7-0.71	11.03	12.01	13.72	16.45	20.29	25.36	31.42	38.34	46.07	54.61
CSV013_1.5-1.51	11.47	12.4	13.94	16.37	19.79	24.33	29.8	36.13	43.32	51.41
CSV013_2.5-2.51	17.65	19.64	22.98	28.06	34.69	42.65	51.07	59.36	67.13	74.12

SAMPLE ID & DEPTH (m)	350	420	500	590	710	840	1000	1190	1410	1680	2000
CSV001_0.1-0.11	43.39	55.99	67.71	77.71	86.93	93.19	97.52	99.76	100	100	100
CSV001_0.5-0.51	44.86	56.48	67.17	76.36	85.08	91.32	96.01	98.92	99.96	100	100
CSV001_0.99-1	56.97	70.73	81.9	90.01	96.11	99.21	100	100	100	100	100
CSV001_1.5-1.51	51.93	65.45	77.19	86.4	93.95	98.24	99.97	100	100	100	100
CSV001_2.5-2.51	74.06	84.95	92.51	97.16	99.69	100	100	100	100	100	100
CSV002_0.8-0.81	99.23	99.54	99.83	99.99	100	100	100	100	100	100	100
CSV002_2.5-2.51	100	100	100	100	100	100	100	100	100	100	100
CSV002_4.5-4.51	100	100	100	100	100	100	100	100	100	100	100
CSV002_5.99-6	98.82	99.27	99.67	99.93	100	100	100	100	100	100	100
CSV003_0-0.01	56.21	63.14	69.28	74.86	80.94	86.19	91.07	95.01	97.77	99.47	100
CSV003_0.2-0.21	41.3	48.25	55.33	62.53	71.02	78.71	86.05	92.07	96.34	99.06	100
CSV003_0.44-0.45	47.83	54.22	60.43	66.62	73.91	80.59	87.06	92.48	96.42	98.99	100
CSV004_0-0.01	59.12	68.11	76.5	83.74	90.46	95.04	98.21	99.83	100	100	100
CSV004_0.8-0.81	62.46	70.08	77.46	84.06	90.45	94.95	98.12	99.81	100	100	100
CSV004_1.7-1.71	55.07	64.15	72.99	80.88	88.5	93.84	97.62	99.65	99.99	100	100
CSV004_2.4-2.41	65.09	73.17	80.77	87.3	93.23	97.04	99.42	99.99	100	100	100
CSV005_0.1-0.11	92.92	93.94	95.03	96.1	97.28	98.25	99.06	99.6	99.9	99.99	100
CSV005_0.5-0.51	96.09	96.57	97.15	97.73	98.35	98.85	99.25	99.55	99.78	99.93	100
CSV005_0.99-1	97.58	98.1	98.69	99.23	99.7	99.91	99.98	100	100	100	100
CSV005_1.7-1.71	92.68	94.43	96.28	97.94	99.34	99.91	100	100	100	100	100
CSV005_1.9-1.91	98.04	98.8	99.41	99.81	100	100	100	100	100	100	100
CSV005_2.4-2.41	92.05	94.73	97.35	99.25	100	100	100	100	100	100	100
CSV005_5.4-5.41	92.24	94.9	97.49	99.33	100	100	100	100	100	100	100
CSV006_0.1-0.11	95.58	96.63	97.75	98.75	99.59	99.94	100	100	100	100	100
CSV006_0.5-0.51	98.14	98.76	99.41	99.88	100	100	100	100	100	100	100
CSV006_0.99-1	97.25	97.74	98.35	98.95	99.54	99.86	99.99	100	100	100	100
CSV006_2-2.01	95.16	95.57	96.1	96.7	97.42	98.08	98.7	99.22	99.61	99.87	100
CSV006_2.7-2.71	95.26	96.23	97.3	98.32	99.26	99.78	99.97	100	100	100	100
CSV007_0.1-0.11	76.83	80.22	83.35	86.4	89.88	92.94	95.71	97.84	99.21	99.92	100
CSV007_0.7-0.71	94.4	96.8	98.26	99.13	99.67	99.87	99.99	100	100	100	100
CSV007_1.6-1.61	46.55	51.85	58.19	65.16	73.53	81.01	87.91	93.38	97.16	99.4	100
CSV007_1.79-1.8	59.71	64.15	69.52	75.39	82.25	88.1	93.17	96.84	99.06	99.98	100
CSV007_2.1-2.11	33.73	42.45	52.82	63.73	75.8	85.36	92.9	97.7	99.87	100	100
CSV007_2.3-2.31	20.72	26.85	35.24	45.29	58.07	69.89	80.97	89.78	95.77	99.28	100
CSV008_0-0.01	97.7	98.46	99.17	99.7	99.97	100	100	100	100	100	100
CSV008_0.4-0.41	87.55	89.61	91.77	93.89	96.13	97.86	99.14	99.83	99.99	100	100
CSV008_0.9-0.91	97.04	97.73	98.47	99.16	99.74	99.96	100	100	100	100	100
CSV008_1.18-1.19	84.88	86.26	88.01	90.03	92.56	94.84	96.91	98.43	99.36	99.89	100
CSV008_1.4-1.41	98.33	98.59	98.85	99.06	99.25	99.44	99.63	99.78	99.9	99.97	100
CSV008_1.9-1.91	82.44	84.48	86.68	88.96	91.65	94.03	96.23	97.97	99.11	99.72	100
CSV009_0.3-0.31	72.79	82.78	90	94.74	97.97	99.5	99.95	100	100	100	100
CSV009_0.8-0.81	86.13	90.17	93.34	95.73	97.71	98.89	99.56	99.88	99.99	100	100
CSV009_1.5-1.51	94.75	96.63	97.96	98.87	99.52	99.8	99.94	100	100	100	100
CSV009_2.4-2.41	97.75	98.54	99.3	99.84	100	100	100	100	100	100	100
CSV009_3-3.01	98.13	98.87	99.44	99.82	100	100	100	100	100	100	100
CSV010_0.6-0.61	89.3	91.1	92.83	94.42	96.06	97.34	98.39	99.17	99.68	99.95	100
CSV010_1.5-1.51	84.9	87.22	89.63	92.02	94.59	96.59	98.09	99.03	99.59	99.92	100
CSV010_2.3-2.31	84.79	86.51	88.32	90.19	92.37	94.33	96.18	97.73	98.87	99.64	100
CSV012_0.1-0.11	64.91	77.5	87.3	94.06	98.69	100	100	100	100	100	100
CSV012_0.8-0.81	61.43	75.12	85.88	93.3	98.36	99.95	100	100	100	100	100
CSV012_2-2.01	51.72	66.77	79.4	88.82	95.99	99.36	100	100	100	100	100
CSV013_0.1-0.11	48.7	55.55	62.34	68.99	76.48	83	89.01	93.83	97.21	99.32	100
CSV013_0.7-0.71	61.94	70.43	78.03	84.47	90.5	94.72	97.79	99.65	99.99	100	100
CSV013_1.5-1.51	58.51	66.91	74.64	81.38	87.92	92.71	96.41	98.78	99.92	100	100
CSV013_2.5-2.51	79.04	83.83	87.61	90.66	93.63	95.9	97.78	99.08	99.84	99.99	100

Table A3.3: Trace and major element concentrations in the vibracore samples (XRF and ICP-MS)

GA SAMPLE #	SAMPLE ID & DEPTH (m)	Ag ICP-MS ppm	Al2O3 XRF %	As ICP-MS ppm	Ba ICP-MS ppm	Be ICP-MS ppm	Bi ICP-MS ppm	CaO XRF %	Cd ICP-MS ppm	Ce ICP-MS ppm	Cl XRF ppm	Cr XRF ppm	Cs ICP-MS ppm	Cu XRF ppm
1419982	CSV003_0.44-0.45	0.47	2.406	3.5	47	0.3	<0.01	42.033	0.86	30.78	523	35	0.36	394
1419983	CSV004_0-0.01	0.1	2.292	4.5	38	0.2	<0.01	43.41	0.37	13.53	207	36	0.3	67
1419984	CSV004_0.8-0.81	0.07	2.617	11.8	37	0.5	<0.01	43.189	0.38	13.53	89	28	0.35	40
1419985	CSV004_1.7-1.71	0.24	2.123	9.6	42	0.2	<0.01	42.331	0.3	15.01	619	25	0.29	31
1419986	CSV004_2.4-2.41	<0.01	2.728	10.2	40	0.2	<0.01	43.778	0.35	15.11	8	36	0.36	31
1419987	CSV005_0.1-0.11	0.05	1.954	9.2	51	0.2	<0.01	44.531	0.24	15.42	47	43	0.25	22
1419988	CSV005_0.5-0.51	<0.01	2.159	7.4	66	-0.1	<0.01	44.181	0.14	16.15	0	22	0.3	35
1419989	CSV005_0.99-1	0.02	4.126	7.3	95	0.4	<0.01	39.688	0.21	24.5	189	31	0.56	23
1419990	CSV005_1.7-1.71	0.13	10.13	19.6	240	1.3	0.1	23.631	0.16	67.79	0	71	1.52	29
1419991	CSV005_1.9-1.91	0.1	24.309	23.2	296	2.8	0.3	1.193	-0.1	276.4	0	128	3.62	39
1419992	CSV005_2.4-2.41	0.25	25.22	35.5	236	3.6	0.3	0.867	0.21	227.7	0	171	4.04	54
1419993	CSV005_5.4-5.41	0.12	23.807	52.2	243	4.2	0.4	1.367	0.3	166.2	346	165	3.39	52
1419994	CSV006_0.1-0.11	0.27	24.223	54	257	3.4	0.3	1.351	0.32	184.2	0	168	3.98	54
1419995	CSV006_0.5-0.51	0.05	1.945	6.7	44	0.4	<0.01	44.941	0.21	14.03	787	32	0.25	30
1419996	CSV006_0.99-1	0.25	2.155	9.5	45	0.3	<0.01	44.597	0.3	14.61	1153	31	0.29	35
1419997	CSV006_2-2.01	0.11	2.137	9.7	51	0.3	<0.01	45.188	0.16	14.57	88	32	0.3	32
1419998	CSV006_2.7-2.71	0.07	2.443	7.7	73	0.5	<0.01	43.129	0.21	18.52	66	25	0.3	17
1419999	CSV007_0.1-0.11	2.68	6.883	15.1	174	0.9	<0.01	33.21	0.15	46.76	0	52	1.08	95
1420000	CSV007_0.7-0.71	<0.01	2.276	9	63	0.3	<0.01	44.029	0.14	15.99	73	21	0.32	40
1420001	CSV007_1.6-1.61	<0.01	10.156	25.8	177	1.2	<0.01	26.398	0.1	63.5	69	82	1.74	34
1420002	CSV007_1.79-1.8	0.06	9.589	72.2	271	1.5	0.1	19.032	0.2	98.59	40	96	1.5	84
1420003	CSV007_2.1-2.11	<0.01	13.626	53.9	225	1.7	0.2	18.751	0.16	152.4	0	211	2.53	37
1420004	CSV007_2.3-2.31	0.08	14.128	60.1	224	1.9	0.3	16.479	0.12	163.5	0	213	2.75	58
1420011	CSV009_0.3-0.31	0.15	2.322	9.4	43	0.3	<0.01	42.601	0.29	14.43	625	181	0.29	231
1420012	CSV009_0.8-0.81	<0.01	1.487	11.1	45	0.3	<0.01	44.469	0.41	13.13	53	21	0.24	41
1420013	CSV009_1.5-1.51	0.07	2.079	11.1	40	0.4	<0.01	44.156	0.17	14.53	125	30	0.27	41

SAMPLE ID & DEPTH (m)	Dy ICP-MS ppm	Er ICP-MS ppm	Eu ICP-MS ppb	Fe2O3T XRF %	Ga ICP-MS ppm	Gd ICP-MS ppm	Ge ICP-MS ppm	Hf ICP-MS ppm	Ho ICP-MS ppm	K2O XRF %	La ICP-MS ppm	Lu ICP-MS ppm	MgO XRF %
CSV003_0.44-0.45	394	0.98	333	0.776	2.6	1.77	0.4	7.5	0.32	0.189	16.7	0.15	2.318
CSV004_0-0.01	67	0.64	233	0.942	2.6	1.02	0.4	1.3	0.22	0.167	7.07	0.08	2.385
CSV004_0.8-0.81	40	0.56	233	1.178	3	0.98	0.3	0.7	0.2	0.164	6.93	0.07	2.544
CSV004_1.7-1.71	31	0.53	210	0.968	2.8	0.95	<0.02	1.2	0.18	0.171	7.48	0.06	2.329
CSV004_2.4-2.41	31	0.53	239	1.15	3.2	1.01	0.2	0.8	0.19	0.178	7.47	0.06	2.597
CSV005_0.1-0.11	22	0.71	205	1.071	2.1	1.05	0.2	1.3	0.23	0.209	7.85	0.09	2.518
CSV005_0.5-0.51	35	0.71	256	1.015	2.6	1.11	0.3	1.6	0.23	0.259	8.03	0.09	2.543
CSV005_0.99-1	23	0.86	349	1.634	5	1.54	0.4	2.6	0.28	0.417	12.08	0.11	2.591
CSV005_1.7-1.71	29	2.34	903	5.081	12.3	4.21	0.8	6.9	0.82	1.137	33.19	0.32	2.225
CSV005_1.9-1.91	39	5.76	2992	9.131	32.6	11.95	1.8	11.5	2.01	1.697	93.06	0.79	0.796
CSV005_2.4-2.41	54	7.45	3558	10.674	31.7	14.88	1.7	9.5	2.68	1.582	102.8	0.99	1.044
CSV005_5.4-5.41	52	7.32	3280	10.565	34.4	13.76	1.4	8.8	2.45	1.604	88.49	0.98	0.98
CSV006_0.1-0.11	54	7.57	3460	10.521	31.2	15.16	1.6	10	2.73	1.617	92.56	0.99	1.019
CSV006_0.5-0.51	30	0.48	196	0.976	2.2	0.89	0.2	1.2	0.17	0.183	7.19	0.06	2.357
CSV006_0.99-1	35	0.5	202	1.037	2.6	0.98	0.2	1.1	0.19	0.194	7.45	0.06	2.458
CSV006_2-2.01	32	0.57	217	0.99	2.4	1.08	0.2	1.2	0.21	0.206	7.6	0.06	2.436
CSV006_2.7-2.71	17	0.85	272	1.08	2.9	1.3	0.2	2	0.29	0.296	9.42	0.11	2.369
CSV007_0.1-0.11	95	1.41	670	3.105	8.2	2.89	0.5	4.3	0.51	0.758	22.68	0.19	2.257
CSV007_0.7-0.71	40	0.64	241	1.019	2.6	1.12	0.2	1.5	0.22	0.253	8.1	0.08	2.478
CSV007_1.6-1.61	34	1.88	880	4.558	12.8	3.68	0.7	4.6	0.66	0.858	31.27	0.23	2.621
CSV007_1.79-1.8	84	4.29	1431	6.073	13.7	7.04	0.9	14.3	1.47	1.197	49.06	0.56	1.789
CSV007_2.1-2.11	37	4.84	2115	5.978	16	9.17	0.9	12.2	1.74	1.061	82.29	0.61	1.905
CSV007_2.3-2.31	58	5.38	2280	6.293	15.8	10.36	0.8	13.4	2.01	1.11	88.96	0.69	1.717
CSV009_0.3-0.31	231	0.62	214	1.078	2.7	1.1	0.2	2.4	0.22	0.17	7.74	0.09	2.568
CSV009_0.8-0.81	41	0.57	178	0.888	1.6	0.93	<0.02	1.9	0.19	0.148	7.47	0.08	2.49
CSV009_1.5-1.51	41	0.5	196	1.022	2.4	0.97	0.2	1.4	0.16	0.162	7.6	0.06	2.515

SAMPLE ID & DEPTH (m)	MLOI Calculate %	MnO XRF %	Mo ICP-MS ppm	Na2O XRF %	Nb ICP-MS ppm	Nd ICP-MS ppm	Ni XRF ppm	P2O5 XRF %	Pb ICP-MS ppm	Pr ICP-MS ppm	Rb ICP-MS ppm	Sb ICP-MS ppm	Sc XRF ppm	SiO2 XRF %
CSV003_0.44-0.45	45.209	0.005	2.3	0.305	3	13.02	4	0.194	40.2	3.66	11	3.5	4	5.271
CSV004_0-0.01	43.426	<0.001	2.4	0.344	1.8	5.8	7	0.138	15.1	1.6	9.8	4.8	2	5.778
CSV004_0.8-0.81	42.975	<0.001	2.7	0.302	2	5.65	6	0.122	8.6	1.51	10.5	3	<1.6	5.53
CSV004_1.7-1.71	45.259	<0.001	2.4	0.397	1.8	5.92	<1.3	0.101	8.7	1.67	10.1	5	<1.6	4.966
CSV004_2.4-2.41	42.022	<0.001	3.2	0.301	2.1	6.06	4	0.116	8.5	1.71	11.2	1.9	<1.6	5.748
CSV005_0.1-0.11	42.05	<0.001	3.1	0.351	2	6.29	5	0.104	7.3	1.73	9.3	4	<1.6	5.803
CSV005_0.5-0.51	41.293	0.005	3.1	0.349	2.4	6.4	16	0.101	7.2	1.84	12.1	1	<1.6	6.7
CSV005_0.99-1	38.37	0.007	4.2	0.385	4.8	9.22	7	0.12	10.9	2.62	20.5	0.4	<1.6	11.101
CSV005_1.7-1.71	25.394	0.024	6.3	0.472	12.1	25.25	17	0.109	25	7.03	57.1	4	14	28.241
CSV005_1.9-1.91	13.164	0.038	2.7	0.294	29.7	82.69	29	0.152	55.4	23.38	116.5	9.3	27	47.088
CSV005_2.4-2.41	13.651	0.024	3.4	0.233	23.9	89.47	47	0.088	53.4	25.27	109.4	10.5	26	45.05
CSV005_5.4-5.41	15.217	0.025	3.1	0.227	21.7	83.88	50	0.087	57.1	21	101.5	4.6	12	44.303
CSV006_0.1-0.11	14.033	0.026	3.2	0.214	24	84.83	37	0.092	56.8	22.97	106.4	4.3	25	45.071
CSV006_0.5-0.51	42.377	<0.001	2.8	0.349	1.8	5.87	<1.3	0.101	8.2	1.58	9.2	5	<1.6	5.368
CSV006_0.99-1	42.066	<0.001	4.6	0.38	2	5.8	3	0.1	7.3	1.66	10	6.1	<1.6	5.408
CSV006_2-2.01	41.506	<0.001	6.2	0.365	2	6.14	9	0.096	7.1	1.65	10.5	0.8	<1.6	5.538
CSV006_2.7-2.71	41.528	0.005	4	0.368	2.7	7.38	<1.3	0.089	7.2	2.12	13.4	0.5	<1.6	7.207
CSV007_0.1-0.11	32.426	0.019	3.1	0.386	8	18.04	7	0.114	18.8	5.05	40.1	0.7	6	18.223
CSV007_0.7-0.71	41.617	<0.001	4.6	0.334	2.4	6.55	<1.3	0.092	6.6	1.82	12.2	7.4	3	6.413
CSV007_1.6-1.61	29.414	0.018	7.1	0.336	10.4	22.97	14	0.137	19.8	6.73	52	4.6	10	22.6
CSV007_1.79-1.8	26.236	0.038	20.9	0.373	12.8	37.94	16	0.101	27.5	10.51	55	8.8	13	30.233
CSV007_2.1-2.11	22.409	0.029	13.3	0.279	14.8	59.82	34	0.161	30.9	16.7	58	4.7	13	30.822
CSV007_2.3-2.31	21.747	0.029	15	0.251	15.8	62.71	36	0.165	32.1	17.48	60.5	5.4	17	32.679
CSV009_0.3-0.31	43.004	0.007	2.7	0.426	3	6.12	392	0.139	18.2	1.72	9.9	4.4	3	5.923
CSV009_0.8-0.81	44.086	<0.001	2.2	0.337	1.6	5.63	3	0.098	6.3	1.61	7.7	7.3	<1.6	4.494
CSV009_1.5-1.51	42.281	<0.001	2	0.36	1.8	6.02	4	0.117	13.2	1.68	9.5	1.1	2	5.75

SAMPLE ID & DEPTH (m)	**Sm ICP-MS ppm**	**Sn ICP-MS ppm**	**SO3 XRF %**	**Sr ICP-MS ppm**	**Ta ICP-MS ppm**	**Tb ICP-MS ppm**	**Th ICP-MS ppm**	**TiO2 XRF %**	**U ICP-MS ppm**	**V XRF ppm**	**Y ICP-MS ppm**	**Yb ICP-MS ppm**	**Zn XRF ppm**	**Zr ICP-MS ppm**
CSV003_0.44-0.45	2.31	4	0.762	2025	<0.06	0.56	6.9	0.182	7.26	28	11.4	0.88	33	289.8
CSV004_0-0.01	1.22	2	0.704	2327	<0.06	0.16	3.9	0.118	6.04	20	7.4	0.53	13	44.8
CSV004_0.8-0.81	1.17	1.5	0.972	2578	<0.06	0.13	3.8	0.115	17.68	31	7.4	0.45	3	25.1
CSV004_1.7-1.71	1.17	2	0.924	2871	<0.06	0.14	5.4	0.098	18.2	34	7.6	0.42	<0.5	48.2
CSV004_2.4-2.41	1.3	1.8	0.969	2593	<0.06	0.14	4.7	0.124	21.44	36	7.6	0.48	4	30.2
CSV005_0.1-0.11	1.28	1	1.001	2581	<0.06	0.15	4.3	0.112	10.71	14	7.9	0.58	1	48.3
CSV005_0.5-0.51	1.23	1.9	0.936	2710	<0.06	0.18	4.5	0.159	8.2	10	8.5	0.63	<0.5	65.1
CSV005_0.99-1	1.99	1.5	0.997	2366	<0.06	0.24	6.7	0.268	6	17	9.8	0.71	4	96.3
CSV005_1.7-1.71	4.76	2.5	2.7	1146	0.6	0.7	15.9	0.658	6.04	40	22.5	2.17	9	243.1
CSV005_1.9-1.91	15.63	4.5	0.47	97.9	1.8	1.77	67.3	1.54	5.89	145	65	5.32	13	443.5
CSV005_2.4-2.41	18.51	4.4	0.189	74.5	1.4	2.17	64.6	1.257	4.88	179	82.1	6.26	25	335.5
CSV005_5.4-5.41	16.54	5.2	0.406	72.2	1.9	2.08	77.6	1.263	5.43	181	89.3	6.38	15	361.9
CSV006_0.1-0.11	17.43	5	0.439	66.5	1.3	2.23	63.4	1.279	5.15	181	87.7	6.48	16	377
CSV006_0.5-0.51	1.1	1	0.919	2504	<0.06	0.13	4	0.117	9.01	17	6.3	0.4	1	45.1
CSV006_0.99-1	1.17	0.9	1.081	2494	<0.06	0.16	3.8	0.126	10.82	16	6.5	0.42	1	35.3
CSV006_2-2.01	1.17	0.6	1.097	2622	<0.06	0.14	3.5	0.136	11.63	17	6.8	0.5	1	40.8
CSV006_2.7-2.71	1.42	1.1	1.018	2542	<0.06	0.21	5	0.175	8.52	15	9.3	0.73	4	73.6
CSV007_0.1-0.11	3.46	2.3	1.919	1821	0.2	0.4	11.2	0.456	4.9	32	15.1	1.29	10	150.1
CSV007_0.7-0.71	1.07	0.6	1.024	2766	<0.06	0.14	4.2	0.153	9.94	18	8.1	0.56	2	54.6
CSV007_1.6-1.61	4.48	2	2.135	1334	0.4	0.62	17.8	0.567	13.48	52	21	1.65	10	161.4
CSV007_1.79-1.8	7.54	1.7	4.358	861.5	0.6	1.09	22.4	0.755	16.8	137	46.3	3.64	12	514
CSV007_2.1-2.11	11.06	2.8	3.926	717.5	0.7	1.38	30.6	0.854	14.53	123	57.4	4.11	13	461.3
CSV007_2.3-2.31	11.93	2.6	4.372	579.9	0.8	1.49	34.7	0.85	12.73	133	60.8	4.58	12	481.4
CSV009_0.3-0.31	1.2	2	1.181	2413	<0.06	0.15	4.2	0.164	10.02	23	7.8	0.57	9	92.1
CSV009_0.8-0.81	1.14	0.8	1.098	2640	<0.06	0.17	2.2	0.112	12.66	29	4.6	0.53	2	52.2
CSV009_1.5-1.51	1.25	0.9	1.131	2610	<0.06	0.13	4.1	0.13	8.25	21	6.4	0.4	7	55.6