4. METHODOLOGY

This chapter outlines a detailed description of the methodologies used in the research project including field work, laboratory analyses and formulation of the erosion hazard assessment models. A Section 87 Permit was obtained from the NSW National Parks and Wildlife Service, Department of Environment, Climate Change and Water (DECCW)[1], prior to the commencement of field work.

4.1 FIELD METHODOLOGY

4.1.1 **Woombah**

4.1.1.1 *Shell sample collection*

A total of six *in situ* shell samples were collected from two locations at Woombah – three from one location at site A and three from one location at site B. A bed of oysters (23 m X 40 cm surface) is exposed along the riverbank at site A. Shells have eroded out of the exposure and are present as a lag deposit on the shoreline. *In situ* shells were collected for comparison with shells found at the site B midden (see Biological Analyses, Chapter 6). The purpose of this comparison was to ascertain whether or not the shells found at site A represented a food source and thus formed a natural shell deposit or whether they constitute part of the Woombah Aboriginal midden complex. Shells from site B were preferentially used for comparison over shells found in surface scatters at site A as the site B (see core diagram 3b, Appendix 1) creek bank exposure is denser, more extensive and contains whole valves and is thus believed to be the source of the shell material found in the surface scatters at both sites.

Four hundred and fifty three grams of *in situ* shell material was collected at a depth of 40-80 cm at random from the site A deposit using the pick (pointy) end of a geopick, ensuring not to damage the shells. One thousand four hundred and nine grams of *in situ* shell material was

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[1] DECCW now operates within the Office of Environment and Heritage

collected from the site B creek bank exposure in the same way, at a depth of 35-69 cm. This depth corresponds to the relatively unfragmented shell material, as ascertained by coring and visual inspection of the creek bank exposure. The material was bagged, labeled and transported to the laboratory.

4.1.1.2 *Sediment collection/coring*

Two methods were used at Woombah to collect sediment for analysis – a corer and a hand auger. Firstly, a coring device was used at site A. The device constituted a handle for turning the corer and a barrel attachment fitted to a shaft. The barrel of the attachment was 300 mm in length and had a diameter of 80 mm. The shoe was 50 mm in length. The barrel comprised two semicircular halves which, once the shoe and shaft were removed, separated so the sore could be removed. Material from the corer was placed in 90 mm wide PVC pipe which was capped, cut into lengths of 1 m then cut in half to make 2 semicircles. The coring process was undertaken 3 times at each core, making a total length of 1 m for each core. Cores were then placed in the PVC half-pipes and wrapped securely with cling wrap.

Due to the difficulties experienced when attempting to unscrew the shoe from the barrel of the corer a different method was employed when collecting sediment at site B. A hand auger was used instead of a hand corer. The barrel of the auger was 1 m in length and tapered from 50 mm wide at the top to 30 mm wide at the tip. Holes were made with this device and the material it contained was scraped out and bagged according to stratigraphy. Separate bags were used for material from different horizons and these were carefully labeled according to depth. Five cores were taken at each site (A and B) roughly parallel to each other and extending from the riverbank north across the floodplain and up onto the first levee. Prior to bagging/wrapping and storing for transport wet Munsell colours (GretagMacbeth, 2000) and field textures were recorded for each horizon in each core sample.

On a return visit to Woombah the stratigraphy of site B was refined using the same hand auger. The augering procedure remained the same however after depths, wet Munsell colours and field textures were recorded the sediment was discarded. Auger holes were made at locations 15.7 m, 29.4 m, 33.6 m and 37.5 m north of the riverbank between core locations 5b and 4b. Another auger hole was made between core locations 2b and 1b on the edge of the floodplain adjacent to the levee rise.

Test cores were also made around the perimeter of the study sites A and B to determine the extent of the disturbed midden material (the area of the A_p layer). This area was then measured and the measurements used in the calculation of ploughing disturbance (see 'Calculation of the effect of ploughing on the Woombah middens').

4.1.1.3 *Surveying*

A survey of sites A and B at Woombah was carried out using a Leica Geosystems TC 600 (http://www.leicaus.com/support/TPS1200/TPS_Legacy_TC_00Manuals.cfm). Survey data was imported into the Grapher 6 program and plan and/or elevation maps were generated (Figures 3.13 and 3.14). Locations of core samples were recorded with a hand-held GPS and added to the GIS model of geomorphic and environmental impacts on sites in the study area (Appendix 6). The slope of the surface above the deposit was measured with a clinometer.

4.1.1.4 *Vegetation coverage estimates*

Percentage tree/shrub and grass cover were estimated at sites A and B using random 1m X 1m quadrats (Barry, 2011). These estimates are used in the erosion hazard risk assessment methodologies.

4.1.2 **Sleeper Island**

4.1.2.1 *Determination of the size of the deposit and collection of cultural material*

An Aboriginal shell midden containing *Crassostrea*, *Anadara*, *Pyrazus ebeninus* and stone artifacts is located on the western tip of the island. The contents of this midden are largely present as a lag deposit at the base of a tidal channel bank. Very little material remains *in situ*. The surface dimensions of the *in situ* and lag deposits were measured with a tape. The depth which the deposit extends back into the channel bank was measured by digging test trenches parallel to the bank. The *in situ* material visible in the eroded channel bank was counted by species. Stone artifacts and shell material present in the lag deposit were collected at random by placing 4 25*25 cm quadrats over the deposit and removing the materials inside. Subsequent to collection the material was sorted into shell and stone artifacts and these different types of material were bagged separately.

4.1.2.2 *Sediment collection/coring*

Two methods were used at Sleeper Island to collect sediment for analysis. Sediment was collected at 4 points across the Island from the midden locality on the western tip in a northeast cross section to the eastern side of the island. The first method was used at core sites 1s, 2s, 3s and 4s and the second at core sites 2s and 3s.

The first method involved using a 1.6 m long core barrel with a 50 mm diameter PVC inner tube. The corer was hammered into the ground using a slide hammer and the depth (penetration) recorded. The corer was then removed from the ground using a jack and the inner tube removed. The amount of sediment in the tube (recovery) was recorded and it was cut to size and capped.

At sites where recovery was poor (2s and 3s) a hand auger was used. At site 2s a 35 cm core was collected as described above and then a hand auger was used to collect sediment from 35-100 cm depth. This sample was bagged according to its stratigraphy as at Woombah site B. At site 3s a

26 cm core was collected and then a hand auger was used to collect sediment from 26-100 cm depth. This sample was also bagged according to its stratigraphy as at Woombah site B. When core and bagged materials were unpacked in the laboratory wet Munsell colours and field textures were recorded.

4.1.2.3 *Surveying*

A survey of Sleeper Island was carried out using a Leica Geosystems TC 600. Survey data was imported into the Grapher 6 program and plan and/or elevation maps were generated (Figure 3.9). Locations of core samples were recorded with a hand-held GPS and added to the GIS model of geomorphic and environmental impacts on sites in the study area (Appendix 6). The slope of the surface above the deposit was measured with a clinometer.

4.1.2.4 *Vegetation coverage estimates*

Percentage tree/shrub and grass cover were estimated at the sites of the *in situ* deposit and surface scatter and also over the island as a whole using random 1m X 1m quadrats. These estimates are used in the erosion hazard risk assessment methodologies.

4.1.3 **Plover Island**

4.1.3.1 *Collection of cultural material*

Minimal cultural material was collected from the stone quarry site on Plover Island. Six stone cores were collected from the *in situ* lens on the western side of the island. No cultural material was collected from the stone artifact scatter on the eastern side of the island. The taphonomic processes affecting the deposits on Plover Island could be determined relatively easily without the removal of much cultural material. The soil around the artifacts removed from the *in situ* lens was severely eroded and it is likely these artifacts would not have remained *in situ* for much longer. Collection of these specimens ensures some information is retained from a deposit facing destruction through erosion. As with all cultural material collected from study sites, these artifacts will be returned to the Yaegl community after the mandatory period of storage at the conclusion of this research project.

Stone and shell material was collected from the lag deposit at the base of Plover Island. Random grab samples were placed into snap lock bags and later separated into stone and shell components for further taphonomic study (see 'Taphonomy' and Chapter 6).

4.1.3.2 *Sediment collection/coring*

Examination of the exposed soil on Plover Island indicated its uniformity around the circumference of the island. As it was also relatively shallow (0.80 m) only one core sample was needed. A 1.00 m long hand auger was used to collect sediment at a location on the western side of Plover Island, directly adjacent to the *in situ* stone artifact lens. Wet and dry Munsell colours were noted for the A and B horizons present in the core. Sediment collected using the hand auger was bagged according to horizon (material from the A horizon in one bag, the B horizon in another). Sample bags were then dated, labelled and stored in a refrigerator until laboratory examinations were carried out.

4.1.3.3 *Surveying*

A survey of Plover Island was carried out using a Leica Geosystems TC 600. Survey data was imported into the Grapher 6 program and plan and/or elevation maps were generated (Figure 3.21). Locations of core samples were recorded with a hand-held GPS and added to the GIS model of geomorphic and environmental impacts on sites in the study area (Appendix 6). The slope of the surface above the deposit was measured with a clinometer.

4.1.3.4 *Vegetation coverage estimates*

Percentage tree/shrub and grass cover were estimated at the sites of the *in situ* deposit and surface scatter and also over the island as a whole using random 1m X 1m quadrats. These estimates are used in the erosion hazard risk assessment methodologies.

4.1.4 **Minnie Water**

4.1.4.1 *Shell sample collection*

The shell deposit was present at the base of the foredunes and the lens was clearly visible due to erosion at the site. Shell material was collected at random by placing 10 25X25 cm quadrats over the exposed face of the deposit and removing the materials inside. Shell material present in trench samples (technique discussed below) was also collected. All shell material was bagged and its location clearly marked. Five random 25X25 cm quadrat samples were also taken from separate locations along the beach within 10 m of the midden deposit. This contemporary shelly beach material was collected for the purpose of taphonomic and biological comparison with the *in situ* midden material. Material was then transported to the laboratory for further analyses.

4.1.4.2 *Sediment collection*

The Aboriginal shell midden deposit at Minnie Water sits at the base of beach foredunes up to 5 m in height. As coring through a dune to such a depth presents many challenges an alternative method of sediment collection was employed. As the sides of the dunes were steep it was possible to dig into them at given depths and obtain samples which, when *in situ*, would have been vertically aligned. The first samples were collected with a shovel from the surface (a depth of 0 cm). The next samples were collected at a depth of 1 m (cores 1 and 2) and 25 cm (cores 3 and 4). The final samples were taken at a depth of 380 cm and included midden material. Sediment was bagged and labelled according to stratum and core and transported to the laboratory for further analyses. When bagged materials were unpacked in the laboratory wet Munsell colours and field textures were recorded.

4.1.4.3 *Surveying*

A survey of the midden site at Minnie Water was carried out using a Leica Geosystems TC 600. Survey data was imported into the Grapher 6 program and plan and/or elevation maps were generated (Figure 3.27). Locations of core samples were recorded with a hand-held GPS and added to the GIS model of geomorphic and environmental impacts on sites in the study area (Appendix 6). The slope of the surface above the deposit was measured with a clinometer.

4.1.4.4 *Vegetation coverage estimates*

Percentage tree/shrub and grass cover were estimated at the site of the *in situ* deposit and over the foredunes using random 1m X 1m quadrats. These estimates are used in the erosion hazard risk assessment methodologies.

4.1.5 **Wooli**

4.1.5.1 *Shell sample collection*

As the midden deposit at this location was buried under a 25 cm thick layer of soil, trenches were dug to determine its vertical and lateral extent (see sediment collection methodology below). Shell material from these trenches was collected and bagged in the field in preparation for examination in the laboratory. Shell samples from each trench were bagged separately and labelled accordingly.

4.1.5.2 *Sediment collection*

As the shells were present as a relatively thin lens (<17 cm) and the watertable sat at a depth of <1 m in the study area a corer was not needed to collect shell and sediment samples. Ten trenches of ~30 cm square and to the depth of the watertable were dug with a shovel. Sediment samples were taken from the exposed, *in situ* sediment lining the walls of the trenches. The stratum and trench number was noted on each sample bag and the samples were stored ready for analysis in the laboratory. When bagged materials were unpacked in the laboratory wet Munsell colours and field textures were recorded.

4.1.5.3 *Map measurements*

Due to technical issues the Leica surveying equipment was not used at the Wooli Aboriginal shell midden. Test trenches indicated the perimeter of the deposit and this was measured with a tape and mapped onto graph paper (Figure 3.28). The thickness of the deposit was determined through the test trenches and this information is presented in the core diagrams of the site. Locations of core samples were recorded with a hand-held GPS and added to the GIS model of geomorphic and environmental impacts on sites in the study area (Appendix 6). The slope of the surface above the deposit was measured with a clinometer.

4.1.5.4 *Vegetation coverage estimates*

Percentage tree/shrub and grass cover were estimated over the deposit and riverbank using random 1m X 1m quadrats. These estimates are used in the erosion hazard risk assessment methodologies.

4.2 LABORATORY ANALYSES

4.2.1 **Biological Analyses**

4.2.1.1 *Percentage Composition by Weight, Size Range and Minimum Number of Individuals*

Shells collected from Woombah sites A and B, Sleeper Island, Minnie Water and Wooli were analysed to determine the percentage composition of constituent species by weight. The size range and total weight of shell species was also measured. After collection from the field shells were soaked for 12 hours in a mixture of water and detergent, rinsed and then cleaned with a toothbrush to remove sediment. Samples were then dried prior to weighing. Firstly, all shell material from each collection site was weighed on an electric balance to determine its total weight. Shells were then separated into species and weighed again. The weight of each species was recorded and percentages based on these weights were then calculated. *Crassostrea* and *Anadara trapezia* shells were then separated into upper and lower valves and these samples were also weighed. They were then sorted until the smallest and largest upper and lower valves were found and these shells were measured to determine the size range of the valves from the sample sites. Size range data were collected from whole valves only. Data are presented in Table 6.1.

Two counts were made on *A. trapezia* material. The first set was based on individual shells which had their umbo intact. Counts for the second set of percentage composition by weight calculations involved counting the highest number of hinges of one side to give the MNI (Ulm, 2006). Only upper valves with their umbo intact were included in MNI *Crassostrea* counts and when counting gastropods, only those specimens with their aperture intact were included.

A percentage composition by weight calculation was used to compare the shell deposits found at Woombah sites A and B to account for all the shell material in the samples. Upper and lower *Crassostrea* valves were also weighed separately in order to determine whether or not there was a taphonomic bias for one valve type. Size range was measured for *Crassostrea* valves as an additional means by which to compare the two deposits. Percentage composition by weight and species was used to compare the Minnie Water *in situ* and lag deposits to help give an indication of site integrity. A comparison of taphonomic and species composition characteristics is broad-ranging and therefore increased in accuracy over a comparison of one of these groups of characteristics alone. Other analyses such as percentage total weight per horizon or stratum and soil: shell ratios will be very useful at sites with multiple strata or occupation layers.

In situ counts were made at Sleeper Island (see field methodology – Sleeper Island) and these were then added to the counts of minimum numbers of individuals. Average weights for the three shellfish species contained in the midden were then calculated, however in *situ counts* were excluded in these calculations as their weights were not measured and therefore did not add to the total weights determined for the sample material.

4.2.1.2 *Number of identified specimens (NISP)*

This is a measure of the number of shell fragments identifiable to a particular taxon (Ulm, 2006). Although this method can be limited by the level of identifiability of fragmented shell it can be useful for examining shell fragmentation rates in deposits containing highly fragmented shell (Ulm, 2006). All deposits contained a negligible amount of highly fragmented, unidentifiable shell. Wet-sieving (3 mm sieve) of the matrix surrounding collected shell specimens from these deposits confirmed this field observation, therefore this method was not applied to these deposits.

4.2.2 **Taphonomic Analyses**

Taphonomic, sedimentological and stratigraphic features were documented at each of the study sites and compiled into tables modified after Kidwell (1991) – Attributes of Shell Concentrations (Tables 6.4, 6.5, 6.7, 6.8, 6.9, 6.10). A different table was compiled for each shell deposit. Additional analyses were performed on shell material from the Woombah Site A and B deposits and the Minnie Water midden and lag deposits in order to refine likely site formation processes.

Shell samples from Woombah Sites A and B were analysed to determine the most common region of breakage and also the percentage of fragmented shell material by weight (Table 6.6). Shell material from the Minnie Water midden and lag deposits was analysed to determine the amount of abrasion and biological modification as a percentage of material affected (Figures 6.8 and 6.9).

4.2.3 **Loss on Ignition – measurement of organic content of soil samples**

Subsamples from each horizon present in the core samples were dried in an oven at 110°C for 24 hours. This material was subsequently prepared for the furnace as follows (Heiri, Lotter & Lemcke, 2001). Metal crucibles were weighed to 2 decimal places using an electric balance. A quantity of subsample was then added and the crucibles were re-weighed. All weights were recorded. Subsample weights were then calculated. Subsamples were then heated in a furnace at 430°C for 48 hours to burn off any organic material. After removal from the furnace material was cooled in a closed container for 15 minutes and then weighed immediately to 2 decimal places using an electric balance. These weights were recorded. The difference between the initial weights after drying at 110°C and the final weights was calculated. The difference in these weights indicates the amount of organic matter present in each of the subsamples (Appendix 2).

4.2.4 **Emerson Aggregate Test**

Aggregate stability was determined using samples from A and B horizon soils at all study sites. The method used to determine aggregate stability was the Emerson Aggregate Test (Department of Sustainable Natural Resources Soil Survey Standard Test Method Version 2; Emerson, 1967). Following are a list of steps used in this study for each sample analysed:

1. Three air-dry aggregates 5-10 mm in diameter were placed, equally spaced, in 75 ml deionised water.
2. After 2 and 20 hours aggregate behaviour was assessed. The presence of slaking or swelling was noted along with degree of dispersion.
3. Emerson Class Numbers were then determined.
4. For samples which showed slaking but no dispersion after 20 hours, 30-40 g fresh air-dry aggregate was placed in a mixing bowl and mixed for 30 seconds with sufficient deionised water to increase the soil moisture content to within the plastic range.

5. A 5 mm cube of the soil was moulded using a spatula and placed in 75 ml of deionised water. The degree of dispersion was rated after 2 and 20 hours and Emerson Class Numbers were then determined using the table in Department of Sustainable Natural Resources Soil Survey Standard Test Method Version 2.

4.2.5 **Sand:Silt:Clay Ratio**

4.2.5.1 *Sample preparation*

Following the methodology outlined in Harfield *et al.* (1985), subsamples from each horizon present in the core samples were dried in an oven at 110°C for 24 hours. They were then ground with a mortar and pestle where necessary. The subsamples were then poured through a sample splitter until a final subsample of ~40 g was obtained. This step ensured a representative subsample was being prepared for the particle sizer. The final subsamples were then placed in a beaker to which a 10% solution of H2O2 was added to digest the organic material present in the sediment. The beakers containing the bubbling samples were then covered, placed on a hot plate in a fume hood and heated to ~50°C. Samples were removed from the fume hood when the bubbling had stopped, as this indicated the organic material had been digested. As the sediment had settled, the liquid was then discarded from each beaker.

Samples were then rinsed into labelled centrifuge tubes with distilled water and each cartridge was axially balanced using an electric balance and topped up with distilled water as required. Samples were centrifuged for 10 minutes at 2000 rpm. After centrifugation the samples were removed from the centrifuge and the supernatant discarded. They were then rinsed and the centrifugation process repeated.

After washing into their labelled beakers samples were placed in a fume hood and mixed with a 10% solution of acetic acid to digest any carbonate material that may be present. Bubbling samples were covered and heated on a hot plate at ~50°C until bubbling had ceased, taking up to 72 hours. The centrifugation process outlined above was then repeated twice. After centrifugation samples were mixed with a deflocculating agent and allowed to stand for 24 hours. They were then wet-sieved through a 2000 µm sieve to separate the larger gravel-sized particles from the material to be analysed in the Malvern Mastersizer (www.malvern.com/mastersizer). The gravel-sized portion was then dried and weighed and the results added to the data obtained from the Malvern Mastersizer.

4.2.5.2 *Particle size analysis*

A Malvern Mastersizer was used for particle size analysis. At least three subsamples were run from each prepared sample. Beakers containing sample sediment were placed under an electric mixer for the duration of the sampling process to ensure representative subsamples were analysed. Subsamples were taken from each beaker using disposable 3 ml droppers and placed into the refractive medium (deionised water) drop by drop until the laser obscuration was within range (10-20%). Laser obscuration for all subsamples from each sample was kept as consistent as possible.

After an initial run the first subsample from each prepared sample was treated with ultrasonics, applied by the Malvern Mastersizer for 30 seconds, and run again. Results of the two runs were then compared. If results were in good statistical agreement ultrasonics were not applied to subsequent subsamples unless the results from those subsamples differed significantly from previous runs. Where the two sets of results (treated with ulttrasonics or not treated) differed significantly the results gained after application of ultrasonics were retained. Average results from retained subsample runs were calculated and these data are presented and analysed in this thesis.

4.2.6 Flood and Tide Hazard Analyses

In order to quantify the flooding hazard at Aboriginal midden sites at Woombah, Sleeper Island and Wooli a method was devised by the researcher which uses information on flood heights and return periods and site elevation. The aim of these calculations was to determine the level of flooding (and thus the return period) to which a site is vulnerable, based on its elevation. The minimum depth of each deposit corresponds to its maximum elevation and this was the level used as a reference flood level, as floods reaching this elevation would totally inundate the deposit. In order to accurately determine the maximum elevation of each *in situ* midden deposit the sites were visited at high tide and a measurement was taken from the water surface to the minimum depth (maximum elevation) of the deposit. This measurement was then added to the known high tide level, giving an elevation in metres above Lowest Astronomical Tide (mLAT), the standard datum for tide height measurements. This elevation was then converted to the Australian Height Datum (mAHD) by adding 0.895, the fixed difference between LAT and AHD at the Yamba tide gauge (see equations 1 and 2 below). Using flood data provided by Manly Hydraulics and the Clarence Valley Floodplain Services (Appendix 4) the flood level matching the maximum elevation of each deposit was located and the corresponding ARI noted (Table 7.5). Thus, the risk of total inundation by flooding was calculated for the sites mentioned above.

1: Distance from high tide water surface to top of *in situ* midden deposit + height of high tide = maximum elevation of deposit (mLAT)

2: Maximum elevation of deposit (mLAT) + 0.895 = maximum elevation of deposit (mAHD)

When assessing the impact of tidal inundation on the Aboriginal shell midden sites at Woombah, Sleeper Island and Wooli two sets of results were generated (Table 7.6). The first set of calculations was based on the 2009-2010 tide predictions for the Yamba and Wooli gauges. The second set was based on the actual occurrence of tides over an 18-20 year period (Appendix 4, data from NSW Department of Commerce, Manly Hydraulics Laboratory).

Tidal predictions for the Yamba tide gauge for the period from July 2009-June 2010 were analysed to determine the predicted frequency of tidal inundation of the sites mentioned above. As tide height is measured in metres above Lowest Astronomical Tide site elevations calculated using equation 1 above were used in the tidal inundation calculations. The maximum elevation of the deposits in mLAT corresponds with the minimum tide height required to fully inundate these deposits. The number of times tide heights greater than or equal to the maximum LAT site elevations were predicted to occur were counted. This gave a predicted frequency of inundation for the twelve months from July 2009-June 2010.

The elevation of Aboriginal shell midden sites at Woombah (A and B), Sleeper Island and Wooli was also used to determine the tidal inundation class of these sites. Tidal inundation classes are based on the frequency of occurrence of measured tide heights over an 18-20 year period and have been formulated by Manly Hydraulics Laboratory. Appendix 4 shows tidal ranges and their corresponding inundation classes. This is a measure of the relative likelihood of tidal inundation of midden sites based on the frequency of tide heights occurring at Yamba and Wooli over the past 18-20 years.

4.2.7 **Calculation of erosion rates**

In order to quantify the erosion clearly visible at Sleeper Island and Woombah river bank site A channel measurements were taken from different sources. Historic parish maps were available for the years 1914, 1915, 1919, 1923, 1926, 1933, 1936, 1943, 1954, 1958, 1961 and 1967 for Sleeper Island and 1912, 1919, 1921, 1931 and 1936 for Woombah (courtesy of the Department of Lands). Topographic maps of the areas dated at 1986 and aerial photographs dated at 2005 were also used.

Measurements of the width of channels between Sleeper and Freeburn Islands, Sleeper Island and the mainland, and Woombah and Yargai Island (part of the North Arm of the Clarence River) were made using a ruler and then converted to distances using the scales provided on the maps and photos.

As there was agreement among the historic sources and among the recent sources the difference between these distances (historic and recent) was used to calculate the difference per year, giving the erosion or deposition rate. Where the channel appeared wider in contemporary measurements the rate calculated represents the erosion rate. Where the channel appeared narrower the rate calculated represents the rate of deposition. The rates calculated are minimum rates; there are no data for the 19 years between 1967 and 1986 so it is not known when the difference in the channel measurements started. Calculation of the erosion and deposition rates using the method outlined above proved inconclusive due to differences in measurements between sources and an absence of data for the 19 year period between 1967 and 1986.

4.2.8 **Calculation of erosion hazard**

4.2.8.1 *Introduction*

Table 4.1 outlines selected methods of erosion hazard assessment. In this context hazard assessment is defined as 'the process of estimating, for defined areas, the probabilities of the occurrence of potentially damaging phenomenon of given magnitudes within a specified period of time. Hazard assessment involves the analysis of formal and informal historical records, and skilled interpretation of existing topographical, geological, geomorphological, hydrological and land use maps' (European Centre on Geomorphological Hazards). Hazard assessment is an essential prerequisite of risk analysis, defined as 'the use of available information to estimate the risk to individuals or populations, property or the environment, from hazards' (European Centre on Geomorphological Hazards).

The methods of erosion hazard assessment outlined in Table 4.1 have a geomorphic rather than archaeological focus and many require complex inputs, algorithms and computer modelling. Of the field-based techniques many are designed for use on agricultural land for impact or suitability assessment; others are formulated for use in specific geomorphic settings such as rivers or riparian zones. The methods used in this study must be standardised in order to gain consistent and reliable results and must be applicable to Aboriginal midden deposits in a range of geomorphic settings.

A number of the methods presented in Table 4.1 use a factorial scoring system where combined impacts are scored and then given an overall ranking corresponding to the degree of erosion impact or suitability for certain land use practices. The factors impacting erosion are themselves largely quantifiable. This ensures reliable data are collected and data on subsequent landscape change can be directly compared with that collected at other points in time. Scoring of these measurements/impacts is somewhat arbitrary and relies on consistent and well-defined methodology. Stocking and Murnaghan (2001) note that development of one's own specific ranking system is appropriate when requiring a specific and comprehensive view of land degradation, providing the system is used consistently.

Three methods have been developed by the researcher to assess erosion hazard at the study sites. The first method assesses factors contributing to erosion using quantifiable and semi-quantifiable outcomes. It has been designed for use by professional archaeologists and geomorphologists. The second method is a rapid, field-based erosion hazard assessment formulated for use by Aboriginal communities as a cultural heritage management tool. This method includes a numerical ranking system, the Erosion Hazard Index, and a set of recommendations for maintenance and conservation of Aboriginal shell midden sites. The third is a GIS model formulated in ArcMap using data on soils, vegetation coverage, slope, Quaternary surface and subsurface sediment age and dominant texture and land use at the landscape scale (Webb *et al.*, 2009). This method also includes a numerical ranking system.

Table 4.1: Selected methods of erosion hazard assessment.

METHOD	DESCRIPTION	ADVANTAGES	DISADVANTAGES	REFERENCE(S)
Landscape processes at archaeological sites located within arid-land river corridors interpreted using analyses of sedimentary structures and particle size distributions.	Investigation of the sedimentological characteristics distinguishing fluvial, aeolian, slope-wash, colluvial and debris-flow-dominant deposits at archaeological sites in the Colorado River corridor, Grand Canyon, Arizona, USA. Identification of depositional facies by combining sedimentary structures with grain size analyses.	• Uses sedimentological analyses in a broader context to gauge contemporary vulnerability of, and risk to, archaeological sites.	• This particular case study focuses on arid zone archaeological sites. • Generation of results requires large-scale field work and extensive laboratory analyses and is thus unsuitable for use in a rapid, field-based methodology designed for use at a grass roots level.	Draut *et al.,* 2008.
Coding system for soil erosion appraisal in the field.	Proforma for recording soil erosion in the field includes climate (rainfall and temperature), vegetation (type, % ground cover and tree/shrub cover), slope characteristics including position and degree of slope, soil characteristics including depth, surface texture and erodibility, and degree of erosion. Accompanying erosion coding system is a numerical ranking from 0 to 5. Each erosion code number is accompanied by a set of indicators.	• Takes into account multiple indicators in a format which can be readily completed in the field.	• Does not take into account that different erosion indicators may be present in different geomorphic contexts.	Morgan, 1995.
Semi-quantitative ranking scale for land degradation	Land degradation and conservation potential based on ranking of sheet erosion,	• Farmer-perspective approach – user-	• Designed to assess agricultural land	Stocking & Murnaghan,

hazard.	rill erosion and crop management considerations. Designed for use by farmers at the detailed field-level. Sheet and rill erosion are given a ranking between 0 and 3 (absent – severe), based on the degree of soil loss as evidenced by field indicators such as evidence of surface wash, pedestal development and root exposure. Crop management considerations are also given a score between 1 and 3, inclusive. These scores are based on the degree to which crop management indicators effectively conserve the soil and act to inhibit erosion. Scores for these three indicators of land degradation (sheet and rill erosion and crop management) are then averaged to produce an overall score between 1 and 3, which corresponds to land degradation hazard	friendly system. • Indicators of land degradation can be assessed, scored and ranked separately with respect to their seriousness – combining indicators gives a more holistic viewpoint and is more likely to include correct weighting of indicators. • Clearly defined method which is well set out.	degradation and conservation – crop management considerations would not be very useful for the current study.	2001; Douglas, 1997.
EHR (erosion hazard rating).	Factorial scoring system for rating erosion risk. Based on 5 categories of erosion: erosivity, cover (mm of rainfall), slope (degrees), erodibility and human occupation (persons/km^2). These categories are rated 1 to 5 in severity of likelihood to cause erosion. Scores for each of these 5 factors are summed to give a total score which is compared with an arbitrary erosion risk classification system. Under this system dominant factors – those with the highest scores within the categories mentioned above – are placed in subgroups. Thus, when areas are mapped according to their erosion risk, subgroups (dominant factors contributing to erosion risk) are also visible.	• Easy to use system. Factorial scoring/classification system. • Can readily include factors which cannot be easily quantified in any other way.	• Although maps show dominant factor subgroups (see Table …), there is independent treatment of each factor (does not allow for interaction between factors). • Factors are not weighted.	Stocking & Elwell, 1973; Morgan, 1986.

Land capability classification.	System developed by the United States Soil Conservation Service and adapted for use in many other countries. It is a semi-detailed assessment of the extent to which erosion risk, soil depth, wetness and climate affect the agricultural potential of the land. Suitability for agriculture and other uses is based on the capability unit, which consists of a group of soils similar in profile form, slope and erosion. Capability units are grouped into subclasses according to their limiting factors and these subclasses are in turn grouped into classes based on the nature of their limiting factor. Each of these land capability classes has been assigned a set of characteristics and accompanying land use recommendations.	• Erosivity data can be combined with information gained from land capability surveys to yield a more detailed assessment of erosion risk.	• Used as an indicator of the potential of arable land. • Used as an indicator of erosion risk due to current farming activity (ie. areas susceptible to agricultural soil erosion). • Attention to recreational use of land is insufficient – according to the capability classification land is only set aside for recreation when it is considered too marginal for farming.	Morgan, 1986.
Rapid assessment technique for determining the physical and environmental conditions of rivers in Queensland.	A relatively simple rapid survey method which can be undertaken by inexperienced staff after a relatively short training period. Catchment waterways are subdivided into small sections using attributes such as geology, stream gradient and land use. Eleven data sheets are used during the survey. Some are completed using existing data and others in the field. Datasets with a similar focus to the current Aboriginal shell midden impacts research include bank condition and scenic, recreational and	• Surveys can be undertaken relatively rapidly by non-scientist laypeople with knowledge of the land. • Framework over which other data can be laid. • Encompasses a broad spectrum of river condition parameters	• Formulae used to derive attributes and weightings are arbitrary, although based on the best available information, and are thus open to debate. • Physical habitat parameters are measured as	Jackson & Anderson, 1994.

	conservation values. Data pertaining to bank condition include the location and extent of any bank instability (erosion, aggradation or slumping) along with factors identified in the field which may be affecting this stability. A subjective assessment of scenic, recreational and conservation values is included in the survey and uses various rating scales to provide overall value assessments for each section. Data contained within the various datasets are then assigned a percentage value which has been appropriately weighted in terms of the importance of each dataset at each survey location. Percentage values can range from 0 to 100%, where 100% represents the standard for local pristine sites or those in very good condition. This allows different standards to be used in different areas. Ratings for individual sections of a river are combined using cluster analysis to give an overall condition rating.	– suitable for ecological and utilitarian management. • Trends or rates of change in condition can be established through follow-up surveys. • Data can be displayed within a GIS. • Ranking scale base on standardised rankings.	indicators of ecological condition and assumptions have been made regarding which parameters are important to measure. • Survey essentially an ecological one – includes some useful parameters for the current study such as bank condition and scenic, recreational and conservation values – along with others which may be less valuable such as water quality and aquatic habitat.	
DEFRA (Department for Environment, Food and Rural Affairs, London) risk ranking scale.	System of erosion risk assessment which aims to be easily understood and implementable by all UK farmers and useable on a field-by-field basis. Soil texture and slope are assessed by the farmer after which a map of ranking from very high to low risk is produced for the farm. A ranking of erosion-susceptible land uses is also provided by DEFRA and this outlines combinations of soil texture, slope	• Designed for non-scientist laypeople with knowledge of the land. • Useable on a field-by-field basis. • Appropriate scale for current research. • Quantitative. • Standardised	• Designed for use on agricultural land. • Doesn't consider the cumulative impact of runoff from a series of connected fields – parcels of land considered in	Boardman *et al.,* 2009.

	and crop type which lead to high risk of erosion.	method.	isolation with regards to field boundary permeability.	
SICOM (site comparison method).	Uses complex algorithms and matrices with many data sources, inputs and variables to generate a COG (comparison group) number. COG numbers range from 0 (high quality) to 5 (low quality) and rank agri-environmental conditions. Results are more likely to be used in political decision-making and to check regional handling and allocation of subsidies rather than to take action to prevent wind and water erosion at a grass roots level. Designed for evaluation of ecological measures at different administrative rather than landscape scales.	• Broad, standardised numerical ranking system which use quantifiable data.	• Many data sources, inputs and variable. • Complex algorithms and matrices are not user-friendly at the grass roots level. • Designed to rank agri-environmental conditions rather than archaeological or broader environmental conditions. • Focus on administrative rather than landscape scales.	Deumlich *et al.,* 2006.
TRARC (tropical rapid appraisal of riparian condition).	A method developed for rapid on-ground qualitative visual assessment of the environmental condition of wet-dry tropical savanna riparian zones. Indicators of riparian zone condition are used by land managers to assess riparian areas in tropical savannas in a consistent and cost-effective manner. These health indicators are grouped into categories which reflect the functions of the riparian zone: vegetation	• Rapid, field-based method. • Health indicators reflect the functions of the riparian zone. • Consistent and cost-effective. • Most appropriate at spatial scales from 1 km to 200 km river	• Focus on savanna riparian zones. • Ranked data format inhibits precise detection of change, thus less suited for multi-temporal analysis, however image data can	Johansen *et al.,* 2007.

	cover and leaf litter, regeneration of native plants, weediness, bank stability and disturbance/pressures. Broad score categories ranging from 0 to 4 (poor to good condition) were created to reduce user variability in visual assessment of riparian health indicators. Each indicator is assigned a score during field survey and these scores are then used to derive a total score out of 100 which reflects the overall condition of the riparian zone studied.	sections.	provide detailed information on gradual change.	
Rosgen Classification and associated Natural Channel Design.	Classifies and predicts the stability and behavior of a river based on its appearance. Morphological, hydraulic and sedimentological data including water surface slope, bedload transport rate, total sediment yield, bankfull mean velocity, shear stress, friction factor and roughness coefficient are calculated and used to classify rivers into different morphological types and stability classes.	• Classification good as a communication tool (types of rivers).	• Very complex requiring advanced formal training courses, even a 2 week course for professional geomorphologists, geologists and engineers. • Past 14 years work, with the exception of Rosgen, 1994, hasn't passed through accepted channels of peer review. • Some peers (Simon *et al.,* 2008; Miller & Ritter, 1996) have issues with classifications	Rosgen, 2008; 1994; Simon *et al.,* 2008; Miller & Ritter, 1996.

			being used in a predictive sense for management purposes – a variety of predicted possible responses is more useful than constrained responses based on Rosgen Classification. • Focus on rivers only.	
BEHI (bank erosion hazard index).	Represents a part of the Pfankuch-Rosgen channel stability rank based on stream characteristics. Measurements of the bank height to bankfull ratio, root depth to bank height ratio, root density (%), bank angle and % surface protection are indexed with a range of measurements falling within each index range. Indexed scores for each of the measurements listed above are then added to give a total score between 5 and 50, corresponding to a hazard or risk rating between very low and extreme, respectively.	• Takes into account a range of quantifiable bank characteristics. • Relatively easy to measure in the field.	• Channel stability ranking only – the current project covers many geomorphic settings.	Rosgen, 2001
ERI (erosion risk index).	Assessment of soil erosion risk using data from soil hydrological characteristics (infiltration-runoff ratio), rainfall aggressiveness and slope. Based on 2 equations incorporating the Fournier Index for determining erosion risk under differing rainfall aggressiveness, and runoff potential as a function of soil structure and soil	• Measured at an appropriate scale for the current research. • Quantitative.	• Too complex for rapid field assessment. • Appears to be designed for use on agricultural land.	Lobo *et al.,* 2005.

	particle size. Used in combination with the PI (productivity index) as a measure of agricultural damage/suitability.			
AUSLEM (Australian land erodibility model).	A computer model designed to predict land susceptibility to wind erosion in western Queensland. It operates on a daily time-step at a 5 km X 5 km spatial resolution. Inputs include grass and tree cover, soil moisture, soil texture and surficial stone cover. Aims to track spatial and temporal variability in dust emissions.	• Daily time-step ie. not static.	• Designed only for measurement of wind erosion. • Complex computer model. • Resolution not tight enough for the current study.	Webb *et al.,* 2009.

4.2.8.2 *Method one: Assessment of disturbance processes, their contributory factors and outcomes*

Appendix 5 shows disturbance processes contributing to erosion of Aboriginal shell middens in the study area. Each process has a set of contributory factors with quantifiable or semi-quantifiable outcomes. Assessment of these outcomes is based on interpretation of field evidence, aerial photographs, current and historic maps, wind rose data and information on tidal flows and flooding. Data sources are also included for each outcome in an adjacent column. Major factors contributing to bank erosion include bank stability, frequency of tidal inundation, position of the bank in a channel and human activity (land and watercourse usage). Factors affecting potential vulnerability to wind erosion include deposit stability (stability of the matrix), exposure to prevailing winds and human activity. Ocean swell is the main factor causing wave erosion. Processes of cultivation and excavation are also considered.

Percentage vegetation cover (grasses and shrubs/trees) was used as a key indicator of bank stability. This variable can be measured relatively easily in the field and supplementary information can be found in aerial photographs. In this study percentage cover of grass and shrubs and trees was calculated in the field. Ground coverage of grasses, shrubs and trees was measured at the base of the plants and is a measure of the vegetation coverage in contact with the ground surface. Vegetation coverage was measured in this way as soil in close proximity to channel banks in the study area appears to be more susceptible to processes such as channel flow, tidal inundation and flooding than to rainsplash. Vulnerability to erosion was then interpreted based on the erosion-cover relationship graph of Stocking (1994, Figure 7.23).

Tide height was used as a key indicator of the susceptibility of a site to tidal inundation. The elevation of the midden deposits was calculated using known tide heights. At high tide the distance between the surface of the water and the top of the midden deposit was measured and this gave a maximum elevation for each site in mLAT (Lowest Astronomical Tide). These values were then used to assign each relevant site a Tidal Inundation Class (calculated using data provided by New South Wales Department of Commerce, Manly Hydraulics Laboratory; Appendices 4 and 5), with classes 1-5 representing most to least often occurring tide heights.

Fetch is a key indicator of wave height and was chosen as it can easily be measured from a topographic map. The width of the channel was measured and this gives a distance over which waves can form on the surface of the water as a result of the action of wind. Bank position in a channel was assessed by looking at the surrounding geomorphology. Whilst not quantifiable, this interpretation can be made relatively easily by studying air photos and topographic maps. Bank position in a channel was divided into 3 possible categories based on geomorphology. The bank could either be situated in an erosional setting on the outside of a meander bend, a depositional setting on the inside of a meander bend, or a sheltered/protected location such as opposite a channel island or in a back channel.

The final key indicator used in the assessment of bank erosion involves a human activity multiplier. Human activity in riverine and estuarine environments of the Clarence River is largely associated with motorised water craft. Boating wash can affect wave height and bank stability and as such, a method was created to include this potential threat in the erosion risk assessment. The human activity component in the assessment of bank erosion involves multiplying the usage intensity by the number of affected factors, in this case wave height and bank stability. A human activity multiplier is also used in the assessment of wind erosion. To calculate the human activity multiplier the intensity of human activity is multiplied by the amount of factors it affects. Intensity of human activity is given a score of 1, 2 or 3. A score of 1 represents minimal activity/impact year round, 2 represents predominantly seasonal usage, such as during the school spring and summer holidays, and a score of 3 corresponds with steady/sustained usage throughout the year. The usage intensity was identified in the field and through informal consultation with the local Indigenous and non-Indigenous communities. Given that the outcome of the human activity multiplier is numeric, it provides a relatively simple, semi-quantitative means of comparison between sites where human activity affects other erosion hazard assessment factors.

Disturbance related to cultivation is a product of human activity. Excavation can be a result of anthropogenic activity or biological activity (bioturbation). Several key indicators are used to assess erosion hazard due to excavation. Anthropogenic excavation is interpreted in this study as any human-induced process associated with the removal of material from an area. The most likely reason for such removal would be building or infrastructure based. Farming is considered separately under the process of cultivation (Appendix 5).

The first key indicator of potential erosion hazard due to anthropogenic excavation involves calculating the percentage of the original deposit remaining *in situ*. This was calculated using a combination of field reconnaissance/survey and examination of topographic maps and aerial photographs and can be summarised in an equation as follows:

Percentage of midden undisturbed = area of *in situ* deposit/area of disturbed shell X 100

The effect of bioturbation at an Aboriginal shell midden sites was calculated in a similar way as illustrated by the following equation:

Percentage of midden disturbed by burrowing = volume of the burrow which has been dug through the midden layer/total volume of the midden layer X 100

If the percentage of the original deposit remaining *in situ* cannot be calculated due to cultural sensitivity and a desire by the relevant land council not to disturb the deposit any further a measurement of the area of apparent disturbance may be used instead. A measurement of the area of apparent disturbance may also be used if a deposit is located in difficult terrain which, for example, can only be surveyed by boat. Information on disturbance as a result of historic anthropogenic excavation can be gained through oral history of past and present landowners, newspaper articles, parish maps and other historic topographic and military maps. In the case of parish maps, however, it must be noted that all historic editions may not be available, leaving information gaps before the first and after the last available editions.

Proximity to roads and Council land use zoning can greatly affect the disturbance potential of a site and hence are included as the final key indicators of potential erosion hazard at Aboriginal midden sites. Proximity to roads can be calculated from current topographic maps by hand or using GIS software. In this study, measurements were taken from hard copy topographic maps and confirmed in ArcGIS. Information on council land use zonings is available from local councils (in the case of this study, the Clarence Valley Council). Midden locations were plotted over a land use zoning shapefile in ArcGIS to determine the zoning of the land on which they are located. It is important to note that while all Aboriginal sites are protected by law in Australia they are often buried in cryptic locations and may not be discovered until excavation works have commenced. In addition, diagnosis of the origin of a shell deposit requires some skill and experience (Attenbrow, 1992); the origin of a shell deposit is not likely to be known by a general observer.

Key indicators used to assess erosion risk due to farming include the area of land clearance or percentage of original deposit remaining *in situ*, slope of the land, distance of crops from the riverbank and history of cultivation in the area. These are similar to the key indicators of human-induced excavation outlined above. The area of land clearance and history of cultivation were measured using the resources described for measurement of these key indicators in the process of excavation. The slope of the land was measured in the field using a clinometer and the distance of crops from the riverbank was also measured in the field by either land- or water-based survey.

The processes of wind and wave erosion were considered at midden sites located close to the coast in areas such as dunes and headlands. Three factors affecting a midden deposit's susceptibility to wind erosion were considered as a part of the erosion hazard assessment performed in this study. They are deposit stability, exposure to prevailing winds and a human activity multiplier. The key indicator for deposit stability is vegetation cover and this is calculated and interpreted in the same way as previously outlined for bank stability.

The key indicators for assessing the effect of prevailing wind at a coastal midden deposit are wind direction and approximate length of daily exposure. Information on regional prevailing wind direction and intensity can be found by examining wind roses, such as those compiled by the Australian Bureau of Meteorology which were used in this study. The closest locations to the study area for which this information is available are Coffs Harbour and Brisbane. These data were used to provide information on regional wind patterns and were validated in the field by observing the characteristics of coastal vegetation (whether it is wind-shaped and in what direction) and the orientation of mobile sand dunes and dune blowouts. Aerial photographs also contain information relating to the local and regional orientation of modern and relict sand dunes.

Wind rose data are broken up into roses reflecting morning (9 am) and afternoon (3 pm) average conditions. As such, the approximate length of daily exposure of a midden site to prevailing winds is given a percentage value of 0%, 50% or 100%. When comparing site orientation with prevailing wind direction as evidenced by regional wind roses and site-specific field evidence, a value of 0% is given to sites which, as their orientation suggests, are sheltered from morning and afternoon prevailing winds. A value of 50% is given to sites which have an orientation exposing them to either morning or afternoon average prevailing winds only. A value of 100% is given to sites which are exposed to morning and afternoon prevailing winds.

Recreational activities associated with tourism in beach environments throughout the study area form the basis for the human activity multiplier associated with the process of wind erosion. Activities such as driving 4WD vehicles on beaches, camping and walking over dunes and headlands for sightseeing or fishing purposes can affect the stability of midden deposits. As previously discussed, this human activity component involves multiplying the usage intensity by the number of affected factors. In this case the affected factor is bank stability.

Ocean swell is the major factor affecting susceptibility of a midden site to sustained or periodic wave erosion. Three key indicators of ocean swell are considered in this erosion assessment methodology. Site elevation and the presence or absence of storm surge deposits and cliffing were recorded in the field. The use of geomorphic indicators that are readily identifiable and measurable in the field is a simple and effective way of ascertaining whether or not wave erosion is affecting midden deposits and their surrounding areas.

4.2.8.3 *Method two: A rapid, field-based erosion assessment methodology*

The development of a straightforward rapid, field-based methodology for assessment of erosion at shell midden sites is an essential cultural heritage management tool. Included in this methodology are an Erosion Hazard Pro Forma and a scoring system using characteristics of field forms and vegetation coverage, taphonomic characteristics of shell material found at a midden site, tidal activity and a standardised template for recording soil aggregate stability (Appendices 3 and 5). Scores obtained in these tables are used to calculate an Erosion Hazard Index for each site which corresponds to a set of recommendations for maintenance and conservation of Aboriginal shell midden sites. Collection of data in this way allows Aboriginal communities and their representatives access to a variety of information pertaining to a site whilst also identifying current and potential destructive impacts.

The layout of the Pro Forma is loosely based on that presented by Morgan (1995) for assessing erosion in the field. Like the Morgan (1995) Pro Forma it contains sections pertaining to land use, vegetation, slope and soil, but is expanded to include landscape characteristics, taphonomy and erosion field forms, in addition to basic information on the location, orientation and contents of a site. The inclusion of these additional characteristics improves its relevance for use in the assessment of erosion as it affects midden deposits.

The first section of the Pro Forma contains information about the location and site type – important background information for any field study. The grid reference for a site can be taken from a topographic map. It is important to note the scale of the map and also the coordinate system (i. e. GDA or MGA in Australia). Alternatively, a GPS reading can be taken at the site. Including an option of either grid reference or GPS reading does not disadvantage communities who don't have access to a hand held GPS. GPS/grid reference conversions can be performed easily using online resources (such as Geoscience Australia's website). The Site Type field requires a brief description of the function of the site, for example open site shell midden with artifacts, open site shell midden without artifacts, open site stone quarry, closed site shelter/cave.

The Current Land Use section gives a list of options for describing the nature of the current land use at a site. More than one box may be checked. The field worker is also required to make a note of the type of farming and recreational activity if applicable. Information on land use is available from a number of sources. Topographic maps contain information on the location of National Parks, State Forests and Crown Land. Land use can also be confirmed in the field. Local Council will have information on land use zoning if a more detailed approach is required.

The next section of the Pro Forma provides a description of the landscape at two scales – the terrain (surrounding area) and the landform (at site). The terrain is measured up to the landscape scale (10 000 km^2; Webb and Phinn*,* 2009) and includes coastal, estuarine, riverine and hillslope/mountainous environments. A variety of landform options are available within each terrain category and the field worker is required to select one from the list. Larger scale terrain features can be identified using maps and aerial photographs and landforms can be identified in the field.

Vegetation is covered in the following section of the Pro Forma. Characteristics influencing erosion include type and amount of cover. Vegetation type can be identified in the field and a general description is all that is required here. It may include a note on the presence/prevalence of exotic versus native vegetation and the basic type of vegetation association, such as open/closed forest, grassland, woody/herbaceous, established/new, mangroves/riparian vegetation, halophytes. Ground, tree and shrub cover are measured as a percentage of land area. Larger-scale vegetation cover can be measured using air photographs and site-scale coverage can be measured in the field. Field study can also be used to ground truth air photo interpretation.

The Tidal Activity section consists of only one question. Tidal influence has been observed to affect some sites in the current study. If a midden deposit is present in a tidal channel it has the potential to be affected not only by tidal activity but also flooding. The purpose of this section is to highlight potential disturbance of tidal activity rather than gauge the severity of this impact, as this requires more complex calculations based on tide height and frequency. The upper limit of tidal activity is included in topographic maps. Tide prediction charts and local knowledge will also provide useful information for completing this section.

Information on the orientation of the deposit is included in the Pro Forma. It is useful to have this information in case further studies of wave direction and fetch and effect of prevailing winds are required. The orientation of a deposit can be measured in the field using a compass or the sun as a guide. Slope is another characteristic which may contribute to erosion hazard. The angle of a slope can be measured in the field using a clinometer. The shape (cross section) can be described and sketched on the Pro Forma.

It is important to consider the effect of certain soil parameters on erosion at midden sites. The depth, thickness and length of a midden deposit can be measured in the field. Field measurements taken at varying points in time can be compared to ascertain whether or not there has been loss of material due to erosion or burying of material due to deposition. Measurement of field texture (for example, Isbell, 1996; Northcote, 1979) can be carried out in the field or at another location after collection of sediment. It is a far more rapid, straightforward and economical alternative to particle size analysis and can be carried out with minimal training. The Emerson Aggregate Test (Emerson, 1967) is a simple analysis yielding information on soil aggregate stability. The only materials required are deionised or rain water, containers and in some cases easily obtainable aqueous chemical compounds.

Taphonomy can also provide useful information about the depositional history of, and geomorphic processes currently acting at, a midden deposit. Some basic measurements and characteristics are included on the Pro Forma in the section 'Appearance of Shells in Midden'. The percentage of exposed *in situ* versus weathered material can give an indication of actual and potential information loss. Rates of information loss can also be calculated by comparing measurements taken at varying points in time. It is important to remember, however, that the exposed material may only provide a snapshot of the amount of material contained within a deposit. Likewise, the amount of visible material weathered out of the deposit may only represent a portion of the total amount of material that has weathered out of the deposit over time. The condition of shells is also important and the Pro Forma includes a subsection where such information can be recorded.

The final section included in the Erosion Hazard Pro Forma includes descriptions of a number of field forms which, based on their size and extent, can indicate the severity of erosion at a site. They form part of a selection of field forms used by Stocking and Murnaghan (2001) to assist farmers in developing countries assess degradation on their land. They can all be identified and measured in the field using basic equipment. An in-depth explanation of the techniques required in identification and measurement of the parameters set out in the Erosion Hazard Pro Forma is included in a handbook available to Aboriginal communities interested in using the techniques.

<u>Scoring System for Use in Conjunction with the Rapid, Field-based Erosion Hazard Assessment for Aboriginal Shell Midden Sites</u>

Systems which aim to score or rank land degradation rely, to some degree, on assigning arbitrary values to field measurements and other quantifiable data. The scoring system formulated for use in conjunction with the Erosion Hazard Pro Forma is based on several key components rather than assigning arbitrary, unweighted scores to all sections. The information contained within the Pro Forma can be assessed on its own merit as it does not rely on a scoring or ranking system to contextualise the data.

The Erosion Hazard Index developed in this research study is provided as a supplement and may be used to prioritise conservation and management of middens and other Aboriginal cultural deposits (Appendix 3). It is made up of four parts, using information from the Pro Forma, which can be added together to give an overall value linked to the severity of erosion at a site. The first involves scoring the severity of erosion based on characteristics of field forms and vegetation. It is a synthesis of characteristics outlined by Morgan (1995), Stocking and Murnaghan (2001), and Stocking (1994). The next provides scores based on the taphonomic characteristics of shell material contained in a deposit. The third part includes the Emerson Class Numbers for strata within the deposit and is a numerical rank of soil aggregate stability based on the Emerson Aggregate Test. The final part includes a score for tidal activity. All scores are equally weighted with a minimum value of zero and a maximum value of three. This alleviates unnecessary bias as it allows all characteristics at all sites to be scored and compared equally. Vegetation, soil, tidal and taphonomic characteristics were chosen for use in this scoring system as they represent key components in midden degradation due to erosion.

Scores are assigned based on the four components outlined above. These four scores are then averaged to give an overall score of the severity of erosion at a site, the Erosion Hazard Index. When results from different sites are compared, higher scores indicate greater erosional disturbance. These scores can be used as an aid in prioritising site conservation.

Recommendations for maintenance and conservation of Aboriginal shell midden sites are included in the Handbook for Use with the Erosion Hazard Pro Forma (Appendix 3) and correspond to the Erosion Hazard Indices. These are general guidelines only. Information on site-specific processes can be collected by archaeologists and environmental scientists using information collected in the Erosion Hazard Pro Forma as a starting point for further study.

4.2.8.4 *Field Trial of the Erosion Hazard Pro Forma*

The purpose of the field trial was to introduce the system to various stakeholders – the Yaegl Local Aboriginal Land Council, archaeologists and environmental scientists – and compare results obtained by the researcher with results obtained by these groups. The field research groups each contained members of each stakeholder group. After a general briefing and outline of the methodology the groups used the Erosion Hazard Pro Forma to collect data at Woombah A, Woombah B, Sleeper Island, Minnie Water and Wooli Aboriginal shell midden sites. They then used the scoring system to obtain an Erosion Hazard Index for each site.

The groups contained field workers with a variety of educational backgrounds. As a minimum standard all volunteers had a high school education. There were also different levels of tertiary education amongst the groups, from Bachelors and Masters degrees to Doctorates. Whilst field workers with tertiary qualifications in archaeology and environmental science could record requisite information on the Erosion Hazard Pro Forma without needing to refer to the accompanying Handbook, high school educated members of the Yaegl Aboriginal community and scientists not specialised in archaeology and environmental science found the Handbook to be a valuable aid. The tertiary educated archaeologists and environmental scientists were also able to demonstrate the methodology to these volunteers which, through hands-on experience, they picked up with relative ease. Gathering data at multiple sites also increased their confidence in working with the Pro Forma.

As is the case with any data collection system, some training is required before it is able to be used with confidence. The ease with which the Erosion Hazard Pro Forma was understood by tertiary educated specialists and was able to be explained to and practised by high school educated members of the Yaegl community suggests its usefulness as a standardised erosion hazard assessment tool for Aboriginal shell midden sites.

4.2.8.5 *Method three: GIS model*

This model was formulated in ArcMap and shows the interaction of factors contributing to erosion at the landscape scale. Detailed results are presented in Appendix 5; data and maps are also included in electronic form in Appendix 6. Data on soils, vegetation coverage, slope, Quaternary surface and subsurface sediment age and dominant texture and land use are used to assess erosion risk at Aboriginal shell midden sites in the study area. Data from each layer have been assigned numerical risk values of 0 (no/extremely low erosion risk), 1 (low risk), 2 (moderate risk) and 3 (high risk) (Table 4.2). Each factor represents a layer in the model and scores for each layer are averaged to give an overall risk value. Multiple shell midden sites can then be ordered according to the degree of erosion risk and conservation efforts can be prioritised where needed.

Vegetation coverage was digitised from aerial photographs obtained through the New South Wales Department of Lands. Based on the erosion cover relationship graph of Stocking (1994), three categories were generated – 20, 40 and 60. These were then merged into one layer to represent vegetation coverage. Category 20 corresponds to a value of 0-20% vegetation coverage and this is given a score of three, high erosion risk. Category 40 corresponds to a value of 40% vegetation coverage and this is given a score of two, moderate erosion risk. Category 60 represents areas of 60-100% vegetation coverage. It is given a score of one, low erosion risk.

Data in the slope layer were sourced from the digital elevation model DEM NSW 9s, courtesy of the NSW Rural Fire Service. Risk categories in this layer were determined using jenks (natural breaks) in the data. Assigning categories in this way is more reliable than using arbitrary values as the categories accurately represent variation in the natural elevation of the landscape. A slope of up to 5.99° is assigned an erosion risk value of 1, representing low erosion risk. Slopes from 6-14.99° are assigned a value of 2, representing a moderate erosion risk. Finally, land with a slope of 15-43.99° is assigned a value of 3, high erosion risk. The value of 43.99° represents the maximum slope in the digital elevation model throughout the study area and surrounds.

Three soil characteristics are used in the erosion risk model. Laboratory analyses were used to determine dominant texture, total organic content and Emerson Aggregate Number of soil samples from the study sites (outlined earlier in this chapter). Results of soil analyses were set out using the same format as Troedson and Hashimoto's (2008) Coastal Quaternary Geology datasets, compiled for the Geological Survey of NSW. The paucity of data in the study area necessitated the use of field data from the study sites. In any case, use of site-specific data following the format of Troedson and Hashimoto (2008) is recommended to ensure accuracy of results as characteristics of local soils may be highly variable, especially in areas with a variety of land uses.

The dominant texture of soils in the midden strata at the study sites was determined using a Malvern Mastersizer (see 'Laboratory Analyses'). Three categories – sand, silt and mixed – were assigned risk values based on their relative erodibilities as outlined in Evans (1980), Lal and Elliott (1994) and Troedson and Hashimoto (2008). Where sand was the dominant texture, these soils were assigned the low risk value of 1. Soils with a mixed texture were assigned a risk value of 2, corresponding to a moderate erosion risk. Soils containing predominantly silt-sized particles were assigned a high risk value of 3.

The total organic content of soils at the study sites was determined in the laboratory (see 'Laboratory Analyses'). These data were then divided into low, moderate and high risk categories. The soils dataset of Troedson and Hashimoto (2008) defines soils with an organic content greater than or equal to 7.50% as having a high organic content. Soils from the study sites which fell into this category were assigned a low erosion risk value of 1. Based on this same dataset, soils with an organic content between 4.00 and 7.49% were assigned a moderate erosion risk value of 2 and soils with a low organic content, between 0.00 and 3.99%, were assigned a high erosion risk value of 3.

The Emerson Aggregate Test (Emerson, 1967; see 'Laboratory Analyses') was also performed on soil aggregates from the midden strata at the study sites. Soils with an Emerson number of 1 or 2 were assigned a high erosion risk value of 3, as these are the most unstable aggregates (Emerson, 1967). Soils with an Emerson number of 3 were assigned a moderate erosion risk value of 2, as these aggregates are stable until soaked to field capacity (Emerson, 1967). Soils with an Emerson number of 4, 5 or 6 were assigned a low erosion risk value of 1 and soils with an Emerson number of 7 or 8, the most stable aggregates (Emerson, 1967), were assigned a very low erosion risk value of 0.

Troedson and Hashimoto's (2008) regional map of Quaternary surface and subsurface sediment age and dominant texture was included in the model as a measure of potential shoreline erodibility. Induration of Pleistocene dunes greatly improves their stability and thus their ability to withstand sea level fluctuations (Troedson and Hashimoto, 2008). Middens located within these sediments are therefore less susceptible to erosion than those located in younger, unconsolidated dunes.

Locations where Holocene age surface sediments overlie Holocene subsurface sand and sand-mud were placed in the high risk category and given a value of 3. Where Holocene surface sediments overlie Holocene subsurface mud a moderate risk value of 2 was used. A low risk value of 1 was assigned to locations where Pleistocene surface sediments overlie Pleistocene subsurface sediments of a variety of textures.

Council land use zoning (data courtesy of the Clarence Valley Council) was also included in the model. Erosion risk values were assigned to different zones based on the nature and scale of development which is prohibited within a zone. National Parks were assigned a value of 0 as development is prohibited within these areas. Small-scale National Parks and Wildlife Service developments undergo strict approval processes. Land use zones assigned a low risk score of 1 include areas of low-density residential development, open space, environmental protection and proposed National Parks. Commercial and industrial development, as well as development affecting environmental processes and wildlife habitats is prohibited within these zones. Rural zones, medium-density residential zones, commercial and village zones were assigned a moderate erosion risk value of 2. High-density residential development, industrial development affecting the value of agricultural land is prohibited within these zones. Rural land set aside for urban expansion, industrial and residential tourism zones were assigned a high erosion risk value of 3 as industry, agriculture and high-density housing are all permitted within this zone, making this land the most intensively used by humans.

Table 4.2: Standard Definitions for GIS Erosion Risk Categories.

LAYER	CATEGORY		RISK	DEFINITION & REFERENCE/SOURCE
VEGETATION COVER	20 40 60		High Moderate Low	0-20% 40% 60-100% Stocking, 1994 Data source: Digitised from NSW Dept. of Lands aerial photographs
SLOPE	Low Moderate High		Low Moderate High	0.00-5.99° 6.00-14.99° 15.00-43.99° Jenks (natural breaks) used to determine categories. Data source: DEM NSW 9s, courtesy NSW Rural Fire Service
SOILS (Dominant Texture)	Sand Mixed Silt		Low Moderate High	Evans, 1980; Lal & Elliott, 1994; Troedson & Hashimoto, 2008 Data source: Malvern Mastersizer (field samples)
SOILS (Total Organic Content)	Low Moderate High		High Moderate Low	0.00-3.99% 4.00-7.49% ≥7.50% Troedson & Hashimoto, 2008 Data source: laboratory analysis
SOILS (Emerson Aggregate Number)	Emerson No.	Risk Score		Emerson, 1967 Data source: laboratory analysis
	1 2 3 4 5 6 7 8	3 3 2 1 1 1 0 0		
QUATERNARY SURFACE/SUBSURFACE AGE & DOMINANT TEXTURE	Holocene Surface/Holocene Subsurface Sand		High	Holocene surface sediments overlying Holocene subsurface sand and sand-mud.
	Holocene Surface/Holocene Subsurface Sand-Mud		High	
	Holocene Surface/Holocene Subsurface Mud		Moderate	Holocene surface sediments overlying Holocene subsurface mud.
	Pleistocene Surface/Pleistocene Subsurface Sand		Low	Pleistocene surface sediments overlying Pleistocene sands and Pleistocene various (mixed texture) sediments.
	Pleistocene Surface/Pleistocene		Low	

	Subsurface Various		Data source and definitions: Troedson & Hashimoto, 2008
LAND USE	8a (national parks)	None	*Prohibited:* All development with the exception of National Parks developments (require consent).
	2a (low-density residential) 5a (special uses) 6a (open space) 7a (environmental protection, conservation/habitat) 7b (environmental protection, ecological significance) 7e (environmental protection, escarpment/scenic) 8b (proposed national parks)	Low	*Prohibited:* Commercial and industrial development, development affecting and affected by coastal processes, development adversely affecting significant vegetation and wildlife habitats, development in geologically hazardous areas. *Subject to consent:* low-density housing, forestry, construction of public utilities, clearing of land.
	1a (rural, agricultural protection) 1b (rural, general rural land) 1f (rural forests) 1i (rural investigation) 1w (rural waterways) 2b (medium-density residential) 3a (commercial) V2 (village zone)	Moderate	*Prohibited:* High-density residential development, industrial development, development affecting conservation value of land, farming prohibited in commercial zone. *Permitted:* agriculture, forestry, recreational and commercial fishing, development of tourist facilities not resulting in environmental degradation, development providing a wide variety of community housing options.
	1e (rural, urban investigation) 2t (residential tourism) 4a (industrial)	High	*Permitted:* Industry, agriculture, development of tourist facilities and high-density accommodation, agricultural land set aside for urban expansion. Data source: Clarence Valley Council

5. STRATIGRAPHIC INVESTIGATION AND INTERPRETATION

5.1 CHARACTERISTICS OF QUATERNARY STRATA

This chapter contains a discussion of Quaternary strata along the mid to north coast of NSW and the southern coastal areas of Queensland. Characteristics, likely formation processes and dates of relevant strata are reviewed, and links are made with stratigraphic data collected in this research project and previous archaeological studies in the Clarence Valley. Contextualisation of the stratigraphy of the study sites enables further interpretation of site formation processes and forms the basis for the development of the erosion hazard assessment methods.

Current research indicates that most dunes in coastal New South Wales have formed since the Penultimate Interglacial period (200 000 – 250 000 yrs BP, Oxygen Isotope Stage 7) (Bryant *et al.,* 1994). Dune barrier plains are present at a number of sites along the east coast of Australia, including the Newcastle Bight, Port Stephens-Myall Lakes region, Evans Head (NSW), and North Stradbroke Island and Rainbow Beach (QLD) (see Table 5.1 for dates and references). The dune barriers identified at Evans Head extend south to the Clarence River. Two near-coastal dune barriers have been identified in the study area: an inner, Pleistocene barrier and an outer, Holocene barrier (Langford-Smith, 1971; 1972; Warner, 1971; Marshall and Thom, 1976; Pickett *et al.,* 1989; Bryant *et al.,* 1994).

Dunes comprising the Pleistocene Inner Barrier system at Evans head are parabolic, with a south to southeast orientation reflecting prevailing wind trends at their time of formation (Thom *et al.,* 1994). The near-coastal Pleistocene Inner Barrier dune system is highly podzolized; a humate (lithified B horizon) stratum is overlain by an A2 horizon composed of leached incoherent quartz sand which is in turn overlain by a peat horizon in areas where channels have been incised through the dunes (Thom, 1965; Warner, 1971; Bryant *et al.,* 1994). Entrenched channels are likely to have been incised through dunes during a period of sea level lower than present (Thom, 1965). Bryant *et al.* (1994) identify a thin (~20 cm) layer of iron nodules forming a crust on top of underlying humate at a site in Jervis Bay, New South Wales. The presence of this crust indicates the humate was exposed subaerially prior to being covered by sands forming the A2 horizon.

Podzolization is thought to have occurred within the Inner Barrier as soil particles from vegetated dunes became mixed with the sand lying below the soil. The period of transgression leading to the Last Interglacial (Oxygen Isotope Substage 5e) caused the watertable to rise and subsequently a hardpan was formed from the layer containing sand and humic material. The hardpan is referred to as humate or sandrock (Ward *et al.,* 1979; Thom *et al.,* 1994). The Outer Barrier, by contrast, is only weakly podzolized (Thom *et al.,* 1994). Dune soils of the early Holocene (~6000 – 9000 years BP) contain comparatively shallow A horizons and only moderately developed B horizons with incipient light yellow to dark brown columns and pipes, unlike the thick humate rich columns and concretions found in sandrock of the Inner Barrier dune system. Thom (1965) noted that no hardpan was present beneath the ridges of this system in the Myall Lakes area and that the watertable lies below the surface of its swales.

The Holocene Outer Barrier also differs from the Inner Barrier in other ways. It is commonly separated from the Inner Barrier by a tract of shallow lagoon or swamp and blowouts are a common feature of the foredune ridge. The removal of sand from these foredunes creates a mobile sand sheet which is blown inland by onshore winds (Thom, 1965).

5.2 AGE DETERMINATIONS

Table 5.1 lists dates obtained from materials located within the Inner Barrier dune complex along the east coast of Australia. The age determinations in Table 5.1 focus on the Pleistocene Inner

Barrier, as McBryde (1982) observed mid-Late Holocene shell middens in the Woombah area situated behind these dunes and stratigraphically overlying possible hardpan sediments associated with them. Angourie is situated along the Clarence coastline, south of the Clarence River and work was undertaken by Warner (1971) in this area. He dated three consecutive strata – the basal humate platform, the grey (leached) sand stratigraphically above the platform and the overlying peat. The dates indicate the strata formed just prior to the Last Glacial Maximum, set at 22 000 years BP (Bard *et al.,* 1990), however the result obtained for the humate platform indicates a younger age than the overlying strata. No replicate determinations were made and Warner (1971) acknowledges the sample taken from this layer may have been contaminated. Also, these dates are reaching the upper age limit of the conventional radiocarbon dating technique (~30 000 years) and contamination can occur in older materials (Thom, 1973).

Evans Head lies to the north of the Clarence River and is located at the mouth of the Richmond River, New South Wales. Dates have been obtained for several Pleistocene strata including offshore sediment contained within the continental shelf at a depth of 53 m (Colwell and Roy, 1983; Table 5.1). Plant root material dated by Colwell and Roy (1983) was considered by the authors to have come from muds associated with interdunal swamps which were a feature of the landscape during the Last Glacial Maximum. The age determination of 18 070±280 years BP (Table 5.1) supports this idea. Organic material from the Inner Barrier sandrock at Evans Head was dated by Langford-Smith (1971; Table 5.1) at 34 000 +1200 -1000 years BP using conventional radiocarbon dating. Another conventional radiocarbon date of 25 900±1100 years BP was recorded by Gill (1967) for the same stratum in the same location. These determinations both indicate formation of the Inner Barrier dunes at a time prior to the Last Glacial Maximum and correlate (within 1 standard deviation) with the age obtained for the grey sandy layer at Angourie. The Evans Head Inner Barrier dates are, however, approaching the limit of reliability for the conventional radiocarbon dating method. Scleractinian corals collected from the Gundurimba Clay, Evans Head, were dated using the Uranium Series Disequilibrium technique (see Table 5.1 for researchers and dates). The Gundurimba Clay is a formation which is widely distributed in the Richmond River Valley (Pickett *et al.,* 1989), however it is not mentioned in the stratigraphic literature pertaining to the Clarence Valley so no direct comparison of dates can be made. A revision of the dates of Drury and Roman (1983) and Marshall and Thom (1976) by Pickett *et al* . (1989) suggests the Gundurimba Clay is most likely Last Interglacial (Oxygen Isotope Substage 5e) in age.

A date obtained from Inner Barrier sandrock at Rainbow Beach, southern Queensland (31 000 +3200 -2200 years BP; Langford-Smith, 1972) is consistent with other radiocarbon ages obtained for sites in Northern New South Wales (Table 5.1). Thermoluminescence age data from the Newcastle Bight area also appear to be consistent with the radiocarbon determinations for the Inner Barrier at Angourie, Evans Head and Rainbow Beach (Table 5.1). Sand dunes at North Stradbroke Island, Southern Queensland, however, are much older and appear to be associated with the Penultimate Glaciation (Oxygen Isotope Stage 6; Table 5.1). A thermoluminescence determination of 76 600±18700 years BP was obtained by Bryant *et al,* (1994) from barrier dunes at Cape Hawk, Myall Lakes, New South Wales but it was suggested by the authors that this deposit had been reworked.

5.3 DEPOSITIONAL SEQUENCE – NEAR-COASTAL INNER BARRIER DUNES

Using age determinations and palaeoenvironmental data presented in the papers appearing in Table 5.1, a possible depositional sequence for near-coastal Inner Barrier dunes in mid-northern New South Wales and southern Queensland is presented. Last Interglacial barrier dunes formed as a result of progradation associated with a sea level similar to, or higher than, the present level. During the Last Glacial Maximum extensive aeolian reworking created dune instability and incorporated younger sediments into the barrier. Progradation associated with the subsequent Postglacial Marine Transgression saw increasing dune stability and a rise in the groundwater table resulting in formation of a humate hardpan, and thus, podzolization. As the Inner Barrier dunes became increasingly vegetated a rich peat deposit formed capping the Inner Barrier system at Rainbow Beach and Angourie (Ward *et al.,* 1979; Warner, 1971).

5.4 STRATIGRAPHIC INTERPRETATION

5.4.1 **Woombah**

Study of the Quaternary stratigraphy of the Clarence Valley allows the archaeological deposits studied in this research, and those previously studied, to be placed in context and provides key information regarding age and stratigraphic integrity of such deposits. The Woombah midden complex is situated on the landward side of the Pleistocene Inner Barrier at various locations along the north bank of the Clarence River's North Arm. McBryde (1982) studied a midden belonging to this complex in depth in 1963 and 1964. The site, which she termed Woombah 1, is located on the eastern site of Woolpack Creek. She also notes the presence of middens in a similar location to those forming a component of the current study however these were not excavated. McBryde (1982) made various notes on the stratigraphic context of the Woombah 1 deposit, however as the study was archaeological in nature and there was a large amount of material to interpret, some details regarding depths of strata are missing. Archaeologically sterile layers were not thoroughly analysed to determine their exact location in the Quaternary depositional sequence. Some notes on the possible palaeoenvironment are included but McBryde (1982) is careful to note the limitations of the study.

Examination of aerial photographs of the Myall Lakes region (Thom, 1965) and the current study location reveals backswamp areas landward of the Inner Barrier dune system. These backswamp areas are likely to have formed during a period of higher sea level than at present. A shallow lagoon-type environment would have been favourable for lithification of lagoon sediments and formation of a crust on top of this layer. This is consistent with the stratigraphy observed by McBryde (1982). Directly underlying the midden strata is a thin white sandy layer which rests on top of a white sandrock deposit. This sandrock deposit is capped by a thin cemented crust. Depths of the archaeologically sterile layers are not noted. Ward *et al.* (1979) define sandrock as being "composed of quartz sands cemented with organic matter" (p. 305) however organic matter appears to be absent from the white sandrock described and photographed by McBryde (1982). If sediment was lithified in a lagoon environment it is unlikely to be overlain by mature solum from which to derive organic material, and organic material on the lagoon bed may also have been minimal. This may explain the lack of organic staining found in McBryde's (1982) white sandrock.

Mcbryde (1982) suggests this white sandrock stratum may have formed during the Last Interglacial and, since the Holocene midden deposit rests directly on this stratum in the excavation area, it may have been formed at this time when a lagoon was present in the area. There are a couple of problems associated with this interpretation. Although the midden deposit is found in close proximity to Woolpack Creek the Clarence River alluvial sediments appear to be absent from the stratigraphy as seen in the excavation pits. This leads McBryde (1982) to suggest occupation at the site whilst it was still a lagoon. As formation of the lagoon would have required sea levels at or above the present level this indicates it would most likely have formed during the Last Interglacial (Oxygen Isotope Substage 5e) as present conditions are alluvial. Midden strata were radiocarbon dated between 2600-3000 and 1400-1800 years BP. Rather than occupation during lagoonal conditions the apparent gap in alluvial sedimentation may be due to erosion from floodwaters or agricultural disturbance, as both these processes are very active in the Clarence Estuary. McBryde (1982) does note a thin layer of brown soil below the dense midden layer which contains only a few shells. This may have been deposited alluvially and some mixing may have occurred with the overlying midden stratum resulting in the presence of a minimal amount of shell material in the otherwise archaeologically sterile soil layer. Also, the matrix of the midden itself may have been deposited alluvially. The excavated Woombah midden comprises shellfish species primarily of estuarine habitat (McBryde, 1982) and this could suggest proximity to an estuary at the time of resource utilisation.

A black sandrock layer stratigraphically below the white sand/sandrock stratum was exposed by McBryde (1982) in a cutting through the Woolpack Creek bank. She suggests this stratum may correlate with the humate platform described at Angourie by Warner (1971). This stratum was radiocarbon dated at 24 810 +1190 -1010 years BP (see Table 5.1 and previous discussion of dates). If these strata are analogous the white sandrock which stratigraphically overlies the black sandrock will be younger than the humate platform. A minimum age for the white sandrock is, however, uncertain due to the aforementioned problems associated with the date obtained by Warner (1971) for the humate platform.

Both the Site A riverbank and Site B creek bank midden deposits in the current Woombah study area are thinner and less extensive than those studied by McBryde (1982), and they are located in a low-lying floodplain area; excavations were undertaken to a maximum depth of 1.0 m. The stratigraphic sequence observed by McBryde (1982) is not seen at Woombah sites A and B. There is no white or black sandrock and no podzolisation. Morand's (2001) soil landscapes map (Figure 2.6) clearly shows sediment associated with Pleistocene Inner Barrier dunes separated from more recent Holocene dune sediments by patches of swampland analogous to that seen by Thom (1965) in the Myall Lakes region of NSW. Orange areas in Figure 2.6 represent Inner Barrier sediments. Swampland is represented by mid-blue and bright yellow areas along the coast represent Holocene Outer Barrier sediments. Aerial photographs of the Clarence River estuary also show patches of swampland between Inner and Outer Barrier dunes as well as areas of alluvium as discussed below.

Although the Woombah study site is situated in an area predominantly comprising Pleistocene Inner Barrier sediments its proximity to both the Esk River and the North Arm of the Clarence River suggests the dominance of alluvial sediment. In his soil landscapes study, Morand (2001) found alluvium overlying Holocene marine sediments in the Woombah study area. He named this sediment type pa (Palmers Island) and noted that it occurred on the deltaic plain of the Clarence River (Figure 2.6). As sediments of this nature lie adjacent to Pleistocene beach ridge plains and their associated sediments (Morand, 2001) this may account for the difference in observed stratigraphy between the middens studied by McBryde (1982) and those in the current study area.

Coring undertaken at the Woombah study site revealed some features of interest. As expected the core taken closest to the riverbank (5.0 m in from edge, core 5b, Appendix 1) contained clayey alluvial sediments with a relatively high organic content compared with other strata (Appendices 1 and 2). However other core samples taken in a northwards facing transect at site B across the width of the floodplain yielded very sandy sediment. Troedson and Hashimoto (2008) also found the Clarence River estuarine-deltaic plain to be a relatively sand-dominated system and they suggest this reflects the geology of the catchment. All cores collected from Woombah site B contained sandy sediments (Appendix 2). Particle size analysis highlights a trend of reduced clay, silt and superfine sediments and an increase in sand-sized sediment with depth. Results also show a thinning of the top, clayey stratum in a northward direction across the floodplain away from the river; in most cases this stratum is underlain by consecutively sandier strata containing reduced organic content (Appendices 1 and 2). This is indicative of a shift from reducing to oxidising conditions with a move north away from the river. Also, the clay appears to be sealing the reduced deeper strata and this is a characteristic conducive to acid sulfate groundwater conditions. Acid sulfate groundwater conditions are not currently considered to be a major impact at this site as the midden deposits are situated above the watertable. A rising watertable could potentially impact the shell midden deposits. The relative thinness of alluvial sediments on a floodplain in such close proximity to a flood prone channel is considered somewhat unusual and may have an impact on the midden deposits at the site. Lack of alluvial sedimentation can leave cultural deposits exposed and thus vulnerable to erosion and disturbance from farming processes.

Cores 5.1b and 5b represent strata at the bottom and top of a levee slope at the edge of the floodplain, respectively (Appendix 1). Sand is present in all strata to a depth of 0.56-0.60 m where the watertable is present. At 15.7 m north of the riverbank, strata seen in core 5.1b lie in relatively close proximity to the river channel, however the thinning clay layer present in cores 4b-1b is absent here. Thus, the extent of alluvial clays on this part of the floodplain is minimal. As Morand (2001) identified Inner Barrier dune sediments directly north of the study site the sandy nature of the floodplain sediments may be a product of their proximity to the dune sands.

A trend towards decreasing organic content with depth is seen in the cores from Woombah Site A, taken at the eastern edge of the study area, although particle size analyses show negligible change in grain size by depth for cores 1a-4a (Appendix 1). Clay could not be identified in the field texture of these sediments, however particle size analyses show minimal clay- and silt-sized particles in cores 2a and 3a (Appendix 2). A possible explanation for this is that loamy soil may have been built up in the area to support agriculture, as the top strata are similar to the strata present in core 1b, taken from the western edge of the study location in an area previously used for farming. Lack of alluvial sediment is a feature of the eastern side of the study area also, and to an even greater extent than the western side (cores 1-5b). Core 5a was taken in close proximity to the riverbank and particle size analysis (Appendix 2) confirms the nature of the sediment in this core differs from that of the other cores taken at Woombah Site A. A much higher percentage of clay- and silt-sized particles, along with superfine particles, are present in this core – characteristics seen in sediment from the Site B floodplain cores.

5.4.2 **Sleeper Island**

Morand (2001) identified sediments on Sleeper Island as belonging to his 'rm' (Romiaka) soil landscape which he describes as extremely low to level tidal flats and saltmarshes within the Clarence Delta containing Quaternary marine and fluvial sediments regularly inundated with tidal waters. He found the area to have a permanently high watertable. Data obtained from coring (Appendix 1 – core diagrams 1-4s and Appendix 2) support Morand's (2001) findings of deep, very poorly drained Humic Gleys, organic and waterlogged saline soils with low wet bearing strength. Field observations confirm the island's banks are highly erodible. Morand (2001) also found potential and actual acid sulfate soil materials throughout the 'rm' landscape. Currently, the Aboriginal midden deposit on Sleeper Island lies above the watertable however this was measured at a depth of 0.21 m in the middle of the island, a low point covered in water kooch; a rise in the watertable may impact on the midden if acid sulfate conditions are present.

Associated with the 'rm' soil landscape is the 'rma' landscape comprising tidal delta sand masses (Morand, 2001). This occurs opposite the eastern and southern sides of Sleeper Island (Figure 2.6) and indicates areas of deposition of Quaternary marine and fluvial sediments. As noted in the Site Descriptions section these areas of deposition lying opposite areas of erosion on Sleeper Island may be indicative of channel dynamics similar to those seen on opposite banks of a river meander bend. Aerial photographs (Figure 3.1) of the Clarence River channels around Sleeper Island show these sediments as areas of deposition opposite the eastern side associated with Freeburn Island and opposite the southern side associated with the mainland.

Cores taken on Sleeper Island show a trend in field texture with depth and across strata. All sediment contained some clay and there is a trend from loamy material in the top stratum through light and heavy clays to sandy clays with increasing depth (Appendix 1 – core diagrams 1-4s). Strata can be traced across the island (Appendix 1). Depths of the Light Clay stratum correspond between cores 2s and 3s, located in the middle of the island, and cores 1s and 4s, taken close to the island's western and eastern banks. When adjusted for elevation, the depth of the Light Clay stratum corresponds neatly between cores. Similarly, depth of the Sandy Clay stratum corresponds between cores. Thus, stratigraphic integrity has been maintained across Sleeper Island. Most of the midden material, however, does not remain *in situ*. Erosion has greatly disturbed the midden, as evidenced by the accumulation of shells and artifacts in a lag deposit at its base. The minimal remaining *in situ* material has likely not been disturbed, but is at immediate threat from erosion, as the tidal channel where it is situated is inundated daily.

There is no trend in organic content with depth or across strata (Appendix 2). The organic content does not appear to be associated with field texture either. Sleeper Island sediments have a higher organic content than those collected from Woombah and this is in keeping with Morand's (2001) findings. As strata on Sleeper Island were relatively easy to distinguish through field texture this was seen as the most appropriate method of studying the stratigraphy at this location. Strata have been correlated across the island for the purpose of investigating the integrity of its midden deposit.

5.4.3 **Plover Island**

Plover Island is a rocky outcrop overlain by a relatively thin (0.80 m) layer of soil. The soil consists of a 0.52 m thick A horizon containing a stone artifact lens at a depth of 0.35-0.45 m and a pedal B horizon at a depth of 0.52-0.80 m (Appendix 1 – core diagram PI). The A and B horizons can clearly be traced around the circumference of the island and bedrock is present below a depth of 0.80 m. The relative thinness of the solum may indicate its youth; exposure to coastal winds will likely lead to removal of topsoil, even in the presence of grasses and shrubs.

The Bare Point Soil Landscape map (Department of Environment, Climate Change and Water, 2010) indicates the soil at this location belongs to regolith class R2 – unconsolidated sands originating from quartz sandstone parent rock. These sediments have a low coherence, increasing their susceptibility to erosion (Hazelton and Murphy, 2007). Field texture results show the A horizon is a loamy sand and the B horizon a clayey sand (Appendix 1 – core diagram PI), showing there may be minor localised variation in the composition of the parent rock. Organic content decreases with depth (Appendix 2).

Troedson and Hashimoto (2008) found headlands north of Plover Island are composed of Triassic to Cretaceous sedimentary rocks of the Clarence-Moreton Basin. Despite low data resolution for the area between Broom's Head and Wooli (due to limited accessibility) geological maps indicate this area is part of the Clarence-Moreton Basin (Troedson & Hashimoto, 2008). The composition of local headlands, coupled with the underlying regional geology, suggests the presence of similar sedimentary rocks of the Clarence-Moreton Basin on Plover Island. As is the case with neighbouring headlands, Plover Island sits adjacent to a Holocene coastal barrier system which, although typically narrow and poorly developed regionally, is present between Iluka and Evans

Head, Brooms Head and Sandon, and other various locations between Yamba and Brooms Head (Troedson & Hashimoto, 2008).

5.4.4 **Minnie Water**

The Aboriginal shell midden site at Minnie Water is located at the base of the dunes adjacent to a rocky outcrop, Rocky Point, at the northern end of Minnie Water Beach. Geological maps show Rocky Point is part of the Clarence-Moreton Basin (Troedson & Hashimoto, 2008 and references therein) and sediment analyses yield similar results to those obtained at Plover Island (Appendix 2). Field texture varies laterally across the midden deposit and overlying strata (Appendix 1 – core diagrams 1MW-4MW). Narrow, unstratified Holocene dunes present along Minnie Water Beach (Troedson & Hashimoto, 2008) terminate at Rocky Point and it is at this location that field texture, aggregate stability and Munsell soil colour of the A horizon soil are the same as at Plover Island (Appendix 2). B horizon soils at Plover Island and Minnie Water adjacent to Rocky Point also have similar characteristics. Although adjacent to Holocene dunes they both contain clay and their Aggregate Stability Class is identical. Munsell colour is also similar. These common characteristics within parts of the soil profiles at Plover Island and Minnie Water may indicate the presence of a similar parent rock at the two locations. The Bare Point Soil Landscape map (Department of Environment, Climate Change and Water, 2010) indicates the soil at this location belongs to regolith class R2, the same as at Plover Island, consistent with the site's coastal location.

Another feature of Rocky Point which was also observed at Plover Island is the presence of coffee rock. This commonly occurs within Pleistocene barrier deposits in the study area and is a result of cementation of subsurface sand grains by organic matter and iron, leaving near-surface horizons leached to white (Troedson & Hashimoto, 2008).

Grain size distribution at the base of the dunes (cores 1MW380, 2MW380, 3MW380 and 4MW380) is variable and also includes a variable proportion of gravel (Appendix 2). The presence of poorly sorted sands and a variable amount of gravel may be a result of reworking due to wind or wave activity. Surface sands sampled from the foredunes (cores 1MW0 and 2MW0) are well sorted, as are sand samples taken at a depth of 1 m (cores 1MW100 and 2MW100). There is a strong correlation between grain sizes of these samples. There is also a strong correlation in grain size distribution between cores 3MW0 and 4MW0, which were taken east of cores 1MW and 2MW (Appendix 2), adjacent to the rocky outcrop at Rocky Point. The grain size distribution differs from cores 1MW0 and 2MW0 and includes a clay fraction. The distinct difference in grain size distributions between cores 3MW0 and 4MW0, and 3MW25 and 4MW25 is indicative of two distinct soil strata, which cannot be seen in the adjacent dunes (1MW and 2MW cores). Results from soil analyses support Troedson & Hashimoto's (2008) observations of narrow and regionally poorly developed Holocene barrier dunes backed to their landward side and/or underlain by Pleistocene barrier deposits.

There is a trend towards reduced organic content with depth in 1MW, 2MW and 3MW cores, although organic content varies between these cores (Appendix 2). There is some lateral consistency between cores 1MW0, 3MW0 and 4MW0 but organic content in core 2MW0 is approximately double the level seen at this depth in the other cores. These variations, coupled with the lack of a trend in reduced organic content with depth in 4MW cores, may be due to small scale variations in vegetation cover and/or soil permeability, and may provide further evidence of the mixed origin of sediments at this site, as highlighted by the results of the grain size analysis.

5.4.5 **Wooli**

The Wooli Aboriginal shell midden is located parallel to the bank of the Wooli River at a depth of 0.25-0.41 m. Geological maps show Wooli is also part of the Clarence-Moreton Basin (Troedson & Hashimoto, 2008 and references therein). Narrow, unstratified Holocene dunes overlie Holocene subsurface sediment, as at Minnie Water and Plover Island (Troedson & Hashimoto, 2008). Similarly to Minnie Water, the majority of core samples across the midden and adjacent sediment comprise sands with a low organic content, however the size-sorting of sediment follows a different pattern at both of these sites. Sands are very well sorted throughout all of the Wooli cores (Appendix 2). Sediment located at the top of the Minnie Water dunes is well-sorted, while sediment located at the base of the dunes is poorly sorted, containing many coarse sand- and gravel-sized particles (Appendix 2). The difference in particle size distribution at these two sites, a low energy riverbank deposit and a high energy aeolian coastal deposit, reflects a difference in their depositional histories.

The presence of poorly-sorted sediment in conjunction with well-rounded shells and pumice at the base of the Minnie Water dunes indicates the Minnie Water midden deposit is likely to have been reworked. At Wooli, the presence of well-sorted fine- to medium-grained sands and fully buried whole shells in relatively good condition indicates a well preserved midden deposit.

Placing the study sites into a stratigraphic context facilitates further investigation into site formation processes. Studying the species composition and taphonomy of the shells present in the midden deposits consolidates understanding of site formation processes. Results and discussion of species composition and taphonomic analyses at the study sites are presented in the next chapter.

Table 5.1: Age determinations obtained from materials located within the Inner Barrier dune complex along the east coast of Australia.

LOCATION	STRATUM	AGE DETERMINATION (yrs BP)	DATING METHOD AND MATERIAL DATED	REFERENCE
Northern NSW – Angourie	Humate platform	24810 +1190 - 1010 (GaK – 2818)	^{14}C, wood	Warner, 1971
	Grey sand stratigraphically above the humate platform	28600 +4400 - 2600 (GaK – 2817)	^{14}C, charcoal	
	Peat bench stratigraphically above the grey sand layer	26800 +1600 - 1300 (GaK – 2816)	^{14}C, peat	
Northern NSW – Evans Head	Offshore (continental shelf 53 m below MSL)	18070±280 (HV-10783)	^{14}C, plant root material	Colwell and Roy, 1983
	Gundurimba clay, widely distributed in the Richmond River Valley	119000±4000 (MMF20572, MMF20602)	$^{230}Th/^{234}U$, Scleractinian corals	Pickett *et al.,* 1989
	Gundurimba Clay	124000 (WRC39143) 128000 (WRC39157)	$^{230}Th/^{234}U$, Scleractinian corals	Drury and Roman, 1983
	Gundurimba Clay	112000±9000 (74630127) 127000±18000 (74630130)	$^{230}Th/^{234}U$, Scleractinian corals	Marshall and Thom, 1976
	Inner Barrier sandrock	34000 +1200 - 1000 (GaK – 2320)	^{14}C, *Agathis robusta* log	Langford-Smith, 1971
	Inner Barrier sandrock	25900±1100 (GaK – 837)	^{14}C	Gill, 1967
Southern Queensland – North Stradbroke Island	Sand dunes – stratum name not established at time of publication	132000±5000 (QMF12385) 122000±4000 (QMF12400) 119000±3000 (QMF12041)	$^{230}Th/^{234}U$, Scleractinian corals	Pickett *et al.,* 1989

	Sand dunes	101000 +7000 -8000 (QMF12385) 108000 +11000 -10000 (QMF12400) 106000 +6000 -8000 (QMF12041)	$^{230}Th/^{234}U$, Scleractinian corals (same samples as used for above determinations)	Pickett *et al.,* 1985
Southern Queensland – Gold Coast	(Freshwater?) peat, 26.8 m below MSL	10585±140 (SUA – 106)	^{14}C, peat	Thom and Chappell, 1975
Southern Queensland – Rainbow Beach	Inner Barrier sandrock	31000 +3200 -2200 (GaK – 3013)	^{14}C , Driftwood embedded in inner barrier sandrock	Langford-Smith, 1972
Central NSW Coast – Forster/Myall Lakes	Reworked barrier dunes – Cape Hawk	76600±18700 (W1377)	TL, sand grains	Bryant *et al.,* 1994
Central NSW Coast – Newcastle Bight	Linear dune ridge/reworked barrier – Williamtown	17700±3700 (W1013) 20300±5600 (W1014) 30500±5700 (W015)	TL, sand grains	Bryant *et al.,* 1994; Thom *et al.,* 1994 (Same sample numbers and determinations appear in both papers)
	Sand dunes – Grahamstown. Stratum name not established at time of publication	142000±6000 (MMF27124) 155000±8000 (MMF27129)	$^{230}Th/^{234}U$, Scleractinian corals	Pickett *et al.,* 1989

6. BIOLOGICAL AND TAPHONOMIC ANALYSES

6.1 INTRODUCTION

In the absence of artifactual material it is necessary to study the biology and taphonomy of shells found in a deposit to determine whether or not it is likely to be an Aboriginal shell midden. In the presence of artifacts, taphonomic study provides vital information on site formation processes. Comparison of biological and taphonomic characteristics with other local Aboriginal shell midden deposits can also help determine whether a deposit is of anthropogenic origin. Study of the species composition of a shell midden deposit also provides information on resource use and availability at the time the deposit was formed and, in the case of sites representing multiple periods of occupation, changes in the availability and exploitation of these resources. The species present are also indicative of palaeoenvironmental conditions. Placing these shell deposits in a cultural and environmental context is an essential precursor to further studies of site formation processes and the development of erosion hazard models and assessment methods.

6.2 SPECIES COMPOSITION

6.2.1 **Woombah**

There are three species present in the site A sample and two in the site B sample, although both sites are essentially *Saccostrea glomerata* deposits with the same species composition. The site B sample consists of disarticulated *Saccostrea glomerata* valves and one *Pyrazus ebeninus* shell. It makes up only 0.005% of the sample by weight and as its presence is most likely incidental it has not been included in the species composition calculations for this sample. Thus, *S. glomerata* dominate the site B sample (Figure 6.1). Species present in the site A sample include disarticulated *S. glomerata* and *Anadara trapezia*, and negligible *P. ebeninus* (Figure 6.2, Plate 1). The weights of *A. trapezia* (one valve) and *P. ebeninus* (one individual) comprise 1.766% and 0.221% by weight respectively (Table 6.1). Thus, as at site B, it is fair to say that *S. glomerata* is the dominant species in this deposit.

Saccostrea glomerata, commonly known as the Sydney Rock Oyster, is an estuarine species which attaches to rocks or mangrove roots in mudflat areas. Its distribution ranges from southern Queensland south to Victoria (Northern Rivers Catchment Management Authority). During the Last Interglacial period *A. trapezia* extended as far south as coastal South Australia and Victoria, however it is now restricted to eastern Australia, where it is common in estuaries and mudflats (Ludbrook, 1984). *P. ebeninus* is a gregarious species abundant on estuarine mud flats which are exposed at low tide (Ludbrook, 1984). Both deposits contain species which inhabit similar environments indicating local resource use by the Aboriginal inhabitants of the area. Indeed, oysters are still prolific in the Clarence estuary and are commercially farmed (see Local Resources and Land Use section). No juveniles were present in samples collected from the WA and WB sites.

The deposit at Meehan's (1982) Wombah 1 excavation site is also dominated by *S. glomerata* and Department of Environment, Climate Change and Water (DECCW) records indicate sites WA and WB are also part of the Woombah midden complex (DECCW Aboriginal Heritage Information Management System). Although not excavated, these sites were noted and their location marked on a map produced as part of the Meehan study. The Yaegl Local Aboriginal Land Council has identified the Woombah midden complex as a significant local cultural site (Ferlin Laurie, personal communication) and signage has been placed at the site of the WB deposit, a product of collaboration between the Yaegl community and DECCW. Based on this evidence the shell deposits at sites WA and WB are considered to be anthropogenic in origin.

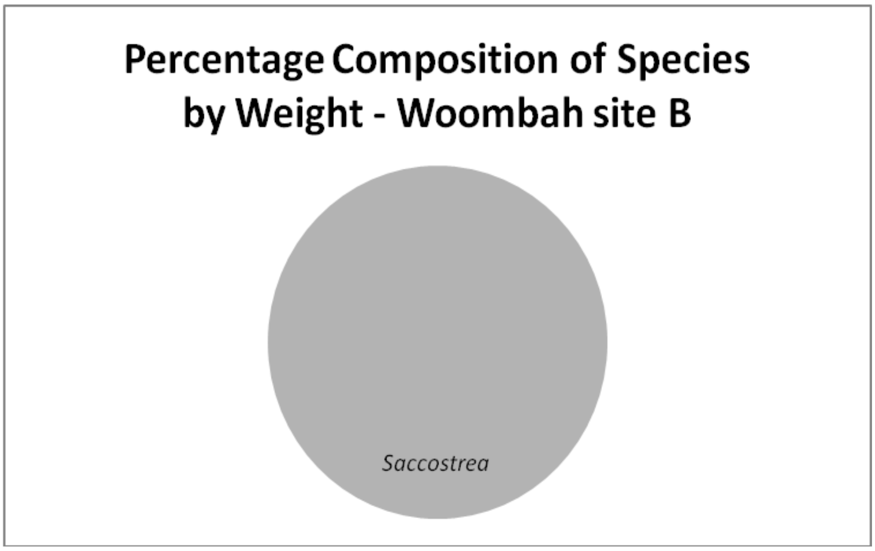


Figure 6.1: Percentage composition of species by weight – Woombah Site B.

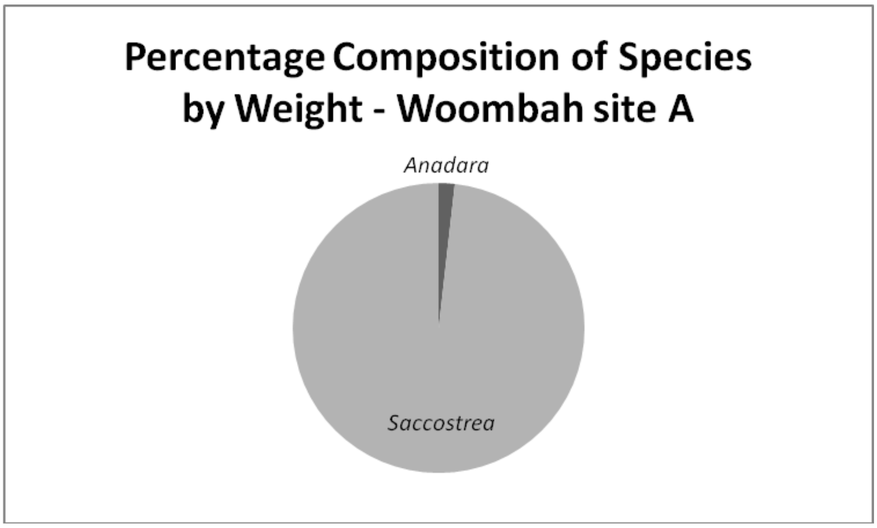


Figure 6.2: Percentage composition of species by weight – Woombah Site A.

Table 6.1: Woombah Site A – percentage composition of species by weight. Size Range (U) = size range of upper valves. Size Range (L) = size range of lower valves.

WOOMBAH SITE A PERCENTAGE COMPOSITION OF SPECIES BY WEIGHT				
SPECIES	*Pyrazus ebeninus*	*Anadara trapezia*	*Saccostrea glomerata*	TOTAL WT. (g)
WEIGHT (g)	1	8	444	453
% COMPOSITION	0.221	1.766	98.013	
SIZE RANGE (U)	n/a	n/a	4.5-9.9 cm	339
SIZE RANGE (L)	n/a	n/a	4.1-7.7 cm	105

6.2.2 **Sleeper Island**

The Sleeper Island midden comprises three species, all of which are edible (Ferlin Laurie, personal communication). *Saccostrea glomerata* is present in similar proportions by both weight (Figure 6.3) and minimum number of individuals (Table 6.2, Plate 1). *Anadara trapezia* is the dominant species, accounting for 71.692% by weight. Percentage composition was also calculated using individual counts in two ways (see Chapter 4, Methodology). No juveniles were present in samples collected from Sleeper Island. Valves both *in situ* and in the lag deposit are disarticulated so it is impossible to determine the exact number of individuals. The sample size is also relatively small and this may have had an influence on the results. Thus, percentage composition based on weight of shell material, as opposed to minimum number of individuals (MNI), appears to be the most appropriate method to use when assessing individual sites in this area, and also when comparing those sites.

The Sleeper Island midden shows a different pattern of resource utilisation to the deposits studied at Woombah. Other midden deposits at Woombah show a similar pattern of resource utilisation to sites A and B in the current research, with *S. glomerata* accounting for up to 95% by weight of shell material at sites studied by McBryde (1982). *Saccostrea glomerata* and *A. trapezia* occupy similar habitats however the species composition of the various midden deposits suggests local resource availability may have varied substantially from site to site. Exploitation of a wider variety of resources, coupled with the presence of stone artifacts, could indicate the Sleeper Island site fulfilled a different function to the oyster middens at Woombah. The position of the Sleeper Island site, present at the rapidly eroding western extremity of the island, may indicate this deposit was once much larger.

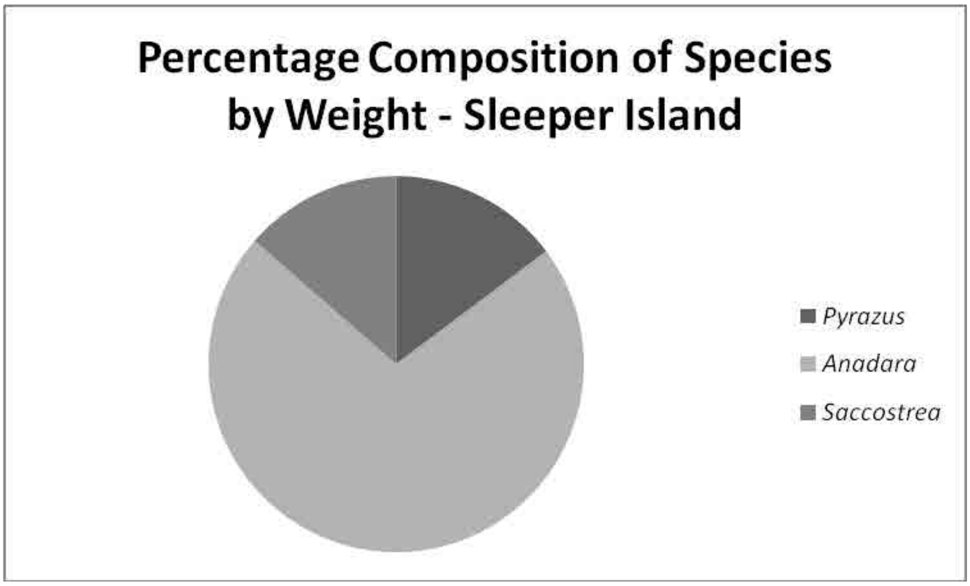


Figure 6.3: Percentage composition of species by weight – Sleeper Island.

Table 6.2: Sleeper Island – percentage composition of species by weight and minimum number of individuals.

SLEEPER ISLAND PERCENTAGE COMPOSITION OF SPECIES BY WEIGHT AND MINIMUM NUMBER OF INDIVIDUALS				
SPECIES	*Pyrazus ebeninus*	*Anadara trapezia*	*Saccostrea glomerata*	TOTALS
WEIGHT (g)	127	624	118	869
% COMPOSITION BY WEIGHT	14.729	71.692	13.579	100
MINIMUM NUMBER OF INDIVIDUALS (MNI)	10	22	6	38
% COMPOSITION BY MNI	25.974	57.143	16.883	100
in situ COUNTS	10	22	7	39
TOTAL MNI	20	44	13	77
AVERAGE WT. (g)	12.6	14.512	19.667	

6.2.3 **Plover Island**

Circumnavigation of the island and examination of its surface yielded no *in situ* shell remains. Soil exposures are easily seen around the entire island and contain Aboriginal stone artifacts. A large lag deposit of well-rounded shell fragments (see subsequent taphonomy discussion) is present at the base of the island on its north side. Identifiable fragments include shells of the genus *Turbo* and high spired gastropod shells likely belonging to several species of whelk (see Chapter 3 for pictures). As there is no evidence of an *in situ* source of these shells on Plover Island, only a brief discussion on their possible origin will be discussed in the Taphonomy section. The absence of any confirmed Aboriginal shell middens on Plover Island does not discount the site from this study. The presence of an extensive Aboriginal stone quarry on the island coupled with stabilised Aboriginal shell middens in the back dunes opposite Plover Island indicates this location was once important for the gathering and use of multiple resources.

6.2.4 **Minnie Water**

The Minnie Water site comprises *in situ* and lag shell deposits (see Chapter 3). Although the proportion of major edible species by MNI is slightly higher in the *in situ* deposit, there is no significant difference between the results when a 5% standard error calculation is applied. Values for edible and non-edible species present in the lag and *in situ* deposits on the other hand fall outside the assigned 5% error margin, indicating a statistically significant difference between the relative percentages of non-edible species present in the two deposits (Figure 6.4).

When the two major edible species, *Dicathais orbita* and *Turbo undulatus*, are considered separately further differences are apparent. While there is no significant difference between the weight of whole and fragmented *T. undulatus* in the *in situ* and lag deposit samples there is a significant difference between the weight of whole and fragmented *D. orbita* shells in both the deposits. Species composition of the two deposits is also variable (Figure 6.5).

The species composition of middens further north – South Beach, Evans Head and South Ballina Beach, Ballina – differs significantly from that of the midden at Minnie Water. Situated in a similar environmental setting and in the same region it is worth comparing these deposits. The South Beach midden is a monospecific assemblage containing Pipi shells present as a compact lens (Meehan, 1982). The South Ballina Beach Pipi midden also contains some oyster shells, although these are in the minority. The stratigraphic integrity of these two deposits appears much stronger than at the Minnie Water site although blowouts do occur at close by Schnapper Point (Meehan, 1982). The Schnapper Point archaeological site, however, only contains stone artifacts, so a direct comparison with the Minnie Water site is not possible. Coupled with the taphonomic evidence (see subsequent taphonomy discussion) the biological evidence presented here indicates the *in situ* deposit at Minnie Water has been reworked, most likely by the action of wind and waves.

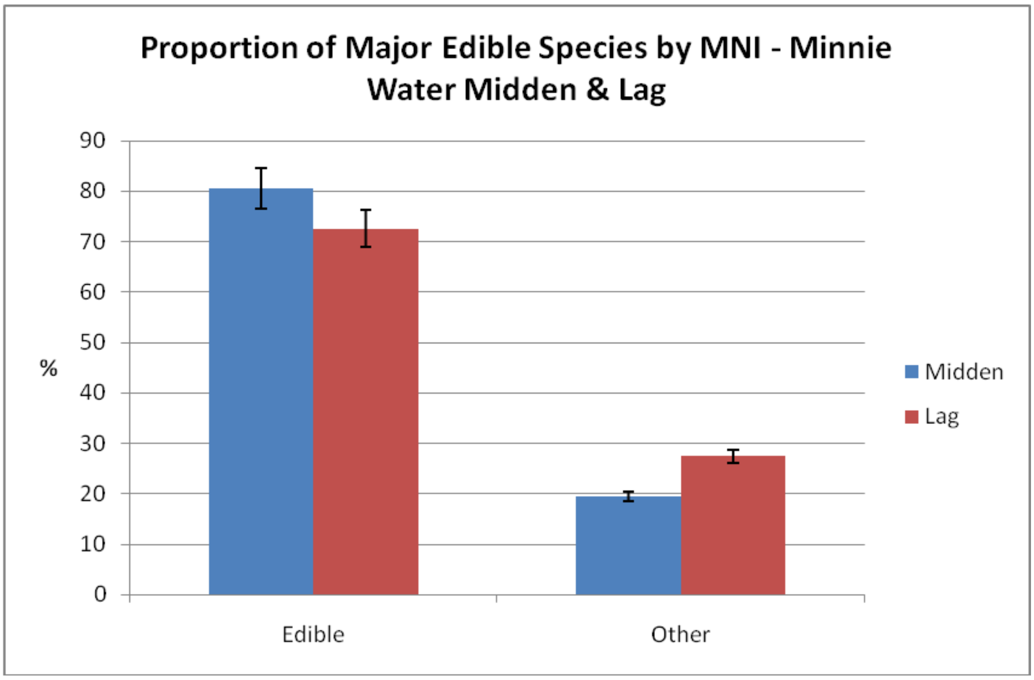


Figure 6.4: Proportion of major edible species by MNI – Minnie Water.

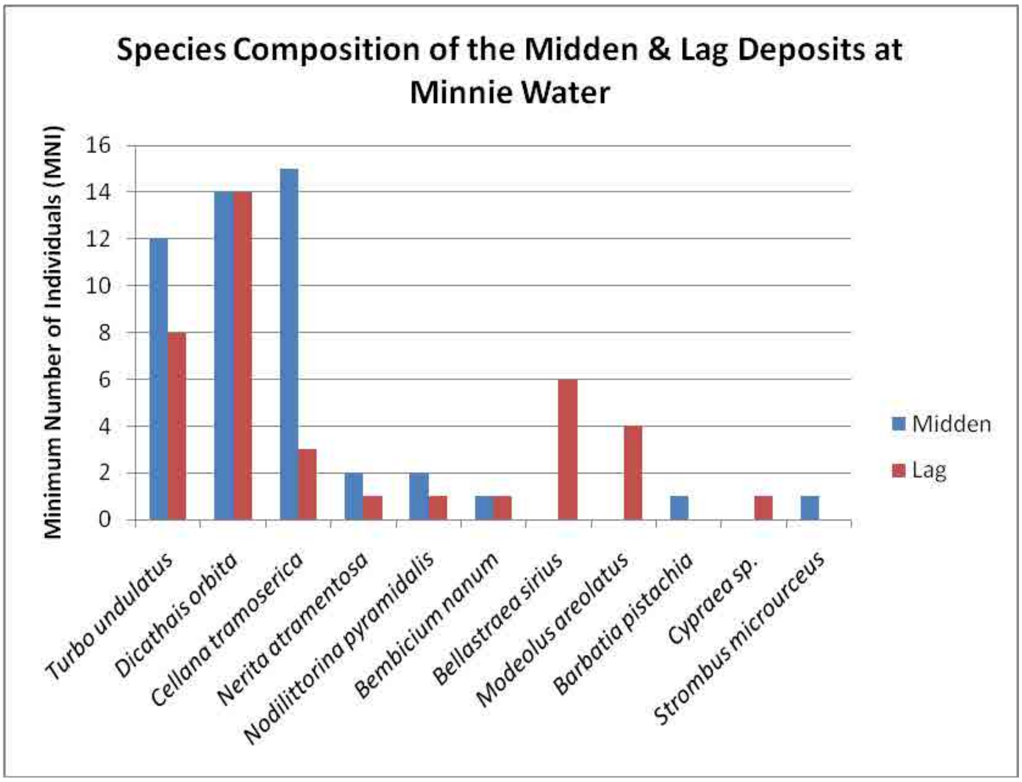


Figure 6.5: Species composition of the midden and lag deposits at Minnie Water.

6.2.5 **Wooli**

The shell deposit at Wooli comprises solely edible species, namely *Anadara trapezia, Pyrazus ebeninus, Saccostrea glomerata, Turbo undulatus and Velacumantis australis* (Table 6.3). *Anadara trapezia* is the dominant species, accounting for approximately half of the shell material by weight. *Pyrazus ebeninus* and *S. glomerata* also have a significant presence. Percentage composition by weight and MNI for *A. trapezia* and *P. ebeninus* is not significantly different when a 5% standard error calculation is applied (Figure 6.6). Values for *S. glomerata*, however, do differ significantly and this is most likely a result of the oyster shell being lighter in weight than the other two major species. Thus, there is an underestimation of up to 9% for the oyster shell contribution. *Anadara trapezia* shells remain in the majority, however, and percentage composition by weight calculations are used as the standard for comparison between deposits in this study.

Species composition of the Wooli deposit is most closely comparable to that of the Sleeper Island deposit. They are both estuarine riverbank deposits although one is present in a high energy, highly erodible environment (Sleeper Island) and the other a low energy depositional environment. Two deposits in locations with differing geomorphic dynamics having a similar species composition indicates shells may have been collected elsewhere up- or downstream and brought to a central location to be consumed. In addition, the distribution of the three major species varies throughout the Wooli deposit (Figure 6.7) and this likely reflects differential distribution by humans. The following taphonomic evidence also supports these conclusions.

Table 6.3: Species composition of the Wooli midden.

TOTALS BY SPECIES	WEIGHT (g)	MNI	% COMPOSITION BY WEIGHT	% COMPOSITION BY MNI
A. trapezia	825.43	60	48.68	41.96
P. ebeninus	607.94	46	35.85	32.17
S. glomerata	245.05	31	14.45	21.67
V. australis	5.5	4	0.32	2.8
T. undulatus	11.77	2	0.7	1.4
OVERALL TOTALS	1695.69	143	100	100

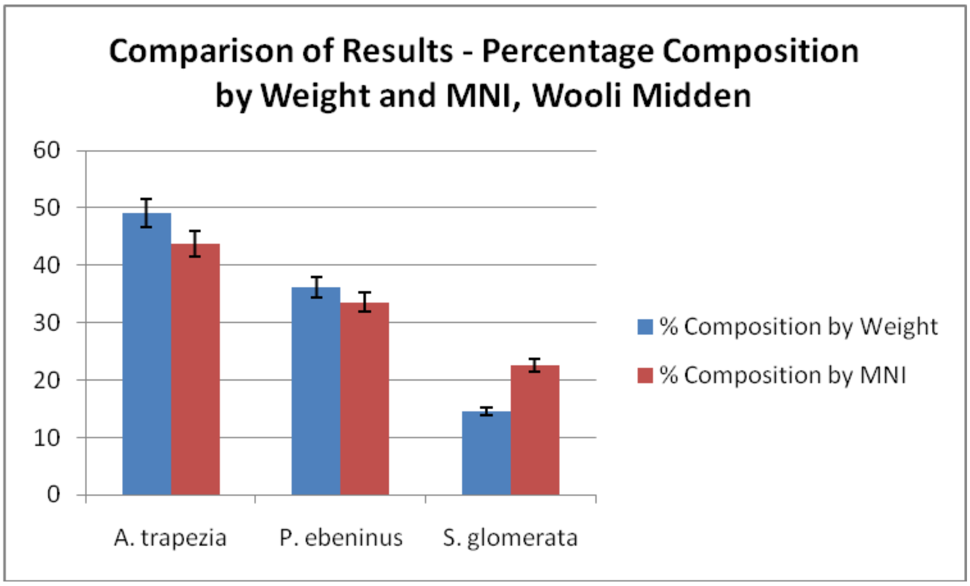


Figure 6.6: Comparison of results – percentage composition by weight and MNI, Wooli midden.

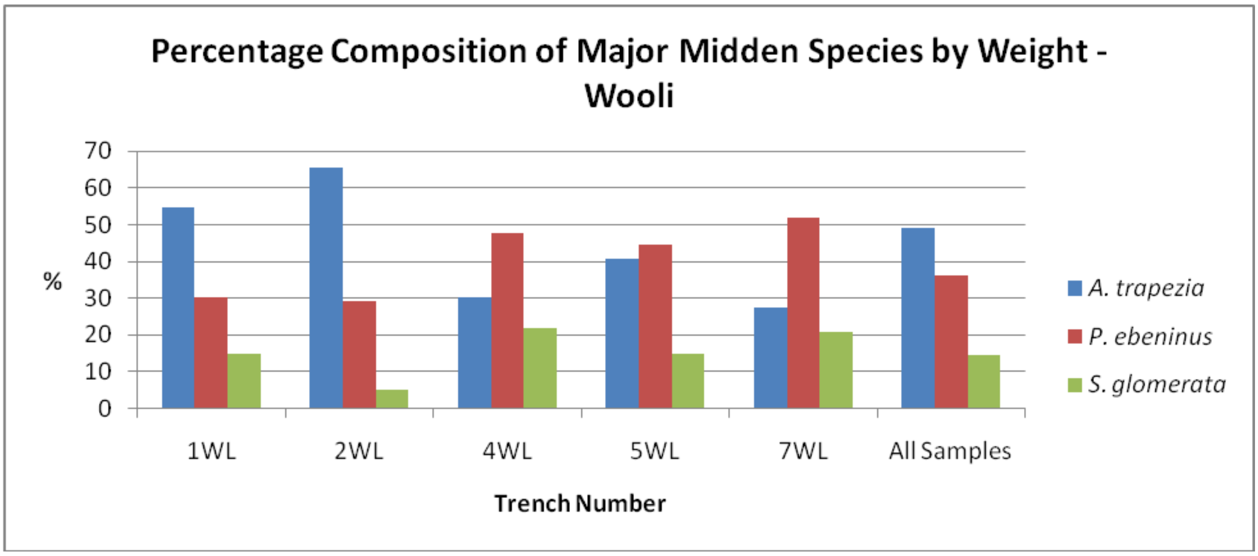


Figure 6.7: Percentage composition of major midden species by weight, Wooli midden.

6.3 TAPHONOMY

6.3.1 **Woombah**

The shells themselves are taphonomically similar at both Woombah site A riverbank oyster bed and site B creek bank midden exposure. Most upper and lower valves at both sites remain largely unbroken and shells do not appear very chalky, although some white material comes off onto the fingers when shells are handled. The nacreous layer is visible on many shells, although it is more commonly seen on the lower valves. Broken edges are angular to sub-angular, with some being sub-rounded, and surface features such as ridges and striae are clearly visible and have not been weathered away. This indicates burial or deposition in a low energy environment, in the absence of a continuous abrasive force.

Although there is a distinct lens in the creek bank exposure shells are randomly oriented within it. Shells at the site A riverbank exposure, however, have a more ordered orientation. Upper valves predominantly lie concave up, with some lying concave down and lower valves lie in a horizontal orientation. This also suggests burial or deposition in a low energy environment. Upper and lower valves are disarticulated at both sites and this indicates the shells did not die in their life position. Shells at the site A riverbank exposure may have been washed to their current position by tidal action post-mortem. Alternatively, they may have been deposited by humans although their burial position differs from the shells found at the site B creek bank midden exposure. Shells present in the creek bank exposure at Woombah site B appear *in situ* but may have been reworked. This is certainly the case for the shell surface scatter found in the A_p and A_o soil horizons at sites A and B. But these shells differ in appearance to those found at the site A and site B exposures, as they are highly fragmented and the depth of the scatter corresponds with the depth of the A_p and A_o soil horizons (see Chapter 5 and Appendix 1).

There appears to be no taphonomic bias towards the presence of upper or lower *Crassostrea* valves at site B. Upper valves in this sample account for 1.558 times more weight that lower valves but this may be attributed to the heavier weight of the upper valves of this species. At site A, however, upper valves account for 3.229 times more weight that lower valves –over double the weight difference at site B. If site A is an Aboriginal midden, this difference may represent a collection bias as the shells were prised off rocks. If site A is a natural shell accumulation this difference becomes harder to explain, as the shells were sampled *in situ*, rather than from their corresponding lag deposit, where a bias towards the retention of heavier shells is expected.

The condition of the shells themselves, as mentioned earlier, at a depth of 35-69 cm in the site B creek bank exposure does not indicate this part of the deposit is a reworked midden. The absence of pumice, gravel or large pieces of organic material such as twigs or branches also supports the idea these shells do not form part of a reworked midden at this depth. Comparison of radiocarbon dates between site A riverbank and site B creek bank shells may prove useful. The shell lenses sampled are present at approximately the same depth and if the apparently *in situ* site B midden material has been reworked we may see a random mixing of ages of shells. If the age determinations correspond between the two sites, site A may have been a food source and site B the discard location. Or site A may represent another midden in the Woombah complex. Taphonomically, the orientation of the shells, and weight ratios of upper and lower *Crassostrea* valves, are the only factors that differ between the site A and site B exposures. Differences between these factors do not provide conclusive evidence the deposits were formed by different agents.

Tables 6.4 and 6.5 (modified after Kidwell, 1991) summarise taphonomic, sedimentological and stratigraphic attributes of the Woombah site A and B deposits, from which shell material was taken for analysis. Features which differed between the two deposits are italicised and bold. From this table it can be clearly seen that the deposits at sites A and B differ negligibly when these broad-ranging factors are taken into account. The dimensions, relative abundance and orientation of shells differ between the two deposits. The dimensions of the two deposits are relatively similar and this feature alone is not diagnostic of site origin. Similarly, the relative abundance of shells in the two deposits does not differ dramatically, and the close-packing of shells is the same in both deposits, indicating they have a similar fabric. As mentioned above the orientation of the shells in both deposits is different. Considering there is no other evidence of a differing taphonomic history the taphonomic, sedimentological, stratigraphic and biological evidence strongly suggests the site A riverbank deposit has the same origin as the site B Aboriginal shell midden.

Analysis of the type of *Crassostrea* fragments present in the Woombah site A and B deposits (Table 6.6) provides further evidence in support of their similar origin. Results show approximately half the shell material present in both deposits is fragmented, and the fragmentation pattern is the same in shells from both deposits, with both upper and lower valves most commonly broken along the ventral margin.

Table 6.4: Attributes of shell concentrations – Woombah Site A.

Taphonomic features	
Articulation	Disarticulated and dissociated
Size sorting	Moderate
Shape sorting	Unsorted
Fragmentation	Some broken
Abrasion	Unabraded
Rounding	A-SA, some SR
Biological modification (bioerosion/encrustation)	Minor: shallow 0.2mm diameter pitting on shell surface
Orientation	***Mixed***
Sedimentological features	
Type of matrix	Clay/mud
Relative abundance (%) of shells	***15***
Close-packing of shells	Loosely packed (matrix-supported)
Associated sedimentary structures	Parallel to riverbank and present within a single, uniform stratum.
Stratigraphic features	
Thickness	0.19 m
Lateral extent	30 m
Geometry	Lens
Internal complexity	None, homogeneous

Table 6.5: Attributes of shell concentrations – Woombah Site B.

Taphonomic features	
Articulation	Disarticulated and dissociated
Size sorting	Moderate
Shape sorting	Unsorted
Fragmentation	Some broken
Abrasion	Unabraded
Rounding	A-SA, some SR
Biological modification (bioerosion/encrustation)	Minor: shallow 0.2mm diameter pitting on shell surface
Orientation	***All disturbed***
Sedimentological features	
Type of matrix	Clay/mud
Relative abundance (%) of shells	***25***
Close-packing of shells	Loosely packed (matrix-supported)
Associated sedimentary structures	Single, *in situ* creek bank shell lens overlain by shells disturbed and destroyed by farming machinery present in anthropogenic soils.
Stratigraphic features	
Thickness	0.24-1.13 m
Lateral extent	32 m
Geometry	Lens
Internal complexity	None, homogeneous

Table 6.6: Type of *Saccostrea glomerata* fragments present in the Woombah Site A and B deposit samples.

WOOMBAH SITE A	**WOOMBAH SITE B**
Lower valves: most commonly broken along ventral margin	**Lower valves**: most commonly broken along ventral margin
Intact shell weight= 52 g	Intact shell weight= 193 g
Fragmented shell weight= 53 g	Fragmented shell weight= 355 g
Total weight= 105 g	Total weight= 548 g
% Fragmented= 50.5	% Fragmented= 64.8
Upper valves: most commonly broken along ventral margin	**Upper valves**: most commonly broken along ventral margin
Intact shell weight= 191 g	Intact shell weight= 514 g
Fragmented shell weight= 148 g	Fragmented shell weight= 424 g
Total weight= 339 g	Total weight= 854 g
% Fragmented= 43.7	% Fragmented= 49.6
Total % Fragmented (upper and lower valves)= 45.3	**Total % Fragmented (upper and lower valves)= 55.6**

6.3.2 **Sleeper Island**

Shell material from the Sleeper Island lag deposit is similar taphonomically to the *in situ* material found at the site. Shells in both contexts appear chalky. Many *Anadara* have holes in their umbo. These holes are much larger than bore holes and the damage most likely appeared post-mortem as shells wouldn't have been collected as a food source if predation had removed the living animal. *Pyrazus ebeninus* shells all appear to have weathered in the same way. On many individuals the stronger columellar remains whilst the shell surrounding it has weathered away. This pattern is indicative of damage caused by an abrasive force such as wind or wave action in a sandy setting, or of acidic conditions. As the *in situ* material was found in soil and the matrix of the lag deposit consists of estuarine mud the former cause is unlikely.

Stone tools were also found in the lag deposit and they all consist of the same material (Plates 6 and 7). Meehan (1982) describes large stone artifacts from the excavated site Wombah 1 as being composed of greywacke. She notes the presence of bipolar pieces and unifacially flaked pebble tools, which is consistent with the artifacts found at Sleeper Island. The suite of stone artifacts found at Woombah and Sleeper Island corresponds with the general trend of technically and diagnostically undistinguished stone tools characteristic of recent levels from sites in eastern NSW described by White (1968). Meehan (1982) notes the greywacke used as a raw material for stone artifacts at Wombah 1 is likely derived from the eastern side of the Clarence Valley. The bedrock geology of the Clarence-Moreton Basin is consistent with this raw material, being composed of flat-lying soft Mesozoic sedimentary rocks (Troedson and Hashimoto, 2008).

Four cores and three flakes were collected in quadrat sampling of the lag deposit and this material constituted a representative proportion of the artifactual material present at the site. As the Sleeper Island midden site is clearly degraded it is impossible to know how much of the original cultural material remains, however Meehan (1982) also notes the Wombah 1 midden site is not rich in artifacts. Stone cores collected include one bipolar core and one retouched core tool (Plates 6 and 7). All flakes collected show bulbar points of percussion; flake scars are also present on one sample (Plate 7A). As minimal cultural material remains at the site it is impossible to gauge with any certainty whether or not the deposit was originally made up of a single, or multiple, occupation horizons.

Table 6.7 (modified after Kidwell, 1991) summarises taphonomic, sedimentological and stratigraphic attributes of the Sleeper Island lag and *in situ* deposits, from which shell material was taken for analysis. These features are typical of an Aboriginal shell midden deposit that is being eroded and reworked by tidal activity (Hughes and Sullivan, 1974; Claassen, 1998; Bonhomme, 1999). *In situ* shell material is present as a poorly sorted lens. Shell material present in the lag deposit is also poorly sorted with regards to size and shape; shells in both taphonomic contexts are disarticulated and dissociated. Minimal abrasion of *Crassostrea* and *Anadara* shells supports redeposition in a low-moderate energy environment subject to tidal action without perpetual high energy wave impact (Gill *et al.,* 1991) and this is consistent with the environmental context in which the midden is found. The pattern of abrasion seen on *Pyrazus ebeninus* shells may be a function of their shape. Experiments on conical shells (mean grain size -0.5ϕ, 1 700hrs) have produced a similar pattern of abrasion to that seen on *Pyrazus ebeninus* shells at Sleeper Island (Driscoll and Weltin, 1973).

Table 6.7: Attributes of shell concentrations – Sleeper Island.

Taphonomic features	
Articulation	Disarticulated and dissociated
Size sorting	Very poor (both *in situ* and lag deposits)
Shape sorting	Unsorted
Fragmentation	*Anadara* and *Crassostrea* all whole, some Whelk broken
Abrasion	*Crassostrea* unabraded, hole in umbonal region in many *Anadara*, Whelk abraded – columellar region remains intact
Rounding	SA-SR
Biological modification (bioerosion/encrustation)	Minor: shallow 0.2mm diameter pitting on *Crassostrea* surface
Orientation	All disturbed (both *in situ* and lag deposits)
Sedimentological features	
Type of matrix	Estuarine mud
Relative abundance (%) of shells	Shells concentrated as a lag deposit, little shell material remains *in situ* (<5%). Density of lag deposit reduced by ~90% on re-inspection 1 year after field work was carried out.
Close-packing of shells	Densely packed in lag deposit, dispersed (matrix-supported) *in situ*
Associated sedimentary structures	
Stratigraphic features	
Thickness	*In situ*: 0.10 m, lag: n/a (surface scatter)
Lateral extent	22.5 m (*in situ* and lag deposits)
Geometry	Lens
Internal complexity	None, homogeneous

6.3.3 **Plover Island**

A large lag deposit of well-rounded shell fragments is present at the base of the island on its north side. Identifiable fragments include shells of the genus *Turbo* and high spired gastropod shells likely belonging to several species of whelk (see Site Descriptions section for pictures). The source of this shell material is unclear. The shell fragments are mobile and there is no evidence of an *in situ* source for the shells on Plover Island. It may be they represent remnants of a once *in situ* Aboriginal shell midden located on Plover Island, have all weathered out and been reworked by wave action.

There are no identifiable artifacts present with the shells. The stones found in the lag deposit with the shells are also very well rounded and reworking by wave action may have obscured surface features pertaining to Aboriginal stone tools. The stones may have also been sourced naturally from the weathering of the rocky material constituting much of Plover Island, also quarried by Aboriginal people. The taphonomic, stratigraphic and sedimentological features presented in Table 6.8 (modified after Kidwell, 1991), coupled with the location of the deposit in the region where waves break at high tide, suggests exposure to high energy wave conditions. Whether or not the deposit is of anthropogenic origin is impossible to know. Even if it represented the remnants of an Aboriginal shell midden information loss has been profound and thus its scientific and anthropological value has been reduced. The presence of other valuable cultural deposits in close proximity to this deposit of unknown origin ensures the area retains its significance as an important Aboriginal cultural site.

Table 6.8: Attributes of shell concentrations – Plover Island lag deposit.

Taphonomic features	
Articulation	Disarticulated and dissociated
Size sorting	Very poor (both cobbles and shell material)
Shape sorting	Unsorted (both cobbles and shell material)
Fragmentation	All shells
Abrasion	Very worn (both cobbles and shell material)
Rounding	Very well-rounded (both cobbles and shell material)
Biological modification (bioerosion/encrustation)	None
Orientation	Random/all disturbed
Sedimentological features	
Type of matrix	Deposit of cobbles of same rock type comprising Plover Island. 0.01-0.3 m diameter, poorly sorted.
Relative abundance (%) of shells	30%
Close-packing of shells	Dispersed
Associated sedimentary structures	None
Stratigraphic features	
Thickness	<0.15 m
Lateral extent	30 m around north side of island

6.3.4 **Minnie Water**

Taphonomic evidence strongly suggests the Minnie Water midden has been reworked. The presence of pumice and complete lack of stratification coupled with the condition of the shells are characteristic of a deposit which has been reworked by the action of wind and waves. Gravel (well rounded and angular grains) is also present. Among the three main edible species, *Turbo undulatus, Dicathais orbita* and *Cellana tramoserica*, the amount of abrasion present on shells does not significantly differ between the *in situ* and lag deposits (Figure 6.8). Other species, however, do show a statistically significant difference between the deposits. This mixing of taphonomic characteristics is indicative of reworking (Claassen, 1998). The amount of biological modification also differs significantly between shells in the *in situ* and lag deposits and is consistently higher among *in situ* shells (Figure 6.9). This suggests a mixed origin of shells in the *in situ* and lag deposits.

Table 6.9 (modified after Kidwell, 1991) summarises taphonomic, sedimentological and stratigraphic attributes of the Minnie Water *in situ* deposit from which shell material was taken for analysis. All of the taphonomic features are indicative of a reworked deposit. The dispersed, matrix-supported packing of shells and lack of internal complexity are also characteristic of reworking (Bonhomme, 1999).

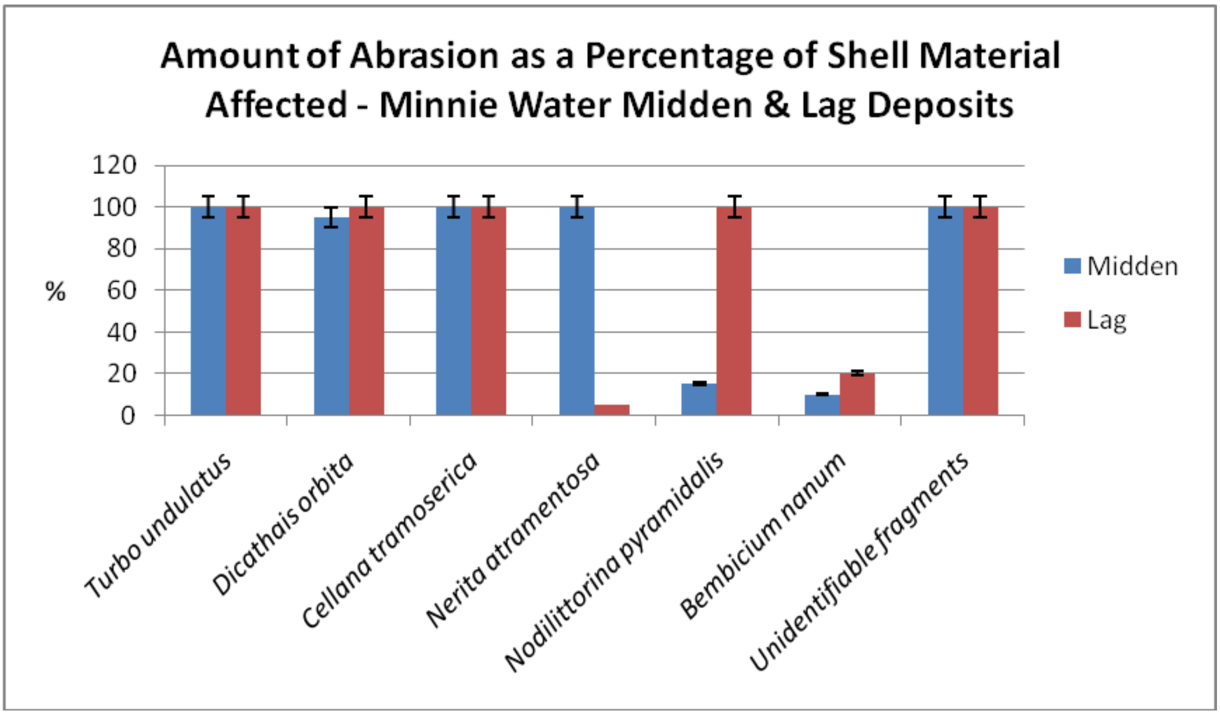


Figure 6.8: Amount of abrasion as a percentage of shell material affected – Minnie Water *in situ* and lag deposits.

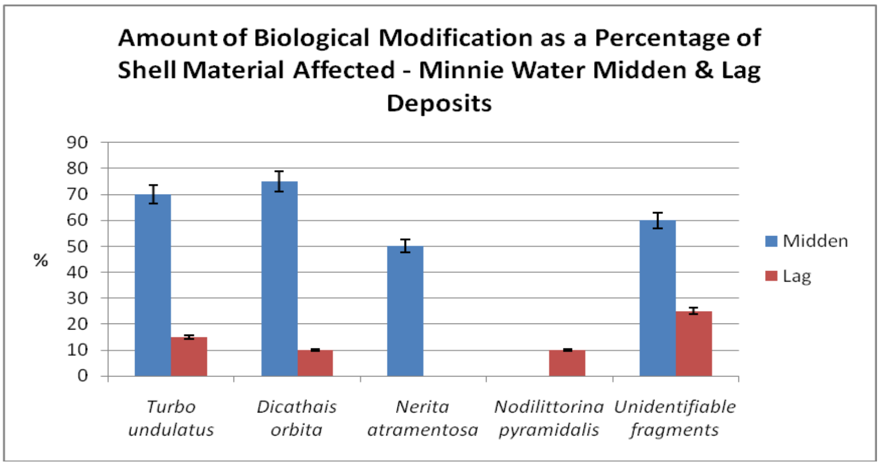


Figure 6.9: Amount of biological modification as a percentage of shell material affected – Minnie Water *in situ* and lag deposits.

Table 6.9: Attributes of shell concentrations – Minnie Water *in situ* deposit.

Taphonomic features	
Articulation	Disarticulated and dissociated
Size sorting	Very poor
Shape sorting	Unsorted
Fragmentation	80-90% shells broken
Abrasion	All shell material abraded. Abrasion present over 95-100% of shell surface in all but 2 minor species.
Rounding	SA-R
Biological modification (bioerosion/encrustation)	>50% coverage over major species and unidentifiable fragments, absent on minor species.
Orientation	All disturbed (both *in situ* and lag deposits)
Sedimentological features	
Type of matrix	Beach sand and gravel
Relative abundance (%) of shells	15%
Close-packing of shells	Dispersed (matrix-supported)
Associated sedimentary structures	Situated at the base of beach foredunes. Poor size-sorting of matrix in stratum containing shells.
Stratigraphic features	
Thickness	0.09-0.92 m
Lateral extent	85.3 m
Geometry	Lens
Internal complexity	None, homogeneous

6.3.5 **Wooli**

In the absence of artifacts biological and taphonomic evidence (Table 6.10; modified after Kidwell, 1991) supports an anthropogenic origin of the Wooli shell deposit. The shells are deposited in a lens of varying thickness, with no internal complexity and they are randomly orientated with poor size and shape sorting. The valves are disarticulated and dissociated. None of these characteristics support natural deposition in a low energy environment (Bonhomme, 1999).

Table 6.10: Attributes of shell concentrations – Wooli.

Taphonomic features	
Articulation	Most disarticulated and dissociated
Size sorting	Very poor
Shape sorting	Unsorted
Fragmentation	Fragmented and whole shells present
Abrasion	Unabraded
Rounding	A-SA, some SR
Biological modification (bioerosion/encrustation)	Very minor: shallow 0.1 mm diameter pitting affecting <2% of shells' surface.
Orientation	Random/all disturbed
Sedimentological features	
Type of matrix	River sand
Relative abundance (%) of shells	70%
Close-packing of shells	Densely packed (bioclast-supported)
Associated sedimentary structures	Parallel to riverbank and present within a uniform stratum of river sand
Stratigraphic features	
Thickness	0.04-0.16 m
Lateral extent	23.3 m (157m^2)
Geometry	Lens
Internal complexity	None, homogeneous

6.3.6 **Conclusions**

Biological and taphonomic study of shell deposits provides key information regarding site origin and site formation processes. This information is essential in the planning and preparation of appropriate erosion assessment techniques and conservation management strategies for Aboriginal shell midden sites. Biological and taphonomic studies of deposits at Woombah, Sleeper Island, Plover Island, Minnie Water and Wooli provide evidence of their anthropogenic origin, in addition to other characteristics of their depositional environment such as processes of reworking, erosion, deposition and the energy level of the environment. This provides a sound framework for the research presented in this thesis.

7. GEOMORPHIC PROCESSES AND MAJOR IMPACTS

7.1 INTRODUCTION

This research focuses on geomorphological impacts affecting the accumulation, preservation and degradation of Aboriginal shell midden sites on the north coast of NSW, Australia. It is the interaction between these site formation processes which affects the degree of erosion or deposition at a site. The following chapter examines the role of major geomorphological impacts affecting the study sites at Woombah, Sleeper Island, Plover Island, Minnie Water and Wooli. Results of the three erosion hazard models presented in Chapter 4 are presented and discussed. Site-specific recommendations for conservation and management, based on the outcome of the models, are also presented.

Anthropogenic modifications to the main shipping channel of the Clarence River estuary from the late 1800's to the late 1900's have had a profound impact on the dynamics of sediment transport within the estuary. The structure of these changes, and accompanying alterations to the flow regime of the estuary, are examined. The scale of these modifications reflects the economic importance of facilitating commercial-scale transport of goods upriver to Grafton and other local ports. It also highlights the importance of adequate planning of such a large engineering project which has a multitude of environmental impacts.

Studying the impact of past sea level change provides valuable information on possible future impacts of such changes. It is important to consider susceptibility of sites to inundation caused by local sea level variation. Local, regional and global data on rates of sea level rise are used to calculate a possible time frame for inundation of low-lying sites. Factors driving local sea level variation are also examined.

In addition to studying the possible impacts of sea level rise, it is also important to understand the risk of inundation due to flooding and tidal activity. Predicted tide heights as well as tide and flood gauge data are used to predict the periodicity of inundation at the study sites, based on their elevation. The risk of, and robustness to, flooding and tidal inundation is a key indicator of erosion hazard.

Three methods for assessment of erosion hazard at Aboriginal shell midden sites have been developed as part of this research project (see Chapter 4). Each is formulated for use by a different stakeholder group and takes into consideration the purpose of data collection, scale at which data is required and levels and areas of expertise of those likely to be collecting the data and using the models. Similar key indicators of erosion are used across all methods however the models are structured differently for ease of use by the different stakeholder groups.

Using site-specific and regional data, the GIS model not only ranks erosion hazard on a site-by-site basis, it also illustrates regional trends and landscape-scale processes. Earth and environmental scientists would be most familiar with information in this format. The comprehensive method designed for use by archaeologists does include regional data however more site-specific data are included. Key indicators of erosion are matched with a site's geomorphic setting and a numerical ranking system is not used. The rapid assessment technique designed for use by the local Indigenous community focuses on collecting reliable data in a timely manner and format which is easy to interpret by both scientists and archaeologists. These simple methods of data collection and analysis yield very similar results to the more complex, scientific analyses used in the other two methods.

7.2 ANTHROPOGENIC MODIFICATIONS TO THE CLARENCE RIVER CHANNEL

There have been three stages in the modification of the Clarence River channel at its entrance to the Pacific Ocean (Figures 7.1 A to 7.1 H). These modifications have transformed the area from a shallow channel containing numerous sand spits and sand bars to a deep-sea port. When Matthew Flinders first landed on the shores of Yamba he was unimpressed by what he saw and, naming the place Shoal Bay, left it without further exploration upstream, as he was certain no major river would be found (Howland and Lee, 2006). In 1854 it became evident to the first white settlers that some modifications to the channel would need to be made if boats were to safely access the port on their way through to Grafton. Stage one focused on directing flows through the south side of the entrance and was named Moriarty's Scheme, after E. O. Moriarty, Engineer-in-Charge for Harbours and Rivers (Howland and Lee, 2006). When this scheme had little success a second, Coode's Scheme, was introduced by John Coode, an English consulting engineer (Howland and Lee, 2006). The third stage was a continuation of recommendations made by Coode. Table 7.1 summarises the channel modifications and their effect on the channel. Figures 7.2 to 7.5 show the current structure of the channel.

Table 7.1: Post-European Channel Modifications to the Clarence River mouth. Source: Howland and Lee (2006).

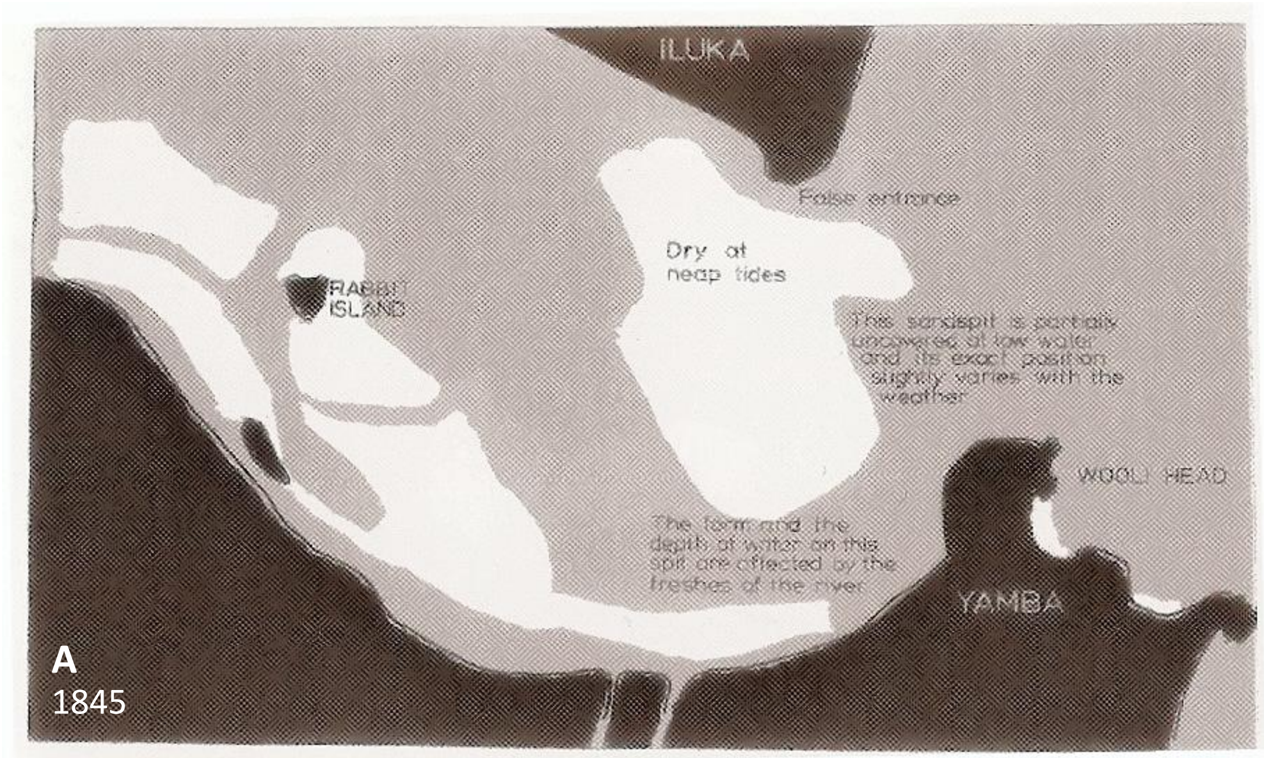
STAGE	MODIFICATION	EFFECT ON CHANNEL
Moriarty's Scheme (1860-1889)	*The Gantry Wall.* A river training wall extending along the Yamba shoreline (Fig. 7.1 C). Built in the 1860's. Building the wall created three bays between it and the original shoreline. These bays were later reclaimed by filling with sand dredged from the river channels and bar. *Moriarty's Wall.* Also built in the 1860's, along with other training walls, on the northern (Iluka) side of the channel.	By fixing the southern channel permanently open and directing flows south by building training walls on the north side of the channel, Moriarty hoped to create a permanent shipping channel on the south side. Instead this caused the shoals and channels on the north side to coalesce into a large spit (Fig. 7.1 B). This caused gradual silting up and widening of the entrance from ~450m in 1862 to ~800m in 1882.

Coode's Scheme (1885-1903)	*Middle Wall, Collis Wall* (off south east side of Goodwood Island) and the *north bank at Iluka* (creating Iluka Bay) (Figs. 7.1 D to F). The main channel was dredged in 1890 by the great flood of that year, assisting the man-made works. Coode also recommended construction of extended breakwaters projecting to sea from both north and south heads.	Coode proposed the reverse of Moriarty's Scheme. He argued flows naturally rushed out to sea via the shorter, northern route. Permanently opening the northern channel was also considered safer by mariners as it was easier to guide a vessel north rather than taking a sharp port side turn across the current to enter the southern channel. Coode's Scheme directed the flow of water and water craft through a stable channel north of the Middle Wall. As a result of these channel modifications sand shoals accreted on the south side of Middle Wall and today form Dart and Hickey Islands. The south entrance closed permanently in 1940 as sedimentation caused Hickey Island to join the mainland (Fig. 7.1 G).
North and south external breakwaters (1950-1971)	A continuation of Coode's recommendations. The southern breakwater was extended by 800m and a northern breakwater 1280m in length was created. The required channel depth of 5.5m was achieved by building the breakwaters 366m apart. A spur was also added along the southern end of Moriarty's Wall running upstream (Fig. 7.1 H).	The construction of extended breakwaters from the north and south heads created a funnel, the tide scouring the bar and thus removing sediment from it. The spur added to Moriarty's Wall created a one metre improvement in the width of the stable river channel.

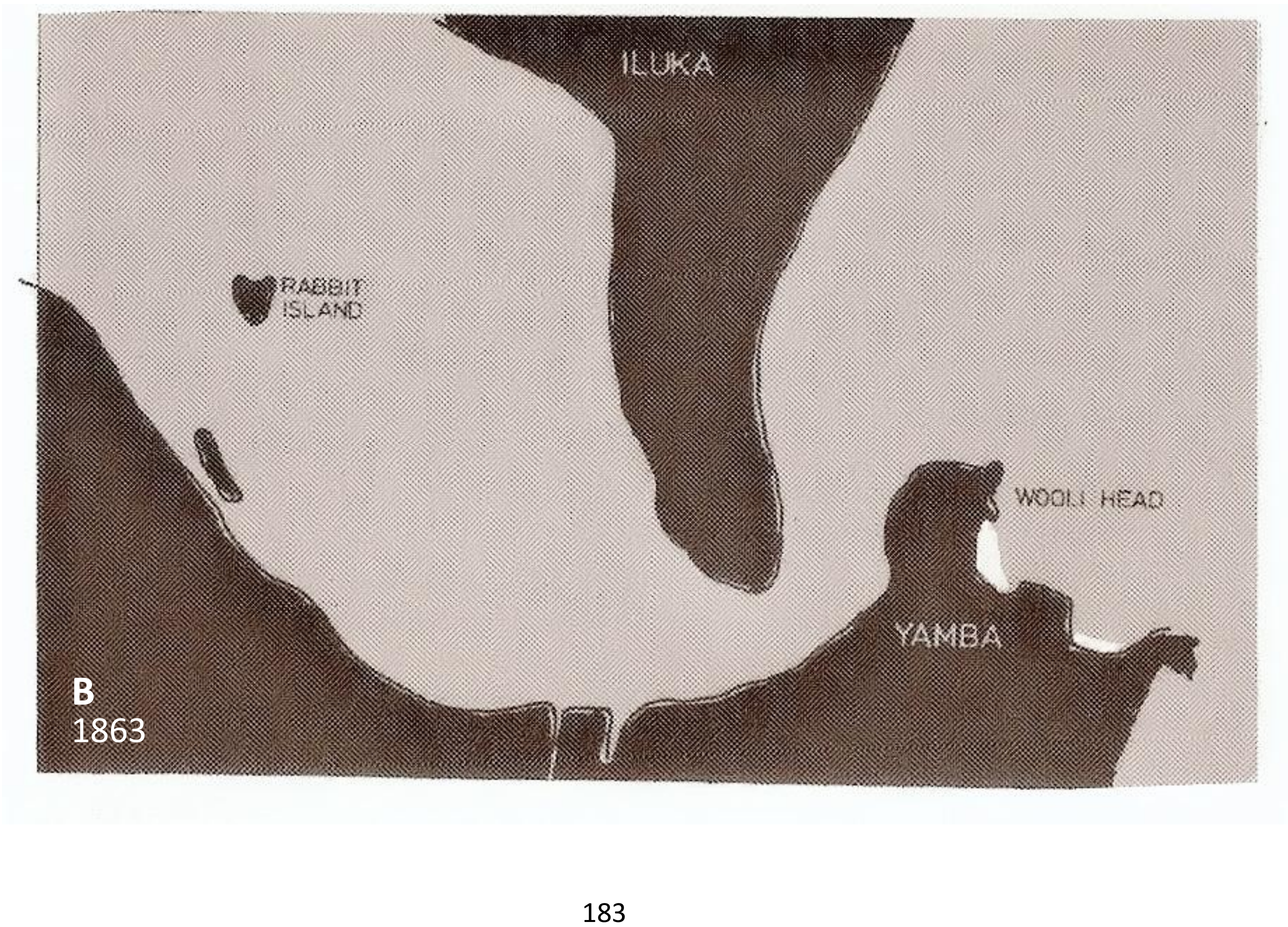
It can be seen that alteration of the natural flow of the Clarence River estuary has had a profound impact on its dynamics and geomorphology. Whilst concentrating the flow has had the desired effect of creating a deep shipping channel, it has also caused sedimentation on the passive (south) side of Middle Wall. It is likely this change in flow regime has had an effect on the study sites at Sleeper Island and Woombah.

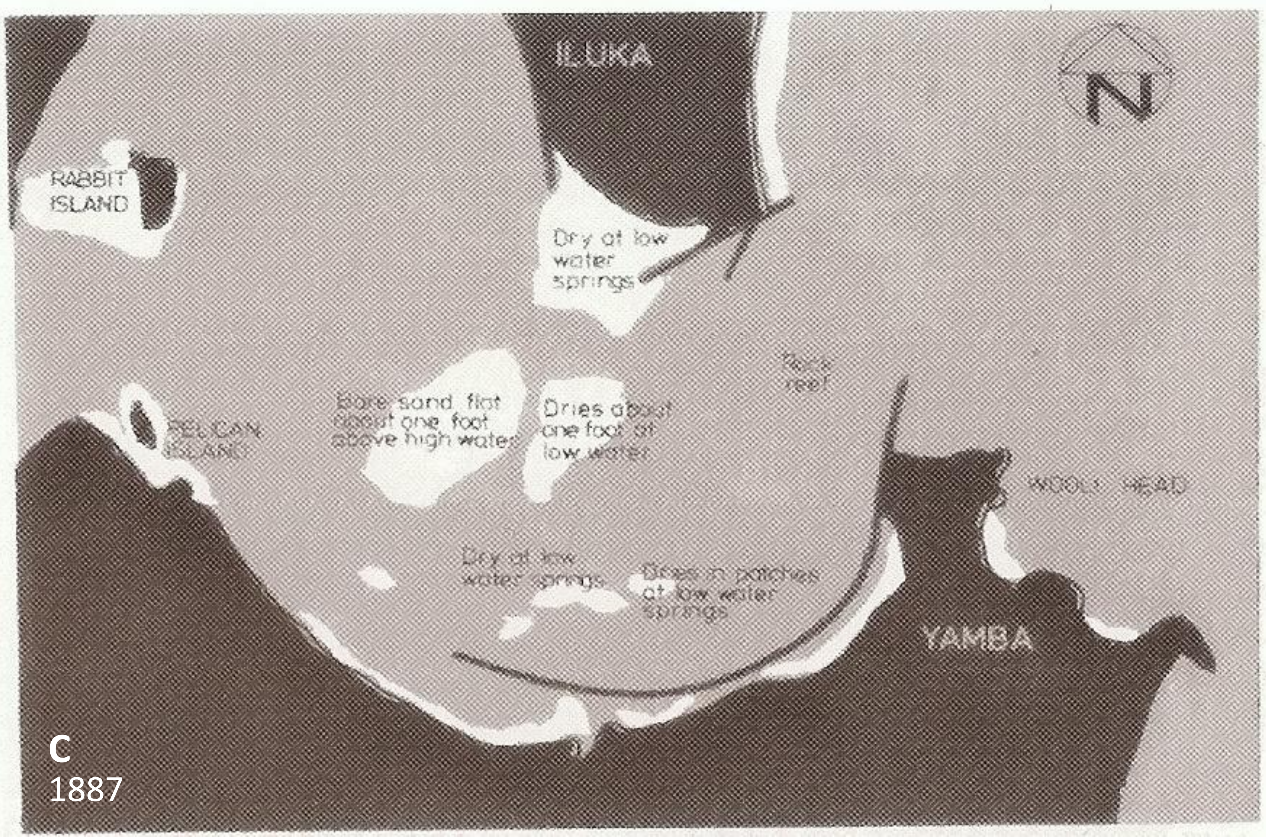
As a consequence of Coode's Scheme (Table 7.1), flow was directed to the north of Middle Wall, causing sedimentation to occur on the south side which resulted in the formation of Hickey and Dart Islands, and the broadening of Rabbit Island (Figures 7.1 D to H). These islands lie immediately east of Sleeper Island. Shallowing of the south channel due to sedimentation may have increased the susceptibility of Sleeper Island to erosion caused by boating wash generated by small recreational vessels with outboard motors. The southern and eastern sides of the island are directly exposed to this threat.

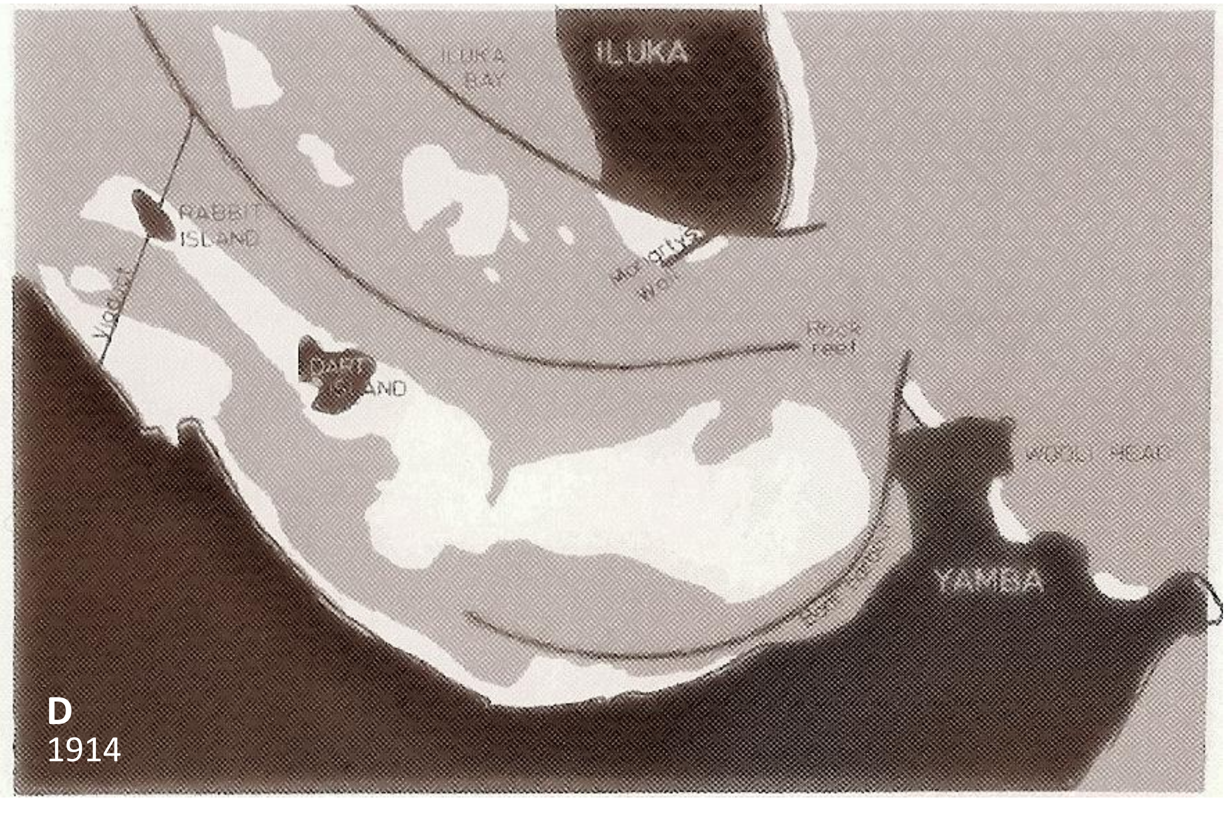
The implementation of Coode's Scheme may have also had an effect on the Woombah study sites, in particular site WA, located in the riverbank. The creation of Collis Wall, Middle Wall and Iluka Bay is likely to have reduced sedimentation on the southern and eastern sides of Goodwood Island, facilitating more effective flow from the North Arm of the Clarence River downstream into the main channel. Facilitation of flow along the North Arm will reduce the likelihood of sedimentation and may in fact cause erosion if riverbanks are not well protected by vegetation. These low-lying estuarine sites are also highly susceptible to erosion caused by flooding and tidal inundation, in particular if the local sea level was to rise. Possible effects of sea level variation are explored in the next section, followed by presentation of results and discussion of the effects of flooding and tidal inundation.

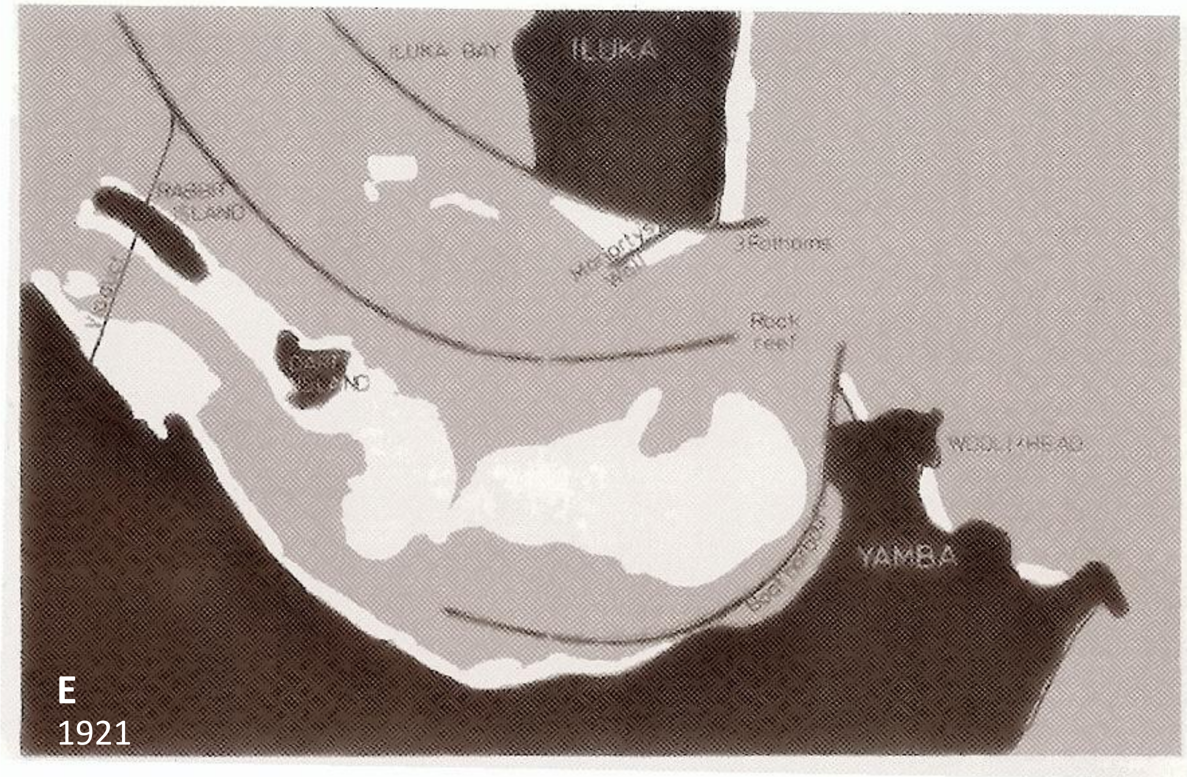


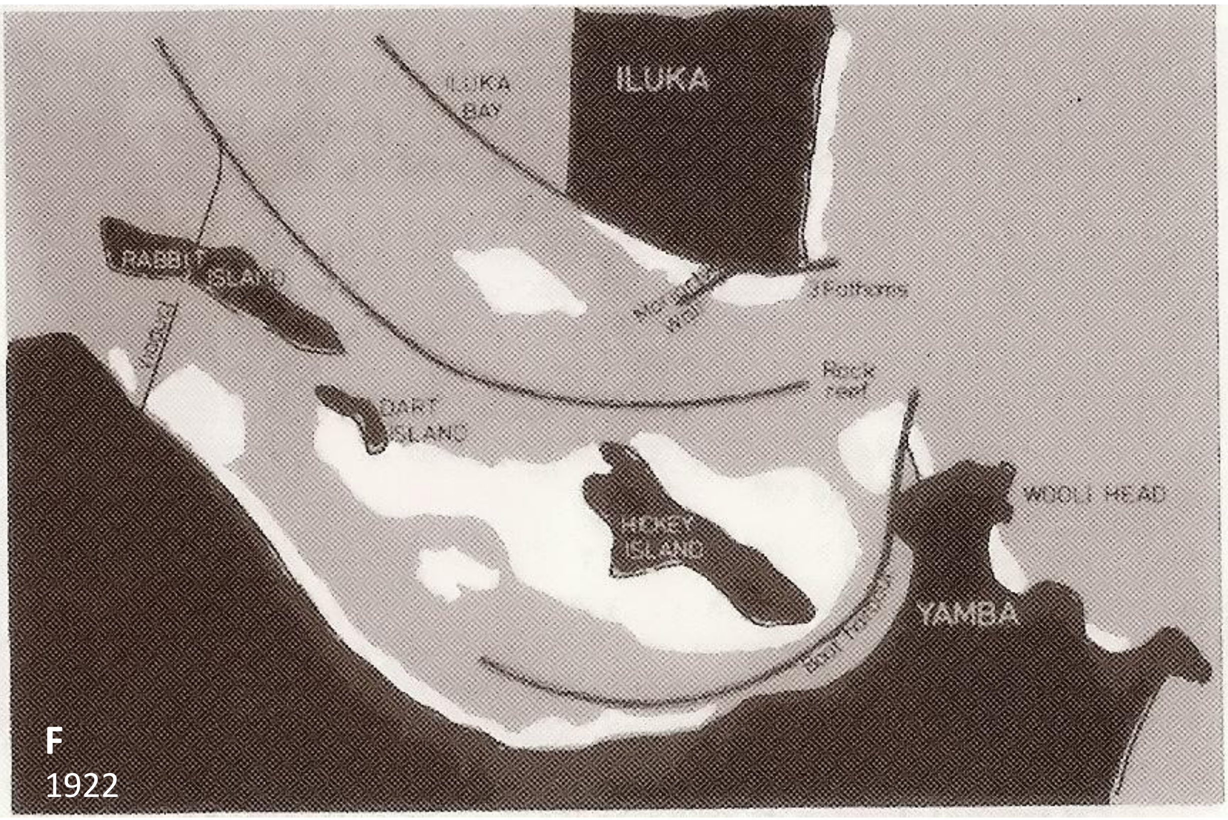
Figures 7.1 A-H: Diagrammatic representation of the anthropogenic modifications to the Clarence River estuary.

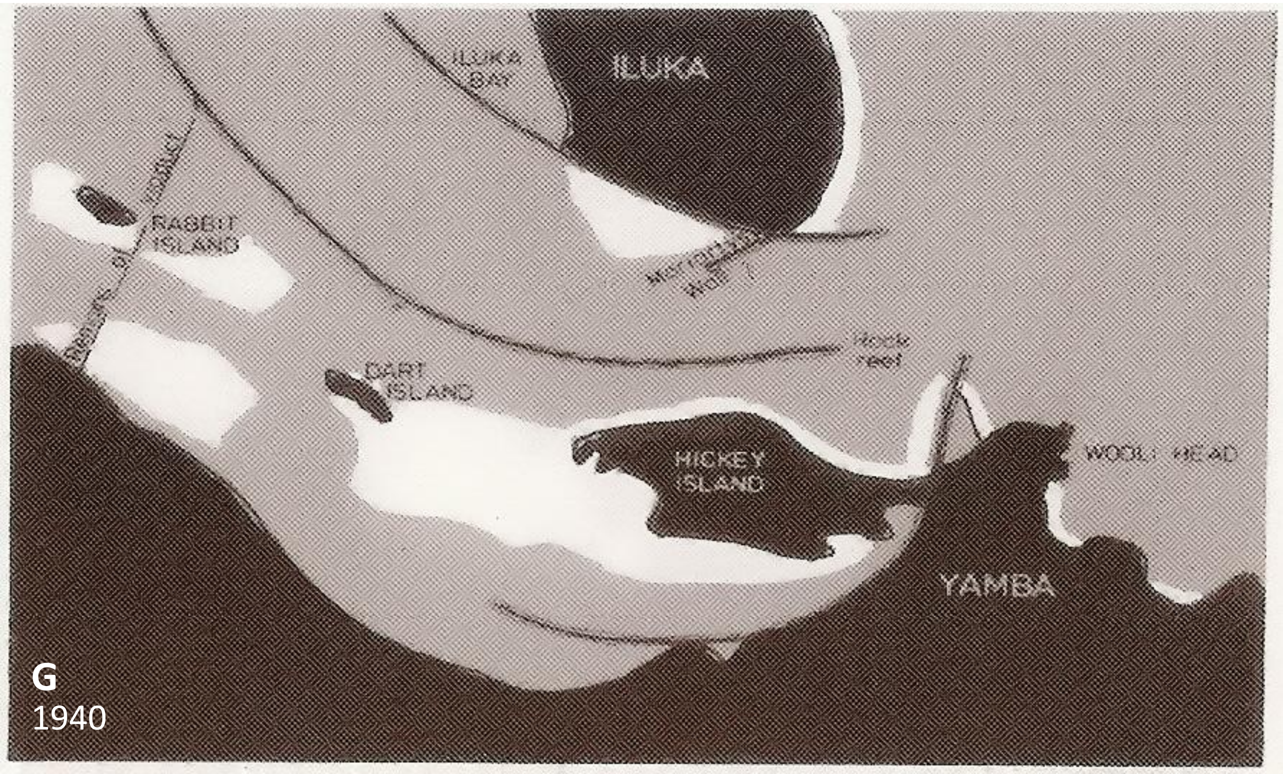



ILUKA
N
RABBIT ISLAND
Dry at low water springs
Rock reef
PELICAN ISLAND
Bare sand flat about one foot above high water
Dries about one foot at low water
WOOLI HEAD
Dry at low water springs
Dries in patches at low water springs
YAMBA
C
1887


ILUKA BAY
ILUKA
RABBIT ISLAND
Moriarty's Wall
Viaduct
Rock reef
DART ISLAND
WOOLI HEAD
YAMBA
D
1914


ILUKA BAY
ILUKA
RABBIT ISLAND
3 Fathoms
Rock reef
DART ISLAND
WOOLI HEAD
YAMBA
E
1921


ILUKA BAY
ILUKA
RABBIT ISLAND
3 Fathoms
Rock reef
DART ISLAND
WOOLI HEAD
HICKEY ISLAND
YAMBA
F
1922


ILUKA BAY
ILUKA
RABBIT ISLAND
DART ISLAND
Rock reef
HICKEY ISLAND
WOOLI HEAD
YAMBA
G
1940

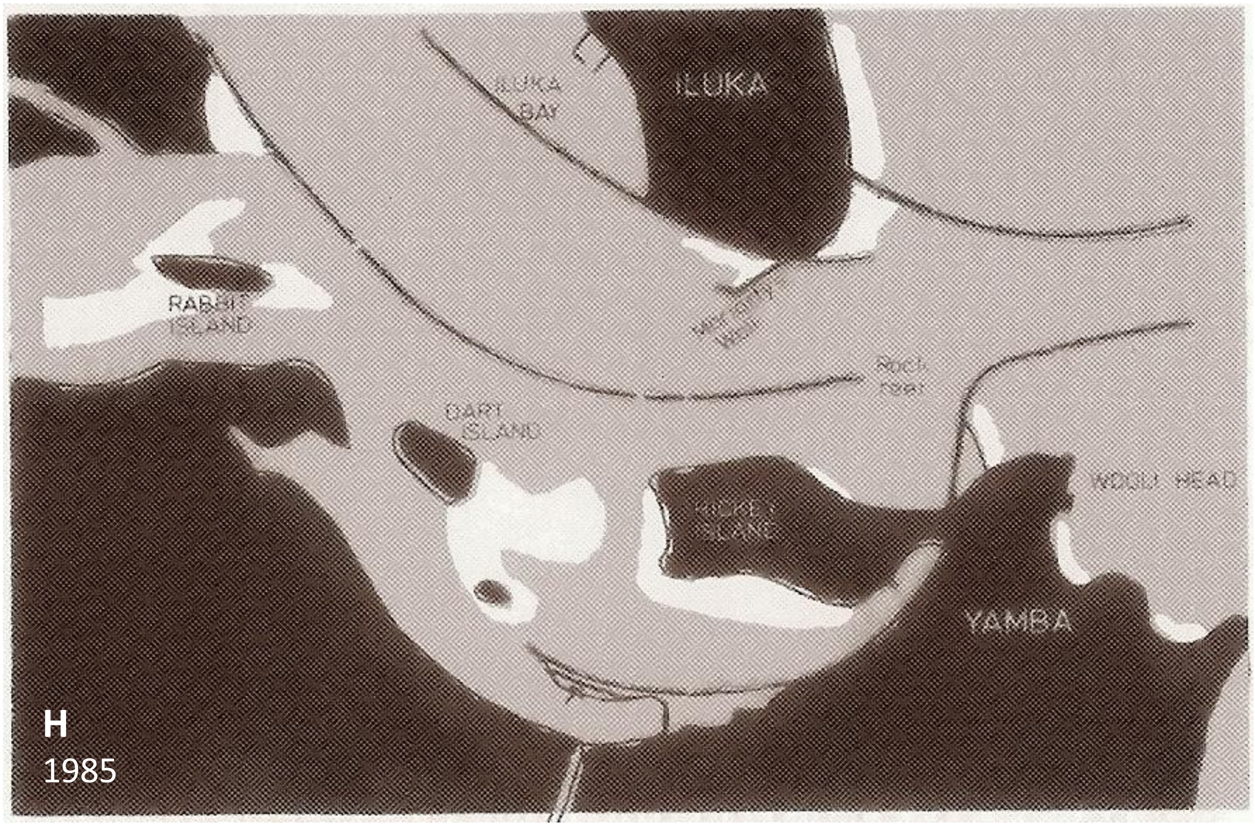

ILUKA BAY
ILUKA
RABBIT ISLAND
Rock reef
DART ISLAND
HICKEY ISLAND
WOOLI HEAD
YAMBA
H
1985

Figure 7.2: The south external breakwater at Yamba. The mouth of the Clarence River lies to the left of the wall.

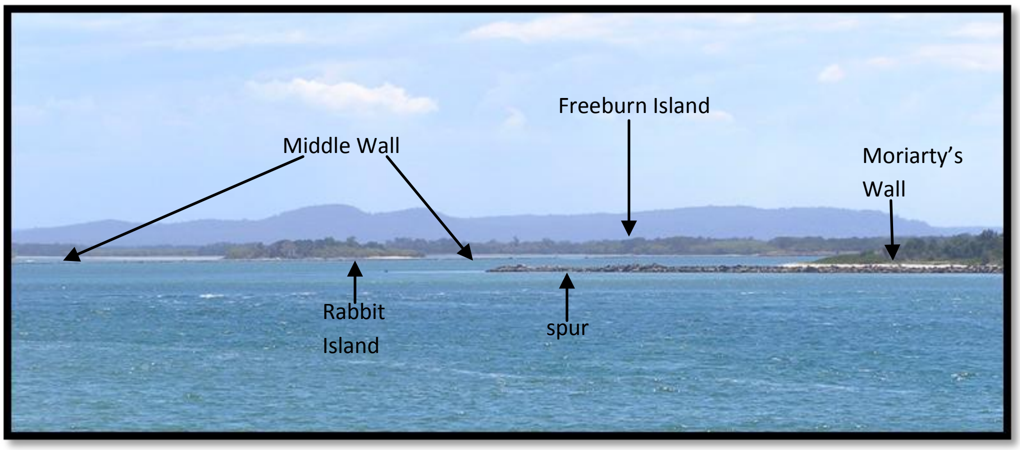


Figure 7.3: Moriarty's Wall, complete with spur directed upstream. Middle Wall can be seen in the background. Ilkua beach lies to the left.

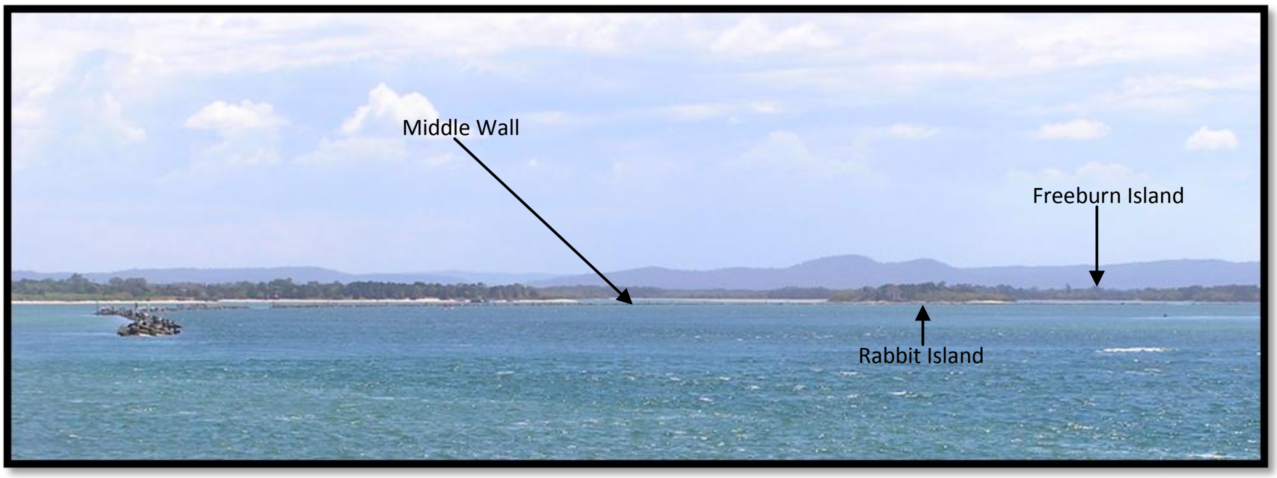


Figure 7.4: Middle Wall as seen from the south external breakwater.

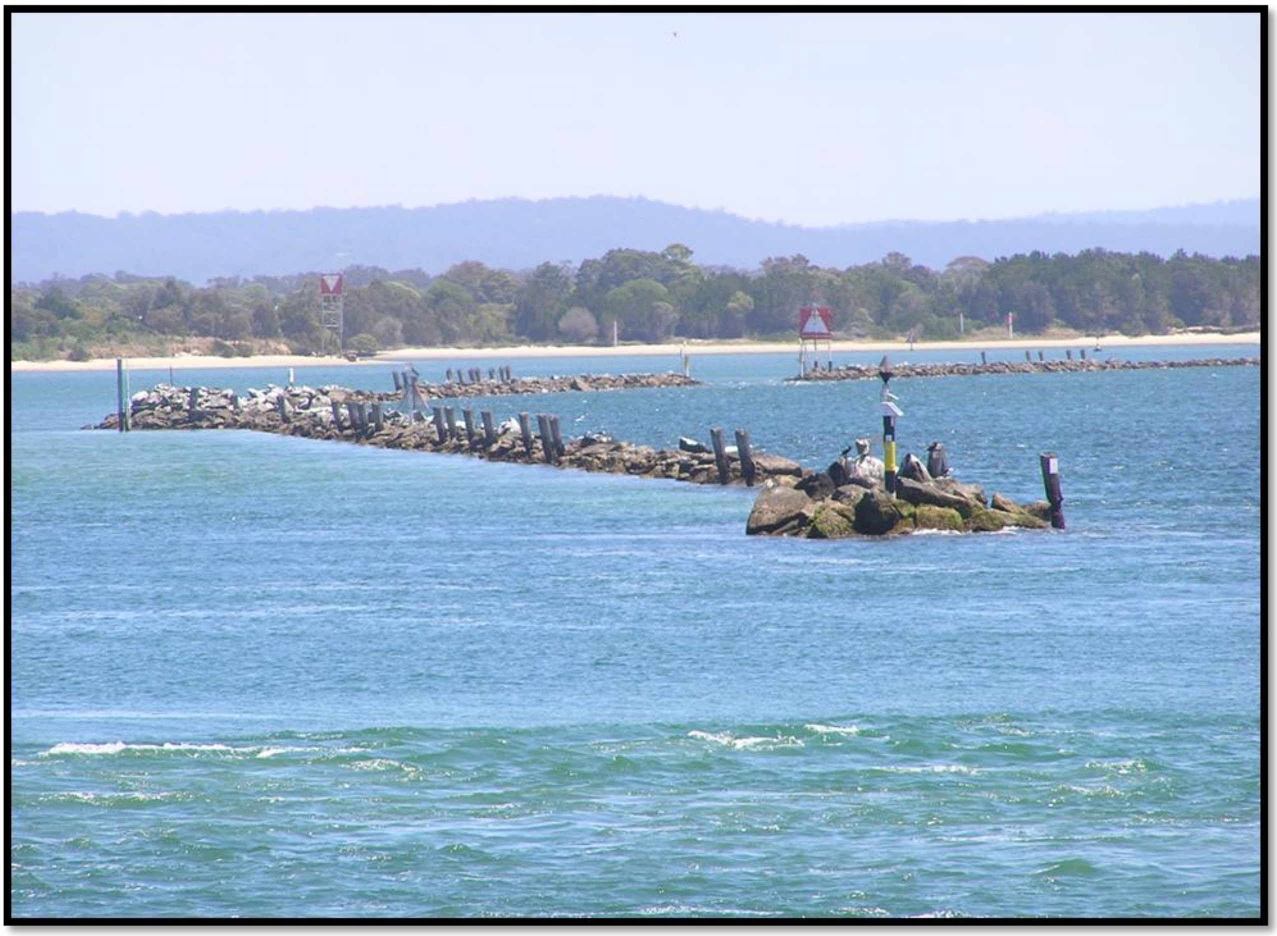


Figure 7.5: Close up of the eastern end of Middle Wall, taken from the south external breakwater.

7.3 SEA LEVEL

It is important to consider the impact of future climate and sea level trends on study sites due to their proximity to the current coastline, and the fact that a number of them are located in low-lying areas (elevation <1 mAHD). The suitability of past global climate and sea level trends as analogues for current and future conditions is investigated, along with causes of sea level change. Holocene sea level proxy data and rates of sea level change for eastern Australia, as well as models of future rates of sea level change are reviewed. The risk of inundation by rising sea level to low-lying midden study sites is predicted based on local sea level data that have been reviewed.

7.3.1 **Sea level during interglacial stages**

The Holocene period (from 10000 years ago to the present) was characterized by warming climates and rising sea levels until around 6000 yrs ago when the current stable interglacial period was attained. Extensive coastal sediment deposits show that in preceding interglacial periods sea level also rose to around the same position as the Holocene (Thom and Murray-Wallace, 1988) and had a profound impact on the geomorphology of coastal estuaries, including the Clarence. The conditions leading to each of these interglacials and the evolution of the sea level and coastal response help to inform an understanding of the current Holocene interglacial, its future trajectory and recent past.

There is much agreement that interglacial Marine Isotopic Stage (MIS) 11 (410 000 to 340 000 years BP) is likely the closest Quaternary analogue to the Holocene (MIS 1) (Masson-Delmotte *et al.*, 2006; Raynaud *et al.*, 2005; Ruddiman, 2005; Berger and Loutre, 2003; Berger *et al.*, 2003; McManus *et al.*, 2003; Bender, 2002; Shackleton, 2000; Petit *et al.*, 1999; Bassinot *et al.*, 1994). Present and predicted future northern hemisphere summer insolation levels are comparable to those present during the MIS 11 interglacial (Ruddiman, 2005; Berger and Loutre, 2003; Milankovich, 1941; Figure 7.6) and atmospheric concentrations of carbon dioxide have a mean value of 278 p.p.m during the ~30 000 year duration of MIS 11, close to the pre-industrial level of 280 p.p.m (Pepin *et al.*, 2001). $\delta^{18}O$ records from both benthic and planktonic foraminifera contained within North Atlantic deep sea cores show values similar to those recorded in the Holocene (McManus *et al.*, 2003). Therefore MIS 11 can be considered a non-industrial analogue of the Holocene interglacial.

However, the way in which the chronologies of the two stages are aligned differs among groups of researchers. The NorthGRIP-community-members (2004) align MIS 11 and MIS 1 at their glacial terminations (Terminations I and V), whereas Ruddiman (2005), Bender (2002), Shackleton (2000), Petit *et al.* (1999) and Bassinot *et al.* (1994) align substage 11.24 (partly glacial) with the Late Holocene (Figure 7.6). Differing alignments of MIS 11 and MIS 1 lead to different interpretations of current and future climate trends.

If MIS 11 and MIS 1 are aligned at their glacial terminations the trend that occurred during MIS 11 suggests insolation in the Late Holocene will continue for another ~16 000 years (NorthGRIP-community-members, 2004). Keeping this alignment of obliquity signals Masson-Delmotte *et al.* (2006) and Raynaud *et al.* (2005) propose a much longer persistence of interglacial conditions. They argue that low orbital obliquity, coupled with minimal northern hemisphere summer insolation, conditions which led to glaciations at the termination of MIS 11, will not occur in the next tens of thousands of years, thus prolonging current interglacial conditions. Given that an interglacial is considered to be “an uninterrupted warm interval in which the global scale environment reached at least the present level of warmth” (Berger *et al.*, 2003, p. 117), Masson-Delmotte *et al.*’s (2006) and Raynaud *et al.*’s (2005) argument suggests temperatures will not fall in the immediate future. It follows that sea level will likely show a similar pattern.

Based on this interpretation of the alignment of MIS 11 and MIS 1 there are two likely risk outcomes at the study sites. Firstly, if sea level remains at its present level, risk of inundation of the study sites will remain consistent. Secondly, if a change in insolation or atmospheric concentration of carbon dioxide causes an increase in global temperatures and subsequent rise in sea level, risk of inundation of the study sites will increase.

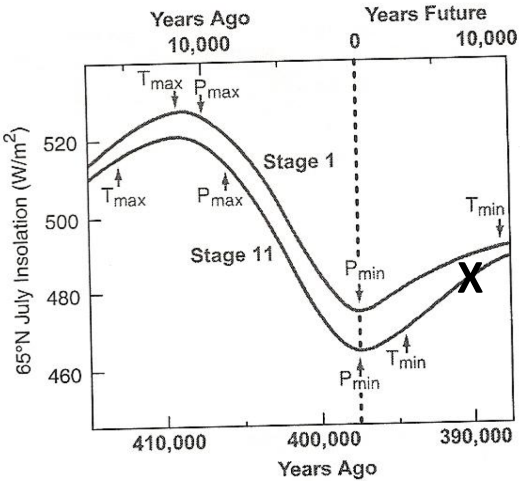


Figure 7.6: Alignment of MIS 11 and MIS 1 based on northern hemisphere summer insolation trends. Source: Ruddiman, 2005. X marks MIS substage 11.24.

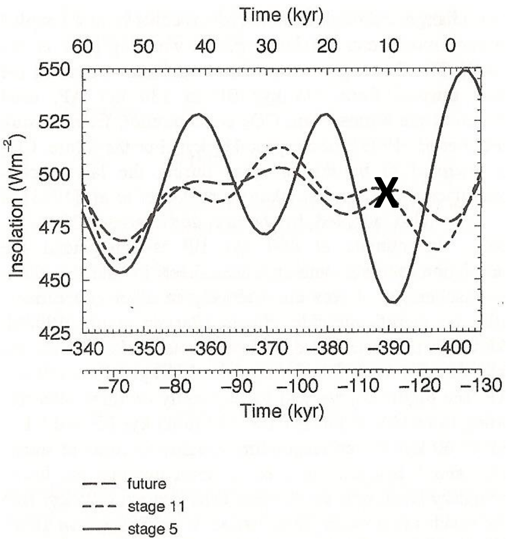


Figure 7.7: Northern hemisphere summer insolation levels during MIS 11 and MIS 5 and predicted future levels. Source: Berger & Loutre, 2003. X marks MIS substage 11.24.

Some researchers, including Bender (2002), Shackleton (2000), Petit *et al*, (1999) and Bassinot *et al.* (1994), align the Late Holocene insolation curve with MIS substage 11.24 (390 000 years BP) using climate proxy signals from the Antarctic Vostok ice core and northern hemisphere summer insolation trends (Figures 7.6 and 7.7). When aligned in this way it is evident that insolation levels are lower during MIS substage 11.24 than during the corresponding MIS 1 (Holocene) time period (Figure 7.6). In addition, instead of continuing to decrease, as happened during MIS substage 11.24, Holocene atmospheric concentrations of carbon dioxide and methane begin similar decreases but then start to increase again from around ~8 000 to 5 000 years BP (Figure 7.8). An increase in the atmospheric concentration of these gases, coupled with a postulated increase in insolation levels, is likely to lead to a rise in sea level based on the trends presented in Figures 7.6 and 7.8. A rise in sea level will increase the risk of inundation to the study sites.

Figure 7.7 shows predicted levels of insolation. Based on these predictions insolation is expected to increase over the next 10 000 years, at which time the level is postulated to mirror the MIS substage 11.24 level (Berger and Loutre, 2003). Although the MIS substage 11.24 insolation level varies between Figures 7.6 and 7.7, predicted insolation levels at +10 000 years are consistent. The predicted 65°N July insolation level of 490 W/m^2 is higher than the current level. A raised insolation level is consistent with the persistence of interglacial conditions, and thus, a similar or elevated risk of inundation of the study sites.

In contrast to both the Holocene and MIS 11, insolation levels during the Eemian interglacial (MIS 5e, Last Interglacial) were much more variable (Berger & Loutre, 2003; Figure 7.7). Greenland ice cores NGRIP, GRIP, GISP2, Camp Century and Renland all contain maximum $\delta^{18}O$ isotopic values 3‰ higher than the present value during the Eemian, indicating temperatures were ~5°C warmer than present for a period during the Last Interglacial (Figure 7.8), the isotopic 'maximum' occurring

~123 000 years BP (NorthGRIP-community-members, 2004). δD (stable deuterium isotope) values obtained from the Antarctic Vostok ice core also support these temperature conditions, with an isotopic 'maximum' occurring ~125 000 – 130 000 years BP (EPICA-community-members, 2004). Despite this evidence which that temperature and level of atmospheric carbon dioxide present during Stages 1 and 5 are not analogous to MIS 11 records, a similar trend in ice volume can be seen to occur through Stages 11 and 5, although the resolution of the records for Stage 1 are not ideal for comparison (Figure 7.8).

Comparison of MIS 11 and MIS 5 shows that the relationship between ice volume, insolation, temperature and atmospheric concentration of carbon dioxide is not straightforward. As the relationship between these variables changes through time it is essential to understand the effects of a variety of potential future sea level scenarios. Relatively minor alterations to the elevation of low lying sites can have a profound impact on their vulnerability to sea level rise, as well as to flooding and tidal inundation. The remainder of this section examines further causes of sea level rise as well as the risk of inundation of the study sites based on regional and local Holocene sea level proxy data and existing models of future sea level change.

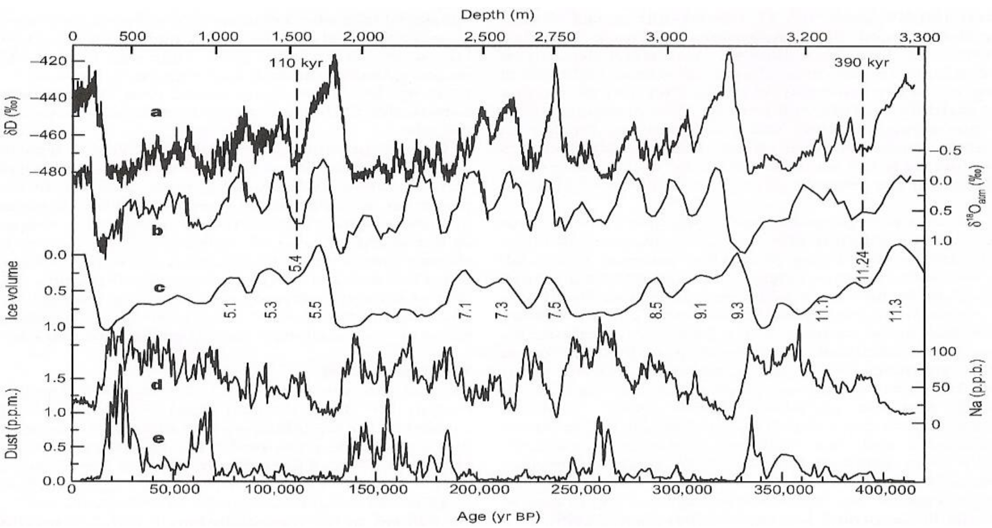


Figure 7.8: Vostok time series and ice volume. Source: Petit *et al.*, 1999.

7.3.2 **Causes of Sea Level Rise**

Factors influencing sea level rise can be non-climatic (geodynamic), climatological or oceanographic. Non-geodynamic changes in ocean volume can be either eustatic or steric. Eustatic sea level change is defined as "the result of water being added to or subtracted from the oceans, mainly through an exchange with ice held in the polar ice caps" (Lambeck, 1990, p. 206). Eustatic sea level change can also have a geodynamic component, being affected by changes in the shape of ocean basins (Lambeck, 1990). Steric changes in sea level result from changes in water density (Patullo *et al.*, 1955). Climatological and oceanographic factors influencing Eustatic and steric sea level include (Goodwin, 2003; Lambeck, 2002):

- **Ocean temperature and salinity**, which affect thermohaline circulation and sea water volume.
- **Ocean currents**, which cause tidal variation in sea level.
- **Surface wind stress** can cause monthly, bi-annual and decadal variability in steric sea level and is linked to the El Nino Southern Oscillation (ENSO) in the Pacific. Fluctuations in wind stress due to ENSO drive equatorial sea level ranges of up to ±0.40 m at Pacific eastern and western basin boundaries (Figure 7.9).
- **Increased ice ablation and meltwater contributions from glacier and ice sheet melting.**
- **Ice accumulation**. Increased precipitation occurs over the Antarctic ice sheets during interglacial periods due to the increased moisture carrying capacity of the warmer air mass, decreased extent of sea ice and increased ocean evaporation (Budd and Simmonds, 1991). These conditions may lead to a lowering of sea level through an increase in snow accumulation across the Arctic (Goodwin, 1998), North America and Europe.
- **Anthropogenic surface water impoundment and groundwater extraction**.

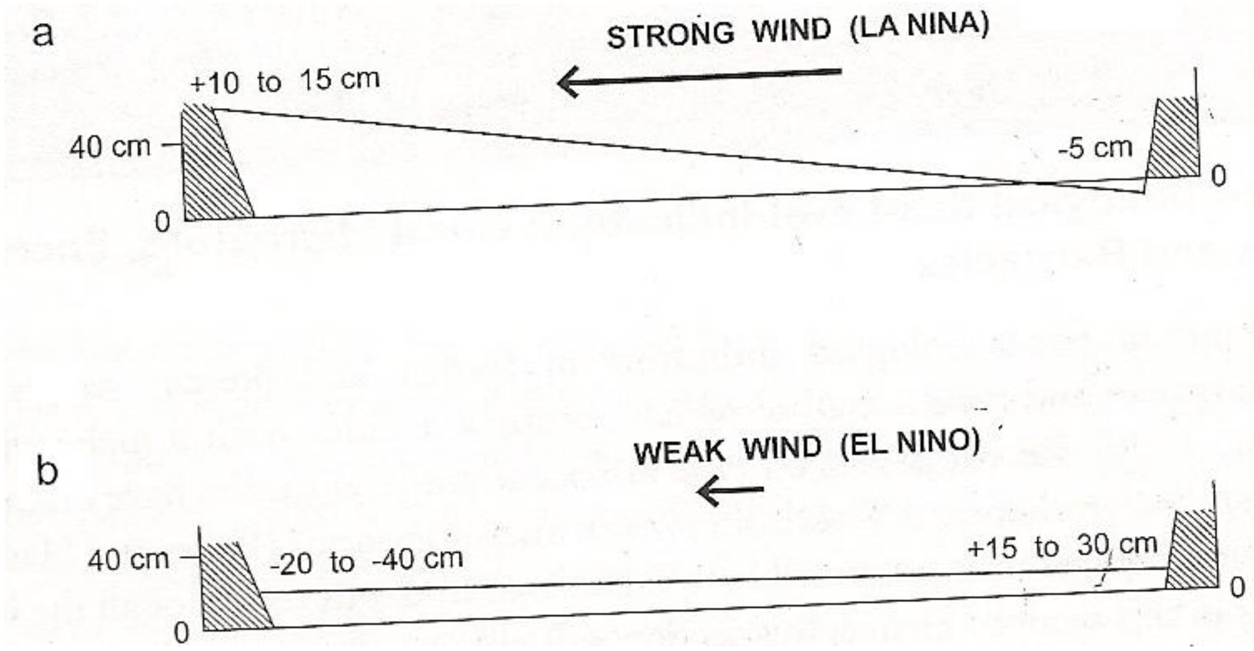


Figure 7.9: The effects of surface wind stress at the east and west Pacific basin boundaries. Source: Goodwin, 2003.

Geodynamic factors include:

- **Glacio-hydro-isostasy**, defined as "the loading of the sea floor by the rising sea during [a] postglacial marine transgression" (Lambeck and Nakada, 1990, p. 145), is illustrated in Figure 7.10. It can be seen that the sea level forms a high stand as a result of added meltwater. The increased ocean volume causes deformation of the crust along the continental margin which responds to the pressure of the water above it. A thin lithosphere and low viscosity upper mantle typically leads to enhanced high stand amplitudes, whilst thick lithospheres and high viscosity upper mantles show high stands with a reduced amplitude (Lambeck, 2002). The upper mantle viscosity appears to be lower for the Australian region than Europe, however lithospheric thickness is comparable (Lambeck, 2002); this may lead to higher amplitude Holocene high stands in Australia. Holocene high stand amplitudes can also be affected by the geometry of the coastline as this affects the distribution of added ocean water (Lambeck, 1990). Figure 7.11 shows higher amplitudes at bays and gulfs and lower amplitudes at open coastline locations; retreat of ocean water from upwarped areas causes flexing of the earth's crust.

- **Tectonism**, which can cause uplift in tectonically unstable locations and yield misleading palaeo-sea level information (Murray-Wallace, 2002).
- **Coastal and inner-shelf bathymetric changes**, which can cause changes in the tidal range at a particular location (Goodwin, 2003).
- **Tsunamis** (Goodwin, 2003).

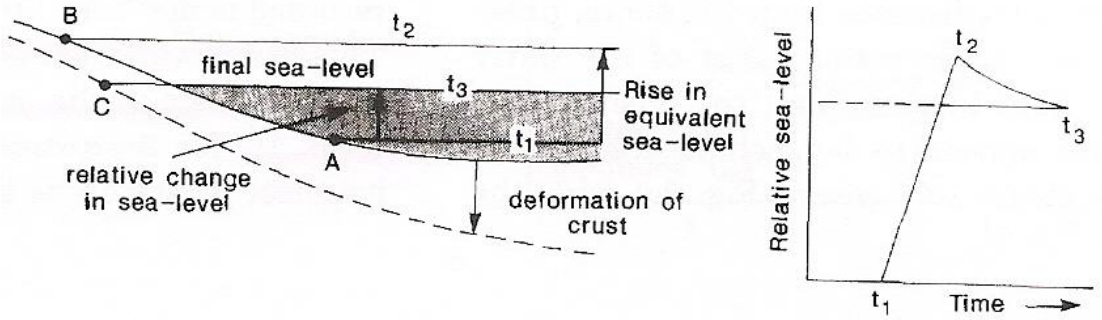


Figure 7.10: The mechanism of hydro-isostasy and its influence on sea level. Source: Lambeck & Nakada, 1990.

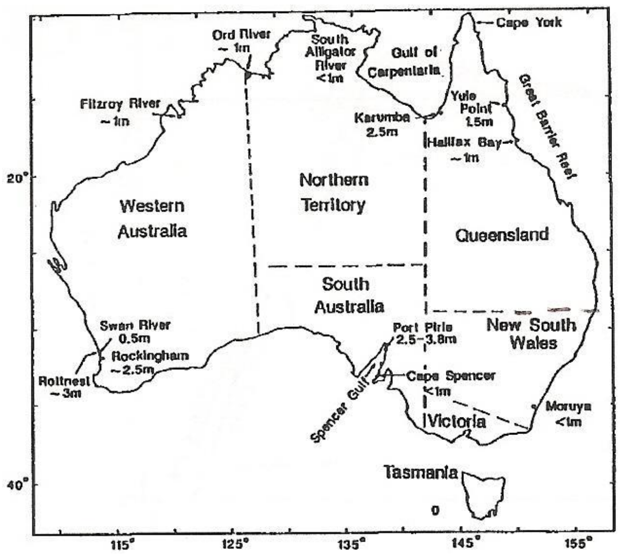


Figure 7.11: Summary of observed Holocene sea level highstands along the Australian coastline, showing higher amplitudes at bays and gulfs and lower amplitudes at open coastline locations. Source: Lambeck, 1990.

To interpret Late Pleistocene and Holocene sea level data it is easiest to study tectonically stable regions (Murray-Wallace, 2002; Goodwin, 1998; Lambeck and Nakada, 1990). However some of the most comprehensive sea level records come from the Huon Peninsula and Barbados but these areas are tectonically active. In such cases the tectonic uplift is so rapid it can be assumed to be constant and, once independently determined, subtracted from the apparent sea level heights. The Australian mainland margin is a passive continental margin situated in a tectonically stable intraplate setting (Brooke *et al*., 2008; Lambeck, 2002; Murray-Wallace, 2002). The continental margin of Australia is considered a far-field site, meaning it is not in close proximity to the location of former ice sheets (present during glacial maxima) (Murray-Wallace, 2002). Sea level change in far-field sites is generally glacio-eustatic in origin and is modulated largely by local hydro-isostatic effects (Nakada and Lambeck, 1989). A minimal hydro-isostatic contribution of <0.50 m per 5000 years has been calculated by Lambeck (2002) for the Australian mainland margin, reinforcing the stability of the region.

7.3.3 **MIS 5e and Holocene sea levels along the east coast of Australia**

Included in Figure 7.15 is a global sea level reconstruction (Waelbroeck *et al*., 2002, red line) and a curve for the Huon Peninsula, Papua New Guinea (Lambeck and Chappell, 2001, solid black lines). The global reconstruction is derived from benthic foraminiferal isotopic records and the Huon Peninsula curve is inferred from the height-age relationships of raised reefs and submerged fossil corals. There is general agreement in the trends of the two curves, although the peaks of the Waelbroeck *et al*. (2002) reconstruction are lower than those measured at the Huon Peninsula. Peak levels during MIS (OIS) 4 and 3 are also lower in the Waelbroeck *et al*. (2002) reconstruction. This may be due to tectonic uplift in the Huon Peninsula region or unrecognised sea water chemistry effects on the benthic record. The two sea level curves in Figure 7.15 show maximum MIS 5e sea levels of -5.0 m to +5.0 m. The post-LGM curve of Lambeck and Chappell (2001) shows a +2.5 m highstand at ~8000 years BP; data for this section of the curve were collected from Bonaparte Gulf, northwestern Australia. The global sea level curve of Waelbroeck *et al*. (2002) does not reflect this highstand. When considering past sea level it is best to use local data from a variety of sea level proxies and check this data against global models, taking into account tectonic setting, glacio-hydro-isostasy and other factors which can affect sea level at local and regional scales.

A variety of sea level proxies along the passive continental margin of Australia have been identified and dated using different methods. Proxies located along the central and northern NSW coastline and in southern Queensland include fossilised fixed biological indicators such as tube worms and barnacles (Lewis *et al*., 2008; Baker *et al*., 2001; Baker and Haworth, 2000; Flood and Frankel, 1989), fossilised corals (Marshall and Thom, 1976; Pickett *et al*., 1989), organic material, such as estuarine shell, *in situ* wood and organic mud (Thom and Roy, 1983), marine shells (Murray-Wallace *et al*., 1996; Thom and Murray-Wallace, 1988) and relict beach sediments (Roy and Boyd, 1996). Agreement of the ages and elevations (and implications of these elevations) between different sea level proxies would add credibility to them.

Fixed biological indicators (FBIs) are “sessile organisms confined to the intertidal zone that upon death become palaeo-sea level indicators” (Lewis *et al*., 2008, p. 75). Species which inhabit a relatively narrow environmental range, such as the tube worm *Galeolaria caespitosa* and a variety of oyster and barnacle species, provide the most reliable palaeo-sea level data for use with the FBI methodology, which takes into consideration the relative height difference between the upper boundaries of relict and current species and assemblages (Baker *et al.*, 2001). It is argued that the resultant palaeo-sea level has only a small margin for error, relative to the habitat of the single species or assemblage present (Lewis *et al*., 2008; Baker *et al.*, 2001). However it is important to note that fixed biological indicators are a proxy for palaeo-sea level. Verification of a variety of indicator species over a broad area is necessary to confirm the biological indicators are *in situ* (within their known habitation zone) and to ensure accuracy of results.

Age determinations can be made from *in situ* fossilised scleractinian corals using radiometric $^{230}Th/^{234}U$ analysis. If multiple determinations are made from common and abundant species this proxy can add valuable information to the sea level record (Marshall and Thom, 1976) in tectonically stable regions. Radiometric ^{14}C analysis of organic material located within relict marginal marine environments can also provide useful sea level data (Thom and Roy, 1983), provided the context of the *in situ* material is accurately gauged, and the environment to which it belongs is narrowly restricted (Sloss *et al*., 2007). Amino acid racemisation (AAR) techniques provide information on relative ages of marine shells (Murray-Wallace *et al*., 1996) and thermoluminescence (TL) dating of quartz grains yields age determinations from relict beach sediments (Roy and Boyd, 1996).

Table 7.2 contains palaeo-sea level information for the central and northern NSW and southern Queensland coastline. Radiocarbon (^{14}C) age determinations of fixed biological indicators show the sea level to be between 1.0 and 1.7 m above present sea level (APSL) for the period between 5500 and 1890 years BP, with small error margins of up to 0.25 m, with one exception of 0.5 m. Constant sea levels through time are not evident, rather sea level appears to fluctuate slightly. An age determination of 3810 years BP from *Galeolaria caespitosa* at Valla Cave was recorded in two separate studies (Baker *et al*., 2001; Flood and Frankel, 1989) although inferred sea levels differ slightly in each study. Verification of a variety of indicator species over a broad area is necessary to confirm the biological indicators are *in situ* (within their known habitation zone) and to ensure accuracy of results.

Data obtained by Thom and Roy (1983) from relict marginal marine environments show a general trend in sea level rise immediately following the Last Glacial Maximum. The radiocarbon age determinations have large errors (analyses were performed over 25 years ago) and there is a sea level discrepancy of 0.8 m between the Port Stephens age determination and one of the Palm Beach determinations. Increasing the sample size and using a contemporary ^{14}C dating method would likely resolve these issues.

In situ fossilised corals at North Stradbroke Island and Evans Head were dated using the $^{230}Th/^{234}U$ method and found to be Last Interglacial in age (Marshall and Thom, 1976; Pickett *et al*., 1989; Table 7.2). Original age determinations (Pickett *et al*., 1985) placed the age of the corals at North Stradbroke Island at 108 000 – 101 000 years BP, providing evidence of a sea level highstand during MIS 5c. The same samples were re-dated (Pickett *et al*., 1989) and found to be of Last Interglacial (MIS 5e) age (Table 7.2). Results from North Stradbroke Island indicate sea level was 1-3 m higher during MIS 5e and those from Evans Head indicate a sea level of 4-6 m higher than present at this time. However sea levels obtained from these corals have a high error margin and more accurate resolution would be beneficial to palaeo-sea level studies.

Anadara valves from the Largs shell bed in the Lower Hunter Valley (Thom and Murray-Wallace, 1988) have a valine D/L ratio of 0.30 (Table 7.2), showing time-equivalence with other Last Interglacial marine strata in southern Australia (Murray-Wallace, 2002). Although a relative dating method, AAR analyses provide a means of corroborating absolute ages obtained using other methods, and are a way of linking relict marine strata throughout Australia. It is important to note, however, that temperature is the primary factor exerting control over racemisation rate; the higher the temperature, the faster L-amino acids will convert to their D-forms (Miller & Bringham-Grette, 1989). Therefore, *Anadara* of the same age exposed to different water temperatures can yield different D/L ratios. Thus, the diagenetic temperature history of the species used for analysis must be able to be estimated with confidence (Miller & Bringham-Grette, 1989).

The elevation of the Largs deposit suggests a Last Interglacial sea level of 4.0 m above present sea level (Thom and Murray-Wallace, 1988). The elevation of the shell bed is above present sea level, indicative of a higher sea level in MIS 5e than the present, however, once again the error range of postulated palaeo-sea level is large (±1.0 m) and a more accurate resolution would be beneficial.

Quartz sand from the Nabiac barrier west of Tuncurry yielded TL ages between 94 400±11 500 and 79 600±680 years BP (Roy and Boyd, 1996; Table 7.2). Based on these ages the barrier could be correlated with either MIS 5c or 5a (sea level regression after the Last Interglacial). Roy and Boyd (1996) have assigned it to MIS 5c, likely based on the elevation of the barrier (Murray-Wallace, 2002). Palaeo-sea level proxies such as those discussed above are absent, however facies architecture suggests deposition at a time when the sea level was at least 10.0 m below its present level (Murray-Wallace, 2002).

Table 7.2: Late Quaternary sea level measurements along the east coast of Australia.

LOCATION	SEA LEVEL (m APSL)	SAMPLE NUMBER	DATING METHOD	CALIBRATED YEARS BP	MATERIAL	REFERENCE
Nambucca Heads (Valla Cave)	1.0±0.1	Beta-30959	^{14}C	3810	Fossil tube worm *Galeolaria caespitosa* as a fixed biological indicator	Flood and Frankel, 1989
	1.7±0.1	VALC1 Waik-8459	^{14}C	3810	As above	Baker *et al*., 2001
	1.7±0.25	Val C7B Waik-8491	^{14}C	3730	As above	Baker *et al*., 2001
	1.0±0.1	Val C6 Waik-8492	^{14}C	3460	As above	Baker *et al*., 2001
Patonga, Broken Bay	1.1±0.25	PAT1 Waik-8495	^{14}C	3650	As above	Baker *et al*., 2001
Caves Beach	1.2±0.1	CaveB1A Waik-8375	^{14}C	2610	As above	Baker *et al*., 2001
	1.3±0.1	CaveB2 Waik-8236	^{14}C	2250	As above	Baker *et al*., 2001
Vaulcluse, Sydney	1.1±0.25	Waik-8234	^{14}C	3250	As above	Baker *et al*., 2001
	1.4±0.5	Beta-132994	^{14}C	5500	Surf barnacle *Catophragmus* as a fixed biological indicator	Baker *et al*., 2001
Port Hacking	1.0±0.1	PortHSite 2A Beta-111205	^{14}C	2230	Fossil tube worm *Galeolaria caespitosa* as a fixed biological indicator	Baker and Haworth, 2000
	1.0±0.25	PortHSite 4A	^{14}C	1890	As above	Baker and Haworth,

		Beta-111204				2000
	1.3±0.1	PortHSite 4B Beta-111206	^{14}C	1980	As above	Baker and Haworth, 2000
	0.8±0.25	PortHSite3 Beta-116620	^{14}C	1350	As above	Baker and Haworth, 2000
	1.4±0.1	PortHSite5 Beta-111203	^{14}C	1920	As above	Baker and Haworth, 2000
Newcastle Bight	-20.4	ANU-1678	^{14}C	10640±400*	Estuarine shell fragments	Thom and Roy, 1983
	-10.7	ANU-1481	^{14}C	9130±400*	Woody peat	Thom and Roy, 1983
	-12.4	ANU-1334	^{14}C	8760±770*	Estuarine shells	Thom and Roy, 1983
Port Stephens	-4.9	ANU-1674	^{14}C	8400±190*	Fibrous peat-reed swamp	Thom and Roy, 1983
Palm Beach, Sydney	-5.7	SUA-1353	^{14}C	8450±270*	Organic mud	Thom and Roy, 1983
	-3.8	SUA-1352	^{14}C	7230±760*	Estuarine shell fragments	Thom and Roy, 1983
North Stradbroke Island	1.0 to 3.0	QMF12385	$^{230}Th/^{234}U$	132000±5000	Coral - *Porites* sp.	Pickett *et al*., 1985; Pickett *et al*., 1989
	1.0 to 3.0	QMF12400	$^{230}Th/^{234}U$	122000±4000	Coral – *Symphyllia* cf. *recta*	Pickett *et al*., 1985; Pickett *et al*., 1989

	1.0 to 3.0	QMF12401	$^{230}Th/^{234}U$	119000±3000	Coral – *Goniastrea aspera*	Pickett *et al*., 1985; Pickett *et al*., 1989
Evans Head	4.0 to 6.0	MMF20572	$^{230}Th/^{234}U$	119000±4000	Coral – *Montipora* sp.	Pickett *et al*., 1989; Marshall and Thom, 1976
	4.0 to 6.0	MMF20602	$^{230}Th/^{234}U$	119000±4000	Coral – *Acropora* sp.	Pickett *et al*., 1989; Marshall and Thom, 1976
Nabiac barrier	-10.0		TL	94400±11500 to 79600±6800	Relict beach sediments (quartz sand)	Roy and Boyd, 1996
Largs, Hunter Valley	4.0±1.0		AAR	Valine D/L ratio = 0.3 (LIG)	*Anadara trapezia*	Murray-Wallace *et al*., 1996

Models have been used by Lambeck (2002) and Lambeck and Nakada (1990) to predict Late Holocene sea levels around Australia. Figure 7.12 shows predicted levels for four locations in NSW, including Nambucca Heads, for the period from 7000 years BP to the present. At Nambucca Heads a maximum sea level of ~0.5-0.9 m APSL occurs 5000 years BP. Sea level predictions are based on the rheological model E14(50), which includes a hydro-isostatic component (Lambeck and Nakada, 1990). Figure 7.13 shows predicted sea levels around Australia at 6000 years BP. Two models incorporating different upper mantle viscosities were used for these predictions and both models incorporate Antarctic melting, including ongoing melting of ~2.5 m equivalent sea level rise, during the past 6000 years. The predicted level for northern NSW, based on an upper mantle viscosity of 10^{20} Pa and a lower mantle viscosity of 1022 Pa, is 0.9 m; a doubling of the upper mantle viscosity yields a predicted sea level of 1.3 m APSL (Lambeck, 2002). The predicted levels for southernmost Queensland are 1.5 m APSL (upper mantle viscosity of 10^{20} Pa) and 2.1 m APSL (upper mantle viscosity of 2 X 10^{20} Pa) (Figure 7.13). The variation among predicted levels from southern Queensland is likely a product of the locations for which the predictions are being made. As mentioned earlier, Holocene high stand amplitudes can be affected by the geometry of the coastline (Lambeck, 1990).

Geographically, the Clarence River estuary is located between the two locations mentioned above, so based on the predictions of Lambeck (2002) and Lambeck and Nakada (1990) it is likely the sea level at 6000 years BP would have been between 0.9 and 1.5 m APSL. Model E14(50) (Lambeck and Nakada, 1990) predicts the sea level at Nambucca Heads 4000-3500 years BP to be ~0.5 m APSL. This differs from sea levels of 1.0 m and 1.7 m APSL during this time, based on data from FBIs at the same location (Baker *et al*., 2001; Flood and Frankel, 1989).

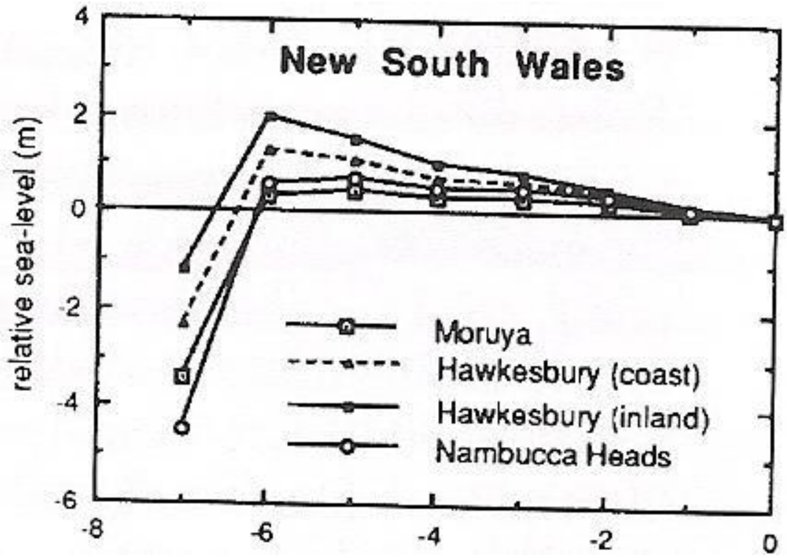


Figure 7.12: Predicted Holocene sea levels for NSW, based on rheological model E14(50). Source: Lambeck & Nakada, 1990.

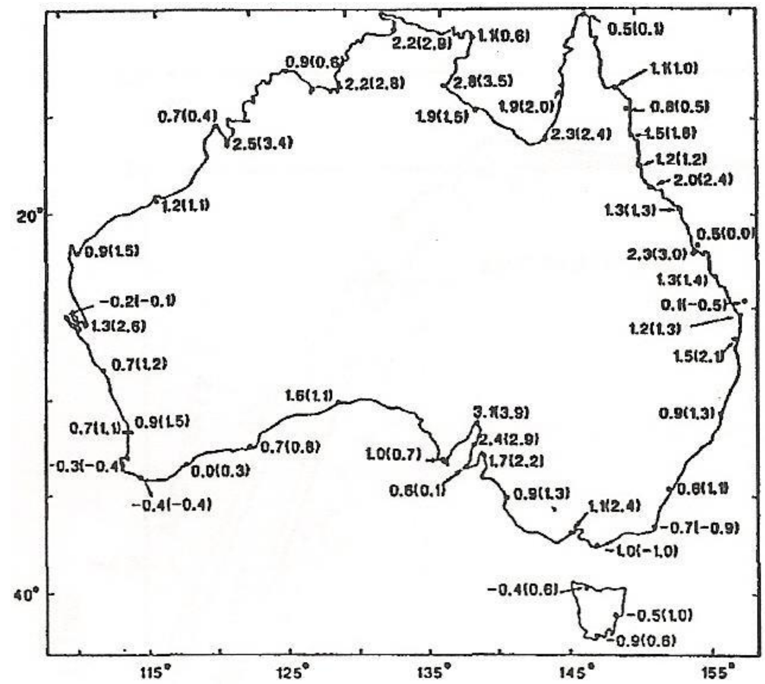


Figure 7.13: Predicted sea levels for the Australian coastline at 6000 years BP, based on based on an upper mantle viscosity of 10^{20} Pa and lower mantle viscosity of 1022 Pa, and an upper mantle viscosity of 2 X 10^{20} Pa and lower mantle viscosity of 1022 Pa (values in brackets); both models incorporate Antarctic melting, including ongoing melting of ~2.5 m equivalent sea level rise, during the past 6000 years. Source: Lambeck, 1990).

Many researchers believe Holocene sea levels in eastern Australia reached their maximum between 7000 and 6000 years BP and started to fall to current levels between 3000 and 2000 years BP (Lewis *et al*., 2008; Baker *et al*., 2005; Lambeck, 2002; Larcombe *et al*., 1995). Figure 7.14 shows a revised Holocene sea level envelope for eastern Australia using extensive data from fixed biological indicators, as well as sea level curves of Baker *et al*. (2005), Larcombe *et al*. (1995) and Chappell *et al*. (1983) for the same region. The curves of Larcombe *et al*. (1995) and Chappell *et al*. (1983) indicate a steady decrease in sea level whereas the curves of Baker *et al*. (2005) and Lewis *et al*. (2008) show some oscillation in sea level. Although the curves all show a peak sea level 7000-6000 years BP followed by a fall to the present level, timing and duration of possible stillstands and postulated sea levels varies, indicating the need for greater resolution of sea level data from many different sources. Evidence and modeling of a raised Late Holocene sea level in eastern Australia has implications for the chronology of Aboriginal shell midden formation. Evidence from sea level studies suggests Late Holocene shell middens occurring at elevations below ~1 m APSL would need to have been formed after about 2000 years BP. Re-evaluation of sea level evidence and modeling, taking into account archaeological evidence, is required to resolve the apparent disparity between fossil and archaeological records.

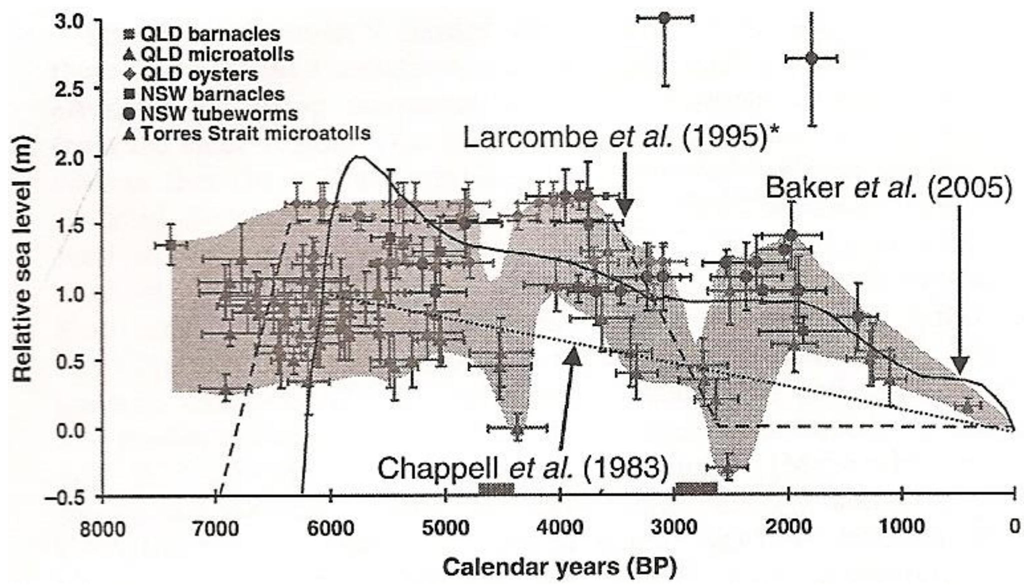


Figure 7.14: Sea level data from fixed biological indicators, forming a postulated sea level envelope for the east coast of Australia. Sea level curves of Baker *et al*. (2005), Larcombe *et al*. (1995) and Chappell *et al*. (1983) for this region are also shown. The Larcombe *et al*. (1995) curve has been recalibrated by Lewis *et al*. (2008).

Source: Lewis *et al*., 2008.

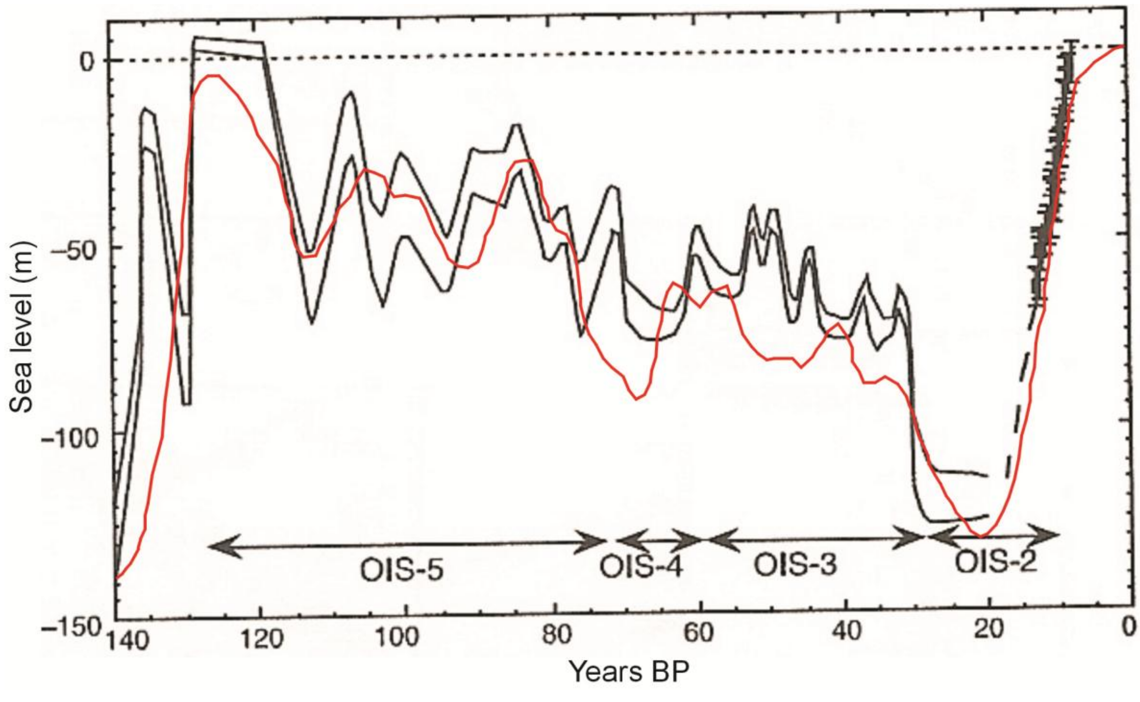


Figure 7.15: Sea level curves of Lambeck and Chappell (2001, solid black lines) and Waelbroeck *et al*. (2002, red line).

7.3.4 **Past, present and projected rates of sea level change in eastern Australia**

Research and review of sea level data obtained from fixed biological indicators suggests an Early Holocene rate of sea level rise of 1.0-2.0 mm/year for the east coast of Australia (Lewis *et al*., 2008). This rate is in agreement with a current global sea level rise of 1.0-2.0 mm/year (Church *et al*., 2001). Records from the Fort Denison tide gauge in Sydney, New South Wales, suggest a sea level rise of 1.16 mm/year based on 81.8 years of recorded measurements (Lambeck, 2002). Lambeck (2002) argues for the reliability of these data, as the tide gauge is situated on rocks remote from harbour installations, is situated in relatively deep water and is unaffected by fresh water riverine input. Measurements at the Newcastle (III) tide gauge have been recorded for 31.6 years and indicate a rate of sea level rise of 1.48 mm/year; considered less reliable than Fort Denison records, the period of data capture is much shorter, the harbour is located on floodplain sediments and is susceptible to perturbation by river discharge (Lambeck, 2002). Bryant (1992) performed an Australia-wide analysis of spatial trends in tide gauge measurements and found a likely current rate of sea level rise of 1.25 mm/year in northern NSW.

Yamba tide gauge records are available from 1987-2007 (from the NSW Department of Commerce, Manly Hydraulics Laboratory) and show a 0.85 mm/yr drop in mean sea level over this time. Lambeck (2002) proposed isostatic corrections of -0.30 mm/yr for Fort Denison and Newcastle (III) tide gauges and -0.33 mm/yr for the Bundaberg tide gauge in Queensland. Application of these correction values to the Yamba data gives an isostatically corrected rate of sea level lowering between 0.52 and 0.55 mm/yr. Data from surrounding tide gauges at Fort Denison, Newcastle (III) and Bundaberg all show an increase in mean sea level between 0.30 and 1.48 mm/yr over a 30-80 year period to 2002 (Lambeck, 2002), contrary to the lowering seen at the Yamba gauge. Adjacent gauges at Ballina (to the north) and Coffs Harbour (to the south) have also recorded a lowering of mean sea level during the period from 1987-2007, however gauges at Brunswick Heads, Tweed

Heads (further north), Port Macquarie and Crowdy Head (further south) recorded a rise in mean sea level during this time (NSW Department of Commerce, Manly Hydraulics Laboratory). These data suggest localised factors are likely to contribute to mean sea level variance.

Possible local effects causing variation in the measurement of sea level data may be related to the position of the Yamba tide gauge. It is situated in the mouth of the Clarence River where peak flood discharges are likely to influence sea level measurements. Also, it is located on sediment. An increase in water volume resulting from peak flood discharges may carry enough weight to cause subsidence of sediment, which has the capacity to alter tide gauge readings.

The usefulness of the Yamba data for assessing long term trends is somewhat limited, as the records currently only extend back 20 years. Despite an overall trend towards lower mean sea level at Yamba, records show oscillations in mean sea level at intervals between one and four years, with a maximum range of 0.168 m over the 20 years from 1987-2007. The duration of the ENSO cycle is typically 3-5 years and historical records show this interval can vary from 2-7 years with El Nino conditions lasting 9-12 months up to 2-4 years and La Nina conditions typically lasting 1-3 years (Queensland Department of Primary Industries, 2009). The 1-4 year oscillations in mean sea level recorded at Yamba between 1987 and 2007 may be a reflection of the ENSO cycle however this appears unlikely in a regional context, given the variability in the measurements at surrounding gauges (both the overall sea level trend and the sea level oscillation patterns) as discussed in the previous paragraph, with some showing a rise in sea level between 1987 and 2007 and others such as Yamba recording an overall fall in sea level.

Postulated future rates of sea level rise vary. Gregory *et al*. (2004) suggest a rate of 7.0 mm/year, based on a 3°C warming in Greenland and melting of the Greenland ice sheet. Most other estimates fall within the range of 1.5-2.0 mm/year (Miller & Douglas, 2004), including a 0.5 mm/year rise as a result of ocean volume change due to atmospheric warming, as derived from ocean temperature and salinity data (Levitus *et al*., 2000). With a transition to La Nina conditions, mean sea level along the east coast of Australia, including Yamba, is expected to rise. In the future, tide gauge records extending through multiple ENSO cycles will provide valuable data on long term sea level trends.

7.3.5 **Effects of current and future rates of sea level rise on study sites in northern NSW**

Table 7.3 shows the number of years until total inundation of Aboriginal shell middens at Sleeper Island, Woombah, Wooli, Minnie Water and Plover Island based on rates of sea level rise discussed above. As data from Yamba show a local trend in falling sea level over the 20 years from 1987 to 2007 they cannot be used to calculate the risk to sites of sea level rise. This trend towards a slight lowering of sea level over a recent 20 year period indicates that, currently, the study sites are likely at minimal risk from rising sea level and factors having a more immediate impact on their destruction can be seen in the erosion hazard table of results (Appendix 5). With other gauges along the east coast of Australia recording a rise in sea level over the past 30-80 years, however, the threat of sea level rise and its possible impacts must be considered. Stable, buried deposits with very low susceptibility to erosion, such as the midden site at Wooli, are in a far better position to remain intact post-sea level rise than sites with a high erosion hazard that are susceptible to riverine and estuarine tides and flooding, such as Sleeper Island. The artifact deposits at Plover Island are considered to be at much lower risk of destruction as a result of rising sea levels due to their elevation on the rocky island. Combined with other factors which are affecting archaeological information loss at low-lying Aboriginal shell midden sites highly susceptible to erosion (Appendix 5), inundation as a result of rising sea level will most likely contribute to further destruction. As the study sites would be increasingly susceptible to storm, flood and wave damage as sea level rose, these dates are considered absolute maxima.

Table 7.3: Number of years until total inundation of Aboriginal shell middens at study sites in northern NSW based on various rates of sea level rise discussed in the text.

Site	Elevation (mLAT)	Years to total inundation at Sydney rate of rise (1.16mm/yr)	Years to total inundation at Newcastle rate of rise (1.48mm/yr)	Years to total inundation at postulated rate of rise for northern Australia (1.25mm/yr)
Sleeper Island	1.92	1655	1297	1536
Woombah Site A	1.93	1664	1304	1544
Woombah Site B	2.25	1940	1520	1800
Wooli	1.86	1603	1257	1488
Minnie Water	1.10	948	743	880
Plover Island	6.21	5353	4196	4968

7.4 FLOODING AND TIDAL INUNDATION HAZARD AT ESTUARINE AND RIVERINE STUDY SITES

As Aboriginal shell midden sites within the study areas at Woombah, Sleeper Island and Wooli are located on the floodplain in close proximity to river channels the impact of flooding and tidal inundation on these sites must be considered. The method formulated for assessing flood risk in this study can be applied to floodplain midden sites if their elevation (m AHD) and flood return period (ARI) for the area are known or can be calculated; risk of tidal inundation can also be calculated using the elevation of sites calculated from a known high or low tide height (see Chapter 4 for a full explanation of these calculations).

7.4.1 **Flooding**

Results indicate the Woombah site A river bank deposit is more susceptible to flooding than the site B creek bank deposit (Table 7.5). Although both sites are situated on the floodplain, the elevation gently increases across the floodplain to the first levee rise. At an elevation of 2.825 m AHD (Table 7.5) the site A deposit is susceptible to flood levels caused by floods with a return frequency of 6.5-9.7 years based on data from the Maclean flood gauge (NSW Department of Commerce, Manly Hydraulics Laboratory) whilst the site B *in situ* deposit has a maximum elevation of 3.145 m AHD (Table 7.5), making it susceptible to floods with a return frequency of 9.7-19.5 years based on data from the Maclean flood gauge (NSW Department of Commerce, Manly Hydraulics Laboratory).

Results were also generated using data from the Palmers Channel flood gauge (Table 7.5; NSW Department of Commerce, Manly Hydraulics Laboratory) and they different significantly from those generated using the Maclean flood gauge data. As the elevations of both Woombah Aboriginal shell midden sites are above the highest recorded flood level at the Palmers Channel gauge for the period from 10/8/1990 – 3/7/2008 the flood magnitude required to inundate these deposits cannot adequately be gauged from the Palmers Channel data. Floods measured at the Maclean gauge show more shorter return periods associated with lower flood heights (Appendix 4, data from NSW Department of Commerce, Manly Hydraulics Laboratory). This difference in height and return period between the gauges at Palmers Channel and Maclean is likely a function of local topography, elevation and historic flood frequency. The flood threshold at the Palmers Channel gauge is 2.00 m AHD, whilst the threshold at the Maclean gauge is 0.60 m AHD (NSW Department of Commerce, Manly Hydraulics Laboratory).

Given the position of Woombah in the Clarence River estuary, calculating susceptibility to flooding of the study sites at this location is best achieved using data from the Maclean flood gauge. The midden sites sit on and close to the riverbank which is situated in the comparatively narrow North Arm of the Clarence River. Similarly, a narrowing of the channel occurs on the western side of Palmers Island. The Woombah midden sites are situated on the floodplain. The maximum elevation of these sites is higher than the highest recorded flood level at the Palmers Channel gauge for the period from 10/8/1990 – 3/7/2008 but within the elevation of floods measured at the Maclean flood gauge during this period.

According to the Manly Hydraulics flood data for 1990-2008 from the Maclean gauge there is no correlation between the maximum rate at which flood water levels rise (cm/hr) and flood ARI. Less severe floods can have the capacity to rise faster or equally as fast as those with a greater ARI. Thus, flood levels considered alongside ARI alone can quantify flood risk and susceptibility of low-lying estuarine and riverine Aboriginal shell midden sites.

The *in situ* midden deposit at Sleeper Island has a maximum elevation of 2.815 m AHD (Table 7.5). At this elevation the deposit is above the highest recorded flood level at the Palmers Channel gauge for the period from 10/8/1990 – 3/7/2008, and thus susceptible to total inundation by flood events with a return period of >18.9 yr based on these data (NSW Department of Commerce, Manly Hydraulics Laboratory). Clarence Valley Council Floodplain Services records for the Palmers Channel gauge indicate flood levels of 2.44 m AHD have a return period of 20 years while a flood reaching 2.86 m AHD has a return period of 100 years. Therefore the in situ midden deposit on Sleeper Island is susceptible to total inundation by floods with a return period between 20 and 100 years.

Data from the Maclean flood gauge for the period from January 1990 to July 2008 show floods with an ARI of between 6.5 and 9.7 years have a corresponding elevation to the *in situ* midden deposit on Sleeper Island. The Palmers Channel gauge has the closer proximity to the Sleeper Island midden and is also located in a similar geomorphological setting to Sleeper Island, indicating its data are more suitable for use in flood risk calculations at Sleeper Island.

Historic flood data obtained from Manly Hydraulics Laboratory and the Clarence Valley Council (Appendix 4) shows flood levels greater than 2.82 m AHD have only been recorded once at Palmers Channel, in 1890. Records at this gauge are incomplete and include the years 1890, 1945-1980 (Clarence Valley Council Floodplain Services) and 1990-2008 (NSW Department of Commerce, Manly Hydraulics Laboratory). The majority of the cultural material associated with the Sleeper Island midden (shells and stone artifacts) is present as a lag deposit at the base of the *in situ* deposit. This material is situated in a tidal channel and is regularly subjected to tidal flows (see tidal inundation discussion below).

The Wooli Aboriginal shell midden has a maximum elevation of 2.755 m AHD (Table 7.5). At this elevation the deposit is above the highest recorded flood level at the Wooli River Entrance flood gauge for the period from 1/5/1991 – 20/10/2009, and thus susceptible to total inundation by flood events with a return period of >19.5 yr based on these data (NSW Department of Commerce, Manly Hydraulics Laboratory). Clarence Valley Council Floodplain Services records for Harold Lloyd Park, site of the Wooli Aboriginal shell midden forming part of this research study, indicate flood levels of 1.80 m AHD have a return period of 20 years while a flood reaching 2.30 m AHD has a return period of 100 years (Wooli River Floodplain Management Plan, 1999). Both these levels are well below the measured site elevation of 2.755 m AHD. The Wooli River Floodplain Management Plan (1999) also estimates a flood level of 4.22 m AHD is the probable maximum flood (PMF) level at the southern caravan park, located ~1.4 km to the north of Harold Lloyd Park. Based on these calculations the Wooli Aboriginal shell midden deposit is susceptible to inundation only by a theoretical extreme flood event.

During mid-2009 a significant flood event occurred in the Northern Rivers region of NSW and road access to many coastal towns in the Grafton-Wooli area was cut off. The damage caused by this flood was witnessed in the field by the researcher. Widespread flooding caused inundation of farmland in and around Pillar Valley, Tucabia and Tyndale and on the Clarence estuary islands. Although floodwaters covered much of the low-lying farmland in the region flood peak levels did not reach the elevation required to inundate the Aboriginal shell midden deposits at Woombah, Sleeper

Island or Wooli. Peak levels of 2.61 m occurred at the Palmers Channel gauge on 23/5/2009 at 2030 and 1.35 m at the Wooli River entrance gauge on 22/5/2009 at 0330 (NSW Department of Commerce, Manly Hydraulics Laboratory).

7.4.2 **Tidal inundation**

When assessing the impact of tidal inundation on the Aboriginal shell midden sites at Woombah, Sleeper Island and Wooli two sets of results were generated (Table 7.6). The first set of calculations was based on the 2009-2010 tide predictions for the Yamba and Wooli gauges. The second set was based on the actual occurrence of tides over an 18-20 year period (Appendix 4, data from NSW Department of Commerce, Manly Hydraulics Laboratory). Results generated from each of these datasets differ considerably; those generated using historic tide level data are considered more reliable. They are based on actual data which have been collected over an 18-20 year period at the Yamba and Wooli River entrance gauges and are more appropriate for gauging longer-term susceptibility to tidal inundation as the period of data capture encompasses perturbations which may be caused by factors such as ENSO. Statistical analyses performed by the Manly Hydraulics Laboratory have allowed for the formulation of tidal inundation classes, based on the frequency of occurrence of measured tide heights (Tables 7.4 and 7.5, Appendix 4) and these can be used to measure and compare the susceptibility of midden sites to tidal inundation. For a discussion of how tidal inundation classes have been applied to midden sites in this study, refer to Chapter 4.

Table 7.4: Tidal range and corresponding inundation class. Source: Manly Hydraulics Laboratory.

TIDAL RANGE (depth mLAT)	INUNDATION CLASS
2.300-2.101	4
2.100-2.001	3
2.000-1.801	2
1.800-0.101	1
0.100-0.001	2
0.000- -0.199	3
-0.200- -0.399	4
-0.400- -0.499	5

LAT=Lowest Astronomical Tide.

Based on their elevation, Woombah site A and Sleeper Island fall into tidal inundation class 2, which includes the second most frequently occurring range of tide heights measured at the Yamba tide gauge for the period from 1/7/1987-30/6/2007, as calculated from the tide height frequency data (Appendix 4, data from NSW Department of Commerce, Manly Hydraulics Laboratory). Woombah site B falls into tidal inundation class 4, as high tides occur much less often at this elevation. The elevation of the Wooli Aboriginal shell midden site is above the tidal range recorded at the Wooli River entrance gauge and thus out of the limits of the tidal inundation classes (Table 7.6). The higher tidal inundation class number prescribed to Woombah site B indicates it is less susceptible to tidal inundation than the midden sites at Woombah site A and Sleeper Island and this is confirmed by the tide data discussed below.

Based on data from the Yamba tide gauge the Woombah site A and Sleeper Island midden deposits have been completely tidally inundated 276 times over the 20 year period from 1/7/1987-30/6/2007, approximately 14 times per year (Table 7.6). When taking into account other risk factors contributing to erosion (Appendix 5 and Erosion discussion) the level of erosion hazard differs at these sites so it is likely other factors are also influencing erosion at these two sites. In contrast, the Woombah site B midden deposit has only been completely inundated 4 times over the same 20 year period (Table 7.6), or once every 5 years. Having a higher elevation than the Woombah site A and Sleeper Island deposits considerably reduces the susceptibility of the Woombah site B midden deposit to tidal inundation and therefore reduces its susceptibility to erosion. The elevation of the Wooli Aboriginal shell midden places it above the tidal range as measured at the Wooli River entrance tide gauge. Tidal inundation is therefore not an erosion risk factor associated with this site.

Separating the effects of tidal inundation and flooding is a taphonomic issue. The rising water levels caused by both these processes can result in erosion. In the case of tidal inundation wave action is the main erosive agent, thus fetch and weather conditions are also important. These are considered in the first erosion hazard model (see Erosion section in this chapter for a discussion of the model; Appendix 5). At Woombah sites A and B and Sleeper Island flooding occurs less often than tidal inundation. Taphonomic evidence (Chapter 6) at the Woombah site A deposit including characteristics of shell material and absence of foreign material such as gravel, pebbles and wood within the matrix of the deposit suggests that bank erosion at Woombah site A and Sleeper Island may be a result of a regular process of stripping, such as that caused by tidal inundation. The presence of lag deposits at the base of the Woombah site A and Sleeper Island midden deposits also supports this conclusion, as flooding causing bank erosion is likely to wash away or re-deposit the shell material at the level reached by the flood waters.

Tidal inundation is considered to be a major factor affecting the lag deposit of cultural material at Sleeper Island (Appendix 5). According to the 2009-2010 Yamba tide predictions (www.bom.gov.au/oceanography/tides/MAPS/yamba.shtml) there are most often two high tides per day. The lag deposit at the base of the *in situ* material is inundated by all high tides, as it is located in a tidal channel. As the majority of the cultural material at the site was present as a lag deposit on first inspection in 2007, and it is this material which is susceptible to daily tidal inundation, tidal activity is currently an important process contributing to site degradation. Evidence of this could be seen on a return visit to the site a year after field work was first carried out; less than 10% of the cultural material first observed in the lag deposit remained at the site.

Results show the majority of estuarine sites studied in this research project are susceptible to flooding and tidal inundation. As such, it is postulated that the occurrence of a relatively minor rise in sea level would greatly increase the frequency of flooding and tidal inundation in the study area. The 0.32 m difference in elevation between Woombah site A and B has a marked influence on relative frequency of flooding and tidal inundation. At lower elevations this difference is even more pronounced (Appendix 4). There is great potential for further study in using flood and tide gauge data to model the effects of sea level rise on flood and tide frequencies at different elevations.

Table 7.5: Site elevation, flood height and flood return period.

SITE	ELEVATION (mLAT)	AHD ADJUST (YAMBA)	ELEVATION (mAHD)	FLOOD HEIGHT (mAHD)	FLOOD RETURN PERIOD (ARI - years) PALMERS CHANNEL GAUGE	FLOOD RETURN PERIOD MACLEAN GAUGE	FLOOD RETURN PERIOD WOOLI GAUGE
Woombah A	1.93	0.895	2.825	2.825	>18.9	6.5-9.7	N/A
Woombah B	2.25	0.895	3.145	3.145	>18.9	9.7-19.5	N/A
Sleeper Island *in situ*	1.92	0.895	2.815	2.815	>18.9	6.5-9.7	N/A
Sleeper Island lag	N/A (present in tidal channel)	0.895	N/A	N/A	N/A	N/A	N/A
Wooli	1.86	0.895	2.755	2.755	N/A	N/A	>19.5

Table 7.6: Site elevation, tidal inundation frequency and inundation class.
^ Based on predicted tidal levels at the Yamba gauge July 2009 to June 2010, Australian Bureau of Meteorology
*Elevation measured as mAPSL
Based on occurrence of tides measured at the Yamba tide gauge over the past 20 years

SITE	ELEVATION (mLAT)	INUNDATION LEVEL	FREQUENCY/yr (YAMBA^)	FREQUENCY (yr/days)	FREQUENCY/yr (YAMBA#)	FREQUENCY (yr/days)	INUNDATION CLASS
Woombah A	1.93	1.93	3	121.7	13.8	26.4	2
Woombah B	2.25	2.25			0.2		4
Sleeper Island *in situ*	1.92	1.92	3	121.7	13.8	26.4	2
Sleeper Island lag	N/A (present in tidal channel)	At high tide	At high tide	>1	At high tide		N/A
Wooli	3.64	3.64	N/A	N/A	N/A		above tidal range
Plover Island	6.4-7.1*	N/A (coastal site)					
Minnie Water	1.1	N/A (coastal site)					

7.5 EROSION HAZARD AT THE STUDY SITES

7.5.1 **Introduction**

Following the discussion of flooding impact at the study sites, erosion is considered to be the primary factor affecting the preservation of Aboriginal cultural deposits at Sleeper Island, Plover Island and Minnie Water. Field observations indicate most of the cultural material has already weathered out of the *in situ* deposit on Sleeper Island and formed a lag deposit at its base. Bank erosion is also evident around the entire island. Erosion of sediment on Plover Island has caused deflation and compaction of the stone artifact deposits. The reworked Aboriginal shell midden at Minnie Water is eroding out of the base of the Rocky Point foredunes. Erosion also affects the Woombah site A riverbank midden deposit, where shells can be seen weathering out and forming a lag deposit at its base.

7.5.2 **Soils**

Erodibility, a measure of the susceptibility of soil to detachment and transport by erosive factors such as wind and water, is influenced by characteristics including texture and organic matter content (Lal & Elliott, 1994). Sandy and coarse loamy sand soils have high infiltration rates (Evans, 1980). This leads to lower runoff rates and although sand sized particles (62.5 – 2000 µm) are easily detached, particles with a diameter greater than 300 µm are not easily eroded by flowing water (Lal & Elliott, 1994; Evans, 1980). Clayey soils, on the other hand, are not easily detached but have lower infiltration rates which may lead to greater runoff and increased erosion (Lal & Elliott, 1994). Evans (1980), however, notes that the rough surfaces of cloddy soils are resistant to rill and sheet erosion as their surfaces have the capacity to store much water. Lal & Elliott (1994) suggest silty soils have the greatest erodibilities, as the particles are easily detached and transported.

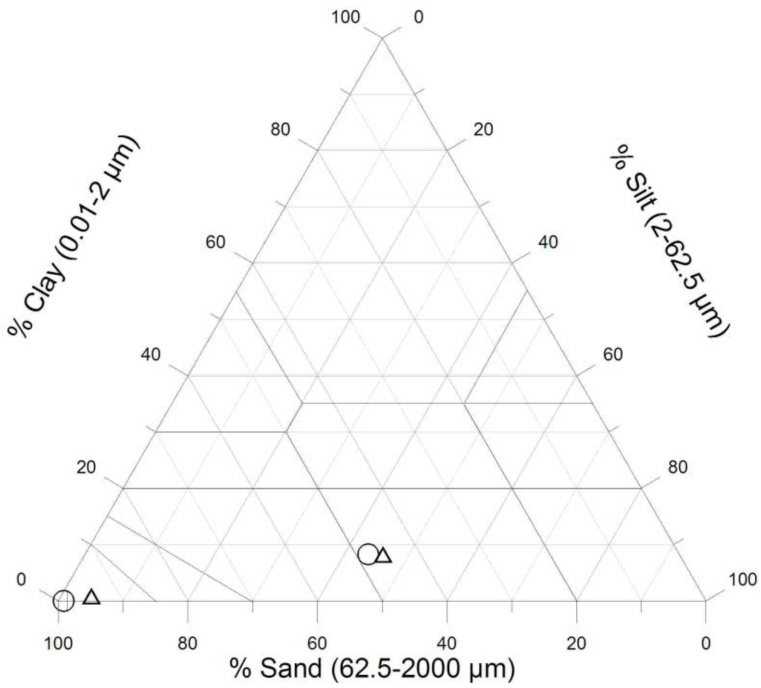


Figure 7.16: Particle size plot Woombah Site A.

Key: △ = A Horizon, O= B Horizon, += C Horizon.

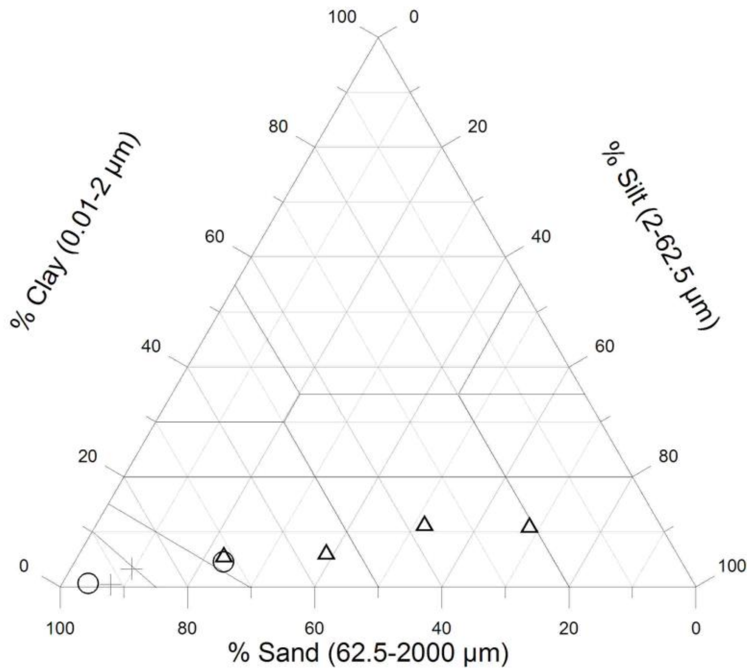


Figure 7.17: Particle size plot Woombah Site B.

Particle size analysis results for A horizons of soils at both Woombah sites A and B (Figures 7.16 and 7.17; Appendix 2) show soils in the sandy silt loam, sandy loam and sand categories and are similar to field texture determinations at site A (Appendix 1). Field texture of the A horizon in cores 2b – 5b at Woombah site B, however, suggested the presence of more clay sized particles than the particle size analysis using the Malvern Mastersizer. Percentage organic content ranged between 4.7% and 9.6% for A horizons of soil cores at Woombah sites A and B (Appendix 2). Based on particle size and organic content results it is likely A horizon soils at Woombah sites A and B have high infiltration, and thus, lower, runoff rates.

Particle size analysis results for B horizons of soils at Woombah sites A and B show a similar distribution to A horizon soils with samples in the sandy silt loam, sandy loam and sand categories. These results are similar to most field texture determinations at sites A and B, with the exception of samples from cores 4b and 5b. Core 5b appears to have a uniform composition showing no clearly defined horizons and was collected in very close proximity to the riverbank. The amount of organic material from the Woombah B horizon core samples measured as high as 3.8%, however most samples were found to have an organic content around 0.95% (Appendix 2). Although organic matter content is much reduced in B horizon soils at Woombah sites A and B, their high sand content (and restricted clay content) is likely to increase infiltration and reduce runoff rates in the same way as the A horizon soils discussed above.

C horizon soils from Woombah sites A and B all fall within the sand category according to the particle size analysis results (Figures 7.16 and 7.17; Appendix 2). These results are consistent with field texture determinations (Appendix 1) at site A but differ from those obtained from cores 3b and 4b. Data obtained from particle size analyses in the laboratory is considered to be of greater value and significance as there is less room for human error and, most importantly, laboratory tests were repeated and averaged (Chapter 4), increasing the reliability of the results. With the exception of cores 3b and 4b, the amount of organic matter found in C horizon cores at Woombah sites A and B is under 0.5% (Appendix 2). Cores 3b, 4b and 5b are the closest in proximity to the riverbank and may represent a different depositional environment to that at the other core sites across the floodplain (see Chapter 5 for an in depth discussion of the Woombah depositional environment). The sandy C horizon soils at Woombah are likely to have high infiltration rates, low runoff rates and low susceptibility to erosion, as medium to very coarse sands are not easily eroded by flowing water (Lal & Elliott, 1994; Evans, 1980).

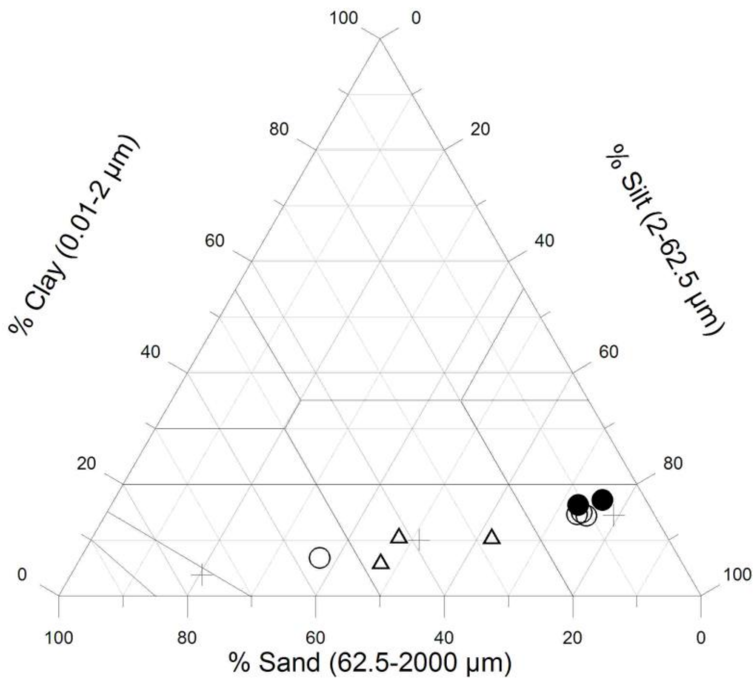


Figure 7.18: Particle size plot Sleeper Island.

Particle size analysis results for A horizon soil samples from Sleeper Island all fall within the sandy silt loam category (Figure 7.18; Appendix 2). Ribbon length attained during field texture measurement did suggest the presence of some clay (Appendix 1) in the A horizon. Percentage organic matter ranged from 7-22% and is not consistent across cores (Appendix 2) but is generally higher than organic matter content in the Woombah A horizon samples. A high organic content coupled with the sandiness of the soil suggests the Sleeper Island A horizon is well drained due to high infiltration rates. The presence of silt sized particles may increase the erodibility of the soil.

The B horizon on Sleeper Island has been divided into B1 and B2 subhorizons. Particle size analysis of B1 samples shows samples from the majority of cores fall within the silt loam category, with one exception falling within the sandy loam category (Figure 7.18). As is the case with horizon A, ribbon length of field texture samples indicated the presence of some clay. Organic content ranges between 5.8 and 8.6% with the exception of core 2s, which yielded a result of 16.3% (Appendix 2). Although B1 horizon soils on Sleeper Island contain relatively high amounts of organic matter which aids in increasing infiltration rates their silt content is likely to increase erodibility. High erodibility of the subsoil has created severe bank erosion on Sleeper Island (see pictures, Chapter 3).

B2 horizon samples also fall within the silt loam category according to particle size analysis. Percentage organic matter was measured as 7.4 and 7.8% in samples from cores 1s and 4s, respectively (Appendix 2). Having similar particle size and organic matter content as the B1 horizon, the B2 soil horizon on Sleeper Island is likely to have similar erodibility characteristics.

Particle size results for the Sleeper Island C horizon are spread across the loamy sand, sandy silt loam and silt loam categories (Figure 7.18). The difference in the particle size results was somewhat unexpected, as field textures of C horizon samples were uniform. Both field texture and particle size results highlight the lack of clay in the Sleeper Island C horizon. Organic matter content ranges from 7.1 to 9.2% which is similar to the amount found in the B horizon. Infiltration is likely to remain high in the C horizon soils however the sandier samples are likely to have lower erodibilities than those with increased silt content.

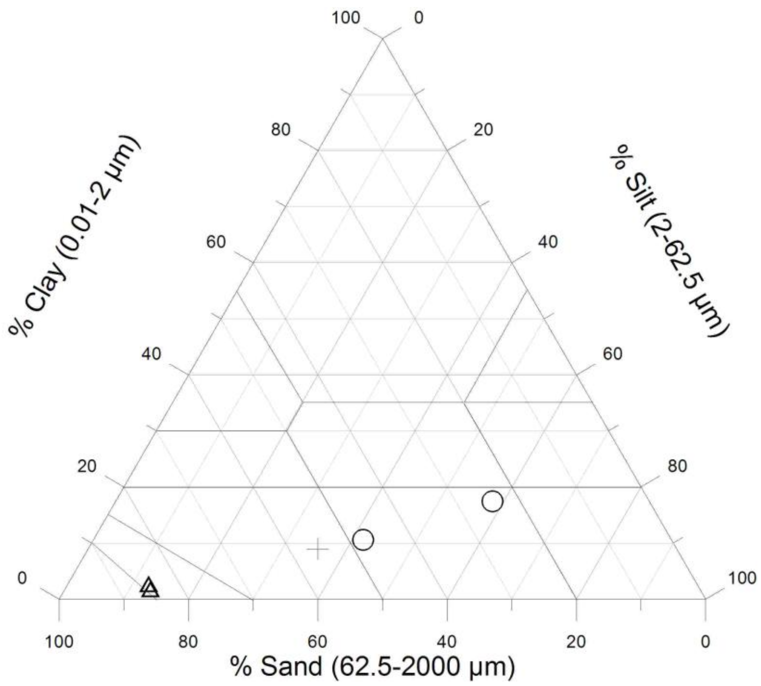


Figure 7.19: Particle size plot Minnie Water.

Particle size analysis results for cores taken at Minnie Water are largely consistent but do show some variations at similar depths (Figure 7.19; Appendix 2). Field texture determinations for the A horizon are constant, however, and all samples fall within the loamy sand category (Appendix 1). A horizon samples from the first two, westernmost cores (1MW and 2MW) contain 100% sand according to the results obtained from the Malvern Mastersizer whereas A horizon samples from cores 3MW and 4MW fall into the loamy sand category, in agreement with the field texture results. Organic content is steady between 3 and 4 percent (Appendix 2), with the exception of the sample from core 2MW, at 7.85%. A horizon sands at Minnie Water have a predominantly fine to medium grain size (125 – 500 µm); medium to very coarse grain size fractions are not easily eroded by flowing water (Lal & Elliott, 1994; Evans, 1980). The combination of grain size, field texture and organic content results indicates A horizon soils at Minnie Water will have high infiltration rates and retention of sediment.

Particle size results for the Minnie Water B horizon fall into the sandy silt loam category (Figure 7.19; Appendix 2). Field texture determinations are mixed (Appendix 1), and include sand (cores 1MW and 2MW), fine sandy clay loam (core 3MW) and sandy clay (core 4MW). The particle size results are more consistent due to the accuracy of the Malvern Mastersizer and the repetition of measurements. Organic content is reduced in this horizon, at 1 – 2%, with the exception of core sample 4MW25, which shows an increase to 6.08%. The presence of a greater proportion of silt-sized particles coupled with a general reduction in organic content in the B horizon indicates may have higher runoff rates and lower sediment retention than the A horizon.

C horizon soils from Minnie Water fall within the sandy loam category, according to the particle size analysis results (Figure 7.19; Appendix 2). Field texture determinations for the majority of cores indicate sediments in this horizon are sands (Appendix 1). Once again, the resolution of the particle size results is more accurate and thus appropriate for use in determining the potential erodibility of soils. Organic matter content is similar to the B horizon, steady at 1 – 2%, with a reduction in core sample 4MW25 to 4.03% (Appendix 2). A reduction in silt-sized particles within the C horizon may decrease the runoff rate and slightly increase sediment retention compared with the B horizon. Increased stability would be favourable as the midden is located within this horizon. Variation in particle sizes between sediment in different cores indicates a mixed origin of these sediments. Cores 3MW and 4MW were taken in close proximity to the rock outcrop at Rocky Point which is a likely source of parent material for sediments stratigraphically above the eastern half of the midden. The western half of the midden, represented in cores 1MW and 2MW, lies directly at the base of continuous beach foredunes which are uninterrupted by rocky headland outcrop.

Particle size analysis results of sediment sampled from in and around the Aboriginal shell midden site at Wooli indicate the presence of well-sorted sands (Appendix 2). All samples from A and B horizons are sands. C horizon samples were unobtainable due to the presence of a high watertable however, given the results of the overlying strata it is likely sediment ling directly below the sampled strata would also constitute well-sorted sand. Field texture results for the B horizon samples are consistent with the results of the particle size analysis (Appendix 2). The field texture of A horizon sands is similar (LS) but indicates the presence of some finer particles. Organic matter in the A horizon is variable (between 1 and 6 percent); it is more stable and slightly lower in the B horizon, with results of 0.38 – 1.22% (Appendix 2). As particle size composition and organic matter content are generally similar in the A and B horizons at the Wooli study site it is likely that infiltration and runoff rates will also be similar. Although the organic content is generally low, the presence of well-sorted sands indicates infiltration rates will be high and runoff rates low.

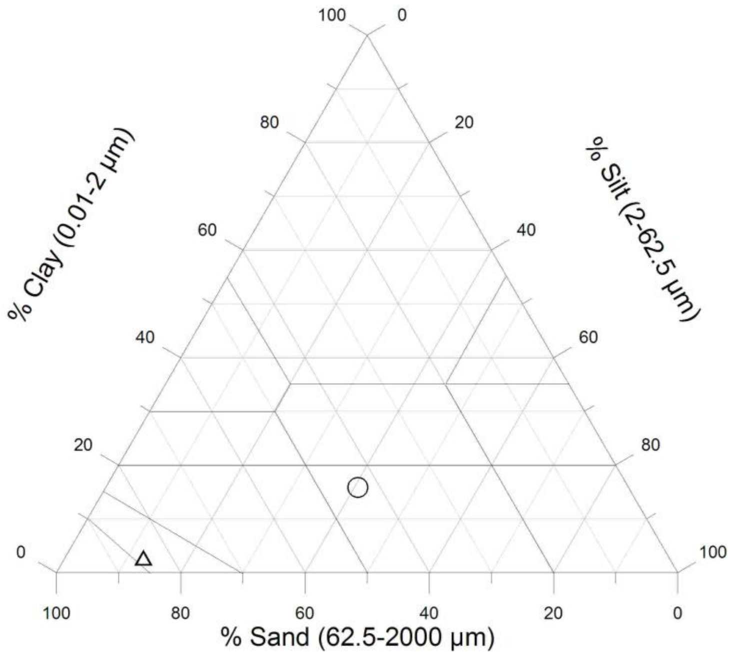


Figure 7.20: Particle size plot Plover Island.

Particle size analysis results for the A horizon soil at Plover Island are consistent with the field texture measurement taken in the field (Figure 7.20; Appendix 2). The majority of particles are sand sized, with some silt and few clay sized particles. Organic content is at the lower end of the moderate category, at 4.124%, according to the definitions used in this research study (Table 4.2; Appendix 1). Based on grain size, field texture and organic content the A horizon soil at Plover Island will have a high infiltration rate. The moderate organic content of the soil will likely reduce sediment retention. Soil characteristics of this stratum, including texture, organic content and Munsell colour, are similar to those of Minnie Water A horizon soils from cores 3MW0 and 4MW0. This link between the strata in a similar geomorphic setting and locality suggests similar bedrock composition along the coastline between Minnie Water and Plover Island. An increase in silt-sized particles within the B horizon at Plover Island (Figure 7.20; Appendix 2) will increase the runoff rate and decrease sediment retention. Reduced organic content will also contribute to decreased sediment retention.

The degree to which soils slake and disperse upon wetting is a key factor in the determination of soil stability (Bennett, Greene & Murphy, 2005). Stability of aggregates collected from A and B horizons (soil and subsoil) at Woombah sites A and B, Sleeper Island, Plover Island, Minnie Water and Wooli was determined by using the Emerson Aggregate Test (Emerson, 1967). This test can be relatively easily carried out with minimal laboratory equipment and with minimal training and is thus useful as part of a rapid, field-based erosion method (Chapter 4) as well as the more detailed approach undertaken in this research project.

Aggregate stability is the final component considered in the study of erodibility of soils in this research project. Soil texture (particle size composition) and organic matter content have been discussed above. It has been suggested that soils with higher clay and organic matter contents have more stable aggregates due to the strength of the bonds between their colloids (Greenland, 1965) and this is supported by Emerson's (1967) research into the characteristics of class 7 aggregates. He notes that organic matter appears to increase the strength of the bonds between the clay crystals in his experimental class 7 aggregates. He also mentions, however, that organic matter could cause aggregates which have been remoulded at field capacity (see Chapter 4) to disperse more readily, due to a reduction in the attractive forces between clay crystals caused by the presence of low molecular weight organic polymers.

A horizon soils at Woombah sites A and B are characterised by the presence of a relatively high amount of organic matter and, based on particle size analysis, high infiltration. Aggregate stability of the A horizon at Woombah site A falls into one of two Emerson Classes, and may be influenced by proximity to the riverbank (Appendix 2). The behaviour of aggregates from cores W1a-W3a places them in class 7 and they are characterised by swelling only and no slaking or dispersion. Aggregates from cores W4a and W5a fall into class 2, characterised by the presence of slaking and some dispersion. Cores W4a and W5a are located in closer proximity to the riverbank, while cores 1-3 were collected further away from the riverbank and closer to the first levee rise. Aggregate stability of B horizon soils at this site varies but there is a general decrease in class number, and thus, stability, with proximity to the riverbank. Reduced stability of the subsoil at Woombah site A may be the result of reduced organic matter but is likely due to a combination of factors also including subtle differences in field texture and previous land use practices. These findings have implications for riverbank stability not only pertaining to the destruction and loss of cultural material but also for suitability of land for sustaining agriculture.

Stability of the A horizon at Woombah site B is lower than at Woombah site A (Appendix 2), with aggregates falling into classes 3 or 2. These results show that differences in soil stability can occur laterally along a floodplain at relatively small scales, given that the sites are less than 1.0 km apart. The trend towards lower aggregate stability with increased proximity to the riverbank is not evident at Woombah site B, nor is the trend towards lower subsoil stability. Aggregate stability of the A and B horizons remains the same with the exception of aggregates taken from core W2b, in which the stability of the B horizon is lower than that of the A horizon (Appendix 2). Organic content differs between A and B horizons at Woombah site B in a similar way to Woombah site A but this appears to have little, if any, influence on soil stability at site B, given that aggregates from most soil/subsoil samples have a similar level of stability.

Emerson Aggregate Test results show A and B horizon soils at Sleeper Island have varying stability. Cores 2s and 3s, taken from the middle of the island, contained class 2 aggregates in both the A and B horizons (Appendix 2). Core 1s, taken at the south western corner of Sleeper Island in close proximity to the midden deposit, shows a change in aggregate stability from class 3 (A horizon) to class 2 (B horizon) and core 4s, taken at the opposite corner of the island, shows a similar trend, with a change from class 7 (A horizon) to class 2 (B horizon). There is a decrease in the organic matter content from the A to the B horizon in all core samples but soil aggregate stability appears to have remained unaffected in the central part of the island as a result of this, as well as a decrease in sand, and increase in silt, content. This may be a result of Island-wide local variation in erosion and/or alluvial deposition. Aggregate stability at the midden site is low (classes 3 and 2) and this is likely to be a contributing factor in the susceptibility of this site to erosion.

Due to the high sand content of the sediment at Minnie Water the majority of samples did not form aggregates and thus the Emerson Aggregate Test could not be performed. Two samples, however, did form aggregates and their stability was tested using the Emerson Aggregate Test. Samples from core sample 3MW0 (A horizon) were found to have an Emerson class number of 3. B horizon samples from core sample 3MW25 fall into Emerson class 2 (Appendix 2). Reduced aggregate stability of the subsoil may be due to a reduction in soil organic matter content. It is interesting to note that the subsoil has a significantly higher clay content than the A horizon

(Appendix 2) yet its aggregates are less stable. It is impossible to consider these results in the broader context of the site, however, as they are the only obtainable results. Similarly to Minnie Water, sediment collected at Wooli could not be tested for aggregate stability as it did not form aggregates.

Aggregates sampled from the A horizon soil on Plover Island fall into Emerson class 7 (Appendix 2). High soil aggregate stability coupled with a moderate organic content and grain size conducive to a high infiltration rate indicates this soil has a high resilience to erosion. B horizon aggregates are less stable, falling into Emerson class 2 (Appendix 2). Poor aggregate stability coupled with an increase in the proportion of silt-sized particles and decreased organic content indicates the erodibility of B horizon soil on Plover Island is significantly higher than the A horizon soil.

Three soil characteristics known to have an influence on soil erodibility have been determined for soil and subsoil samples from Aboriginal midden sites in the study area. These are field texture (particle size composition), organic content and aggregate stability. While strong trends in the relationships between these factors remain inconclusive, together they provide comprehensive information with which to assess the soil erodibility at multiple midden sites. Inferences pertaining to infiltration and runoff rates, field capacity and aggregate stability increase understanding of the susceptibility of soils to erosion.

7.5.3 **Causes of erosion on Sleeper Island**

Wave erosion is considered to be the primary geomorphic impact affecting the preservation of the Aboriginal shell midden site on Sleeper Island. Field observations indicate most of the cultural material has already been washed out of the *in situ* deposit and formed a lag deposit at its base. The banks of Sleeper Island are subject to daily tidal inundation (see Flooding and Tidal Inundation Hazard discussion) and bank erosion is evident around the entire island.

Anthropogenic modification of the flow regime of the Clarence River estuary (Table 7.1; Figures 7.1 A-H, 7.2, 7.3, 7.4 and 7.5) has altered the depositional environment, causing redistribution of sediment within the estuary. The construction of training walls off Freeburn Island (Middle Wall), Goodwood Island (Collis Wall) and the north bank at Iluka created a permanently open north channel (Howland and Lee, 2006). As a result of these works, sand shoals accreted on the southern side of Middle Wall, forming Dart and Hickey Islands, and permanently closing the south entrance by 1940. A greater volume of water flows through the main, deeper shipping channel north of Middle Wall (Howland and Lee, 2006).

Although Sleeper Island is located on the south side of Middle Wall in relatively close proximity to areas of sediment accumulation associated with the construction of river training walls both its east and west banks are bare and eroded, falling steeply into the adjacent channel. It is clear from examination of aerial photographs that the western side of Sleeper Island is situated on the outside of a channel meander (see Figures 3.1 A and B). Erosion along the west bank occurs opposite a large accumulation of sand adjacent to the mainland. This is also a feature of the eastern bank; areas of deposition occur opposite areas of erosion in the channel running between Sleeper and Freeburn Islands.

Although vegetation is present on the floodplain, grasses and shrubs/trees such as mangroves are absent around the island's banks. This leaves sediment exposed and vulnerable to erosion. Benefits of vegetation cover include physical soil binding by stems and roots and increased faunal and biological activity leading to improved soil structure (Stocking, 1994). Mangroves play an important role in sediment stabilisation (Krauss *et al.,* 2008; Riley & Kent, 1999). Mangroves are generally present along the banks of the creek that runs east through the island but are absent in the section of its banks where the Aboriginal midden is found. The determinants of mangrove distribution are varied and complex (Manson, Loneragan & Phinn, 2003) and need to be considered at the microtopographic scale, which refers to the topographic expression and composition of particular landforms (Thom, 1984). In a wave-dominated barrier lagoon (Thom, 1984) such as the Clarence River estuary these landforms are subject to varying degrees of tidal modification.

The distribution of mangroves on Sleeper Island and adjacent banks is most likely a function of the depositional environment and the elevation of natural seedling recruitment among species present. Mangrove communities develop best in sheltered depositional environments where a steady accretion of sediment leads to a gradual elevation of the sediment surface in relation to sea level (Hutchings & Saenger, 1987). Gradually elevated areas of deposition in tidal areas are exposed above the water for longer and when inundated by the tide they are covered with shallower water compared with areas adjacent to steep embankments. Field observations and evidence from aerial photographs support this idea, as they show the presence of mangroves on estuary island and mainland banks adjacent to sand bars. Perhaps the sand bars act to buffer banks from exposure to the full current associated with changing tides, creating a more favourable environment for mangrove growth.

Conversely, mangroves are absent from the banks of Sleeper Island, which lie opposite the areas of deposition mentioned above, and which fall steeply into the channel. Riley and Kent (1999) have shown that mangrove propagules need to establish at a particular elevation – the elevation of natural recruitment. The geomorphic process of erosion forms a steep embankment, thus removing the area of sediment corresponding with the elevation of natural seedling recruitment (Figure 7.21). The area suitable for mangrove growth has disappeared from the banks of Sleeper Island.

Exposed tree roots provide further field evidence of erosion. Some trees have become uprooted and have fallen into the channel due to extreme soil loss around their roots (Figure 7.22). Stocking and Murnaghan (2001) have developed a technique to assess soil loss in the field by measuring the difference between the mark of the original soil level on the tree trunk and the current soil level. This technique was developed for use by farmers on their farmland. It requires the age of the tree to be known and the tree must also be present *in situ* for reliable measurements to be made. Unfortunately the trees with exposed roots present on Sleeper Island do not meet these criteria.

Another factor likely to contribute to bank erosion at the Sleeper Island midden site is wash generated by motor boats not observing the speed limit, or by driving with outboard motors too close to the surface of the water to suit the speed at which they are travelling. As the midden is located on the edge of Sleeper Island in close proximity to a popular fishing spot it is highly susceptible to the actions of irresponsible boat skippers.

Wave height is also an important factor to consider when assessing bank erosion, and fetch is a key indicator of the potential hazard of this process. Given that both bank stability and wave height can be influenced by human activity, a human activity multiplier, taking into account these two factors, was used to gauge the impact of human activity at midden sites (Appendix 5). Whilst the resultant value is somewhat arbitrary, the same formula is used for all sites. Numerical values provide a semi-quantitative assessment measure for the factor of human activity as well as providing a relative scale of the importance of human activity as a destructive force across sites (see explanation in Chapter 4). The human activity multiplier gives a value of 6 at the Sleeper Island midden site (see Chapter 4 for an explanation of the calculation) and this is a relatively high value when compared with other study sites (Appendix 5). Sustained anthropogenic usage of the waterways of the Clarence River estuary around Sleeper Island, coupled with its influence on wave height and bank stability, increase the vulnerability of this site to erosion.

Examination of parish maps indicates special licenses for farming were issued between 1915 and 1958, and that the area was leased for dairy and agriculture between 1915 and 1925. It is important to note that these are minimum estimates, as maps are not available for all years. Although a cement bridge has been built between Sleeper and Palmers Islands and there was evidence of cattle grazing from the adjacent Palmers Island property on first inspection of Sleeper Island, this activity has since ceased upon request of the Yaegl Local Aboriginal Land Council. Sleeper Island is currently zoned 7(a) environmental protection (ecological significance) by the Clarence Valley Council.

The nature and amount of destruction of midden sites occurring within the study period can yield information on the relative importance of the disturbance processes and their corresponding factors presented in Appendix 5. On returning to the Sleeper Island midden site one year after field work was carried out it is estimated that less than 10% of the cultural material first observed remains at the site. The extent and rapidity of this degradation is somewhat alarming. Loss of material has occurred *in situ* as well as from the lag deposit. *In situ* material is more susceptible to removal through erosion caused by lack of vegetation cover and vulnerability to boating wash above the level of the average high tide. Occurring steadily and daily throughout the year, waves caused by boating wash inundate the *in situ* deposit more regularly that the tides (see Flooding and Tidal Inundation discussion), making boating wash a more influential factor in the degradation of the

Sleeper Island midden. Although Sleeper Island has a history of being farmed (Appendix 5), the island is not currently being used for dairying or agriculture.

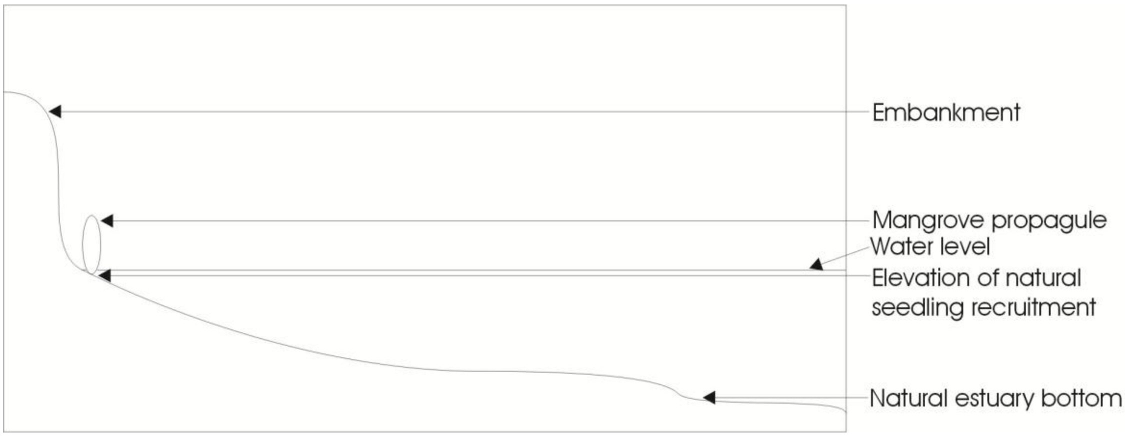


Figure 7.21: Elevation of natural seedling recruitment on an eroding river bank (modified after Riley and Kent 1999:208).

Figure 7.22: Tree root exposure around the bank of Sleeper Island.

7.5.4 **Causes of bank erosion at Woombah**

Inspection of the river bank in the vicinity of the Woombah site A midden reveals erosion. Shells from the river bank deposit have formed in a lag deposit at its base. Bank erosion is present but appears less severe than at Sleeper Island. This is likely due to a few factors. Firstly, there is a higher level of vegetation (mangrove) coverage at the Woombah site A riverbank deposit (Appendix 5). The slope of the bank at Woombah site A and Sleeper Island is the same (Appendix 5) so the presence of mangroves at Woombah site A appears to stabilise the deposit to some degree. Secondly, the situation of Woombah site A in the narrow channel of the North Arm of the Clarence River provides some protection against the erosional conditions characteristic of the outside of a river meander. Thirdly, although wave fetch is potentially longer at Woombah site A than at Sleeper Island human activity associated with boating has a lower frequency and thus, a lower impact, as expressed by the human activity multiplier result of 2. Sleeper Island is also exposed to southerly winds, increasing the potential for wave erosion at the site.

Field observations coupled with local knowledge indicate wash generated from the use of motor boats is likely to occur less frequently than tidal inundation at Woombah site A. The elevation of the site A deposit also indicates it is highly susceptible to flooding (see Flooding and Tidal Inundation discussion). Thus, of the erosive factors contributing to bank erosion at Woombah site A, flooding and tidal inundation appear to play a larger role than direct human activity although past human activity has contributed significantly to observed disturbance of the Woombah midden complex.

There is no indication of historic farming activity shown in parish maps, although these records are incomplete. Woombah site A and B middens are located on small blocks which are part of the village of Woombah, and which were subdivided prior to the construction of the 1912 parish map. Discussion with the current tenants revealed the properties where sites A and B are located, as well as Yargai Island (opposite) had been used in the past to grow citrus and apples. A fragmented subsurface shell layer found at Woombah site B is evidence of past use of farming equipment, although farming is not currently occurring at sites A or B. It is important to note, however, that the land at Woombah sites A and B is currently zoned 1(a) rural (agricultural protection) and 1(r) rural (residential) by the Clarence Valley Council.

Dense mangrove growth aids in stabilising what remains of the *in situ* material at the Woombah B creek bank site. As is the case at Woombah site A, a steep bank slope appears to be stabilised by the growth of mangroves, likely supported by lower salinity associated with drainage lines (Harty & Cheng, 2003) running into the creek from adjacent properties coupled with low energy conditions (Hutchings & Saenger, 1987). Previous faming activity has significantly reduced the extent of the *in situ* midden material (see 'Use of farming machinery and the Woombah site B Aboriginal midden deposit'). The vulnerability of this site to tidal inundation and flooding is low, and is discussed in detail in the section on flooding and tidal inundation hazard.

Table 7.7: Hazard outcomes and factors contributing to erosion at the study sites.

SITE	GEOMORPHIC SETTING	HAZARD OUTCOMES:			DIFFERENCE IN FACTORS CONTRIBUTING TO EROSION
		RAPID ASSESSMENT	DETAILED ASSESSMENT	GIS ASSESSMENT	
WA	Riverbank	2	Moderate	1.86	Slope of bank: high, vegetation cover: moderate, land use zoning: rural (agricultural protection).
WL	Riverbank	0.3	Minor	1.5	Slope of bank: low, vegetation cover: high, land use zoning: open space.
WB	Tidal channel	1.75	Minor	1.57	Vegetation cover: high.
SI	Tidal channel	2.75	Major	2.14	Vegetation cover: low.
MW	Coastal - foredune	2.75	Major	2	Exposure to ocean swell: high.
PI	Coastal - rocky outcrop	0.67	Moderate	1.57	Exposure to ocean swell: low.

7.5.5 **Use of farming machinery and the Woombah site B Aboriginal midden deposit**

While erosion hazard at the Woombah site B Aboriginal shell midden is currently considered low (Table 7.7; Appendix 5) past use of farming machinery at the site has disturbed up to 95% of the deposit (Appendix 5, Chapter 4 for a discussion of the calculations used to determine this percentage). Were farming of crops to resume in the area, however, it is likely the hazard to the remaining *in situ* material would not significantly increase as it is present in and around a well-vegetated creek bank and crops would most likely not be sowed in this location. The creek's banks are steep and the water flow intermittent so it is unlikely livestock would be attracted to, or allowed to graze in, the area.

7.5.6 **Erosion rates at Woombah and Sleeper Island**

Given that erosion has been identified as a key geomorphological process affecting the preservation of the Sleeper Island and Woombah site A Aboriginal midden deposits, determining erosion rates at the two sites allows for quantification of this hazard. As both sites are currently eroding the risk is real and immediate. Measurements were taken from historic parish maps, recent topographic maps and aerial photographs to determine whether or not the width of relevant channels has changed over the last century (see Chapter 4 for a full discussion of this process).

Parish maps which include Sleeper Island are available for the years 1914, 1915, 1919, 1923, 1926, 1933, 1936, 1943, 1954, 1958, 1961 and 1967. These include the parishes of Harwood, Taloumbi and Yamba. All these maps post-date the channel works undertaken as part of Moriarty's and Coode's Schemes so pre-modification measurements were not available for this study. The research does not require comparison of erosion rates over time (ie. pre- and post-channel modification), but focuses on contemporary rates to build an understanding of the immediate risk to the midden site on Sleeper Island.

With the exception of three maps (Taloumbi 1933 and Yamba 1914 and 1926) all channel width measurements taken from the east and south sides of Sleeper Island are in agreement. The Yamba maps do not show Sleeper and Freeburn Islands in detail, rather simply as outlines, so the reliability of these measurements may be questionable. That leaves one measurement – Taloumbi 1933 – as anomalous. This measurement of the channel between Sleeper and Freeburn Islands is

202 m narrower than the measurements for other years, including a measurement dated only 3 years later (Harwood parish map 1936). The measurement for the south side of Sleeper Island taken from Taloumbi 1933 is also anomalous. It shows the channel between the south side of Sleeper Island and the mainland to be 100 m narrower than measurements taken from all other maps including the Harwood 1936 parish map. As all other channel measurements are in agreement it may be concluded that channel width between Sleeper and Freeburn Islands and between Sleeper Island and the mainland remained relatively constant between 1915 and 1967. As all these channel measurements are the same this would indicate that bank erosion is too difficult to identify using historic maps of this resolution.

Channel measurements obtained from recent topographic maps (1986) and aerial photographs (2005) differ from the data obtained from the parish maps. Firstly, they show the channel between Sleeper and Freeburn Islands to be narrower than the parish maps. Examination of aerial photographs (Figures 3.1 A and B) suggests this may be a result of deposition on the Freeburn Island side. This island has become larger as a result of channel modifications; sedimentation has occurred south of Middle Wall as flows are directed through the northern channel (Howland and Lee, 2006). Based on the difference between the 1967 and 1986 channel measurements a minimum rate of deposition of 12 m/yr was calculated. This is a minimum rate as no channel measurements were able to be taken between these years. This rate is rather excessive and likely not a true indication of sedimentation/erosion rates at this location. It is only based on two measurements from differing sources. The erosion rate was calculated to be zero based on measurements made from parish maps alone from 1915 to 1967. Similarly, channel measurements obtained from recent topographic maps and aerial photographs show the channel width has not changed from 1986 to 2005, indicating bank erosion is too difficult to identify at that resolution.

Secondly, these measurements indicate the channel between Sleeper Island's south side and the mainland has increased, with a minimum erosion rate of 5.2 m/yr between 1986 and 2005. Although slower than the rate of deposition calculated above, this value is still considered unreasonable for the same reasons as given above. Maps from different sources and years may represent high or low water levels and this may account for some of the variation observed, however rates do still seem excessive when calculated using this method.

Thirdly, channel measurements from the recent sources quoted above indicate the width of the Clarence River's North Arm at Woombah site A to have decreased when compared with measurements taken from parish maps. A rate of deposition of 3.9 m/yr, again based on the difference between the 1967 and 1986 measurements, was calculated. Both the banks of the North Arm at this location (Woombah and, opposite, Yargai Island) appear denuded and major sedimentation has not been observed in the field or from examination of aerial photographs (Figures 3.9 A and B).

Research has not uncovered any event occurring only between 1967 and 1986 which may have caused channel change at this time. The north and south external breakwaters were built between 1950 and 1971 and other training walls were already in place by that time (Howland and Lee, 2006, European channel modifications section). According to data obtained from Palmer's Channel and Maclean flood gauges flooding does not appear to have been more frequent between 1967 and 1986, although a flood with an ARI greater than 1 in 20 years was recorded at both gauges during this time (1967, Appendix 4). Another flood with an ARI greater than 1 in 20 years was also recorded at the Maclean gauge in 1974 (Appendix 4). The difference in channel width measurements between the historic parish map data and the recent data may be an issue of scale as the parish map data are in general agreement, as are the other, recent data.

7.5.7 **Causes of erosion on Plover Island**

Plover Island is located on the north side of the mouth of the Sandon River, 26 km south of Yamba, and is connected to the mainland by a permanently dry sand spit. The *in situ* stone artifacts and those forming surface scatters on the island are present at elevations of ~7.5 m and ~10 m respectively, so are not under direct threat from normal ocean swells. Cliffing, another field indicator of wave erosion, is absent at artifact elevations on Plover Island. Evidence of storm activity, such as pumice, gravel, foreign cobbles, broken shells and other debris is not present on Plover Island at the aforementioned elevations, so storm surges do not appear to be threatening the deposits either. Plover Island is zoned 7(c) environmental protection (coastal foreshore) by the Clarence Valley Council.

While the archaeological deposits on Plover Island are not susceptible to wave erosion, deflation of stone artifacts suggests wind may be a factor causing erosion. The closest locations for which wind rose data are available are Brisbane, to the north, and Coffs Harbour, to the south. Data from these two locations, whilst not local, was used to understand general regional trends in wind direction (Appendix 5). Regional wind rose data are supported by field observations pertaining to the appearance of vegetation on and around the island, and also by the orientation of adjacent mobile sand dunes. Data and field observations suggest morning southwesterly prevailing winds and afternoon northeasterly prevailing winds. As the surface stone artifact scatter is located on the top of Plover Island it is exposed to both morning and afternoon prevailing winds. The *in situ* deposit is located on the western side of the island and is only exposed to morning southwesterly winds.

Vegetation cover varies across the island. Grass cover over the surface scatter is high at 80% (Appendix 5) and is only absent along walking tracks, as discussed below. Tree and shrub cover is absent along the eastern (seaward) side of the Plover Island where the surface scatter is located.

This may be due to the strength of the prevailing winds, as soil depth is constant over the island. Grass appears to be stabilising areas of the surface scatter where it is present however areas where grass is absent appear to be eroding. Therefore, vegetation cover appears to be an important factor in the prevention of erosion of the artifact surface scatter on Plover Island. Grass cover is absent and tree and shrub cover minimal (10%) at the *in situ* stone artifact exposure on the western side of the Plover Island. The slope of the exposure is steep at 90°and exposed tree roots are also present here, providing further field evidence of erosion. As is the case on Sleeper Island, the ages of trees on Plover Island are not known with certainty, so the erosion field assessment technique of Stocking and Murnaghan (2001) cannot be performed.

Well-worn walking tracks and a path worn from climbers wishing to reach the top of the island are causing erosion and degrading the deposits. The walking tracks on the top of the island have been made through the surface scatter of stone artifacts, where the undisturbed parts of the deposit are covered in thick grass, offering protection from wind erosion. The *in situ* stone artifact deposit is present at the most popular location where people climb to the top of the island and, as a consequence, little *in situ* material remains here. As the *in situ* stone artifact deposit is less exposed to prevailing winds, human activity appears to be a more important factor in the degradation of this site. Constant exposure to winds from all directions increases the vulnerability of the surface stone artifact scatter to wind erosion. If this deposit can be kept vegetated and free of walking trails destruction due to wind erosion will be reduced. Using the standardised method for this study (see Chapter 4) a human activity multiplier of 2 has been calculated for the Plover Island stone quarry location, taking into account the predominantly seasonal human activity and the number of erosive factors it affects. With proper management of walking tracks the unvegetated areas of the stone artifact surface scatter have a good chance to become revegetated. Diverting the walking tracks would not only increase vegetation cover over the deposit but also reduce the human activity factor.

As very little cultural material remains in the *in situ* stone artifact deposit on Plover Island minimal erosive force would be required to remove it from its location. The Yaegl Aboriginal community may wish to relocate this material to the site of the more stable surface scatter.

7.5.8 **Causes of erosion at Minnie Water**

The disturbance processes identified as contributing to erosion at the Minnie Water Aboriginal shell midden site are presented in Appendix 5. The foredunes at Rocky Point are highly exposed and vulnerable to the impacts of wind and wave erosion. Very low levels of woody and non-woody vegetation cover contribute to low deposit stability and indicate maximum vulnerability to sediment loss, according to Stocking's (1994) erosion cover relationship graph (Figure 7.23). Also, the deposit faces south, exposing it to morning south and southwesterly prevailing winds and afternoon south, southeasterly and easterly prevailing winds. Examination of regional wind roses and field evidence such as alignment of dunes, dune blowouts and the shape and stature of local trees indicates winds from these directions constitute the majority of winds at the site.

A human activity multiplier of 2 has been calculated for the site (Appendix 5). Minnie Water has only a small community of permanent residents and tourism is mostly seasonal, largely following the pattern of the New South Wales and Queensland school holidays. Activity on and around the dunes such as four wheel driving, which is permitted on local beaches but not on the dunes, and bush/beach walking can affect the stability of the deposit by destroying vegetation and moving sediment in unvegetated areas. Rocky Point is zoned 8(a) (National Parks and Nature Reserves) by the Clarence Valley Council, reflecting its location in the Yuraygir National Park. This offers the deposit some protection against erosive factors such as excavation, however the deposit is still vulnerable other anthropogenic and non-anthropogenic factors as discussed here.

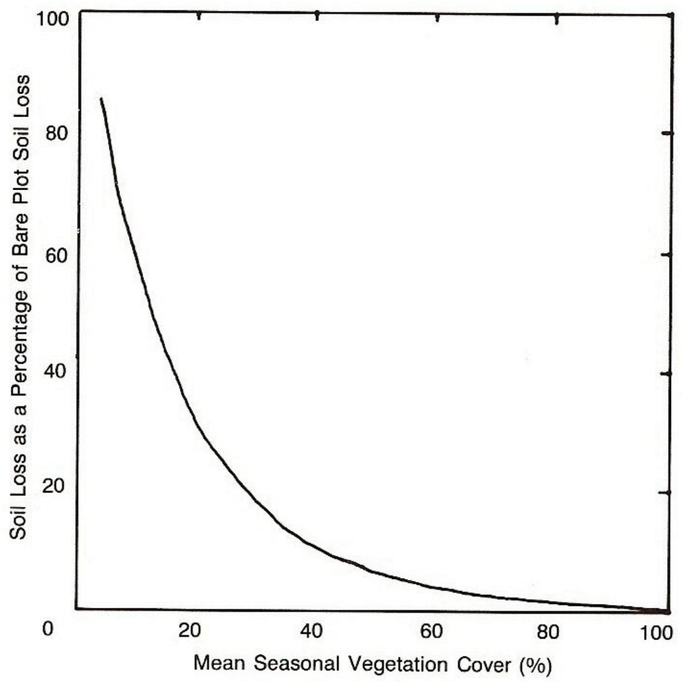


Figure 7.23: Erosion-vegetation cover relationship. Source: Stocking, 1994.

Ocean swell is the driving force behind wave erosion. The relatively low elevation of the deposit, coupled with its close proximity to the ocean, contribute to its vulnerability to wave erosion. Cliffing, another key indicator of wave erosion, is present around the Rocky Point headland adjacent to the midden deposit. There is evidence the midden deposit has been reworked (Chapter 6) and this is the clearest indication of its vulnerability to wave erosion. Other field indicators of erosion – tree root exposure and soil pedestals – are also present at the site (Figures 7.22, 7.24 and 7.25). The rapid field-based and detailed scientific assessments classify the erosion hazard at Minnie Water Aboriginal shell midden as major. Processes of wind and wave erosion have already affected the site and its position in the landscape continues to influence its susceptibility to erosion.

Figure 7.24: Soil pedestal at the Minnie Water Aboriginal shell midden site.

Figure 7.25: Tree root exposure at the Minnie Water Aboriginal shell midden site.

7.5.9 **Wooli**

The Aboriginal shell midden at Wooli is the only study site which appears to be unaffected by erosion. This is likely due to a combination of factors which, once their roles are adequately understood, may aid in preservation efforts at other Aboriginal shell midden sites in similar geomorphic contexts. The midden deposit at this location was buried under a 25 cm thick layer of soil. Prior to study it was not registered on the AHIMS database and it was local knowledge, coupled with minimal shell material which had been brought to the surface by burrowing animals, which initially led the researcher to the site.

Burial in a low-energy depositional environment adjacent to the east bank of the Wooli River offers significant protection to this shell midden site. Gently sloping well vegetated banks are also a feature of the site. This contrasts greatly with the steeply sloping denuded banks of Sleeper Island in the Clarence River estuary. The distribution of mangroves at Wooli is most likely a function of the depositional environment and the elevation of natural seedling recruitment among species present. As discussed earlier, mangrove communities develop best in sheltered depositional environments where a steady accretion of sediment leads to a gradual elevation of the sediment surface in relation to sea level (Hutchings & Saenger, 1987). The resultant gently sloping surface provides an area of sediment corresponding with the elevation of natural seedling recruitment (Riley and Kent 1999; Figure 7.21), thus encouraging mangrove growth.

As the midden deposit lies under the perimeter of a public park, zoned 6(a) (open space) by the Clarence Valley Council, the past, present and future impact of human activity was considered (Appendix 5). Parish maps from 1898 - 1955 indicate this land was for lease, generally noted for public recreation. There was no evidence of farming activity or development during this time. The Parish maps also show the Parish of Wooli Wooli was declared a bird and animal sanctuary

05/07/1940. The deposit is currently buried under a well-vegetated piece of land which protects it from any permitted leisure activities at a public park. After consultation with the Yaegl Local Aboriginal Land Council a proposed walkway running parallel to the riverbank will now be elevated in order to preserve the site.

Bioturbation has been identified as the only process currently causing erosion at the site. Burrows ~22 cm deep and ranging in diameter from 5-12 cm are present along the western perimeter of the deposit (Figure 3.30) and information obtained from several employees of the Clarence Valley Council suggests the smaller burrows may have been made by magpies and the larger ones by bandicoots for feeding. Bioturbation appears to have caused some size sorting of the shell material in the vicinity of the burrows. The majority of the material which has been brought to the surface is small and fragmented, with only a few small whole *Anadara* valves present. Examination of the burrows shows the larger shell fragments and whole valves and shells remaining *in situ*. Whilst the process of bioturbation is easily recognisable at the site the current *in situ* material estimate remains very high at 99.98%; the integrity of the deposit is not currently being compromised by this process. Regular monitoring of the damage caused by this process is recommended to ensure it can be promptly rectified if necessary.

7.5.10 **Conclusion – causes of erosion at the study sites**

Visual inspection of the Aboriginal midden sites at Sleeper Island, Woombah riverbank and Minnie Water confirms they are vulnerable to erosion. Although attempts to quantify this hazard for Sleeper Island and Woombah riverbank site A by calculating erosion rates have proven inconclusive the erosion hazard ranking systems developed as a part of this study (Table 7.7; Appendix 5) provide a semi-quantitative assessment of erosion hazard at Aboriginal shell midden sites. Using the same hazard ranking scale to assess all study sites allows for prioritisation of conservation efforts. Despite a large amount of shell material having already weathered out of the Woombah riverbank midden there is more present *in situ* than at Sleeper Island. Taking into consideration the factors discussed above as likely causes of bank erosion, erosion hazard at this site is considered only moderate when compared with the extreme situation on Sleeper Island. Similarly to Sleeper Island, erosion hazard at the Minnie Water Aboriginal shell midden site is considered as major, although it is caused by different factors given its different geomorphic setting.

Plover Island is also considered to be at moderate risk. While walking tracks have definitely disturbed the deposits, the north side of Sandon Point appears to see less tourist patronage than the south side and other nearby towns such as Broom's Head, as access is via a 10 km unsealed road and there is only a small camping ground at which to stay. Of those observed fishing, many walked around the base of the island rather than over and around the top. Erosion hazard at the Wooli Aboriginal shell midden site is extremely minimal. Comparison of this site with other sites in a similar geomorphic context which are affected by erosion will aid in conservation efforts, as factors in need of remediation will be identified.

It is worth noting that when calculating erosion hazard each Aboriginal midden site is considered of equal cultural value. As certain sites which are more complete, larger or contain artifacts are considered potentially more valuable to the archaeological and scientific communities, Aboriginal communities have their own methods of assessing significance which may differ from scientific and archaeological perspectives. One of the aims of this study is to provide the Aboriginal community with hazard assessments for sites located in specific environments. It is then their responsibility to act on that knowledge as they see fit.

7.5.11 **Validation of the erosion hazard assessment models**

7.5.11.1 *Results of the field trial – validation of the rapid field assessment methodology*

Field trials were conducted in order to validate the usefulness of the rapid field assessment methodology for the assessment of erosion hazard at Aboriginal shell midden sites (see Formulation of an Erosion Hazard Methodology in Chapter 4; Figures 7.26 and 7.27). Close agreement of results obtained by the different groups participating in the trial would indicate the strength of the methodology. Results of the field trials are presented in Appendix 5.

There is a high degree of agreement between the researcher's assessments and those obtained in the field trial. As the scores for each component are almost always uniform the Erosion Hazard Index for each site is also consistent. If there is an inconsistency the score of only one component varies. This variation is minimal and does not exceed one category. For example, the scores for the vegetation and field forms component vary at Woombah site A (WA), but not by more than one. One group gave a score of 2, corresponding to moderate erosion based on these characteristics, while the others, including the researcher, gave a score of 1, corresponding to slight erosion. Scores for the vegetation and field forms component also vary at Woombah site B (WB) but, as at site WA, by no more than one. This slight variation, however, does not adversely influence the Erosion Hazard Index. Ordering of sites from most to least severe erosion hazard is consistent across all groups of results. In addition, the erosion hazard indices for each site all fall into the same recommendations for maintenance and conservation categories (Appendix 5).

Feedback from Yaegl community representatives, archaeologists and environmental scientists involved in the field trials was positive. Whilst minor changes were made to the Pro Forma and accompanying Handbook to ensure ease of interpretation, the methodology was well-received. Of particular interest to the Yaegl community are the recommendations for maintenance and conservation of Aboriginal shell midden sites (Appendix 5). This highlights the importance of grassroots community involvement in management of Aboriginal cultural resources. The consistency of results and positive stakeholder feedback across field trial groups shows the Erosion Hazard Pro Forma and accompanying scoring system and maintenance and conservation recommendations are a robust tool for the management of Aboriginal shell middens in northern New South Wales, Australia.

Figure 7.26: Field trial of the Erosion Hazard Pro Forma system at the Minnie Water Aboriginal shell midden site.

Figure 7.27: Field trial of the Erosion Hazard Pro Forma system at the Sleeper Island Aboriginal shell midden site.

7.5.11.2 *Comparison of results obtained using the rapid field-based erosion hazard assessment and the comprehensive methodology presented in Chapter 4 and Appendix 5*

Results obtained using methods one and two outlined in Chapter 4 have been summarised to facilitate a comparison of these methods (see Appendix 5 for detailed results). Study sites presented in Table 7.7 have been grouped according to their geomorphic setting and results can be compared in several ways. The first involves examining the degree of agreement between results obtained using the different methods. Although one method involves a scoring system and the other does not, comparison of results is still possible, as many of the data collection categories are similar. Sites yielding the highest erosion hazard score based on the rapid, field-based assessment method are also considered a major erosion hazard when assessed using the detailed erosion hazard methodology (SI and MW). There is also strong agreement between results obtained for study site WL, which shows only very minor susceptibility to erosion. Rapid assessment scores for sites WA and PI place them in the middle of the erosion hazard spectrum for sites studied. This corresponds with the moderate erosion hazard assessment indicated by the comprehensive methodology. Greater data resolution is a feature of the comprehensive methodology for scientists and archaeologists and this may explain the difference in results obtained for site WB. Nevertheless, as the rapid, field-based assessment is designed for use as a precursor to the more detailed methodology, this, and future, discrepancies are likely to be resolved after the further scientific analyses comprising the second erosion hazard assessment are carried out.

Prioritisation of sites in need of conservation based on the level of erosion hazard provides another means by which results obtained using the two methods can be compared and aligned. When ordered from highest to lowest erosion hazard according to the rapid, field-based assessment methodology the sites at Sleeper Island and Minnie Water are placed ahead of Woombah site A, Woombah site B, Plover Island and Wooli. When prioritised according to results obtained using the comprehensive methodology for scientists and archaeologists the sites at Sleeper Island and Minnie Water are placed ahead of Woombah site A and Plover Island, with Woombah site B and Wooli being considered low-risk. The discrepancy between results obtained for Woombah site B is still evident when results are interpreted in this way.

As well as allowing comparison of methodologies, the results also show the similarities and differences in factors contributing to erosion of Aboriginal shell midden sites in similar geomorphic contexts and this information can be used as an aid in midden conservation. The far right column of Table 7.7 shows this information. When comparing Woombah site A and Wooli, showing moderate and minor erosion hazard respectively, it can be seen that slope, vegetation cover and land use zoning are quantifiable factors which differ between the two sites. Vegetation cover is the main quantifiable factor which differs between Sleeper Island, with a high erosion hazard, and Woombah site B, with a low erosion hazard. The Aboriginal shell midden site at Minnie Water has a high exposure to ocean swell and erosion hazard at this site is also high. The artifact deposits on Plover Island, however, have a very low exposure to ocean swell and erosion hazard is reduced at this site. Investigation of the causes of these differences and possible ways to remediate them is a key process in midden conservation.

7.5.11.3 *Comparison of results obtained using the rapid field-based erosion hazard assessment and the GIS model*

Comparison of results obtained using the rapid field-based erosion hazard assessment method and the GIS model is presented here in order to validate the methods. Obtaining the same results using two different methodologies indicates they are both sound models of erosion hazard in the study area and highlights their potential for use further afield. Table 7.7 shows the erosion hazard scores obtained using the two methods.

Using both the methodologies, sites are ranked in the same order from highest to lowest erosion hazard. The scores themselves are different but this is purely a reflection of the different structure of the models and clearly does not affect the outcome. Both models are multi-layered, taking into account the variety of factors contributing to erosion at shell midden sites in different geomorphic contexts however the ways of identifying these factors and collecting data differ between them, as each model is targeted towards a different stakeholder group.

Comparison of results obtained using both methods shows the reliability of simple field data collection techniques, such as soil field texture, Emerson Aggregate Test (Emerson, 1967), quadrat mapping of vegetation coverage and presence/absence of field indicators of erosion such as soil pedestals, exposed tree roots and rills, in accurately indicating erosion hazard at a site. The more complex, technically derived layers and scoring system of the GIS model complement the field data and strengthen its validity. The main advantage of the rapid field-based erosion hazard assessment method is that simple, reliable data can be collected in the field in a timely manner with minimal impact on the landscape. Similarly, data collection for the GIS model has minimal impact on the landscape. The soils layers (dominant texture, total organic content and Emerson Aggregate Number) are the only layers which require data collected in the field. Data for all other layers is available in, or can be formulated from, existing digital data.

7.5.12 **Conclusions – studying the causes of erosion**

This chapter presents research findings based on a holistic study of the causes of erosion at the study sites. Consideration of the impact of anthropogenic channel modifications, past, present and future sea levels, flooding, cultivation, excavation, vegetation coverage, soil properties and the action of wind and waves on the geomorphology of the study area has facilitated formulation of three erosion hazard models.

Erosion at the study sites is caused by the interaction of a number of factors. The erosion hazard models illustrate the role played by each of these factors and their interactions. It is particularly important to tailor erosion hazard assessment methods for different stakeholder groups. The methods presented in this thesis have been formulated for use by archaeologists, environmental scientists and Local Area Land Councils. Each method assesses a similar set of factors in a way which is easiest to interpret by the different stakeholder groups. Facilitation of discourse between these stakeholder groups is an important step in Aboriginal cultural heritage management.

The numerical ranking of sites allows for prioritisation of conservation efforts and also highlights the relative importance of factors contributing to erosion at a particular location or site type. It also allows formulation of more relevant site-specific conservation recommendations to be undertaken with greater confidence. It is these recommendations which are most important to Indigenous community groups as they form the guidelines by which they are able to more effectively manage their cultural heritage. The following chapter outlines the recommended actions for conservation of the study sites.

8. RECOMMENDED ACTIONS FOR CONSERVATION OF THE STUDY SITES

A key outcome of the study of the role of erosion in the degradation of Aboriginal shell middens on the north coast of New South Wales is the formulation of site-specific conservation recommendations (Table 1.8). These were developed within the framework of the general guidelines incorporated in the Handbook for Use with the Erosion Hazard Pro Forma (Appendix 3). Ultimately it is up to the Aboriginal community to decide whether or not to proceed with these recommendations.

Scientific and archaeological judgment of the importance of a site can differ from its cultural importance to the Indigenous community. From a scientific and archaeological perspective the contents of the midden on Sleeper Island appear far too greatly diminished to warrant the extensive monitoring and conservation work required at the site. Bank erosion is currently occurring so rapidly that total loss of cultural material will occur within a relatively short amount of time. The cultural significance of this site, however, does not disappear with the loss of its cultural remains (Ferlin Laurie, personal communication). Rehabilitation of the area, therefore, may still be seen as desirable by the local Aboriginal community.

Likewise, the reworked midden site at Minnie Water appears to be of little scientific and archaeological value. The highly disturbed nature of this deposit makes it very difficult to gain valid information on its original condition such as species composition, timing and duration of occupation and resource utilisation. Culturally, however, this site is still of importance and the recommended dune stabilisation measures will benefit the local environment in addition to preserving a culturally significant site.

Much of the cultural material at Woombah Site B has been reworked and destroyed by farming equipment but the small portion which remains *in situ* in the creek bank has been acknowledged as an important part of the Aboriginal cultural history of the area and DECCW signage at the site explains the deposit's place as part of the much larger Woombah midden complex, much of which has been reworked or destroyed due to farming and construction of roads and houses. As it is likely Woombah Site A is also part of this midden complex, conservation recommendations have also been included for it. This is a smaller deposit, however it is much more intact. Stabilisation of the riverbank at this location will not only help to conserve this cultural resource, it will also remediate degradation caused by farming.

In many ways the midden deposit at Wooli holds the key to sustainable conservation and management of riverbank middens in the study area and, indeed, further afield. By studying why this deposit is at such low risk of erosion we can better understand how to remediate and conserve other sites in similar environments, as well as identify locations where other cultural deposits may remain intact and undiscovered. A combination of low bank slope, low energy, depositional conditions and high vegetation coverage afford this site the requisite protection from erosion. Replication of a selection of these parameters at other more vulnerable sites may prove useful in their conservation and management. The following chapter illustrates the broader applications of the erosion hazard assessment methodologies developed in this study using national and international examples.

Table 8.1: Conservation recommendations for the study sites.

SITE	MAJOR FACTORS CONTRIBUTING TO EROSION	CONSERVATION RECOMMENDATIONS
WA	Slope of bank, vegetation coverage and land use	Increase vegetation coverage by encouraging the growth of native and/or habitat-specific vegetation such as mangroves. Closely monitor the effects of farming, for example crop planting too close to the riverbank, erosion due to livestock, change of farming type. Retaining walls may be used to prevent loss o further sediment if increasing vegetation coverage is not successful or only partially successful.
WL	N/A	Currently low risk. Monitor site to ensure conditions remain the same.
WB	N/A	Currently low risk. Monitor vegetation coverage to ensure it remains consistent.
SI	Vegetation coverage	Increase vegetation coverage by encouraging the growth of native and/or habitat-specific vegetation such as mangroves.
MW	High exposure to ocean swell	Encourage vegetation growth at the base of the foredunes to protect against wind and wave erosion. This will also guard against erosion due to runoff.
PI	Human activity	Designate a walking track around the artefact scatter, rather than through it. This will encourage vegetation growth over exposed areas of the scatter, helping prevent loss of soil due to wind erosion and human activity.

9. CONCLUSIONS

9.1 BROADER APPLICATIONS OF THE METHODOLOGIES DEVELOPED IN THIS RESEARCH PROJECT

9.1.1 **Introduction**

The methodologies developed in this research project address a deficit in archaeological and geomorphological studies, as well as Aboriginal cultural resource management at the grassroots level. Although the focus of research and cultural heritage management is expanding towards a multidisciplinary approach (Constante, Pena-Monne and Munoz, 2010; Rabett *et al.,* 2010; State of the Environment Report, Tasmania, 2009; Cremeens and Lothrop, 2009; Erlandson, Rick and Peterson, 2005; Butzer, 2004; Morhange *et al.,* 2003; Erlandson and Moss, 1999; Deacon, 1996; Van Nest, 1993; Gilbertson, 1981) the role of environmental factors, such as erosion, in causing site degradation need to be more comprehensively understood. This will allow for more adequate and site-specific management of Aboriginal cultural sites.

Many documents exist which contain guidelines regarding the treatment of Aboriginal cultural sites (for example, Queensland Government Conservation Management Profile website; Victorian National Parks and Wildlife Service Wilson's Promontory National Park Aboriginal Cultural Heritage Management Plan; State of the Environment Report, Tasmania, 2009; Erlandson, Rick and Peterson, 2005; Erlandson and Moss, 1999; Deacon, 1996; Gilbertson, 1981), and these sites are protected by law (Aboriginal and Torres Strait Islander Heritage Protection Act 1984 and relevant State legislation) but few of these documents address the methods required for assessment, reporting and management of soil erosion at the grassroots level and higher. A process-based approach to Aboriginal cultural heritage management requires a shift in archaeological research priorities. It also requires greater Aboriginal community involvement in identifying culturally significant sites, in addition to archaeologically significant sites from which we can deduce information regarding past cultural and environmental conditions.

In many archaeological studies information on site and regional geomorphology is used to track changes in human behaviour and adaptation to their environment over time (Pollard, 2009; Bar-Yosef Mayer and Beyin, 2008; Compton and Franceschini, 2004; Barham, 1999; Deacon, 1996; Erlandson *et al.,* 1996; Miller *et al.,* 1995; Lasiak, 1991; Avery and Underhill, 1986). Recognition by archaeologists that coastal and estuarine environments are dynamic is an important first step in cultural resource management. However, in addition to using geomorphological techniques to reconstruct past environments they must also study current impacts to ensure adequate and appropriate management guidelines are in place.

Gaining as much information as possible from threatened sites is only the beginning. Effort must also be made to preserve these sites as best as possible by applying site-specific and regional information on landscape change. Focussing on shell midden sites the following review will highlight the importance of studying erosional processes at these sites and show that geomorphological information gathered from existing studies can be applied to the methodologies developed in the current research project.

9.1.2 **International examples**

Worldwide, studies of shell middens in coastal, estuarine and alluvial environments have contributed valuable information to the fields of archaeological and geomorphological research (for example, Constante, Pena-Monne and Munoz, 2010; Garcia-Ruiz, 2010; Rabett *et al.,* 2010; Cremeens and Lothrop, 2009; Pollard, 2009; Bar-Yosef Mayer and Beyin, 2008; Casana, 2008; Erlandson, Rick and Peterson, 2005; Butzer, 2004; Compton and Franceschini, 2004; Morhange *et al.,* 2003; Blintiff, 2002; Erlandson and Moss, 1999; Deacon, 1996; Erlandson *et al.,* 1996; Miller *et al.,* 1995; Van Nest, 1993; Katupotha and Wijayananda, 1989). Although much of this information has been collected for other purposes the following sites have the potential to be re-examined using the methodologies developed in the current research project.

Dune middens along the Southwest Cape of South Africa have been studied for a number of purposes. Archaeological studies aim to understand how shellfishing behaviour has changed over time in response to a changing coastline (Tonner, 2005; Compton and Franceschini, 2004; Miller *et al.,* 1995; Avery and Underhill, 1986). Geomorphic information has been used to develop a chronostratigraphy in order to place cultural midden sites within a regional lithostratigraphic framework (Butzer, 2004). One study touches on management of these middens through the National Monuments Act and acknowledges the need for site-specific management guidelines for vulnerable archaeological sites in dynamic coastal environments (Deacon, 1996). Deacon (1996) discusses a variety of causes of site degradation, including the increased pressure of development and unsustainable dune stabilisation methods, showing that sites can be vulnerable to mismanaged projects which actually aim to help conserve them.

This study in particular highlights the need for well-informed site-specific management practices in vulnerable environments. Information gained from chronostratigraphic studies (Butzer, 2004) can be used as the basis for study into the effects of erosion at midden sites along the Southwest Cape, South Africa. Stratigraphic studies provide preliminary information on site integrity in order to target locations for further research and application of erosion hazard assessment methodologies.

Site formation processes at dune middens in Sri Lanka have been used to understand mid Holocene sea level trends (Katupotha and Wijayananda, 1989). These middens exist up to 3 km inland of the present coastline so it is likely vulnerability to, and causes of, erosion will differ with changing geomorphic environments. Tailoring specific management strategies for sites situated over a range of distances from the current coastline requires a deep understanding of the causes of erosion over a range of geomorphic environments. The information gathered in this study could be used to identify sediment sampling locations. Analysis of these sediment samples would provide much of the requisite information for the erosion hazard assessment methodologies developed in the current study. Other information required in the Erosion Hazard Pro Forma would be readily available in the field.

Site formation processes are also being studied at an upland alluvial shell midden site in Tran Ang, Vietnam (Rabett *et al.,* 2010). Unlike most coastal shell middens, this site contains freshwater and terrestrial molluscs. As previously discussed, studies of site formation processes provide valuable background information for the application of the methods developed in the current study. As upland sites have received relatively little attention compared with their coastal counterparts (Rabett *et al.,* 2010), application of erosion hazard methodologies would provide much-needed information to a growing pool of knowledge in this area.

Studies of alluvial archaeological deposits in Marseilles and the Mediterranean have focussed on distinguishing between human and natural causes of erosion (Constante, Pena-Monne and Munoz, 2010; Garcia-Ruiz, 2010; Casana, 2008; Morhange *et al.,* 2003; Blintiff, 2002). Radiocarbon dating and biostratigraphy of marine and terrestrial sediments have been used to reconstruct past land use patterns and population change. Pinpointing causes of erosion, whether they be natural or anthropogenic, is an integral part of site- or environment-specific conservation.

Blintiff's (2002) comprehensive review of studies attempting to distinguish between natural and anthropogenic causes of erosion in the Mediterranean provides a good starting point for identification of archaeological sites where erosion hazard methodologies could be applied. Sediment samples collected in Morhange *et al.*'s (2003) study could provide useful preliminary data on site formation processes and causes of erosion. Study of floodplain sedimentary sequences in small basins in the Northern Levant (Casana, 2008) provides useful localised information, as does Constante *et al.*'s (2010) study of valley fill and associated terrace sequences in Northeast Spain. Garcia-Ruiz's (2010) study of historic and prehistoric land use practices throughout Spain could lead to the development of maps showing this information. These maps could then be incorporated into a regional GIS erosion hazard model. It is also likely Garcia-Ruiz's (2010) research would have identified field indicators of erosion, information which can be used in the Erosion Hazard Pro Forma developed in the current study.

Geoarchaeological studies at upland alluvial sites in the Ohio Valley (Cremeens and Lothrop, 2009), Western USA (Patton and Schumm, 1981) and Western Illinois (Van Nest, 1993) have used cut and fill deposits to identify ephemeral stream processes. Understanding these processes and if and how they differ at specific sites leads to a deeper understanding of archaeological site formation processes. Information on sites formation processes, as well as soil characterisation and distribution (Patton and Schumm, 1981; Cremeens and Lothrop, 2009), can be applied to the erosion hazard assessment methods developed in the current study. The alluvium, colluviums and upland loess soil profiles at archaeological sites in Western Illinois (Van Nest, 1993) form an ideal starting point for further studies in regional site-specific erosion; information on historic land use can be mapped as part of a GIS erosion hazard model.

Archaeological studies of dune midden sites along the Oregon coast (Erlandson and Moss, 1999), at San Miguel Island, California (Erlandson and Rick, 2002; Erlandson, Rick and Peterson, 2005; Erlandson *et al.,* 1996) and in North Carolina (Hosier and Eaton, 1980) have focussed on site formation processes, reconstruction of cultural and palaeoenvironmental conditions and the impact of recreational vehicle use near sites, respectively. Erlandson and Moss (1999) highlight the need for rapid data collection with minimal impact at vulnerable coastal shell midden sites. They also discuss the difference between archaeological and cultural value of archaeological sites. These are important points in the holistic management of cultural resources. Coupled with this ethos, the collection of pollen samples, faunal remains and sediment for stratigraphic and palaeoenvironmental analyses (Erlandson and Rick, 2002; Erlandson, Rick and Peterson, 2005; Erlandson *et al.,* 1996) makes the sites on San Miguel Island ideal locations for the application of erosion hazard methodologies. It is a dynamic coastal environment with unique archaeological and cultural significance.

Erlandson, Rick and Peterson (2005) discuss both positive and negative impacts of the anthropogenic modification of the dunes on San Miguel Island. Prehistoric midden formation has added structural integrity, while historic farming activity has caused erosion. Study of human impact through time helps build a comprehensive picture of the site-specific causes of erosion.

Hosier and Eaton (1980) focus on the impact of recreational vehicle use on dune middens in North Carolina by mapping vegetation coverage and stratigraphy. This information forms an integral part of the regional GIS erosion hazard model developed in the current study and as such provides a basis for further research into site-specific erosion hazard at these sites.

These examples of research from around the world show how studies with different aims have collected information useful for regional and site-specific erosion hazard assessment. Placing the current research into this context shows how the erosion hazard assessment methodologies can be applied to shell midden sites in a variety of geomorphic environments. Following is a table outlining Australian examples of Aboriginal shell midden sites where the erosion hazard assessment methods developed in the current study could potentially be applied.

Table 9.1: Examples of Australian sites where the methodologies developed in this study could be applied.

LOCATION	ENVIRONMENT	PURPOSE OF STUDY	APPLICATION OF THE INFORMATION TO THE METHODS DEVELOPED IN THIS STUDY	REFERENCES
Woombah, NSW north coast	Estuarine	Part of the midden complex studied in the current research project. Focussed on research into resource utilisation – technology, economy and land use in an estuarine environment.	• Stratigraphic information: disturbance/deposit integrity. • Mapping: location of Pleistocene and Holocene sediments, thus the relative stability of the various stratigraphic layers.	McBryde, 1982
Port Hacking, NSW	Estuarine	Track changes in the distribution of mangroves and salt marsh and possible causes of these changes. Attempts to distinguish between natural and anthropogenic disturbance.	• GIS vegetation coverage mapping. • Erodibility: sediment samples at field locations can be used in particle size analyses. • Erosion Hazard Pro Forma can be used at the field sites.	Williams & Meehan, 2004
Burrill Lake, NSW south coast	Estuarine	Research Late Holocene resource utilisation and document changes in the stone tool industry.	• Radiocarbon dating and stratigraphic information: disturbance/deposit integrity. • Mapping: location of Pleistocene and Holocene sediments, thus the relative stability of the various stratigraphic layers.	Lampert, 1971
Schnapper Point and South Beach, Evans Head, NSW north coast	Dunes	Archaeological study of a stone artefact assemblage uncovered due to a severe storm series in 1971. Archaeological study of South Beach pipi middens, also containing stone artefacts.	• Threats identified: 1971 storm series, Late 19th Century alluvial gold mining, South Beach middens in RAAF bombing range, residents recall periodic erosion of sections of the deposits. • Use of erosion hazard assessment methods to better understand the impact of these threats and formulate site-specific management strategies.	McBryde, 1982

Bundjalung Reserve, Evans River, NSW north coast	River bank	Archaeological study of a midden containing shells, charcoal and stone artefacts.	• Site truncated due to flood mitigation works at the end of the 19th Century. • Use of erosion hazard assessment methods to better understand the impact of these threats and formulate site-specific management strategies.	McBryde, 1982
Currarong, NSW south coast	Rock shelters	Archaeological study of three rock shelter sites focussing on accurate radiocarbon dating and resolution of stone tool technology and bone and shell artefacts; resource exploitation.	• Stratigraphy and sediment analyses: study of site formation processes. • Sound base for study of erosion hazards.	Lampert, 1971
Disaster Bay, NSW south coast	Dunes	Pre- and Post-contact Aboriginal shell midden – study of changes in resource exploitation and technology pre- and post-European settlement.	• Highly stratified and intact midden: can use as a benchmark to assess causes of erosion at other local sites if discovered.	Colley, 1997
Captain Stevenson's Point, Mallacoota, VIC	Dunes; rocky headland	Archaeological analysis, detailed Quaternary geomorphology and geology, vegetation, vertebrate and invertebrate surveys – middens eroding out of rocky headlands and foredunes, large mobile transverse dune systems.	• Severe disturbance in nearby Genoa River valley as a result of clearing and development: erosion hazard assessment of both sites useful due to their vulnerability. • Comprehensive information collected at Mallacoota a sound starting point for application of the erosion hazard assessment methods developed in the current study.	Coutts, Aplin and Taylor, 1984
Discovery Bay, VIC and SA	Dunes	Archaeological study of highly vulnerable middens to document important information before it is lost.	• Massive coastal erosion occurred during the past 4000 years – periodic erosion of Holocene dunes with large areas devoid of	Godfrey, 1989

			vegetation, large deflated shell and artefact deposits. • Use of erosion hazard assessment methods to gain a deeper understanding of the causes of erosion and to formulate site-specific conservation measures.	
Younghusband Peninsula, SA	Dunes	Consider the impacts of past and present land use on the stability of coastal barrier dunes. Acknowledges both natural and anthropogenic causes, with a focus on 4WD activity.	• Interdisciplinary approach similar to the one undertaken in the current study: field survey, mapping, soil shear strength, aerial photographs, archaeological survey, interviews, documentary and cartographic historical sources: potential for application of the erosion hazard assessment methods developed in the current study.	Gilbertson, 1981
Robe Range, SA	Dunes	Track Quaternary geomorphic change through the study of Pleistocene and Holocene coastal deposits in a tectonically stable area.	• Detailed geomorphic (sea level and dune building) history known: impact of erosion on middens located in this area could be studied within the context of the established geomorphic framework.	Cann, DeDekker & Murray-Wallace, 1991; Cann *et al.,* 1999
Tasmania	Dunes	Management of Tasmania's Aboriginal cultural heritage. Acknowledges the significance of sites in both cultural and scientific contexts.	• Identifies possible anthropogenic threats to Aboriginal cultural heritage: development, agriculture, recreational activities (eg. 4WD and quad bike usage on dunes), density of road networks and walking tracks, vandalism and climate change. • Call for more effective management strategies: potential for application of the	Tasmanian State of the Environment Report, 2009

			erosion hazard assessment methods developed in the current study.	
Perth, WA	Beach	Identify diagnostic forms and process controls of low energy beaches, including waves, tides and water levels.	• Potential for application to coastal archaeological research and erosion hazard assessment.	Jackson *et al.,* 2002
Central Coast, WA	Dunes	Assess the physical impacts of 4WD related tourism, determine likely levels of degradation.	• Blowouts, deflation plains and extensive mobile sand sheets common in the area – erosion hazard when coupled with increasing development and 4WD use: if middens are found at this location there is the potential for application of the erosion hazard assessment methods developed in the current study.	Priskin, 2003
Cape Range Peninsula, WA	Rocky headlands and estuarine lowlands	Archaeology: argue for a long and sophisticated exploitation of coastal resources – Aborigines followed and adapted to the changing coastline. Environmental factors contributing to dune blowouts – site aspect and shelter, vegetation coverage and nature of shoreline – identified but not used in the formulation of a management strategy.	• Threats and issues identified: reduction in the extent of the mangrove community and associated biota, patchy vegetation around dune blowouts, high exposure to onshore winds, deposits at low energy sites protected by mangroves are highly preserved. • Need to take the next step and formulate site-specific management strategies at vulnerable sites – Erosion Hazard Pro Forma can assist.	Priskin, 2003
Western Cape York Peninsula, QLD	Coastal shell mounds	Show that hunter-gatherers can exert as much influence on the environment as primitive cultivators.	• Information gathered on the distribution of plant species growing on shell mounds and the shell contents of the mounds: can	Priskin, 2003

			augment the study by performing sediment analyses and using the Erosion Hazard Pro Forma in the field.	
Meriam Islands, Torres Strait	Dunes	Behavioural ecology: prey choice, differential field processing and transport.	• Stratigraphic information: disturbance/deposit integrity. • Historic and current land use: GIS map layer – part of a broader GIS erosion hazard model. • Sediment samples from excavation pits can be used in erosion hazard assessment.	Bird *et al.,* 2002
Saibai Islands, Torres Strait	Dunes	Resolve the timing and extent of prehistoric horticultural activity.	• AMS dating, sedimentary and pollen analyses: stratigraphic integrity/interpretation. • Stratigraphic information: disturbance/deposit integrity. • Erodibility: sediment samples at field locations can be used in particle size analyses. • Deposit elevation: assist in determining threat from rising sea level. • Field analysis using the Erosion Hazard Pro Forma.	Barham, 1999

9.1.3 Australian grassroots programs

In addition to the studies presented in the previous table there exist a number of grassroots Aboriginal cultural heritage management programs where the methodologies developed in this study could be very usefully applied. The current research could add much value to grassroots cultural heritage management programs. Once the impacts on sites have been identified the use of the Erosion Hazard Pro Forma allows a standardised method of reporting, encouraging communication between Local Aboriginal Land Councils, municipal councils and other relevant authorities such as the National Parks and Wildlife Service and regional Catchment Management Authorities. Standardised records also provide a benchmark by which to compare progress or further destruction to a site, as well as facilitating site-specific management strategies. Following are some examples of such grassroots programs.

A Shoalhaven City Council/Department of Infrastructure, Planning and Natural Resources Aboriginal heritage study identified issues associated with the management of Aboriginal cultural heritage in the Shoalhaven River estuary (Umwelt Australia Pty Limited, 2005). The Comprehensive Coastal Assessment – Aboriginal Cultural Landscape Planning Project identifies cultural sites and their significance but does not take the next step in identifying impacts on these sites. Issues associated with the management of local Aboriginal cultural heritage include the absence of a strategic management plan, poor environmental condition of the Shoalhaven River and floodplain and the need to record and research Aboriginal heritage at a regional level rather than focussing solely on recording information at potential development sites. The assessment report also addresses the need to incorporate Aboriginal community values in the management strategy. Use of the Erosion Hazard Pro Forma would address these issues by allowing the local Aboriginal community to have important scientific and cultural input into the management of their heritage in the Shoalhaven area.

The Murrumbidgee Irrigation Wetland Rehabilitation Management Plan (http://www.mirrigation.com.au/BBS/Future.htm), incorporating Murrumbidgee Irrigation, Griffith Municipal Council and Griffith Local Aboriginal Land Council, goes a step further in its cultural heritage management plan. It aims to protect sensitive Aboriginal cultural sites from erosion and other disturbances by installing fencing, walkways and firebreaks and revegetating with native plants. This awareness of erosion and disturbance to sites is an important first step in their management, although it appears fairly generalised. Implementation of the Erosion Hazard Pro Forma system will augment knowledge of localised and regional disturbance processes and thus aid the relevant groups in their conservation efforts.

The Border Rivers-Gwydir Catchment Management Authority have produced a Practical Guide to Soil Erosion (Miller, 2008) aimed at assisting farmers in the assessment, treatment and prevention of soil erosion on their farms. Farmers and other community members who have used this handbook will have a good understanding of the basic soil testing methods for, and field indicators of, erosion. As such, they would be well placed to use the Erosion Hazard Pro Forma, as it contains similar basic principles and soil testing methods. It also outlines erosion mitigation strategies, some of which may be helpful at Aboriginal sites.

Protection of Aboriginal cultural heritage on farmland is important, as these sites are particularly vulnerable to the effects of land use practices. It is essential that farmers have a good relationship with their local Aboriginal community and Land Council and do not feel threatened by loss of farmable land if significant Aboriginal sites are present. Implementation of the Erosion Hazard Pro Forma model has the potential to open lines of communication between these groups, ensuring Aboriginal cultural sites on farmland are managed adequately and not ignored.

Monash City Council, in suburban Melbourne, Victoria, has undertaken background research in order to identify impacts on local Aboriginal sites as part of their draft Aboriginal Cultural Heritage Management Plan (http://www.monash.vic.gov.au/city/history/c-previous-a.htm). These sites have been identified by the Local Aboriginal Land Councils as being culturally significant. The report also discusses the importance of the identification and management of culturally significant sites as well as those considered by the non-Aboriginal community as archaeologically and scientifically significant. As the research and management area covers a number of Local Aboriginal Land Councils the Erosion Hazard Pro Forma would be a useful standardise assessment tool allowing inter- and intra-Land Council communication.

The Victorian National Parks and Wildlife Service have implemented an Aboriginal Cultural Heritage Management Plan at Wilson's Promontory National Park (http://www.parkweb.vic.gov.au/education/resources/aboriginal.pdf). The plan addresses key issues such as site conservation, tourism and sustainability of employment opportunities within the local Aboriginal community. It aims to protect places of cultural and archaeological significance within the framework of the Archaeological and Aboriginal Relics Preservation Act, Aboriginal and Torres Strait Islander Heritage Protection Act and the Native Title Act. Management strategies include the development of a cultural heritage program, interpretive and education programs, identification and mapping of significant sites in order to minimise disturbance and rehabilitation of sites as necessary. Another key management strategy is the formalisation of a consultative process with the Aboriginal community and traditional owners. A standardised method for assessment and reporting of erosion hazard would be a very useful component in this process.

The online Queensland Conservation Management Profile was developed by the Queensland Government, Queensland Environmental Protection Agency and Queensland Parks and Wildlife Service – the Cultural Heritage Review Group (http://www.derm.qld.gov.au/register/p02313aa.pdf).

This site aims to increase public education and awareness of Queensland's Aboriginal cultural heritage by providing descriptions of various types of occupation sites and outlining threats, state and federal legal management guidelines and providing further information sources. Although many Indigenous communities have limited or no access to online resources, providing online access to the Erosion Hazard Pro Forma and accompanying handbook would help increase exposure and availability of this very useful resource.

In Western Australia, the Burrup Peninsula Conservation Reserve Management Plan was required before the Reserve was handed over to the Native Title claimant groups (Discussion Paper on Management Plan for Burrup Peninsula Conservation Reserve, 2003), the Ngarluma Yindjibarndi, Yaburana Mardudhunera and Wong-goo-tt-oo. This discussion paper outlines the natural and cultural significance of the Reserve, key management objectives and potential threats. Key management objectives include the preservation and promotion of Aboriginal cultural heritage values, natural and environmental values and archaeological values. The Erosion Hazard Pro Forma addresses these management objectives by providing information on potential threats which can be used in the management plan. The Erosion Hazard Pro Forma could also be used in similar situations where appropriate management plans are required before repatriation of traditional land is complete.

Aboriginal cultural heritage management programs across Australia are at varying stages of development. The Erosion Hazard Pro Forma provides a standardised system of recording and reporting scientific and cultural information at Aboriginal sites. Its potential applications range from preliminary assessment of erosion hazard at culturally and archaeologically significant Aboriginal sites to part of a sustainable cultural heritage management plan and a key component of inter- and intra-Land Council communication in regards to repatriation of traditional lands. Further afield, and at the academic level, a combination of the erosion hazard assessment methodologies developed in this research study can assist our understanding of site formation processes at cultural sites by providing a standardised and comprehensive model of the process of erosion.

9.2 CONCLUSION

This study addresses the need for greater understanding of the past, current and future effects of erosion at Aboriginal shell midden sites. Community engagement at all stages of the research project, from selection and approval of study sites to participation in field work and field trials of the Erosion Hazard Pro Forma system, formed an integral part of the research. An initial meeting with members of the Yaegl Local Aboriginal Land Council and elders identified their issues of concern relating to the destruction of Aboriginal shell midden sites. The researcher's aim to use relatively non-invasive data collection techniques was discussed and approved, and specific sites requiring study were identified by Aboriginal community representatives. Permission was granted to study these sites. At least one Yaegl community member was present during data collection at field sites. This not only ensured transparency of objectives, it also provided a valuable learning experience for both the researcher and the community members.

Field trials were undertaken to refine the methodology presented in the Erosion Hazard Pro Forma, gain feedback on the usefulness of the system and educate the local Aboriginal community in its use. It also encouraged discourse between the Aboriginal community and trained archaeologists and environmental scientists, a useful learning experience for all participants. Continuous engagement with the Aboriginal community was facilitated through regular written and verbal research updates. Undertaking a research project of this nature has provided the researcher with a unique opportunity to engage with the Yaegl community and provide them with a valuable, user-friendly cultural heritage management resource as well as performing technical analyses to generate results.

Using geomorphic analysis techniques increased understanding of the effects of site formation processes on the archaeological record, allowing for a comprehensive interpretation of archaeological information. This study used a holistic approach, combining information on a number of factors affecting erosion at the study sites. Soil analysis techniques, such as particle size analysis, loss on ignition and aggregate stability, were used to determine the erodibility of midden sediments. Mapping the slope, vegetation coverage and land use at Aboriginal shell midden sites was another important technique used to determine the susceptibility of these sites to erosion. In addition, the use of local flood, tide and sea level data addresses the susceptibility of low-lying sites to these processes. Research has shown that a relatively minor increase in sea level would significantly increase the vulnerability of low-lying sites to the effects of flooding and tidal inundation.

A number of causes and impacts of erosion were identified at the study sites. Causes of erosion were both anthropogenic and non-anthropogenic in origin. Human activities such as boating, walking, cultivation and excavation have a lasting and ongoing impact at Sleeper Island, Woombah and Plover Island. Historic farming practices, which include the processes of cultivation and excavation, have increased the vulnerability of low-lying sites to erosion by stripping native vegetation, steepening banks and altering the texture, and therefore erodibility, of the soil. These practices have also directly disturbed the midden deposits at Woombah. Recreational activities also cause erosion. At Sleeper Island, boating wash further degrades its already steep, denuded banks and walking tracks on Plover Island bisect a partially covered stone artifact scatter. Lack of vegetation coverage, coupled with exposure to prevailing winds and ocean swell are the primary factors influencing erosion of the unconsolidated dunes at Minnie Water. The combination of these factors has lead to increasing exposure of the Aboriginal shell midden situated within these dunes, which has also been reworked by wind and ocean swell. Minimal disturbance at the Wooli Aboriginal shell midden deposit is due to its burial in a low energy environment, gentle bank slope, high vegetation coverage and minimal anthropogenic impact.

Combining data on multiple impacts has shown the relationship between, and relative importance of, each of these impacts at individual sites. Comparison of the effects of these impacts at sites situated in similar geomorphic settings has also lead to the identification of environment-specific factors and sets of factors which appear commonly in specific environmental contexts. At riverbank sites, bank slope, vegetation coverage and land use zoning were the major factors influencing erosion. Woombah Site A has a steeper bank slope, lower vegetation coverage and more intense current and historic land use zoning than the riverbank site at Wooli, and a higher erosion hazard ranking. Vegetation coverage was the major factor influencing erosion at sites situated in tidal channels. There is much lower vegetation coverage at Sleeper Island than at Woombah Site B, and thus Sleeper Island has the higher erosion hazard ranking. Exposure to ocean swell, as a result of site elevation, was the major factor influencing erosion at coastal sites. The Minnie Water foredunes are highly exposed to ocean swell and, as such, have a higher erosion hazard ranking than the archaeological deposits on Plover Island, a rocky outcrop with relatively high elevation.

Three erosion hazard assessment methods were developed to study the relationship between, and relative importance of, these impacts. Each method was formulated to address the needs of a different stakeholder group. The first method comprises an assessment of disturbance processes, their contributory factors and outcomes. Each process has a set of contributory factors with quantifiable or semi-quantifiable outcomes. Assessment of these outcomes is based on interpretation of field evidence, aerial photographs, current and historic maps, wind rose data and information on tidal flows and flooding. Sites are given an erosion hazard ranking of low, moderate or high, based on this evidence. This method is suitable for use by archaeologists as it uses relatively simple scientific analyses combined with historical data.

The second method comprises a concise Erosion Hazard Pro Forma and accompanying instructional handbook and has been designed for use by Local Aboriginal Land Councils and community members. It uses simple field analysis techniques such as quadrat mapping of vegetation coverage and shell density, slope and soil field texture measurements and documentation of shell condition to facilitate rapid site documentation and erosion hazard assessment. Scores are compiled for each site, based on the information collected. Each score corresponds with a set of conservation guidelines based on the degree of erosion hazard and contributing factors.

The final method involved the formulation of a GIS model. Layers were created for vegetation coverage, slope, soil characteristics, Quaternary surface/subsurface age and dominant texture of sediment and land use. Soil characteristics data were sourced from laboratory analyses and all other data were sourced from the Clarence Valley Council and other Government Departments. Categories within these layers were ranked 3 (high erosion hazard), 2 (moderate erosion hazard), 1 (low erosion hazard) or 0 (no erosion hazard). Site points were then plotted on the model and erosion hazard scores were generated using the scoring system. Study sites were then ranked in order from highest to lowest erosion hazard. As it is a regional model an erosion hazard score can be generated for any point included in the map area. This method is suitable for use by environmental scientists and those with a basic knowledge of GIS software as it requires an understanding of sediment analyses techniques and ArcMap software, and interpretation of sedimentary and spatial data.

Agreement between the erosion hazard assessment methods indicates their strength and usefulness as standardised techniques for determining the relative importance of erosive factors at Aboriginal shell midden sites. Study sites are ranked in the same order according to the results generated using all three methods. Sleeper Island, Minnie Water, Woombah Site A, Woombah Site B, Plover Island and Wooli are ranked in order from highest to lowest erosion hazard according to all three methods.

The three erosion hazard assessment methods developed in this study address the needs of a range of stakeholders. Each of the methods take into account the needs and abilities of different groups. Although the methodologies differ in a technical nature they are all comprehensive enough to provide quality information on the causes and effects of erosion at Aboriginal shell midden sites. Similar results were obtained when technical processes, such as particle size analysis, were substituted with simpler techniques requiring less time and equipment, such as soil field texture measurement. The scope of the data collected and analysed using highly technical processes is greater, however agreement between the results obtained using all methods shows simpler techniques can also be used with confidence. Simpler techniques have the advantage of being easier to teach and standardise and they are also more cost effective and easier to perform in a timely manner in the field.

Identification of the causes and impacts of erosion benefits a number of stakeholder groups. Municipal Councils can use the information when refining their land use zonings and processing development applications. Information can be used by the Department of Environment, Climate Change and Water (DECCW) to augment their Aboriginal sites register. As well as the discovery of sites not already included in the register, vital information on the type and severity of erosion hazard, and corresponding conservation guidelines, could now be included in the register. Guidelines formulated as part of this research project pertain to the frequency of monitoring required for sites, based on their calculated erosion hazard index, and conditions to monitor, based on their specific vulnerabilities. Category 1 and 2 sites, such as Wooli, Plover Island and Woombah Site B, require checking of vegetation coverage, shell condition, tidal activity and land use every 1-2 years. In the case of Plover Island, it is recommended the public walking track be diverted around the artifact scatter, as this will allow for an increase in vegetation coverage, protecting the site from prevailing winds.

Category 3 sites, such as Woombah Site A, require yearly monitoring of vegetation coverage, shell condition, tidal activity and land use. Increasing native and/or habitat-specific vegetation coverage is also recommended to reduce erosion, as is close monitoring of the effects of farming, such as crop planting too close to the riverbank. If the type of land use at a site appears to be causing further erosion the assessor is advised to contact local council, the Department of Environment, Climate Change and Water Aboriginal Heritage Section or the National Parks and Wildlife Service to discuss their concerns.

Category 4 sites, such as Sleeper Island and Minnie Water, require very close monitoring and remediation. They should be visited at least once every six months to monitor changes in vegetation coverage, shell condition, tidal activity and land use. Increasing native and/or habitat-specific vegetation coverage is also recommended to reduce erosion. Collaboration with local council, the Department of Environment, Climate Change and Water Aboriginal Heritage Section and/or the National Parks and Wildlife Service is strongly recommended as they possess the skills, manpower and equipment to aid in remediation works.

This information is also useful for Government agencies when making policy decisions. The research findings also have great value within the scientific community as they add to the growing body of knowledge on the effects of geomorphology on both human- and non-human-induced erosional processes. Finally, the most important benefactor is the Aboriginal community. Understanding and identification of the causes of erosion at shell midden sites increases confidence in the management of these cultural resources. The formulation of general and site-specific conservation guidelines allows the Aboriginal community to take greater ownership in the management of their cultural resources. This is considered by the Yaegl Local Aboriginal Land Council to be the most important outcome of the study.

Potential areas for further study are summarised in the following points:

Further explore the link between sea level rise and increased frequency of/susceptibility to flooding and tidal inundation at low-lying sites through application of the methodology developed to assess risk of flooding and tidal inundation. Study the frequency of tidal inundation and flooding at given elevations and create a model, using this data, to explore what would happen at varying sea levels. This would be a great opportunity to collect comprehensive data at a fine resolution, starting by matching tide gauge data with measured elevations. This information would be very useful for urban and regional planning, as well as conservation work.

Study the potential applications of the erosion hazard assessment methodologies at other archaeological site types. This information can be used to modify the existing methods and/or develop further appropriate methods of erosion hazard assessment at such sites.

Encourage and implement the use of the erosion hazard assessment methodologies at shell midden sites within areas covered by other Local Aboriginal Land Councils.

Re-survey and monitoring of existing study sites – follow up on results achieved by the local Aboriginal community regarding remediation and site conservation. Ascertain whether or not the methods are suitable for achieving long term remediation and conservation goals.

Augmentation and standardisation of the site card system. Review the current format of site cards, used to record information on Aboriginal archaeological sites, and formulate a more user-friendly system. Review the current location of cultural sites listed in the AHIMS database, as many of the coordinates are incorrect. This is a time-consuming process, as sites need to be re-surveyed, however it is necessary to ensure accurate and effective cultural heritage management.

The erosion hazard assessment methodologies developed in this study have potential applications both within Australia and at sites overseas. The standardised, systematic approach has relevance for shell midden sites in a range of geomorphic contexts. Education, awareness and community engagement are an integral part of effective cultural heritage management, as is a deep understanding of the processes which degrade cultural sites. This research study yields positive results in both these areas and, as such, provides effective cultural heritage management strategies.

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Yamba Tide Prediction Chart 2009-2010: www.bom.gov.au/oceanography/tides/MAPS/yamba.shtml

PLATE 1

A, B: *Pyrazus ebeninus* (Bruguiere, 1792) found in the *in situ* midden deposit at Sleeper Island.

C: *Saccostrea glomerata* (Gould, 1850) found in the *in situ* midden deposit at Sleeper Island.

D: *Anadara trapezia* (Deshayes, 1839) found in the *in situ* midden deposit at Sleeper Island.

E, F: *Saccostrea glomerata* found in the *in situ* Woombah Site A midden deposit.

G, H: *Saccostrea glomerata* found in the Woombah Site B midden deposit.

PLATE 2

A: *Strombus microurceus* (Kira, 1959), Minnie Water *in situ* midden deposit.

B: *Nodilittorina pyramidalis* (Quoy and Gaimard, 1833), Minnie Water *in situ* midden deposit.

C: *Velacumantis australis* (Quoy and Gaimard, 1834), Minnie Water *in situ* midden deposit.

D: *Cellana tramoserica* (Holten, 1802), Minnie Water *in situ* midden deposit.

E, F: *Dicathais orbita* (Gmelin, 1791), Minnie Water *in situ* midden deposit.

G: *Turbo undulatus* (Solander, 1786), Minnie Water *in situ* midden deposit.

H: *Barbatia pistachia* (Lamark, 1819), Minnie Water *in situ* midden deposit.

I, J: *T. undulatus* fragments, Minnie Water *in situ* midden deposit.

K: *Bembicium nanum* (Lamark, J. B. P. A. de, 1822), Minnie Water *in situ* midden deposit.

All scale bars = 1 cm.

PLATE 3

A: *Turbo undulatus*, Minnie Water lag deposit.

B: *Cellana tramoserica*, Minnie Water lag deposit.

C: *Modiolus areolatus* (Gould, 1850), Minnie Water lag deposit.

D: *Velacumantis australis*, Minnie Water lag deposit.

E: *Nodilittorina pyramidalis*, Minnie Water lag deposit.

F: *Cypraea* sp., Minnie Water lag deposit.

G: *Bembicium nanum*, Minnie Water lag deposit.

H: *T. undulatus*, Minnie Water lag deposit.

I, J: *T. undulatus* fragments, Minnie Water lag deposit.

K: *Nerita atramentosa* (Reeve, 1855), Minnie Water lag deposit.

All scale bars = 1 cm.

PLATE 4

A-C: *Pyrazus ebeninus*, Wooli midden deposit. Note the chalkiness present on specimen C.

D-F: *Saccostrea glomerata* fragments, Wooli midden deposit.

All scale bars = 1 cm.

PLATE 5

A-C: Stone artifacts, *in situ* deposit, Plover Island.

D-F: Dicathais orbita fragments, lag deposit at base of Plover Island. Note the rounded and polished edges of the specimens.

G: Likely *D. orbita* fragment, lag deposit at base of Plover Island.

H, I: Rounded stones, lag deposit at base of Plover Island.

All scale bars = 1 cm.

PLATE 6

A-D: Stone artifacts, Sleeper Island lag deposit. Red letters a-d show the locations of points of percussion.

All scale bars = 1 cm.

PLATE 7

A-D: Stone artifacts, Sleeper Island lag deposit. Red letter ‘a’ shows flake scars.

All scale bars = 1 cm.

APPENDICES

APPENDIX 1

CORE DIAGRAMS

Sediment samples were taken from each stratum, as defined by their field texture (left column). Each core is presented as a separate diagram and then a summary diagram showing midden deposit stratigraphy is included for each site.

Key to soil texture abbreviations:

S = Sand

LS = Loamy Sand

CS = Clayey Sand

SL = Sandy Loam

FSL = Fine Sandy Loam

SCL- = Light Sandy Clay Loam

L = Loam

LFsy = Loam Fine Sandy

SiL = Silt Loam

SCL = Sandy Clay Loam

CL = Clay Loam

SiCL = Silty Clay Loam

FSCL = Fine Sandy Clay Loam

SC = Sandy Clay

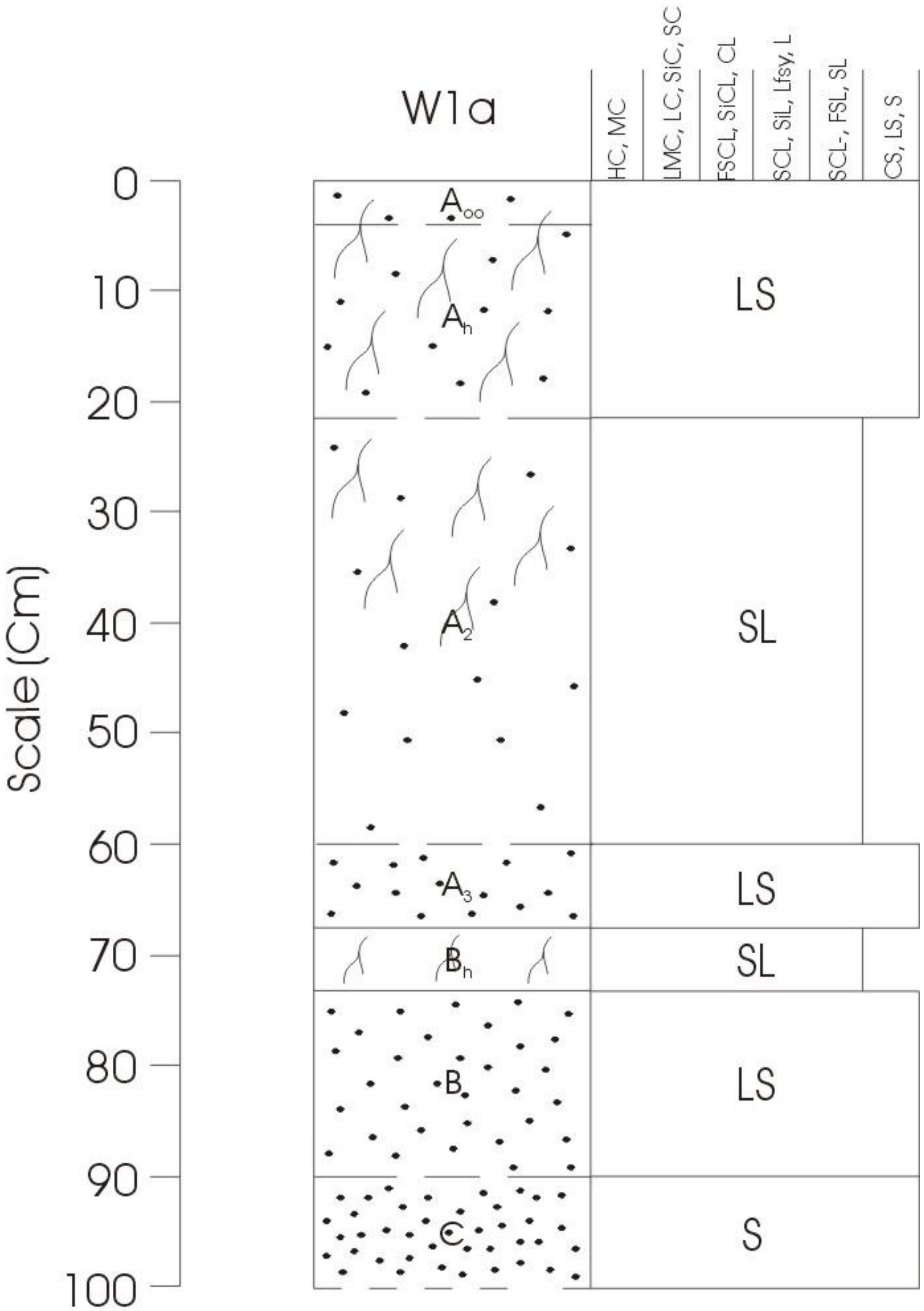
SiC = Silty Clay

LC = Light Clay

LMC = Light Medium Clay

MC = Medium Clay

HC = Heavy Clay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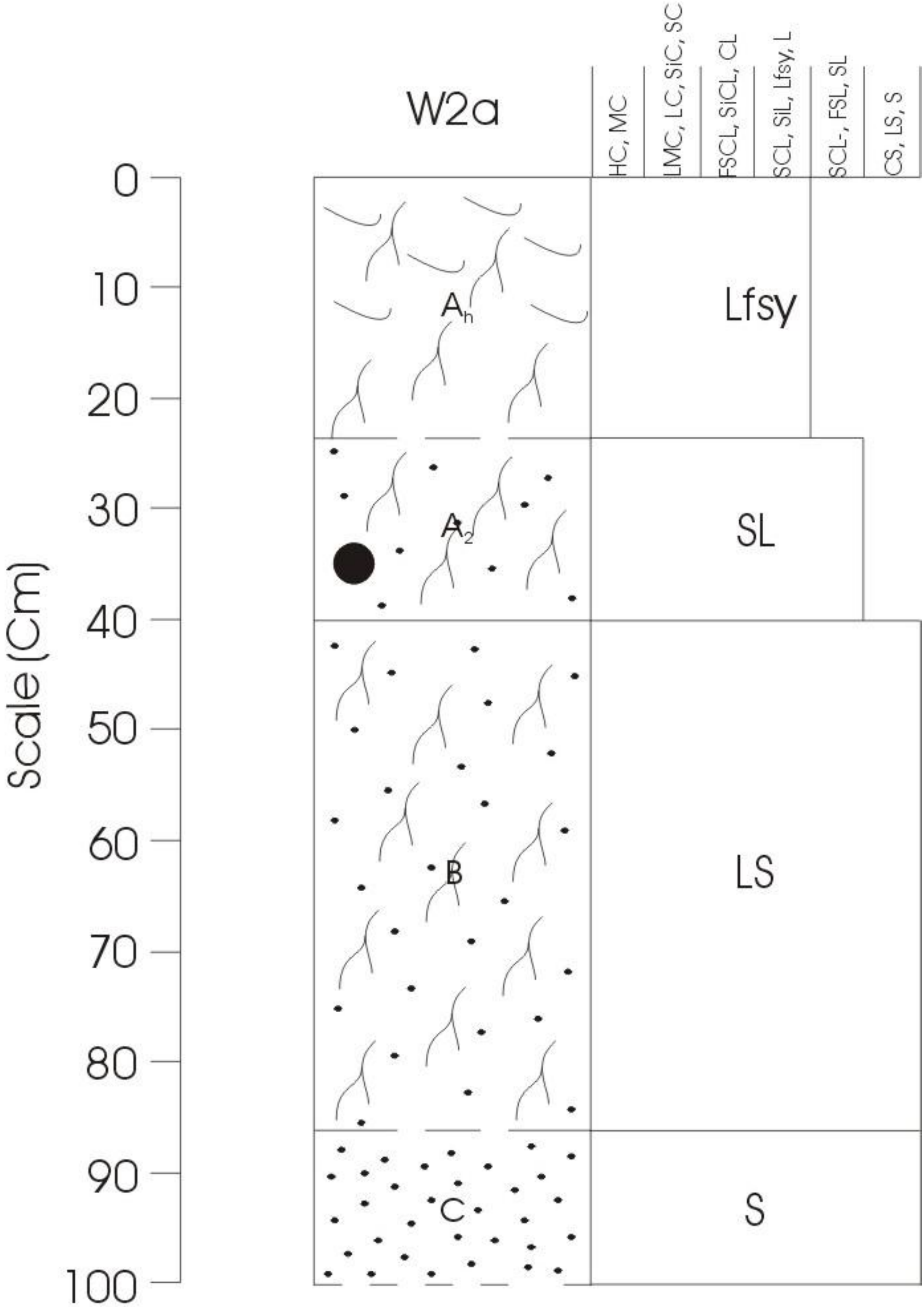
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
Scale (Cm)
0
10
20
30
40
50
60
70
80
90
100
A₀₀
Aₕ
A₂
A₃
Bₕ
B
C
LS
SL
LS
SL
LS
S


W2a
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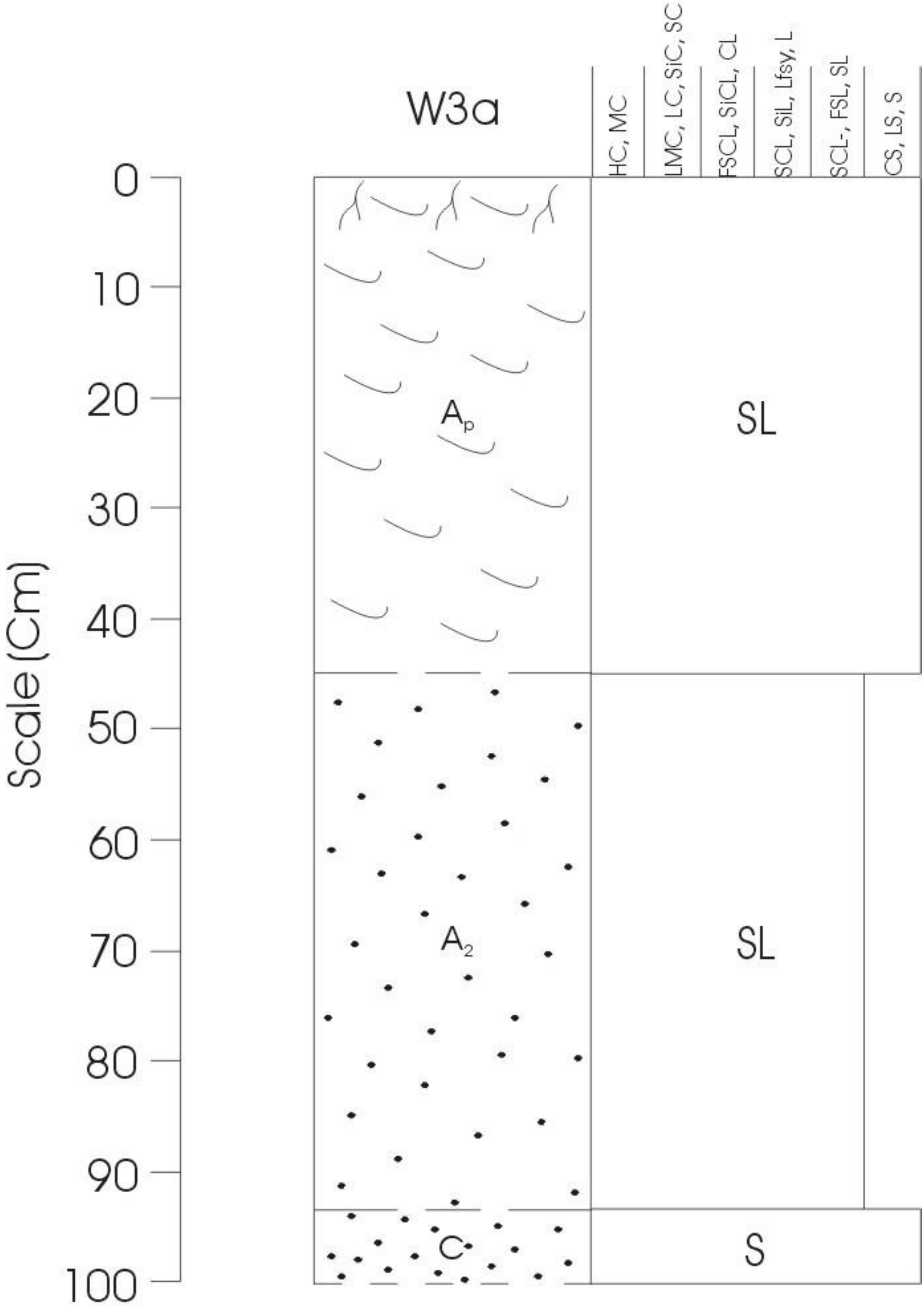
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
0
10
20
30
40
50
60
70
80
90
100
Scale (Cm)
Ah
A2
B
C
Lfsy
SL
LS
S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HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
Scale (Cm)
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10
20
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60
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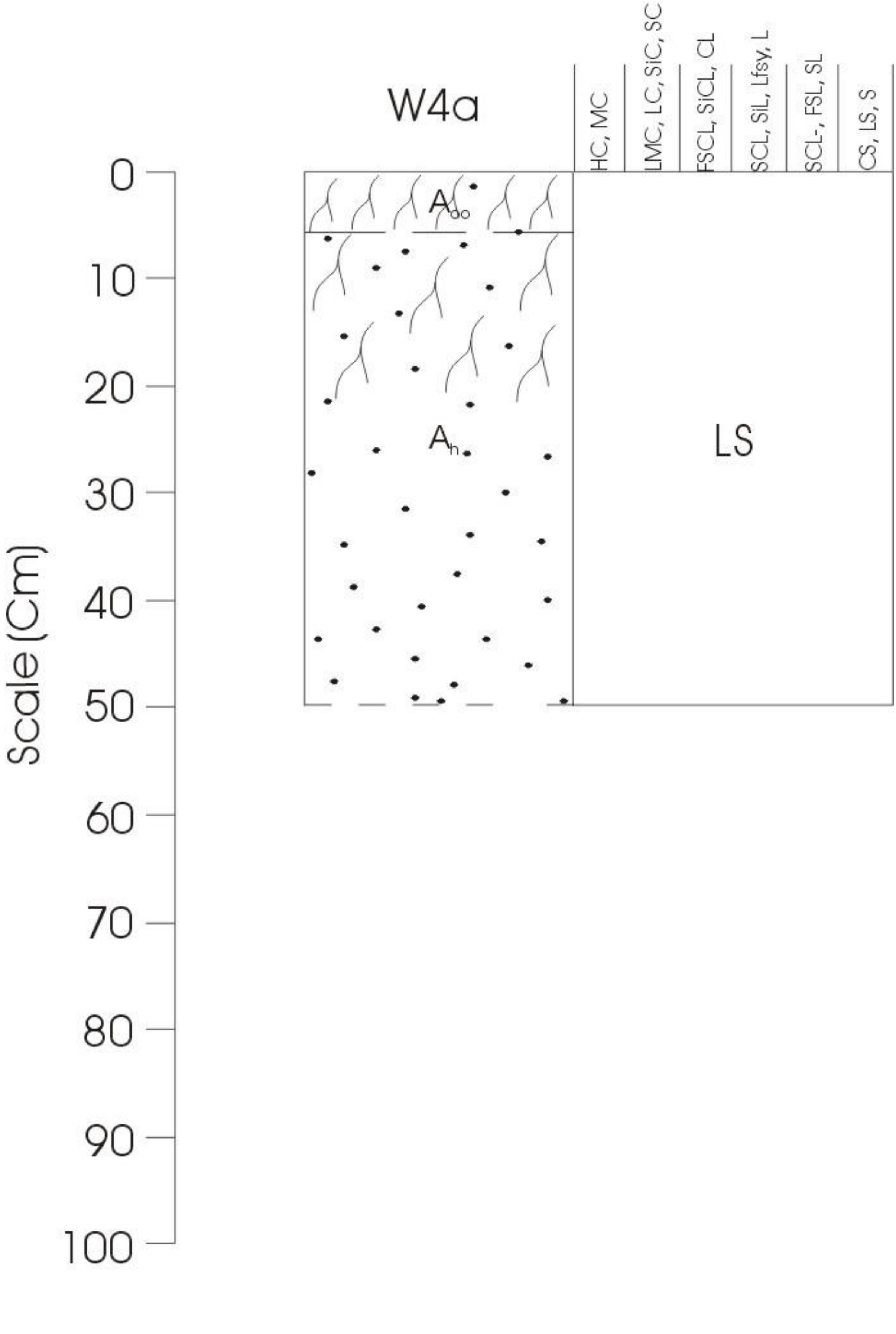
80
90
100
Ap
A2
C
SL
SL
S



W4a
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LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
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30
40
50
60
70
80
90
100
Scale (Cm)
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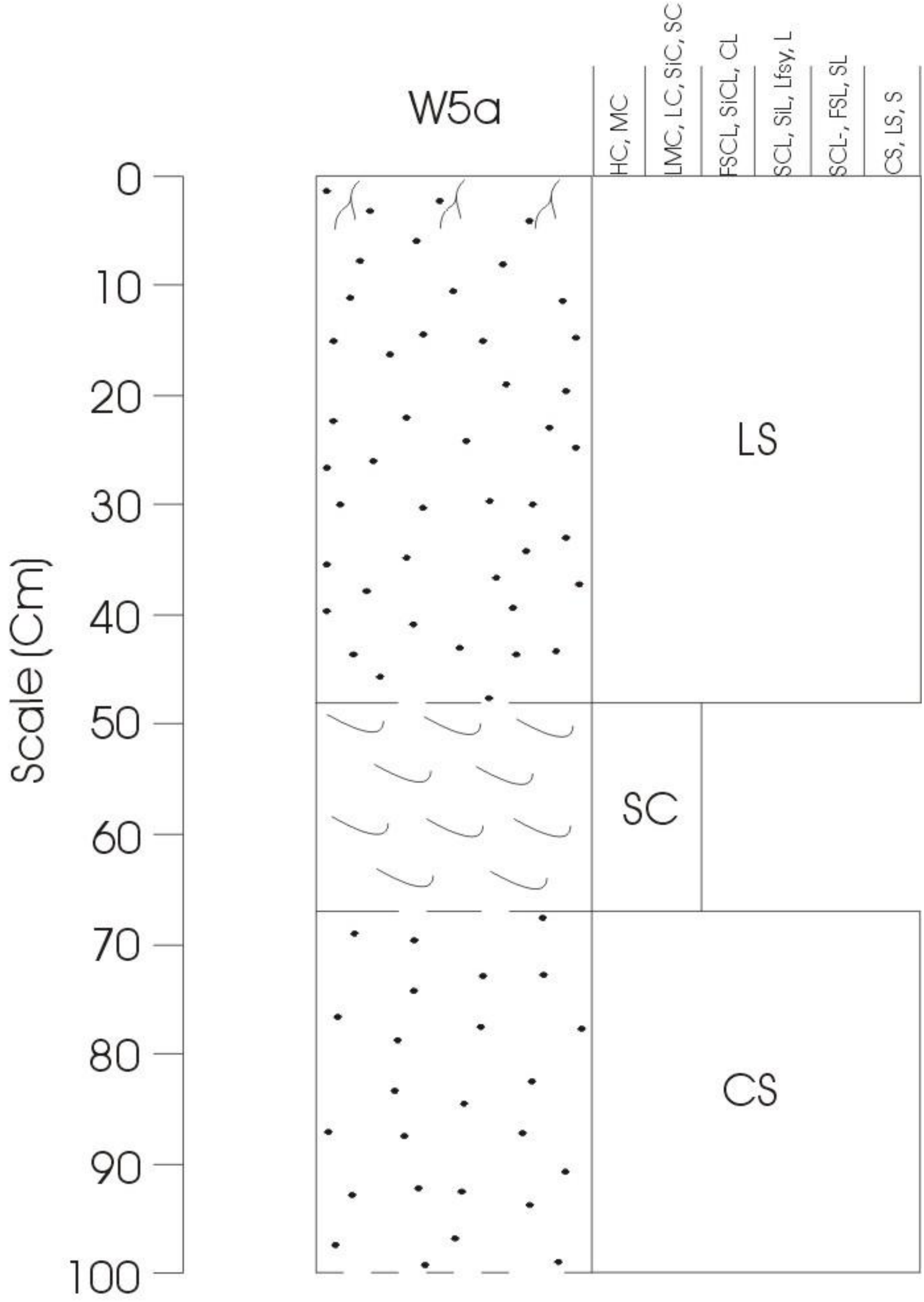
Ah
LS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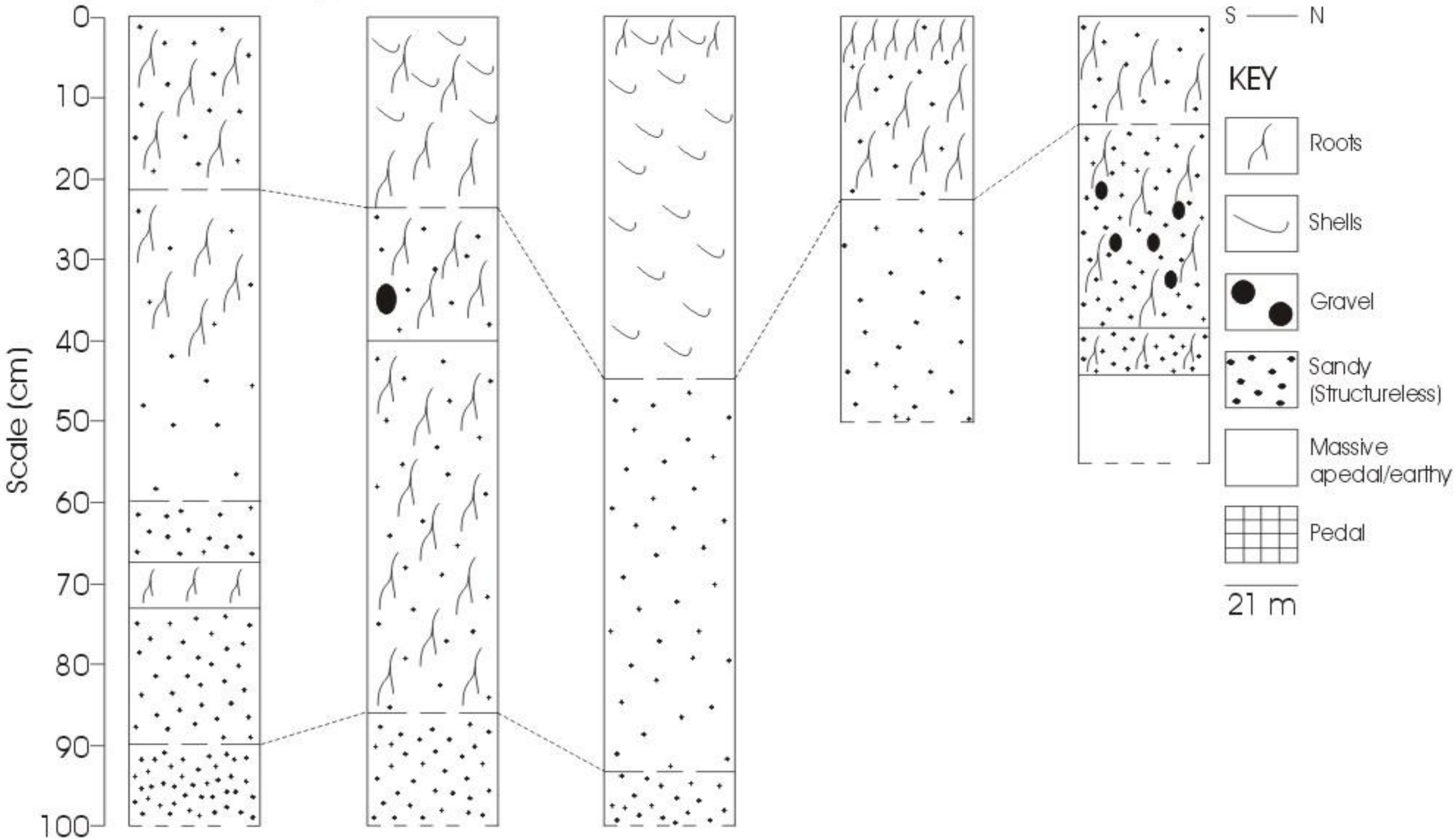
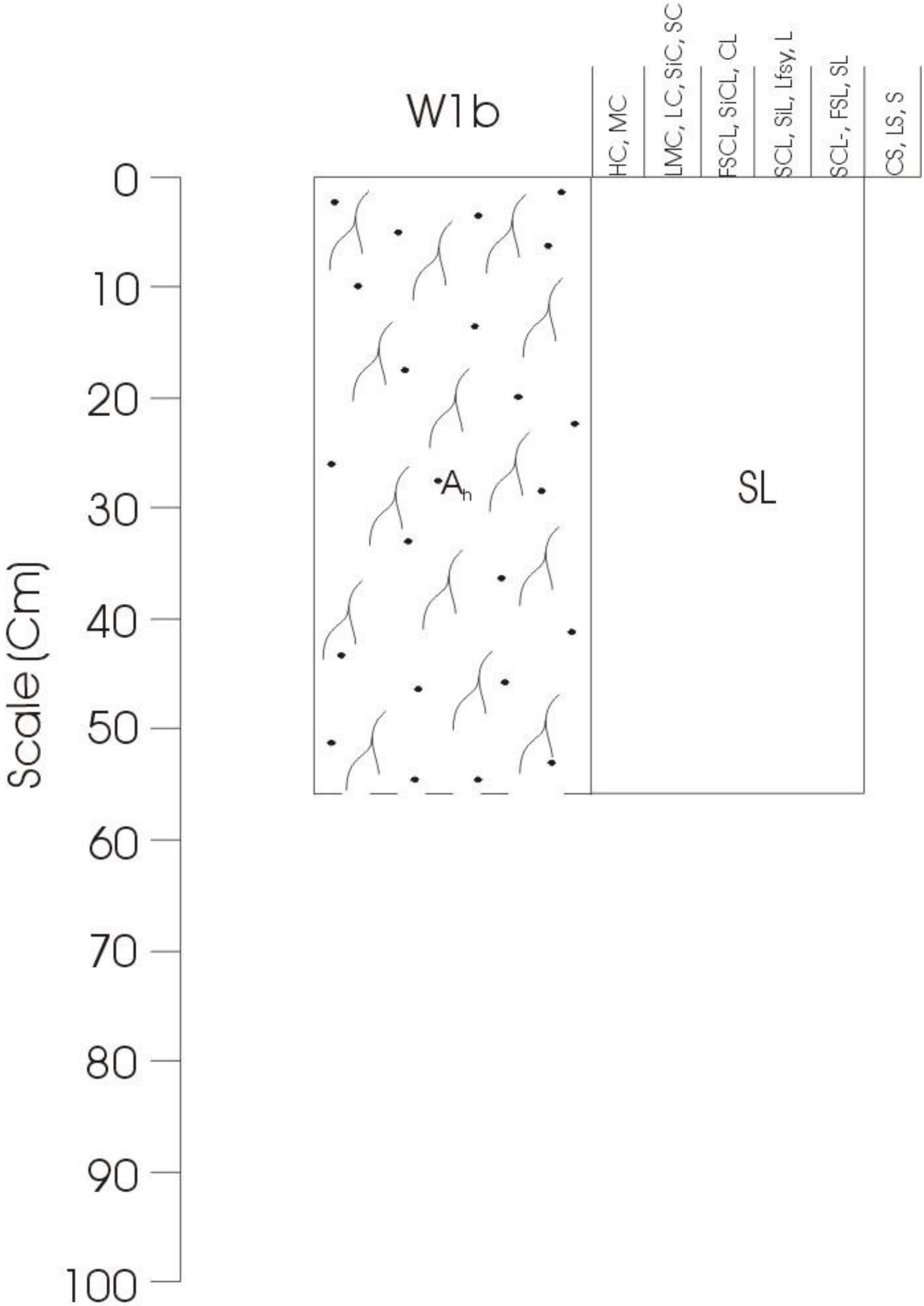
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
Scale (Cm)
0
10
20
30
40
50
60
70
80
90
100
LS
SC
CS

Core Stratigraphy - Woombah site A





W1b
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LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
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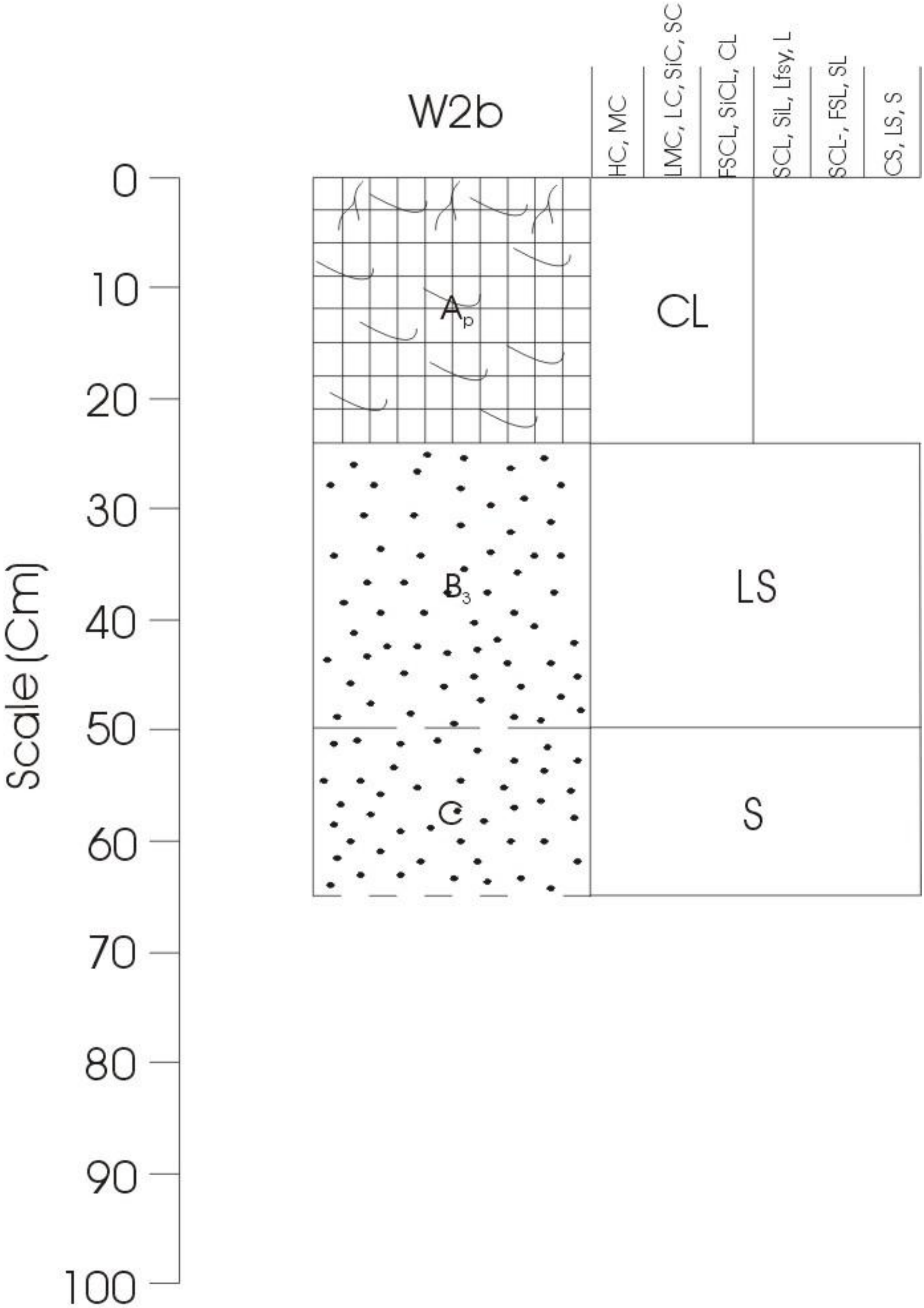
20
30
40
50
60
70
80
90
100
Scale (Cm)
A_h
SL


W2b
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
Scale (Cm)
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10
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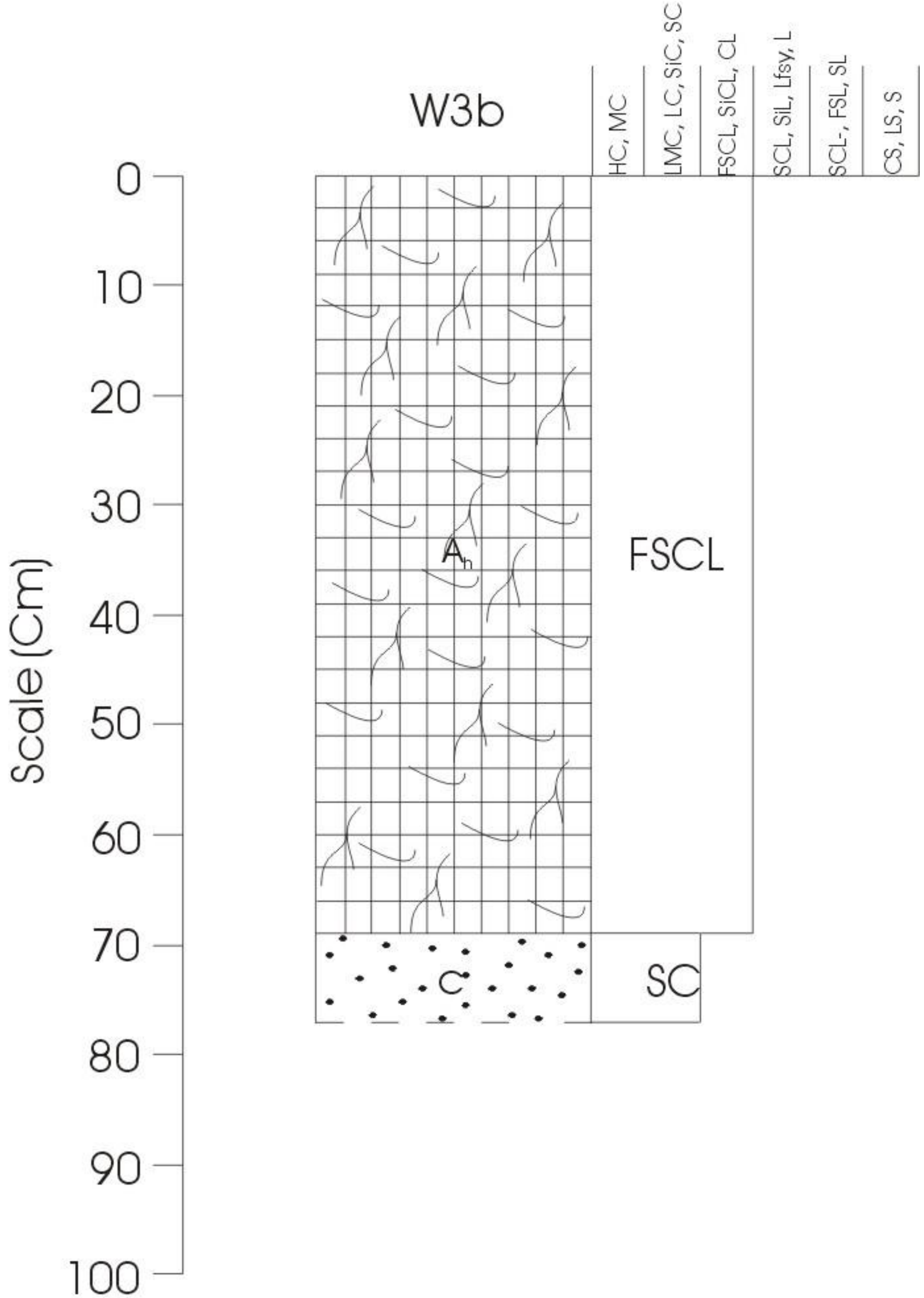
90
100
Ap
B3
C
CL
LS
S


W3b
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
Scale (Cm)
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FSCL
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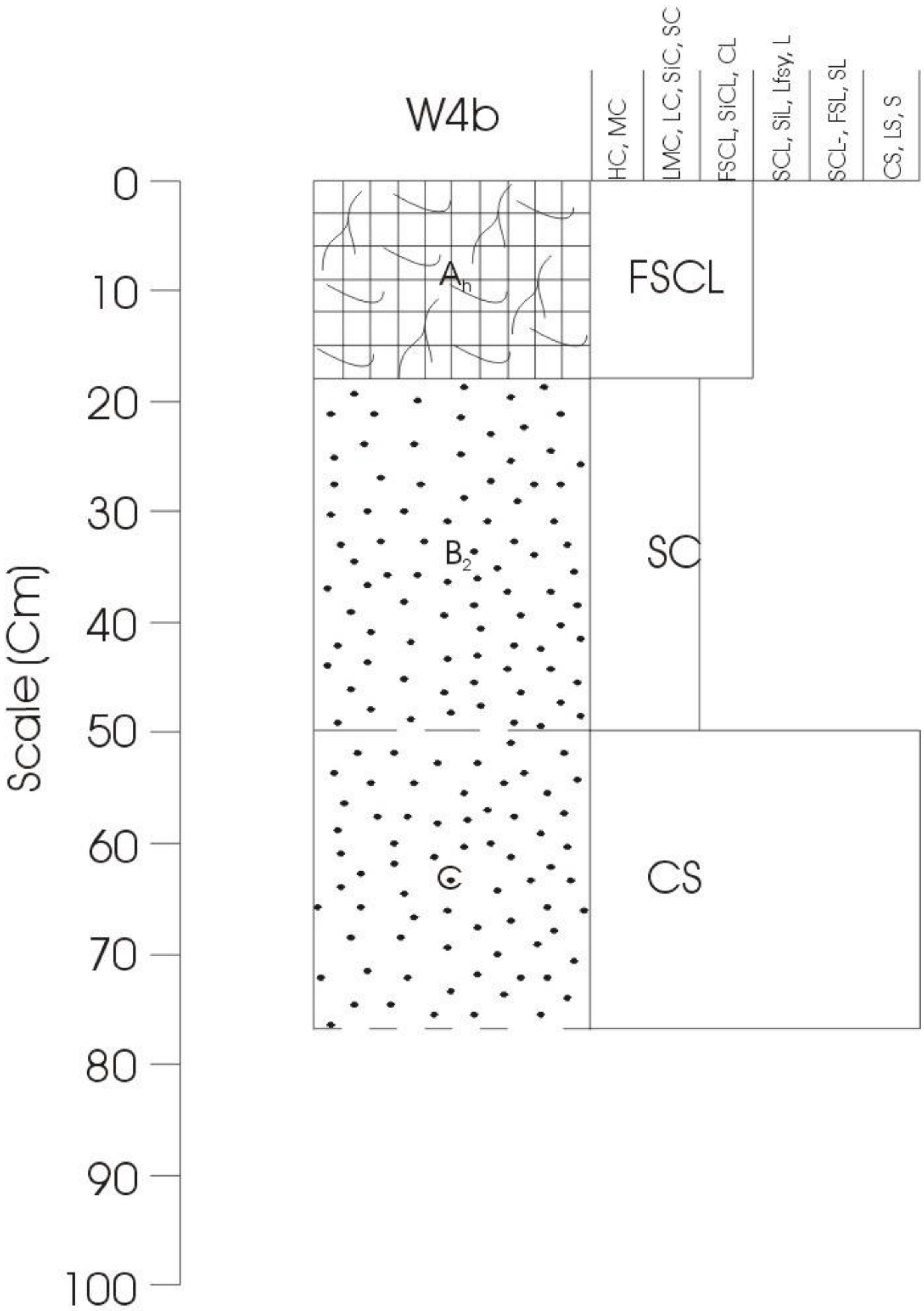
SC


W4b
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
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Scale (Cm)
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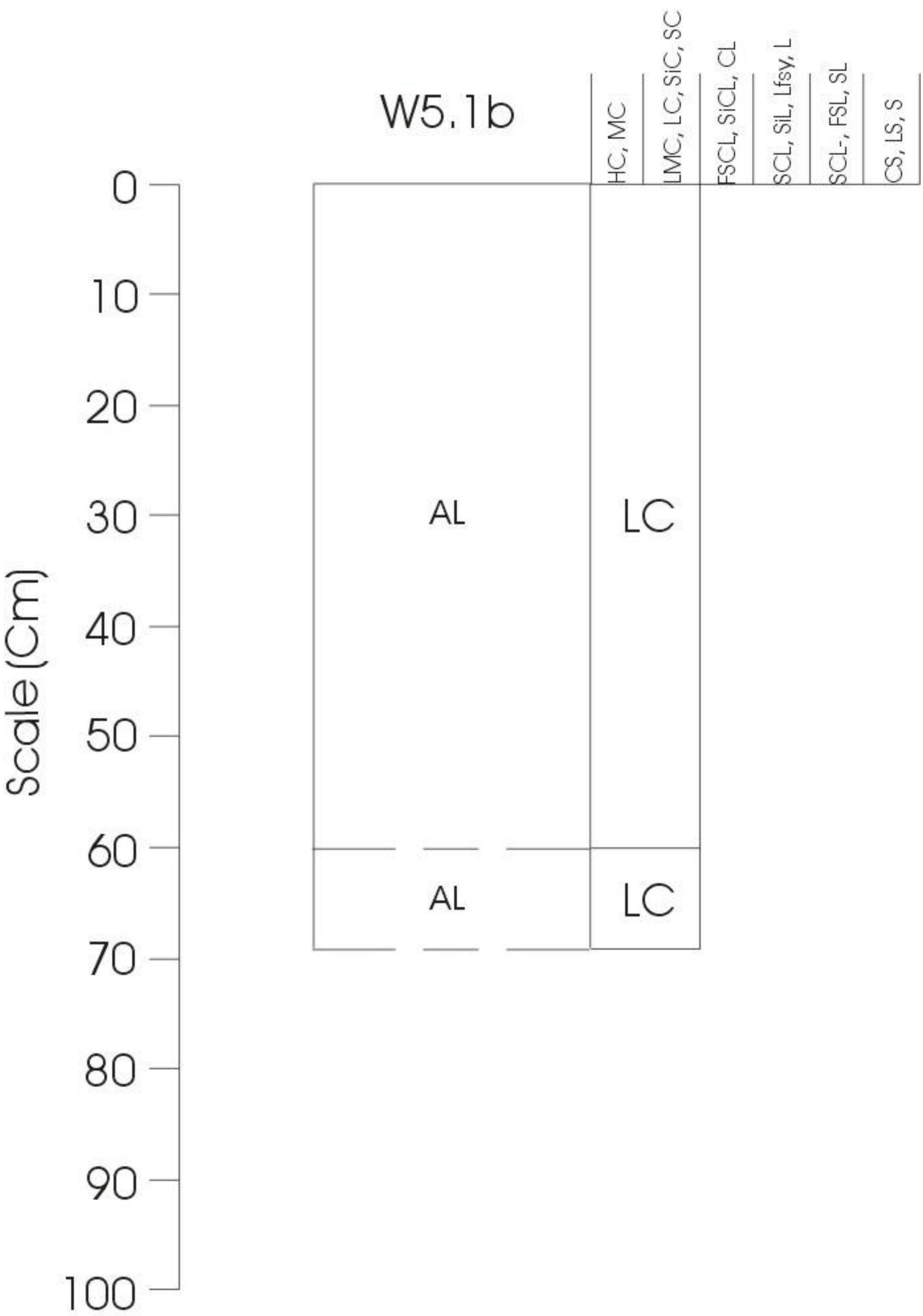
FSCL
B2
SC
C
CS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SCL-, FSL, SL
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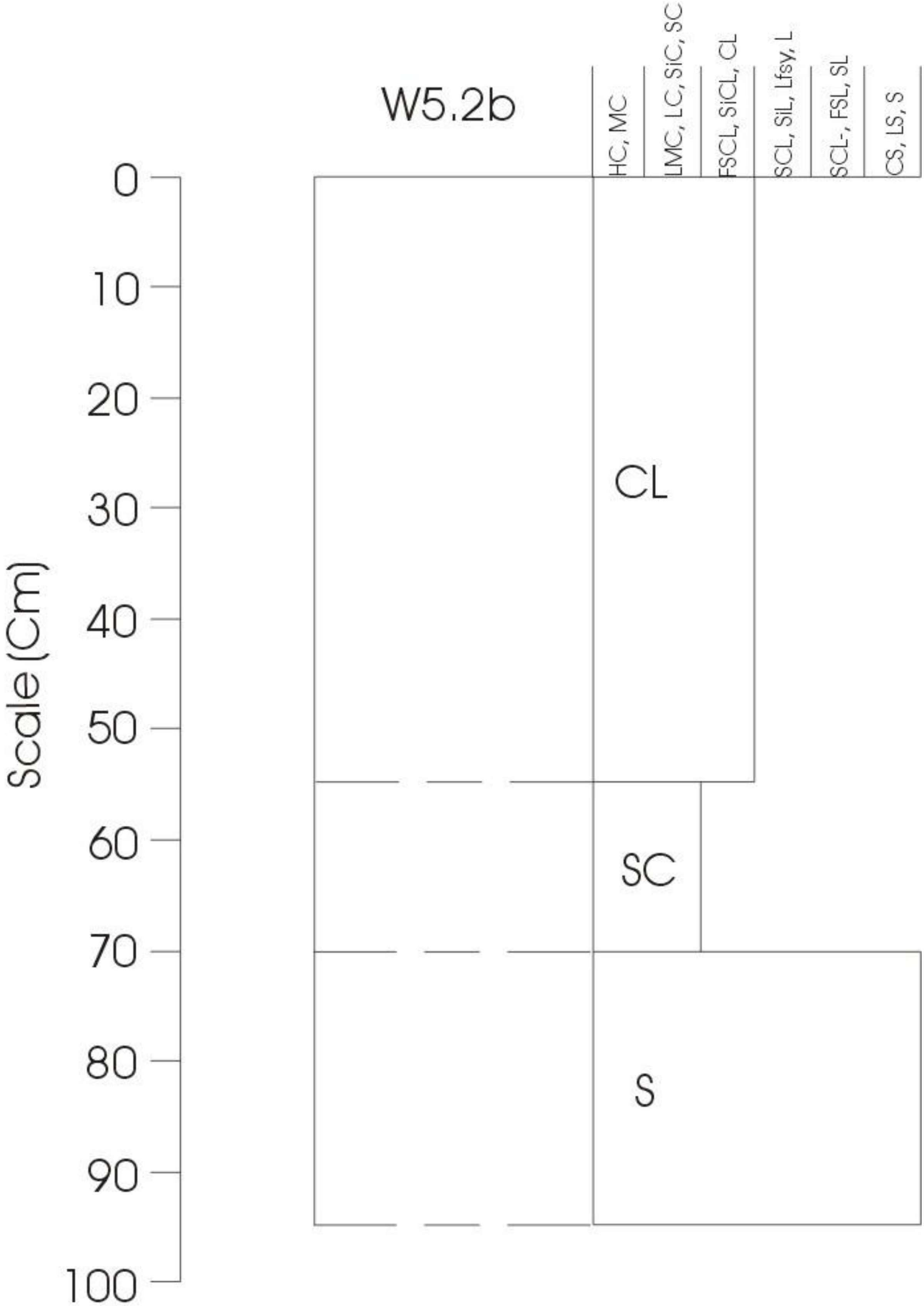
100
AL
LC
AL
LC


W5.2b
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LMC, LC, SiC, SC
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SCL-, FSL, SL
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90
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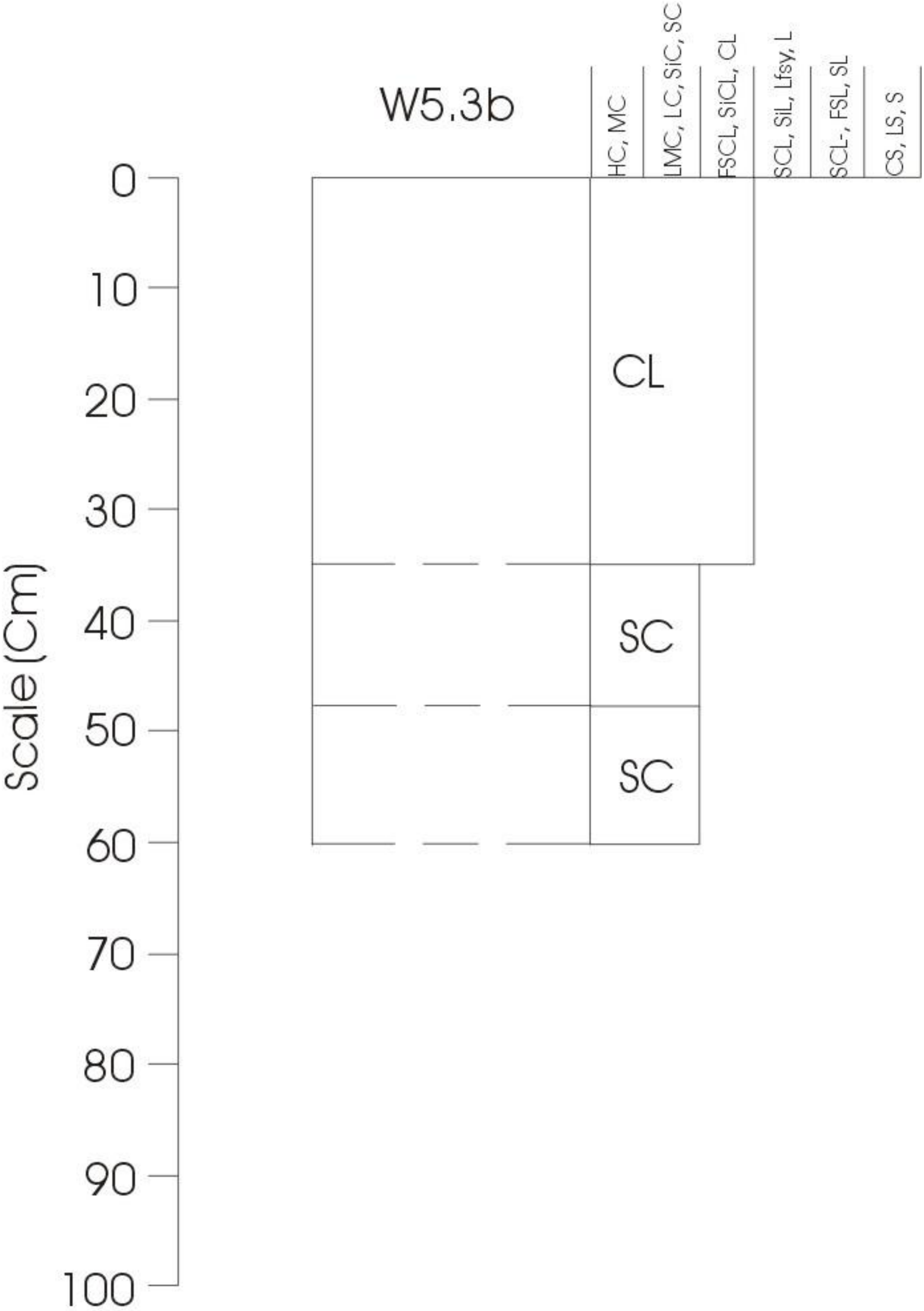
Scale (Cm)
CL
SC
S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LMC, LC, SiC, SC
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SCL, SiL, Lfsy, L
SCL-, FSL, SL
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Scale (Cm)
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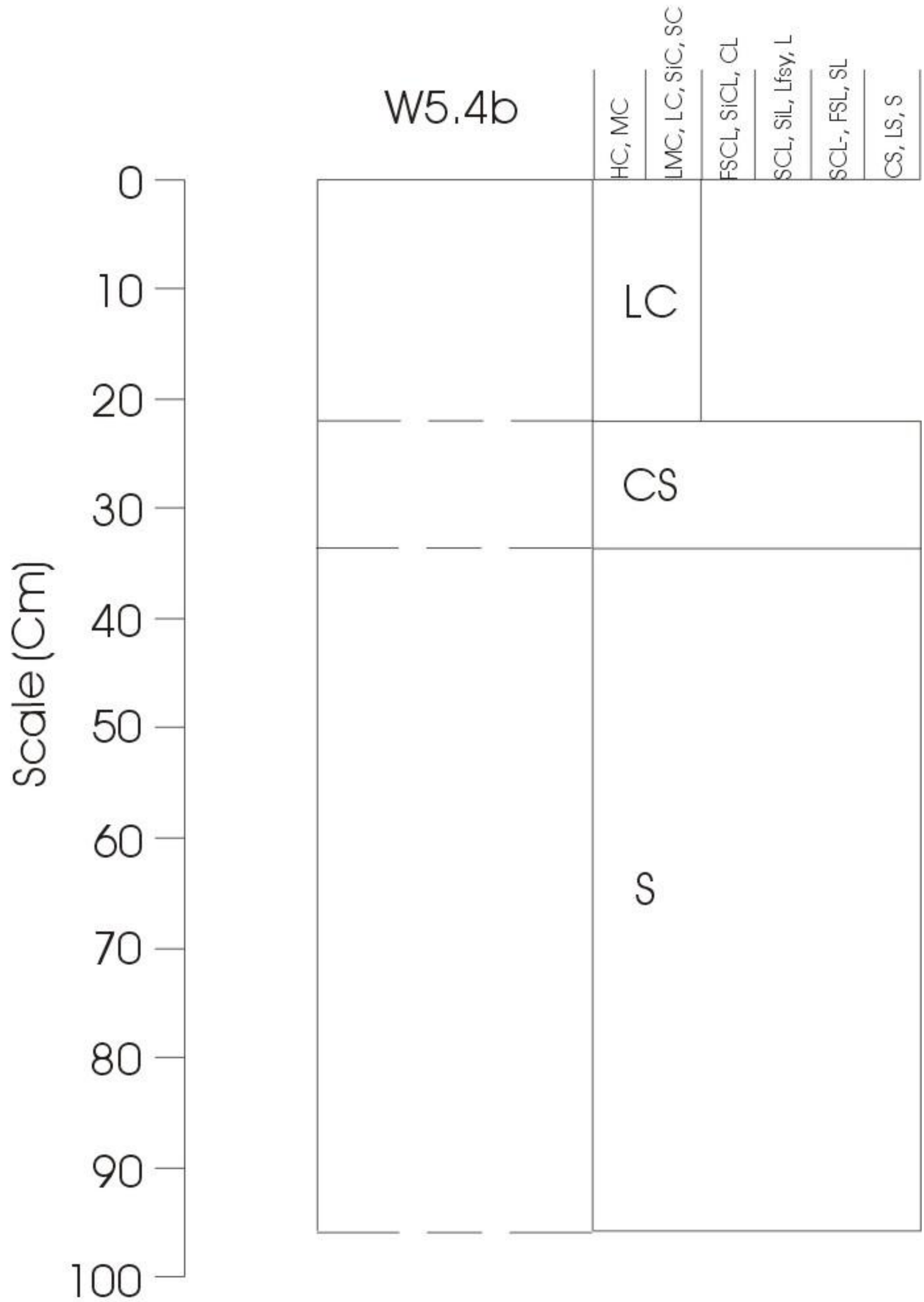
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LMC, LC, SiC, SC
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SCL-, FSL, SL
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Scale (Cm)
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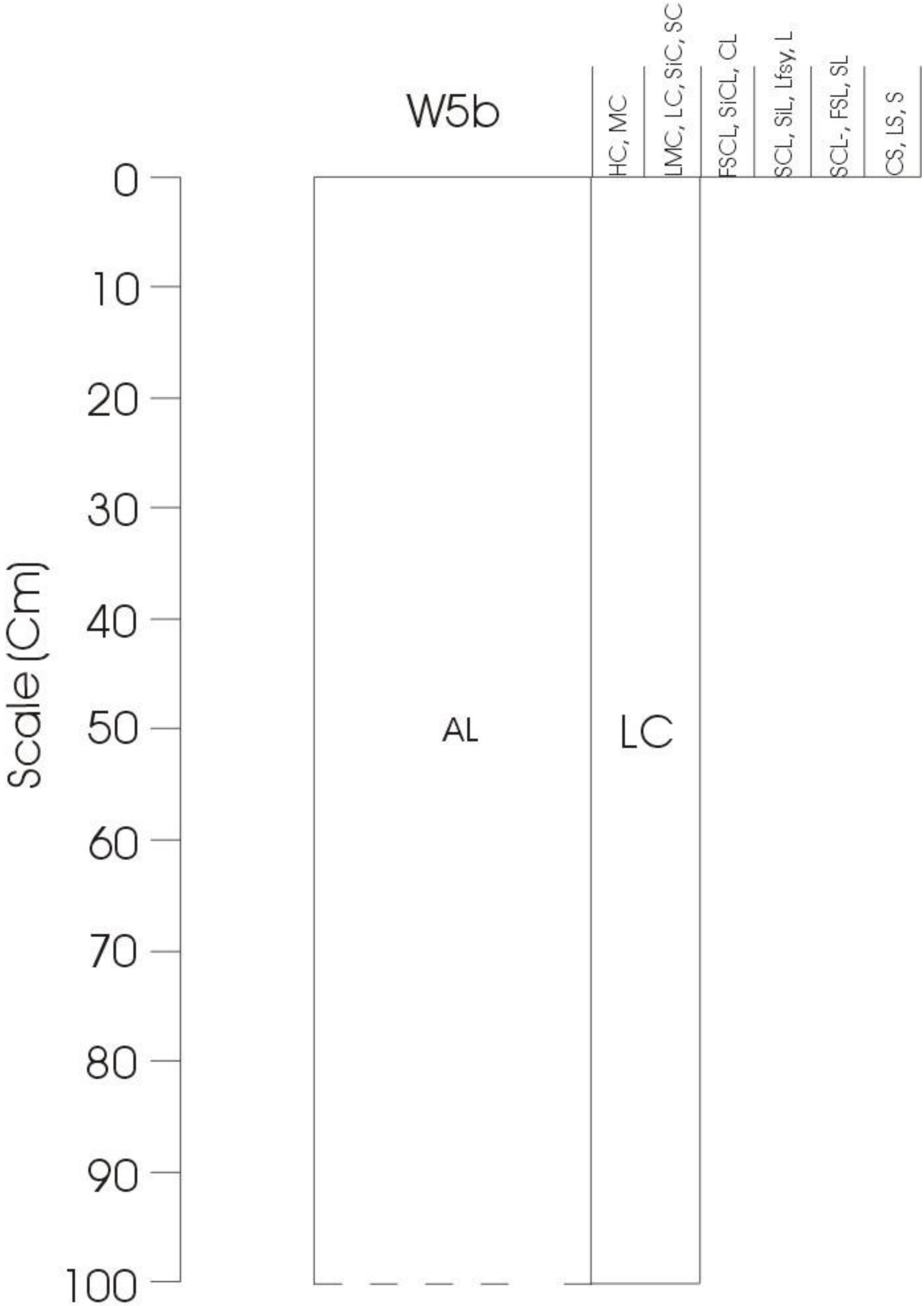
CS
S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LMC, LC, SiC, SC
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SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
Scale (Cm)
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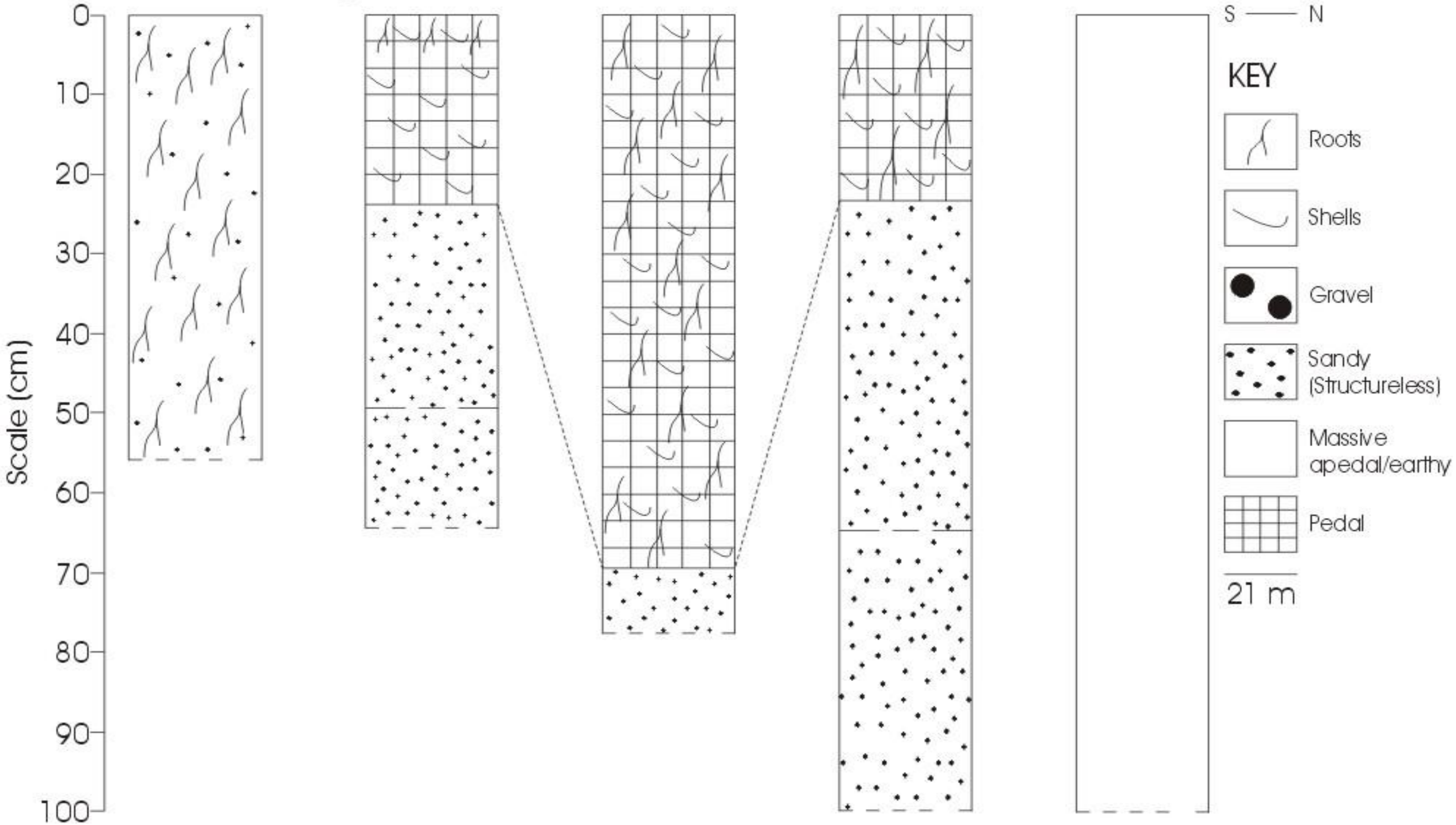
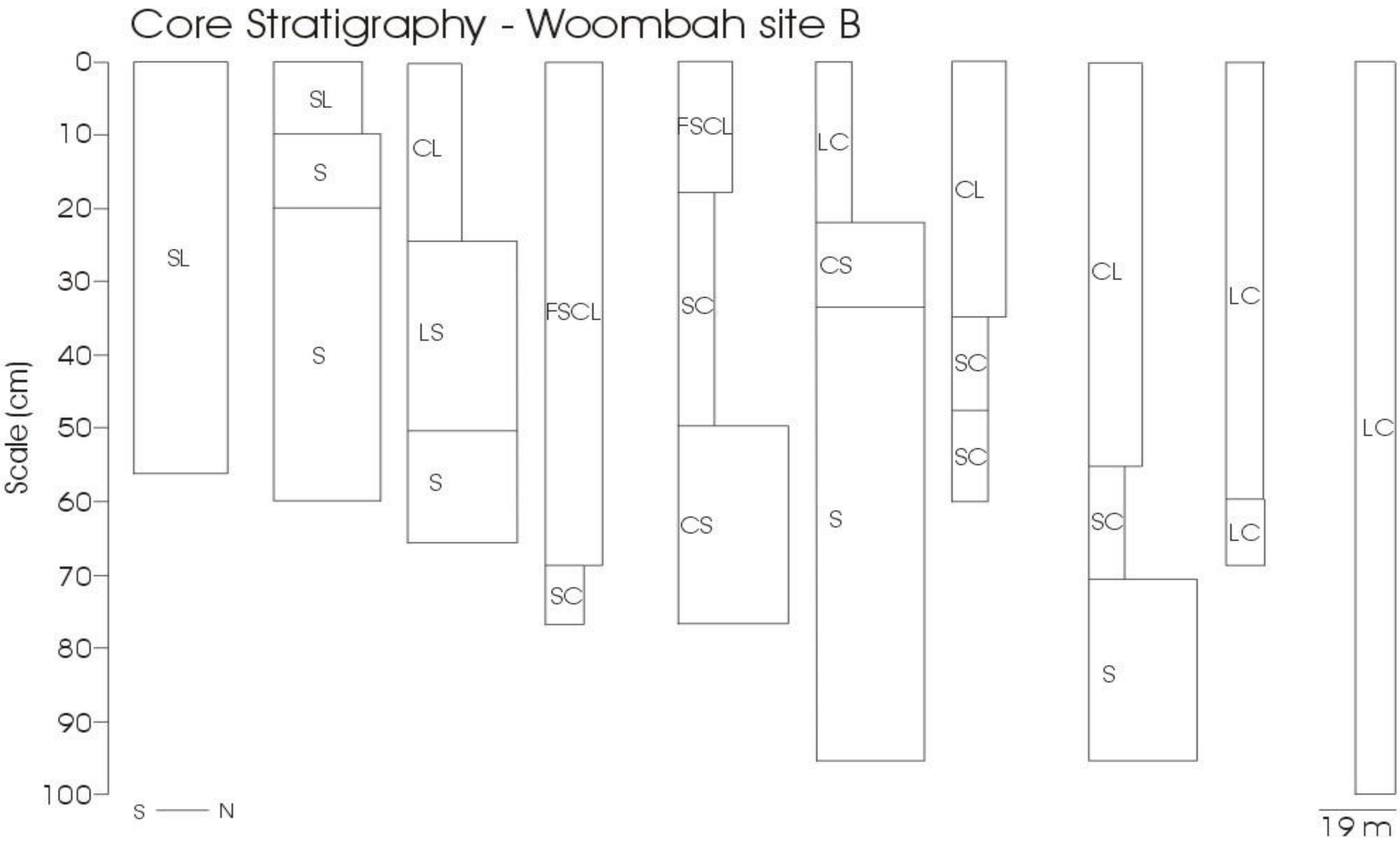
Core Stratigraphy - Woombah site B





Core Stratigraphy - Woombah site B
Scale (cm)
0
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CL
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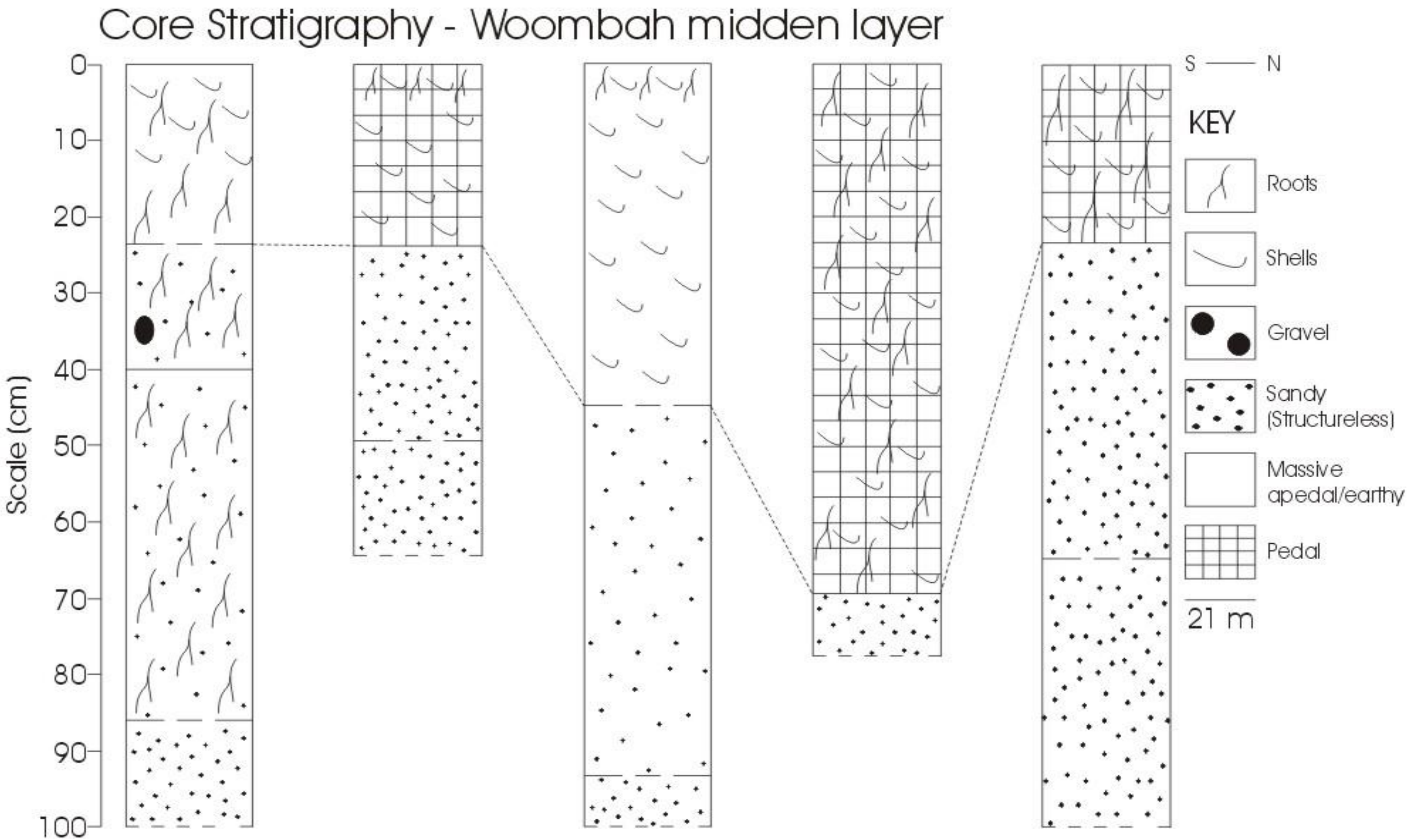
Core Stratigraphy - Woombah midden layer
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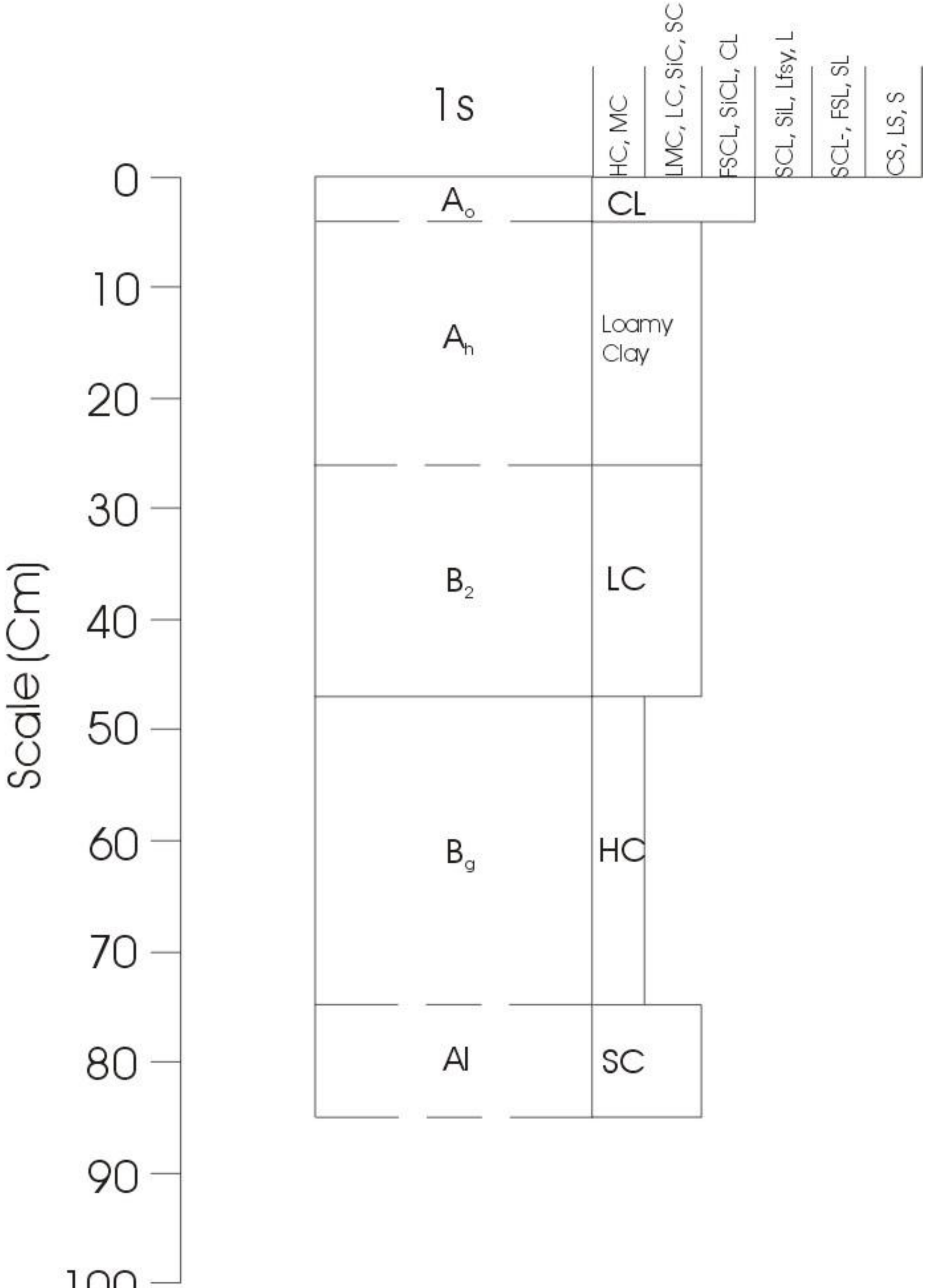
Scale (cm)
S — N
KEY
Roots
Shells
Gravel
Sandy (Structureless)
Massive apedal/earthy
Pedal
21 m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SCL, SiL, Lfsy, L
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CS, LS, S
Scale (Cm)
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Loamy Clay
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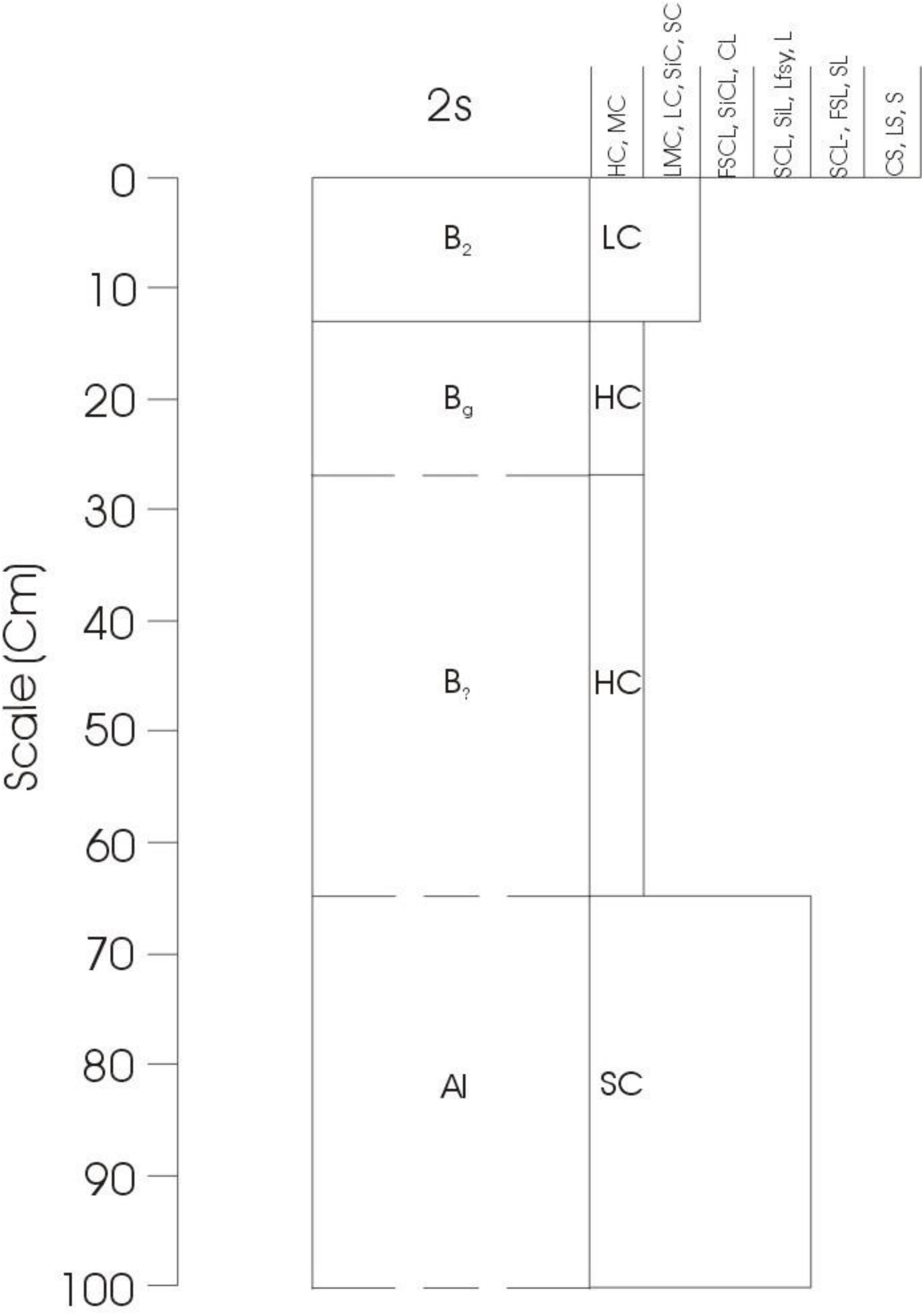
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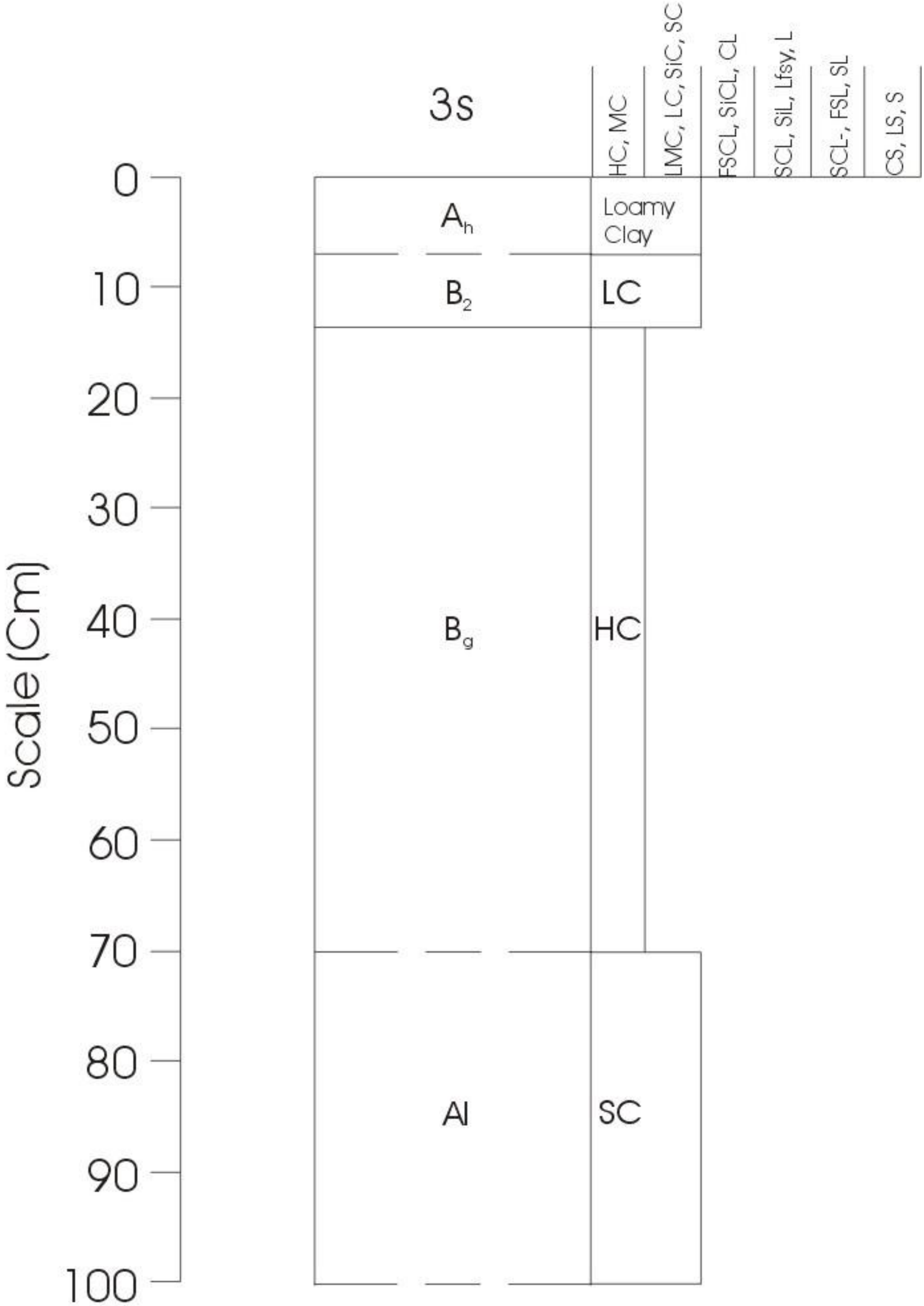
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LMC, LC, SiC, SC
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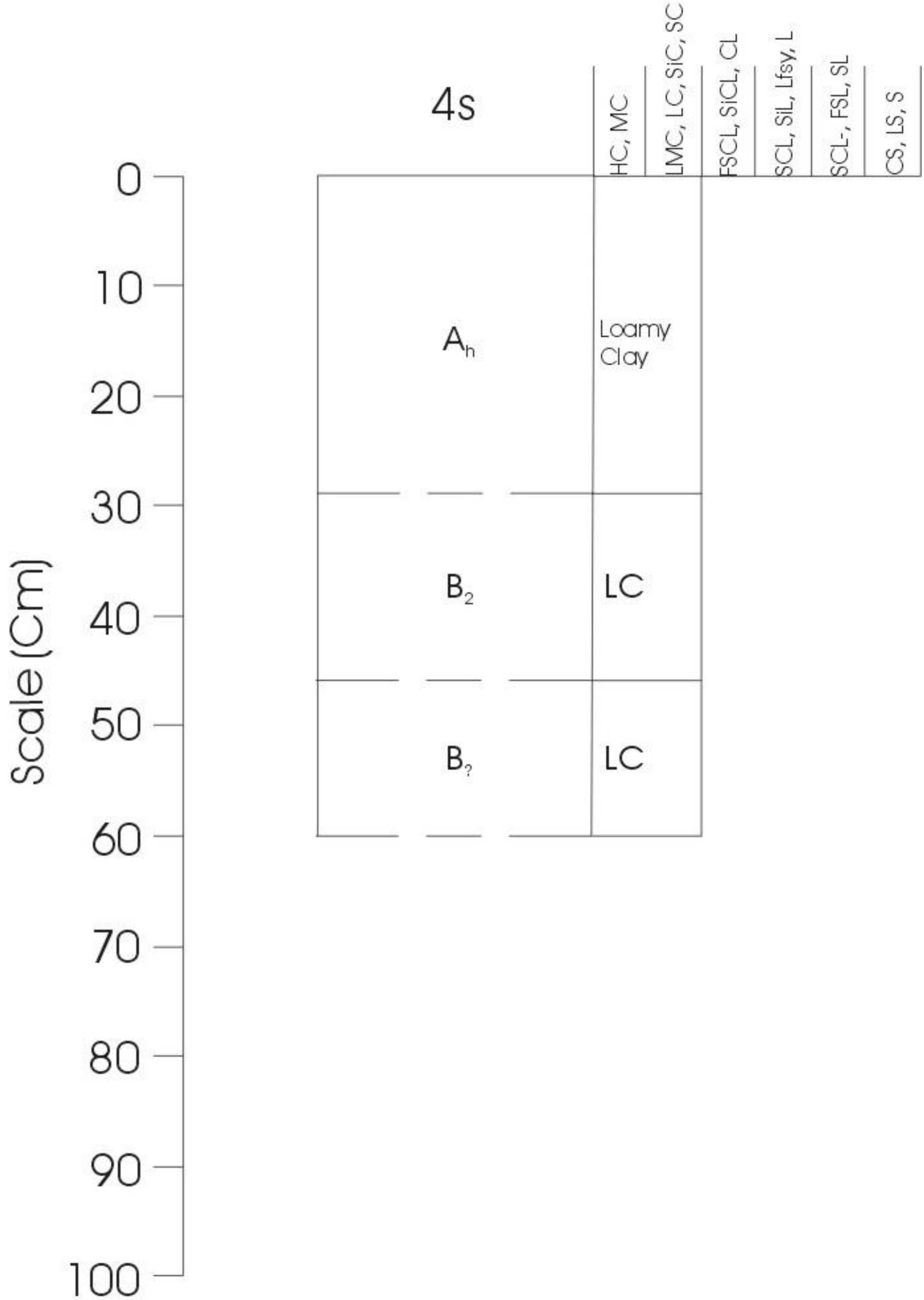
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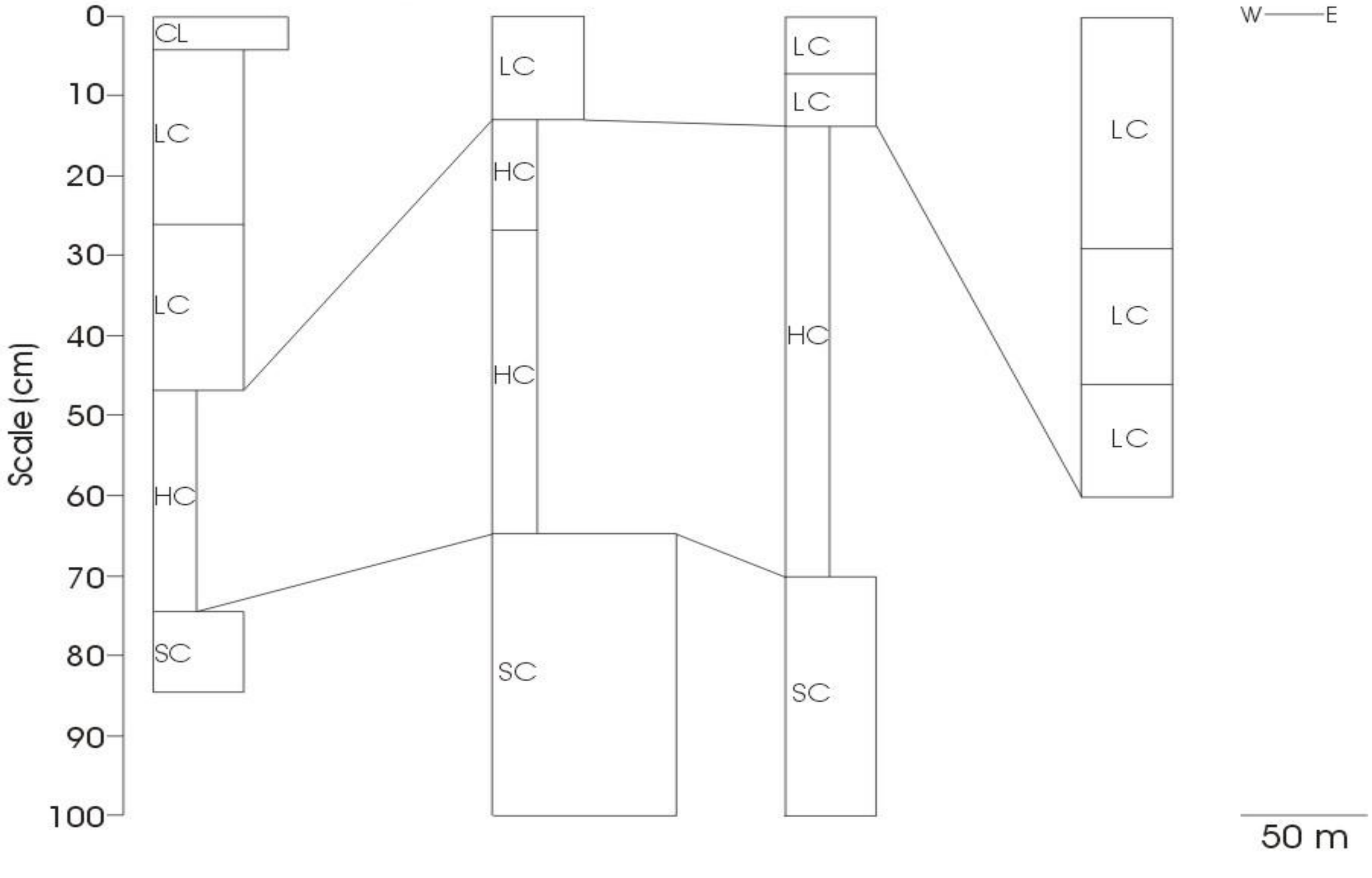
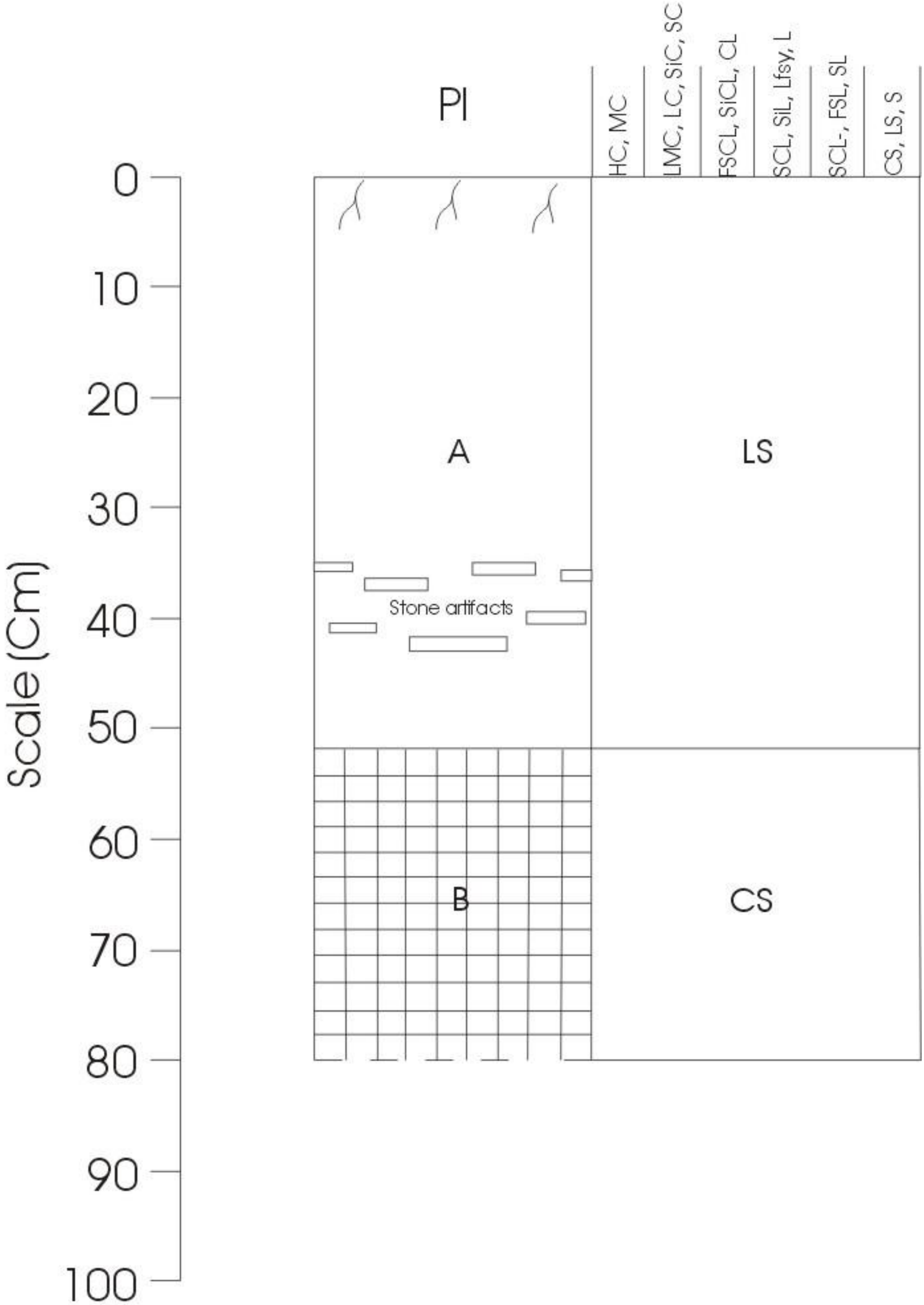
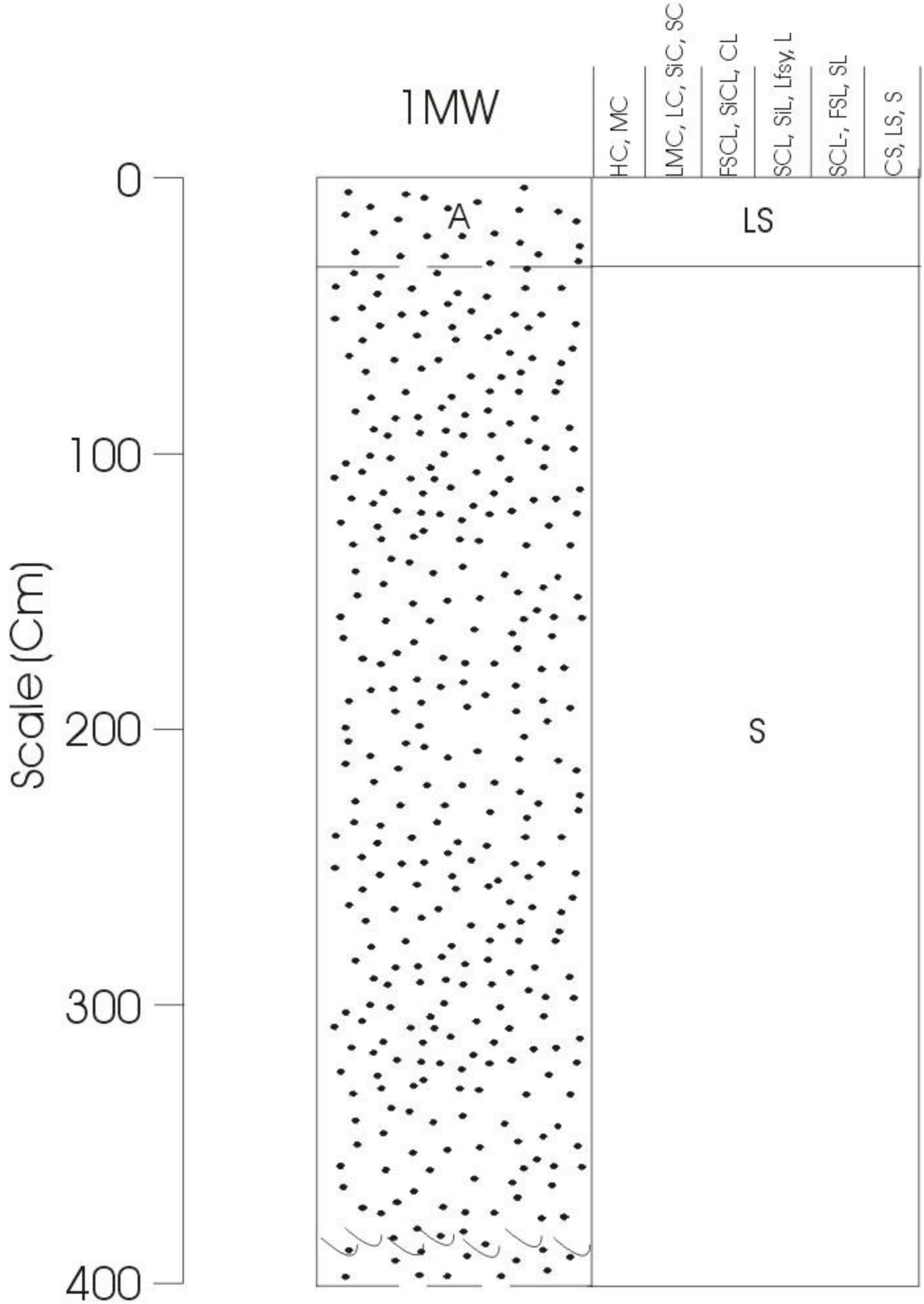
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
Scale (Cm)
0
10
20
30
40
50
60
70
80
90
100
A h
Loamy Clay
B 2
LC
B ?
LC

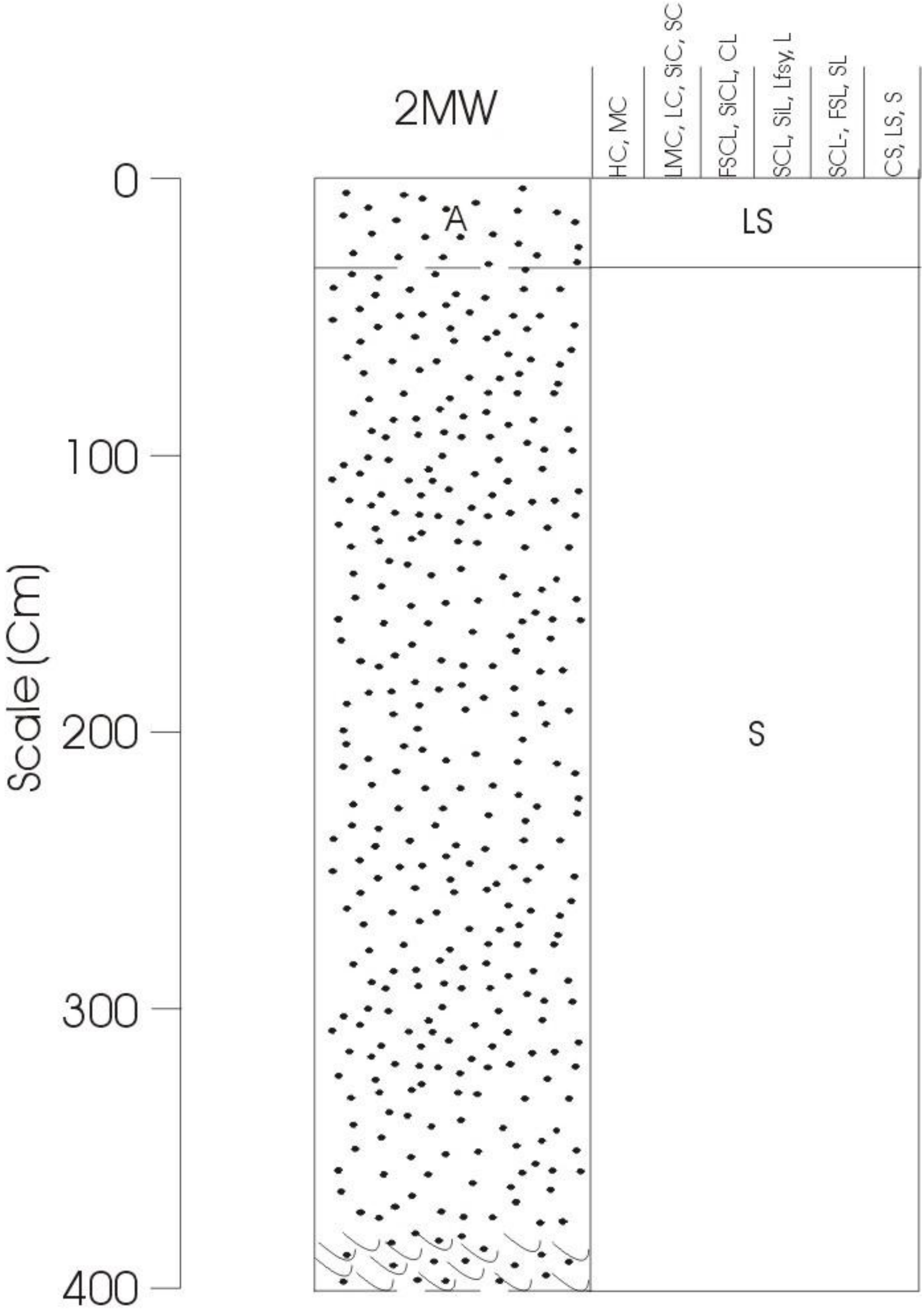
Core Stratigraphy - Sleeper Island

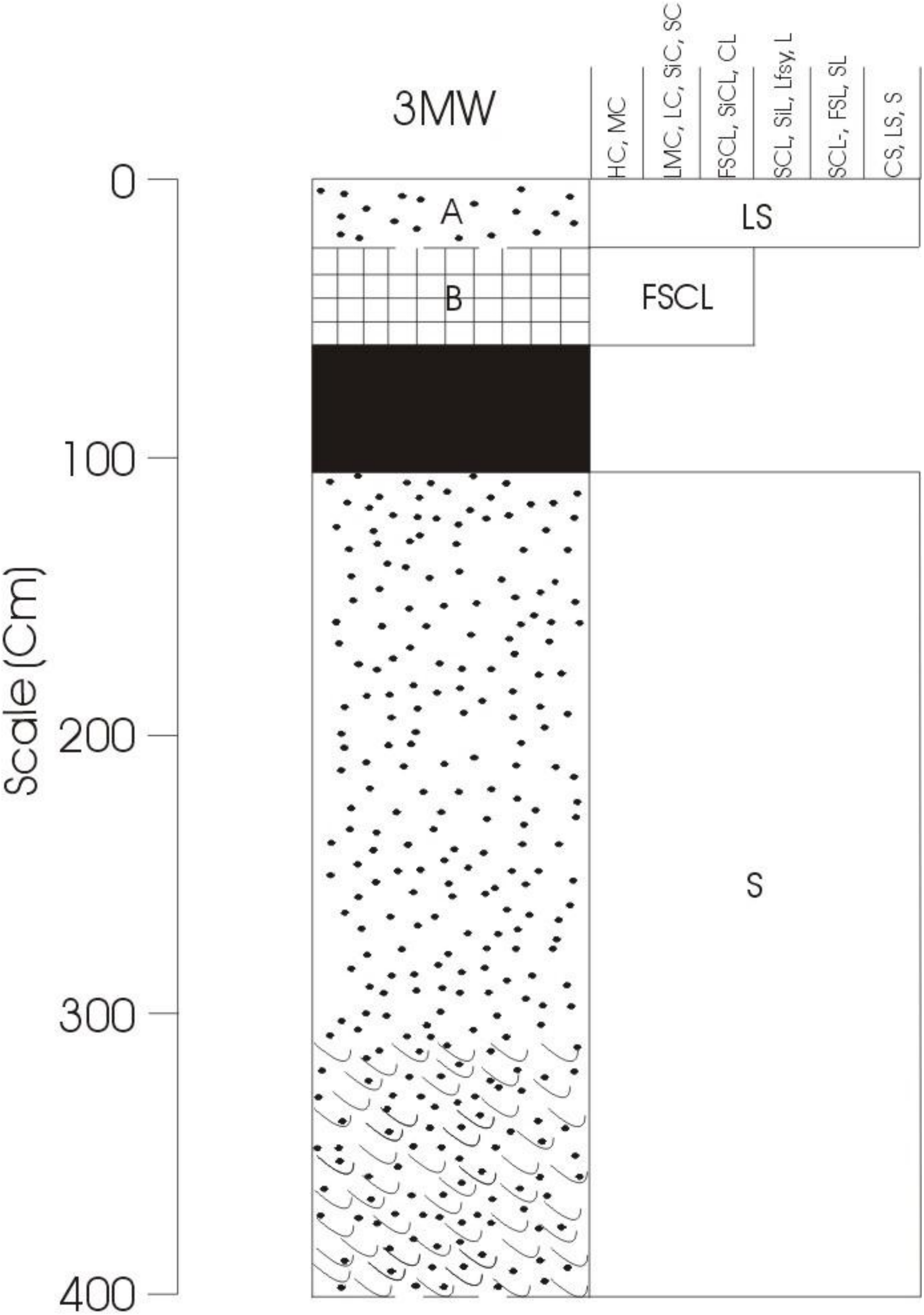




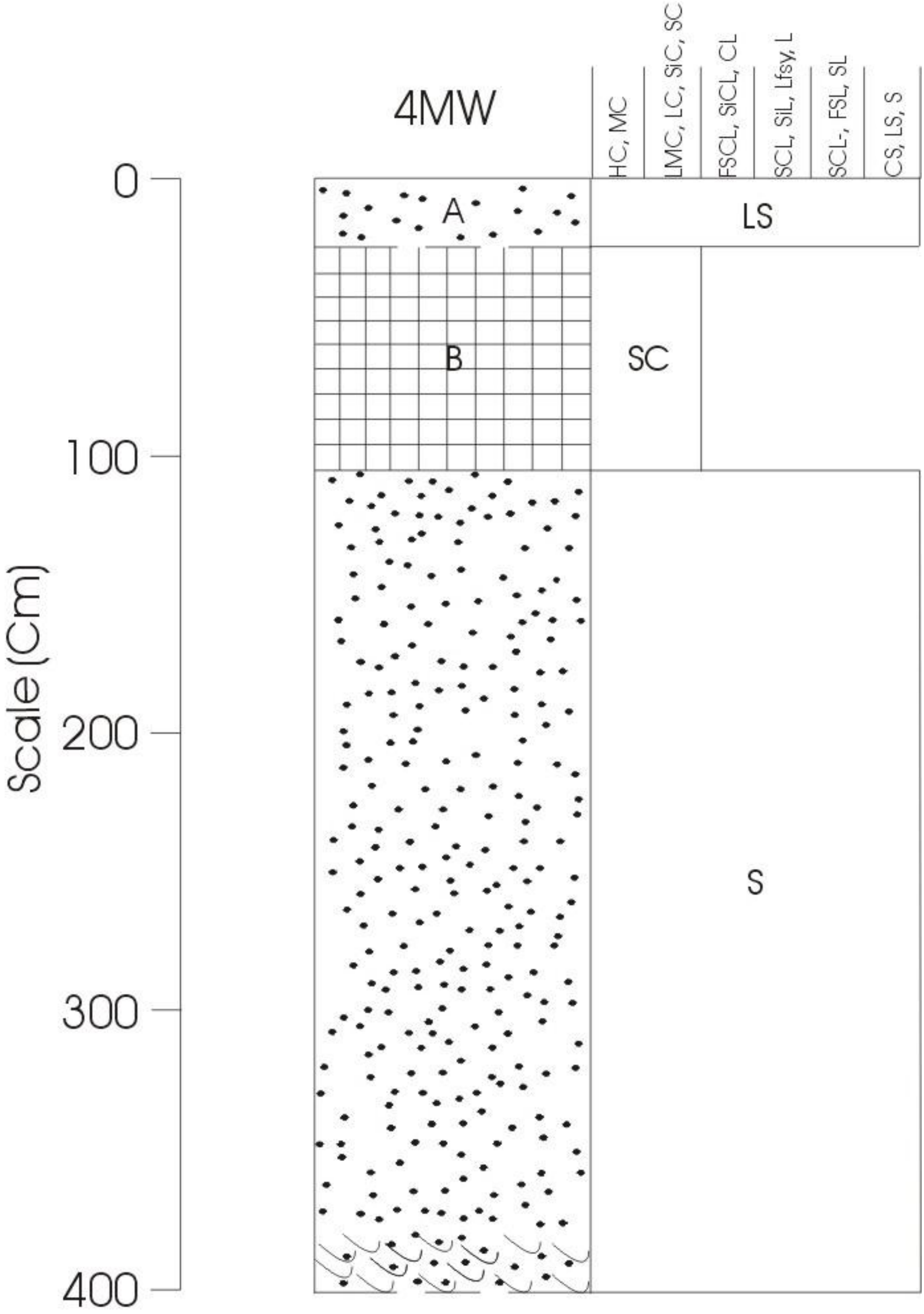
Pl
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
0
10
20
30
40
50
60
70
80
90
100
Scale (Cm)
A
Stone artifacts
B
LS
CS


1MW
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
0
100
200
300
400
Scale (Cm)
A
LS
S

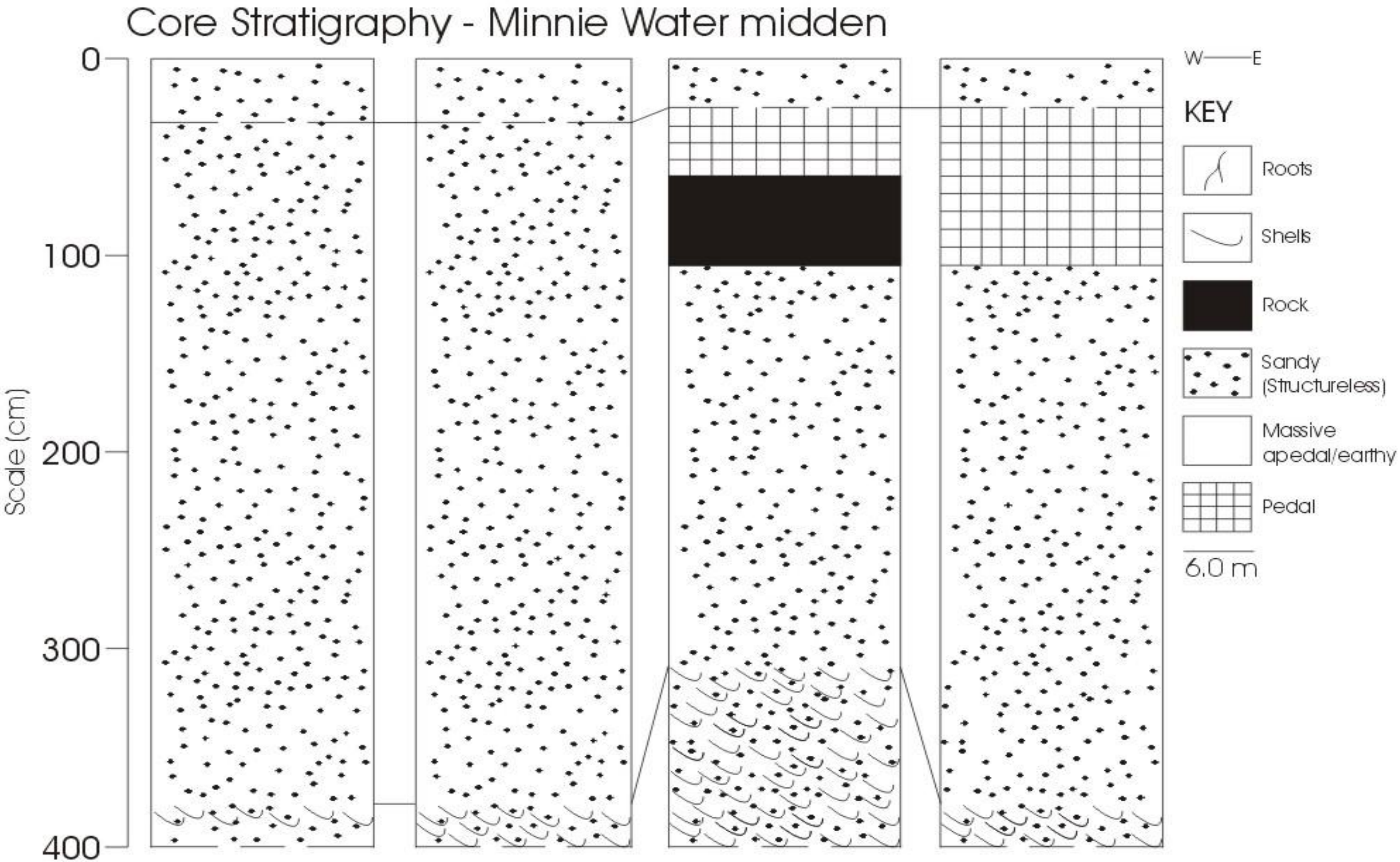

2MW
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
Scale (Cm)
0
100
200
300
400
A
LS
S

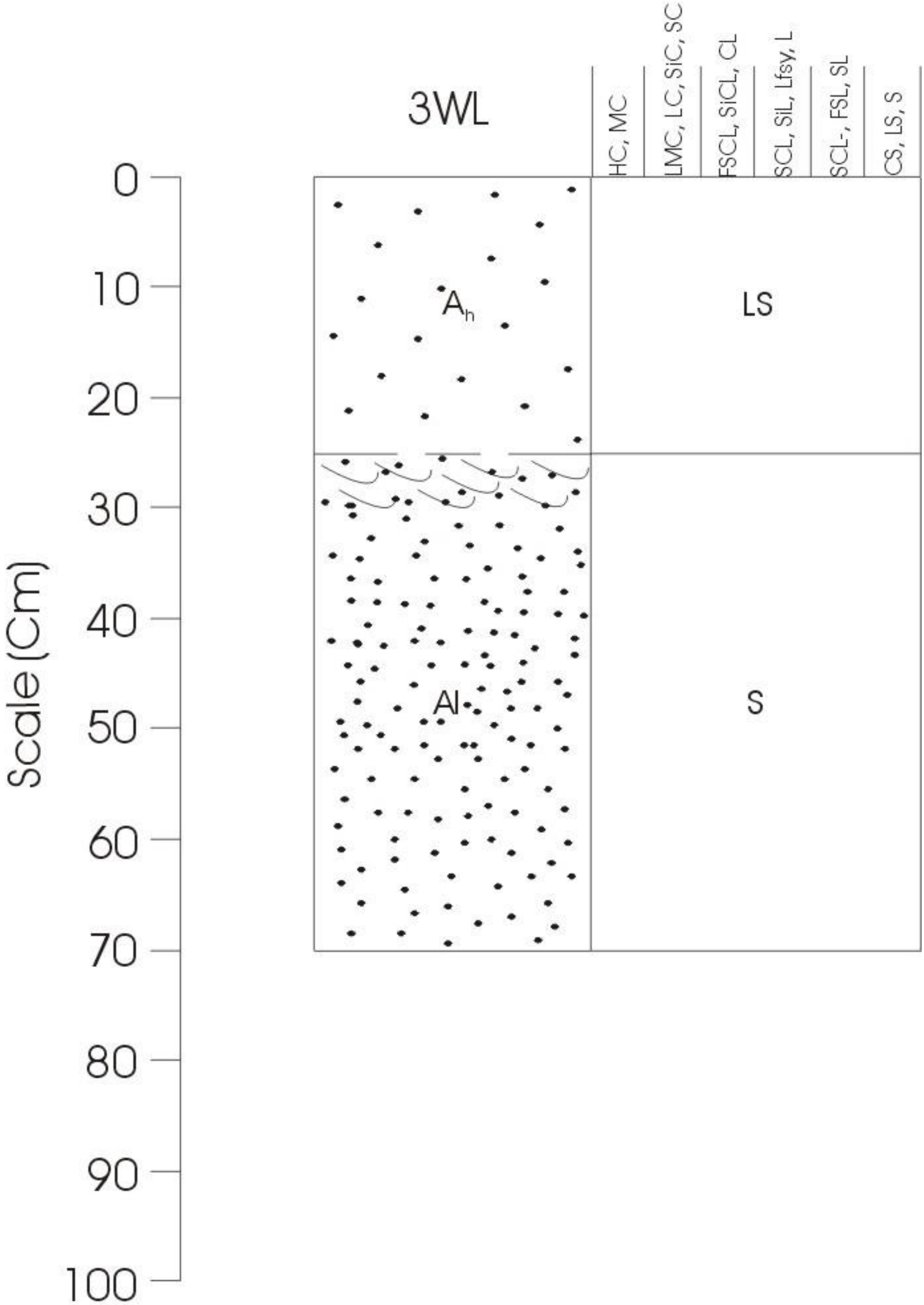


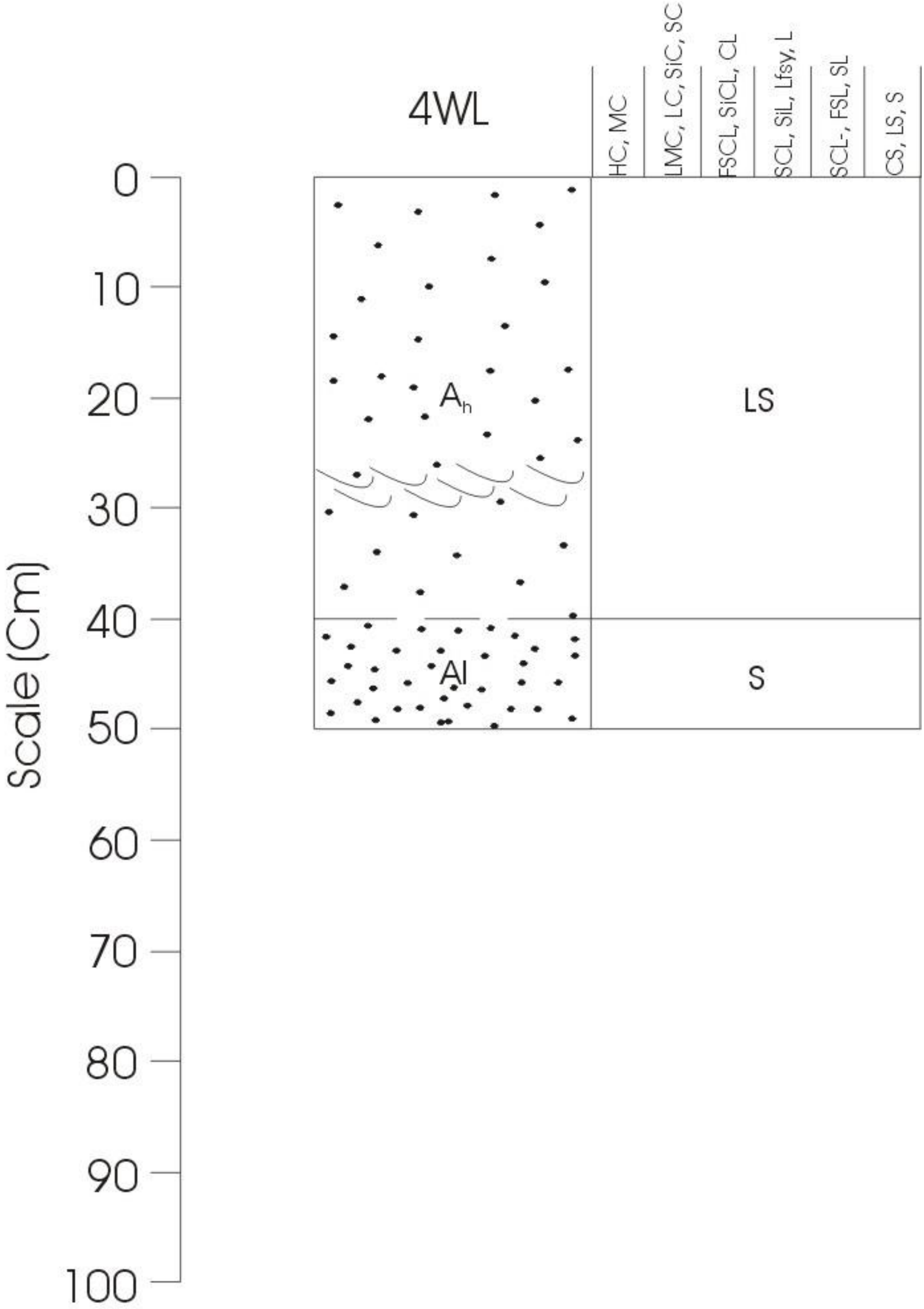
3MW
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
0
100
200
300
400
Scale (Cm)
A
B
LS
FSCL
S

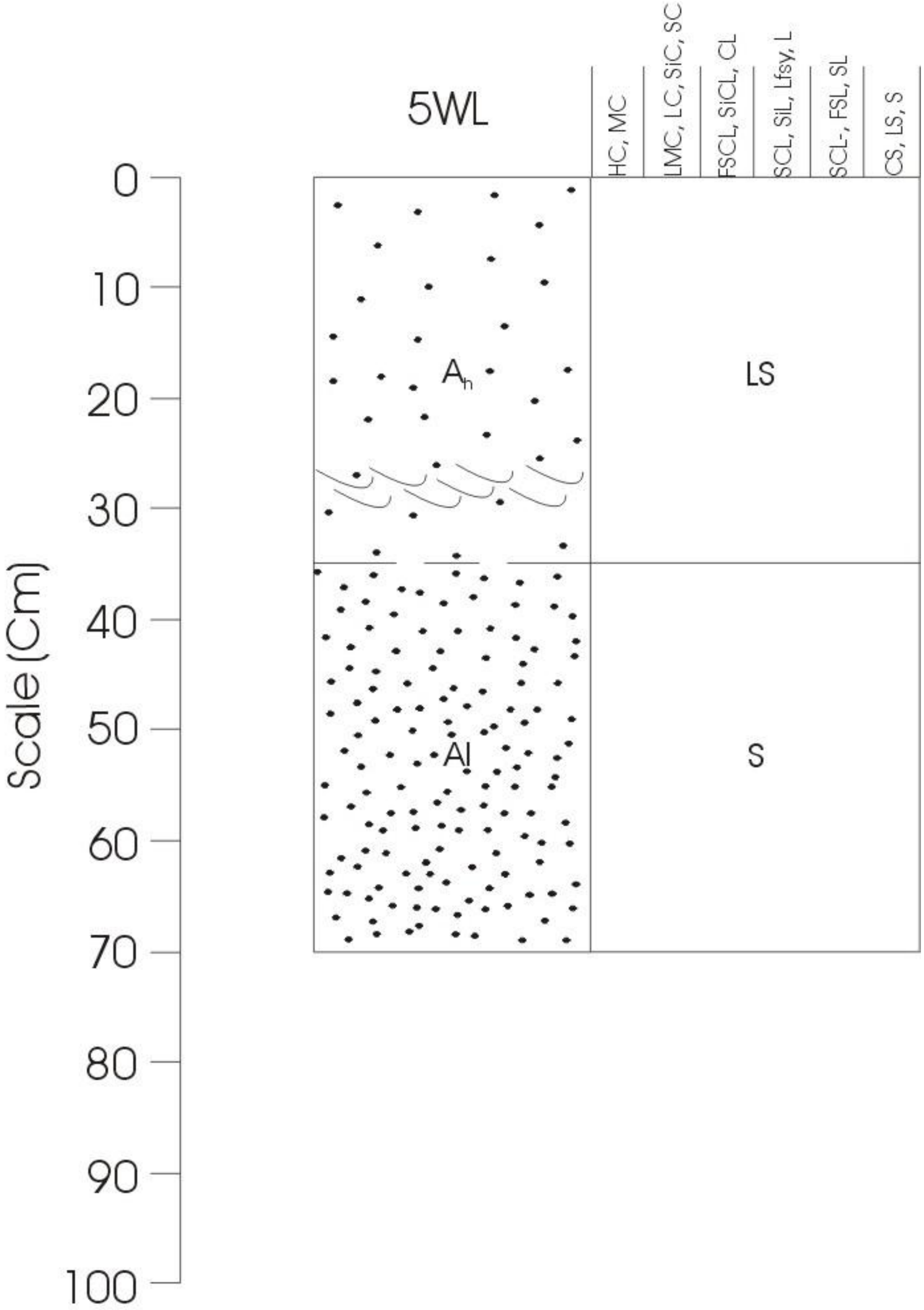


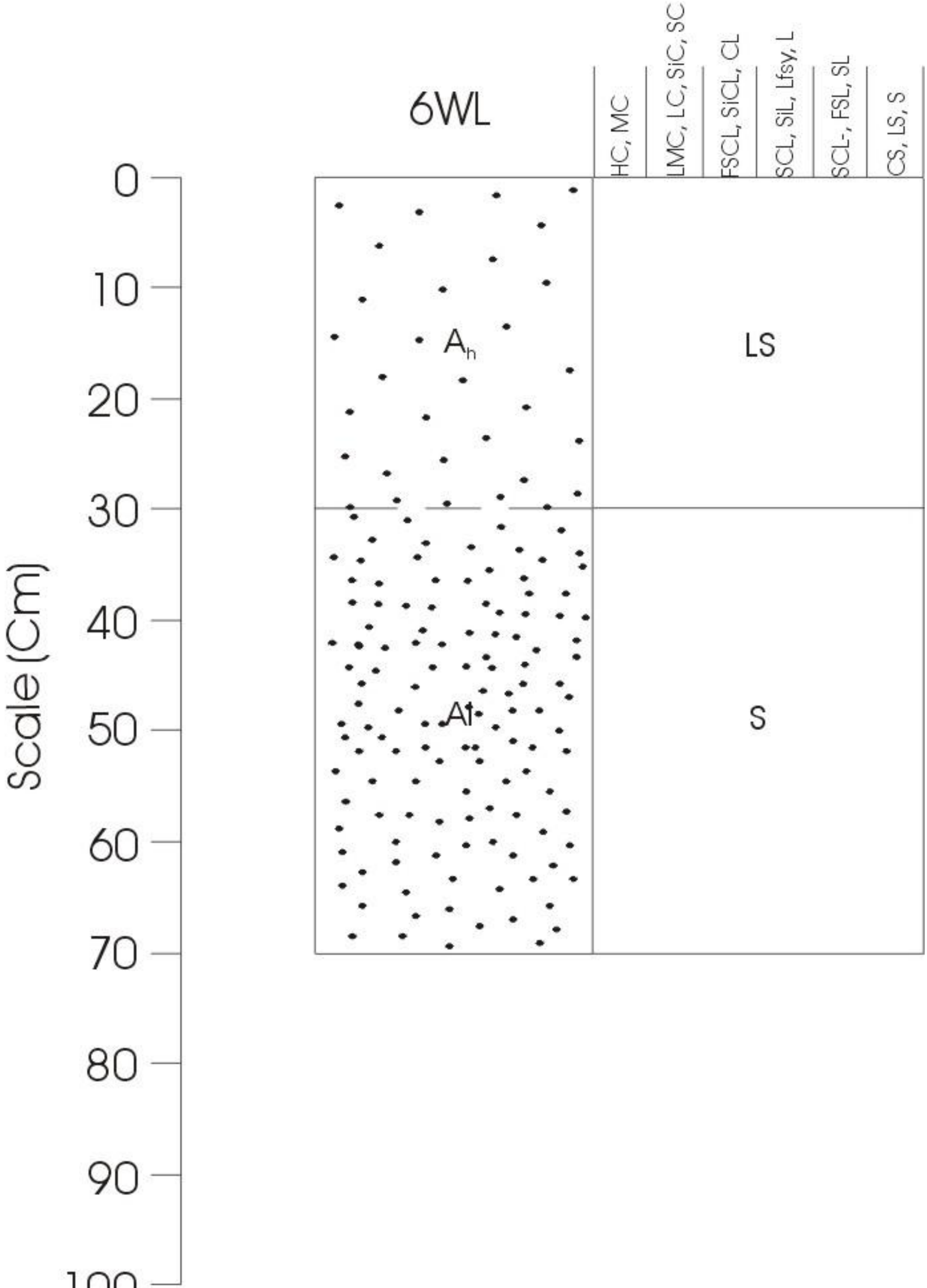
4MW
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
0
100
200
300
400
Scale (Cm)
A
B
LS
SC
S

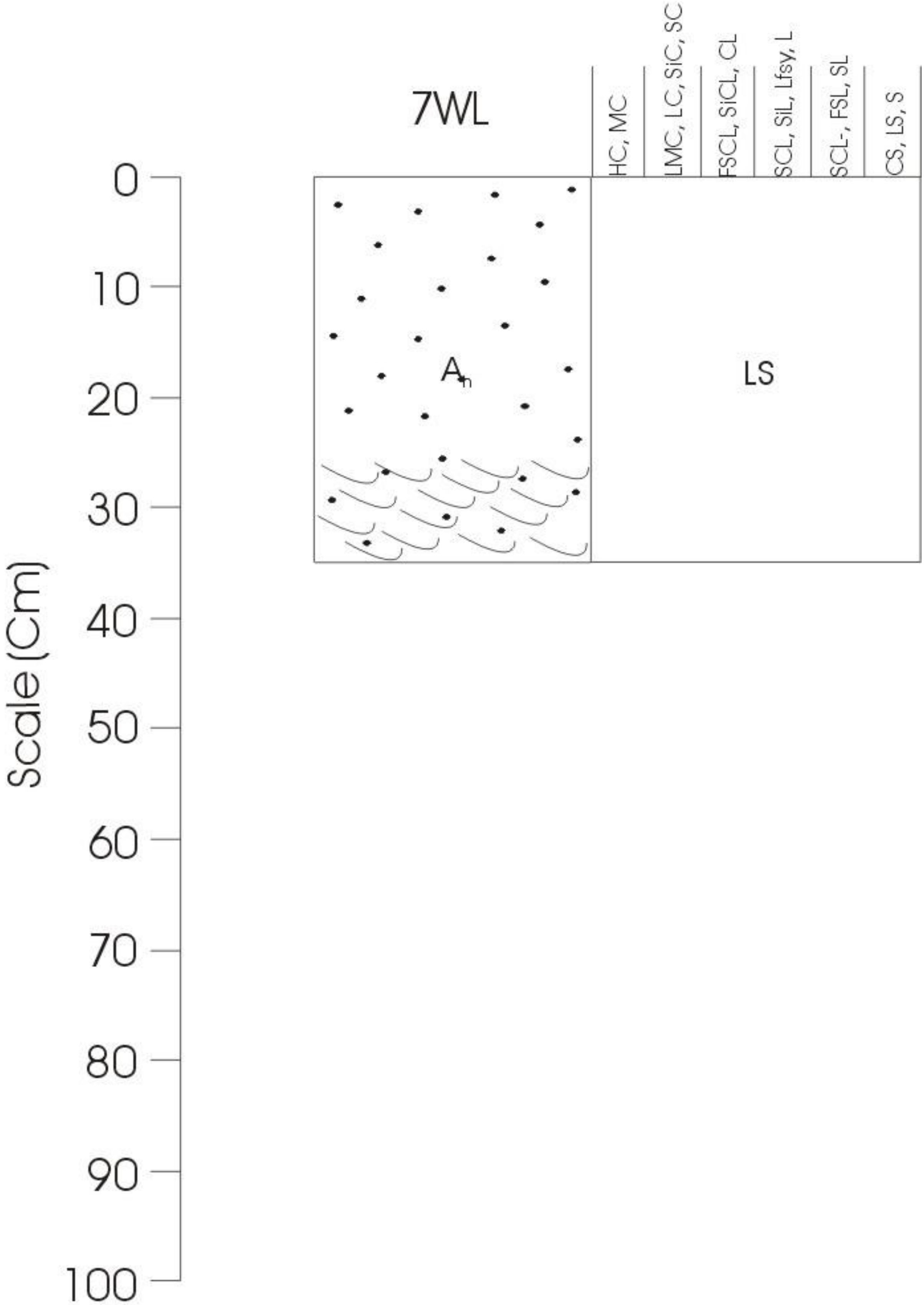

Core Stratigraphy - Minnie Water midden
0
100
200
300
400
Scale (cm)
W——E
KEY
Roots
Shells
Rock
Sandy
(Structureless)
Massive
apedal/earthy
Pedal
6.0 m

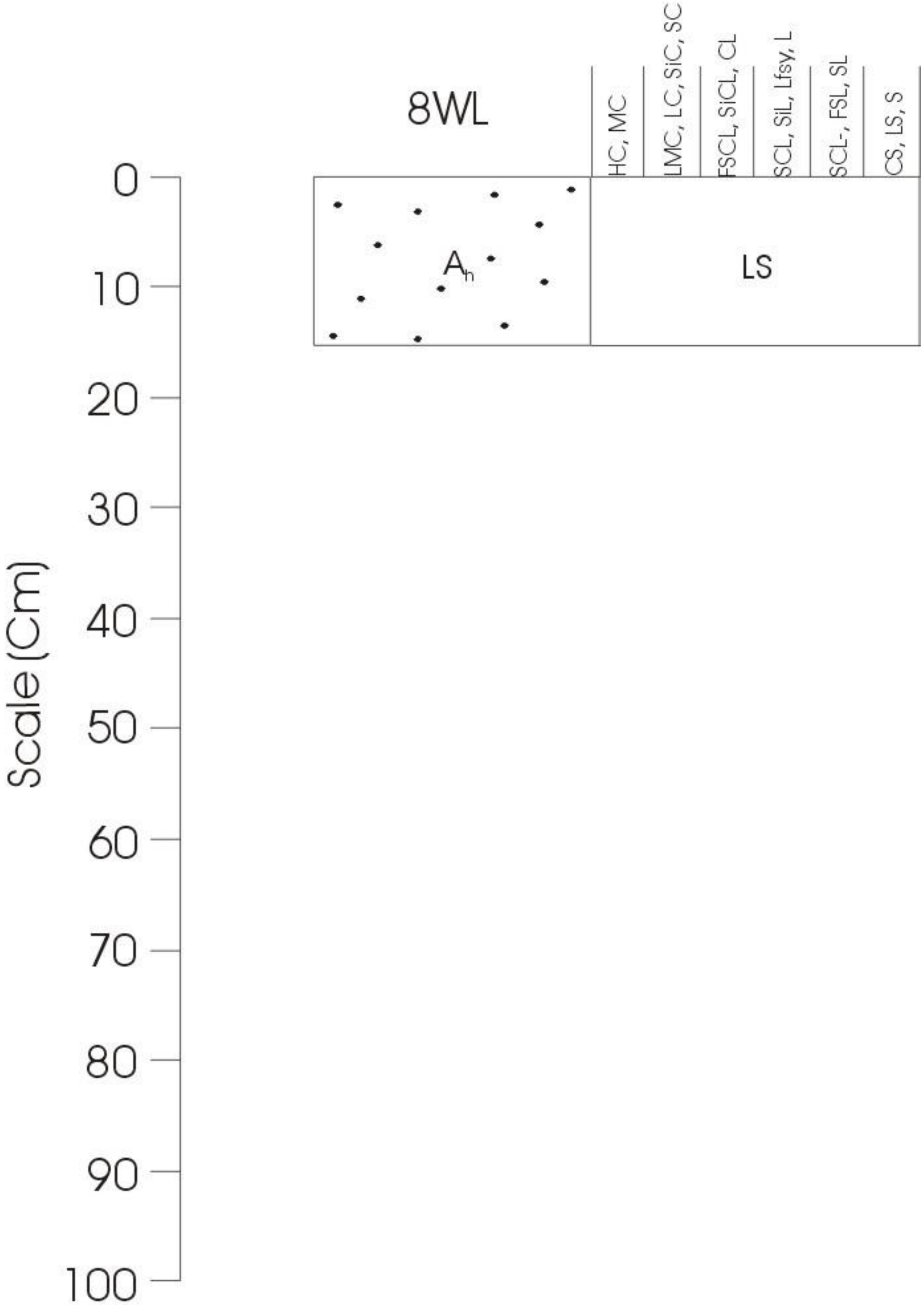

3WL
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
Scale (Cm)
0
10
20
30
40
50
60
70
80
90
100
A_h
LS
Al
S


4WL
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
0
10
20
30
40
50
60
70
80
90
100
Scale (Cm)
Ah
LS
Al
S

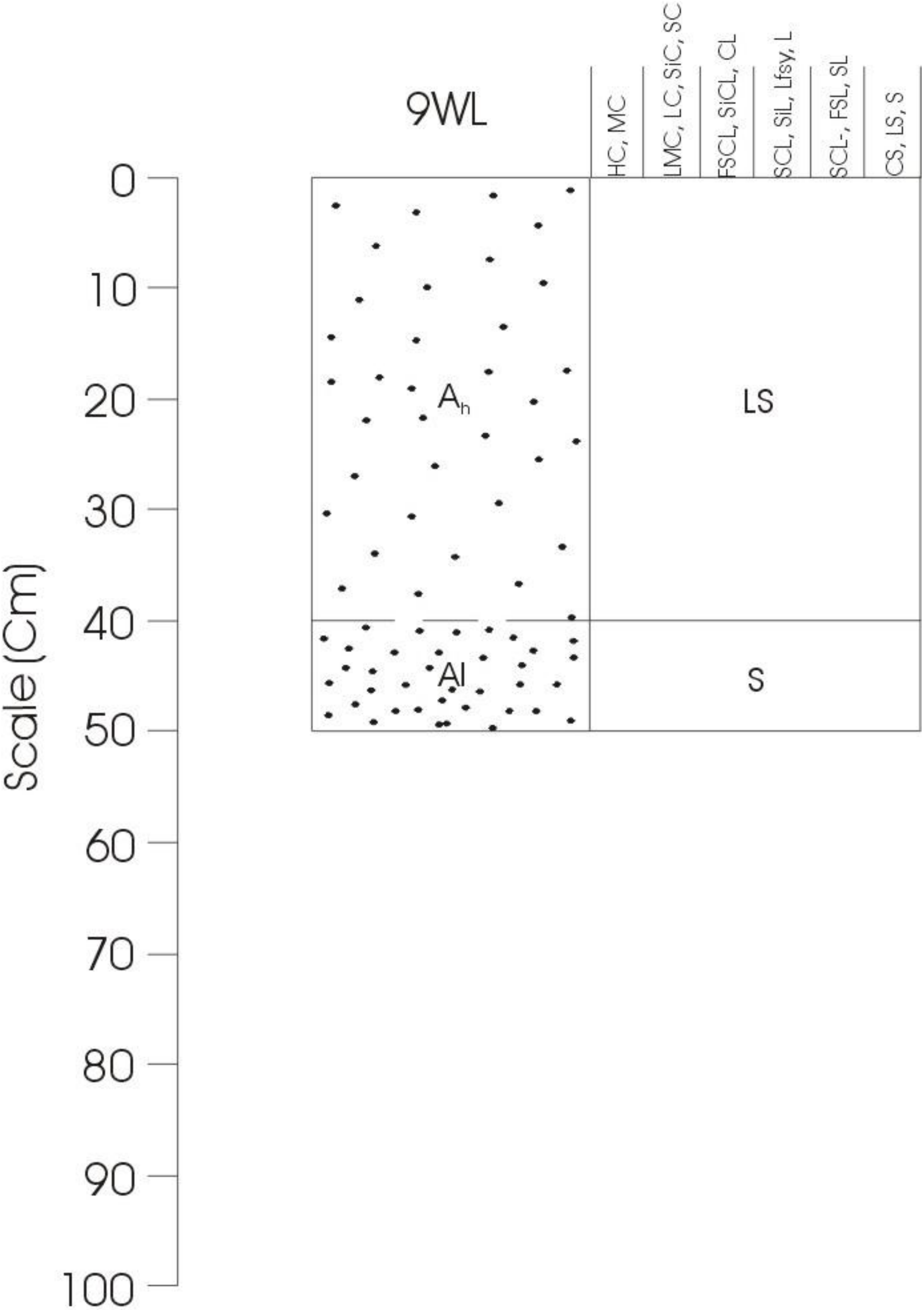

5WL
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
0
10
20
30
40
50
60
70
80
90
100
Scale (Cm)
A_h
LS
Al
S


6WL
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
Scale (Cm)
0
10
20
30
40
50
60
70
80
90
100
Ah
At
LS
S

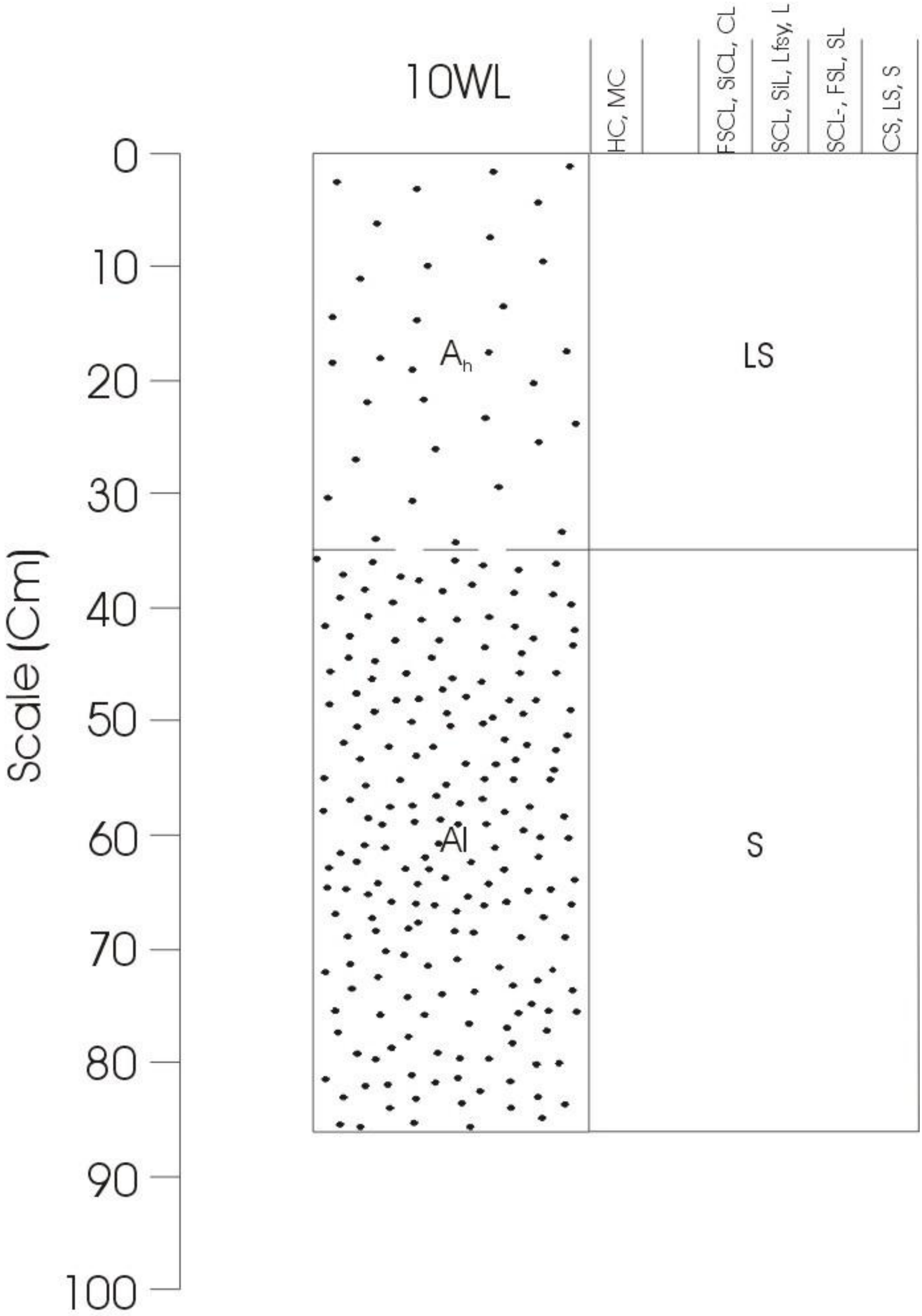

7WL
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
0
10
20
30
40
50
60
70
80
90
100
Scale (Cm)
Ah
LS



8WL
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
Scale (Cm)
0
10
20
30
40
50
60
70
80
90
100
A_h
LS

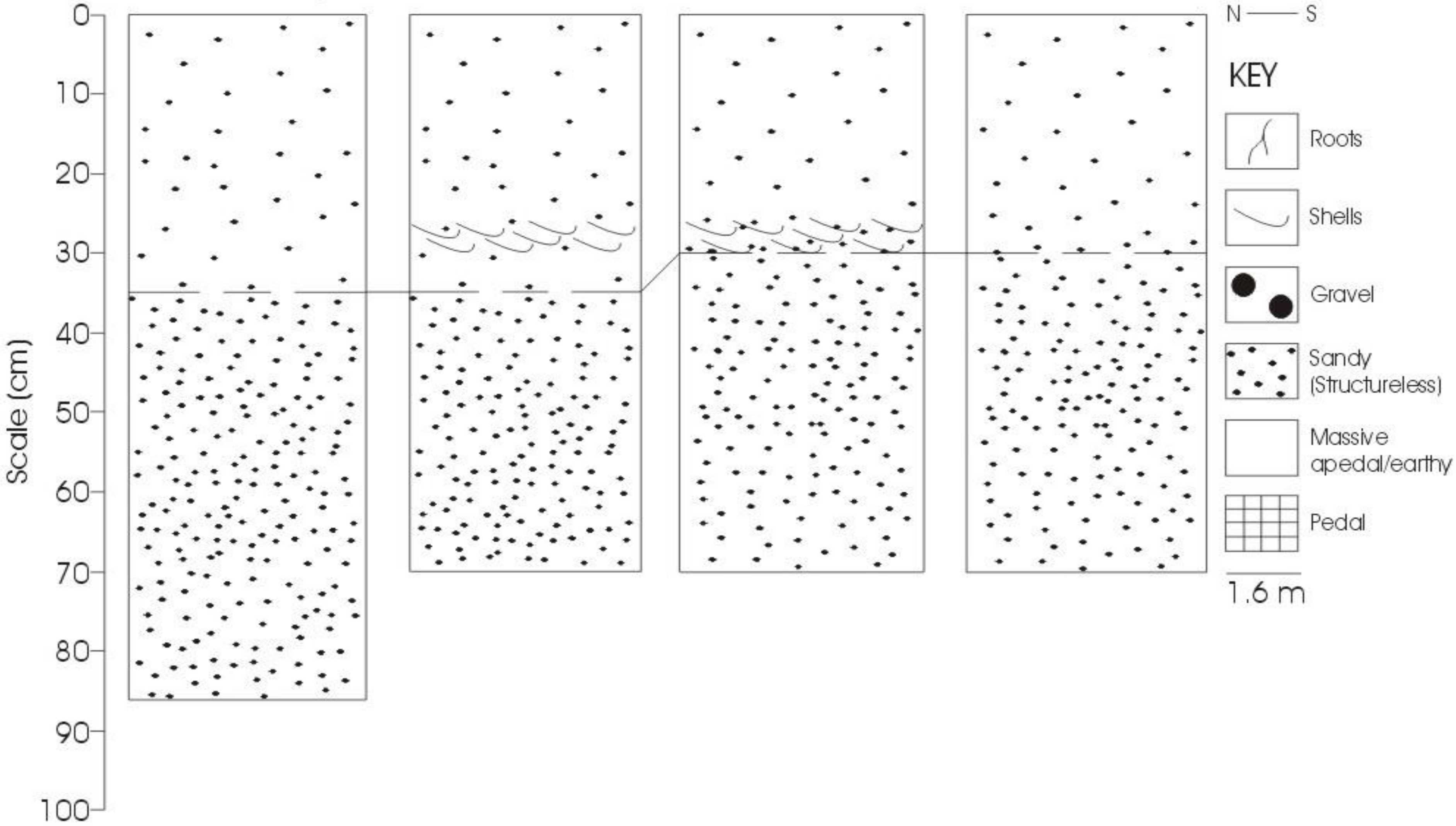


9WL
HC, MC
LMC, LC, SiC, SC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
Scale (Cm)
0
10
20
30
40
50
60
70
80
90
100
A_h
LS
Al
S

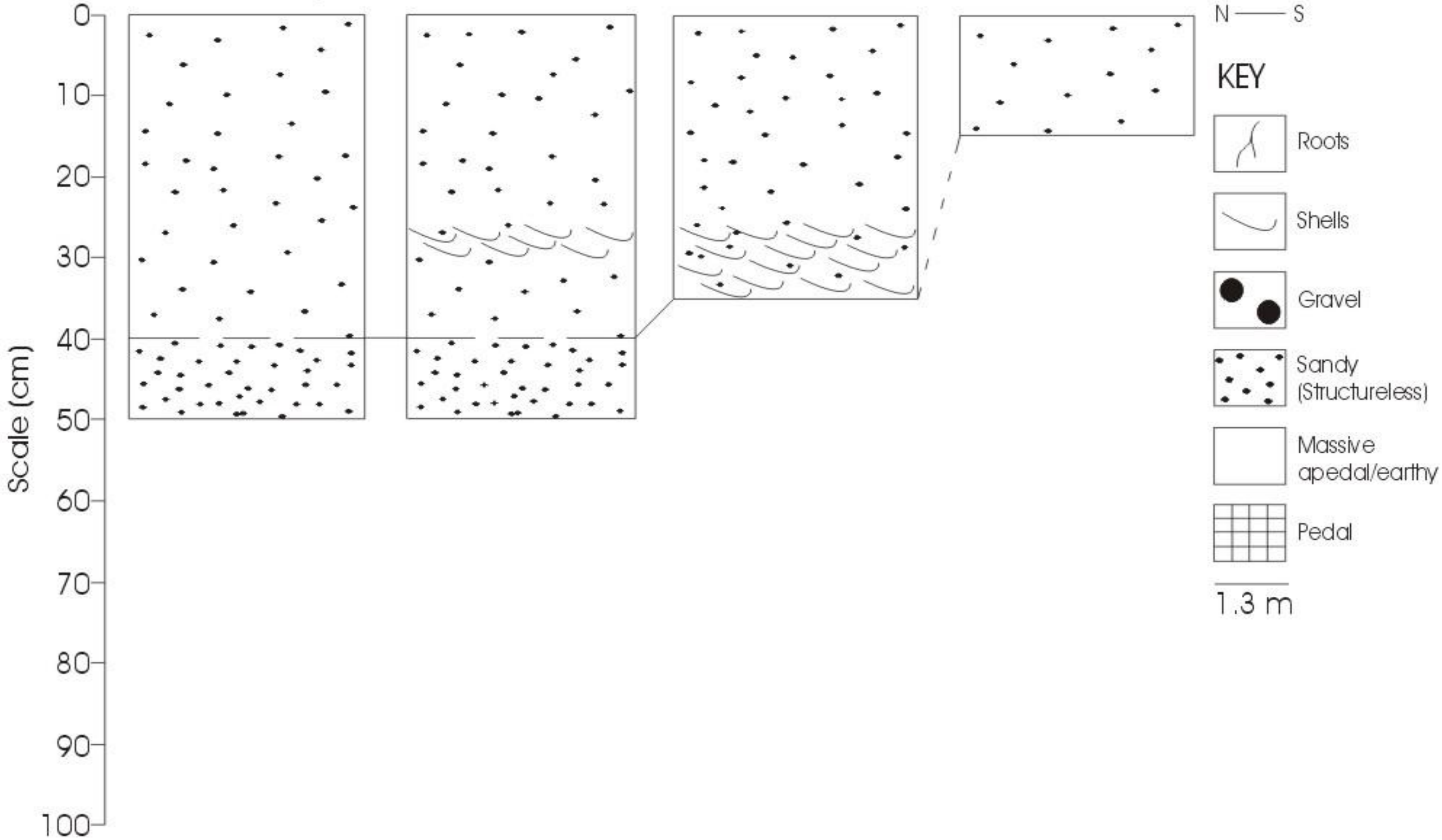


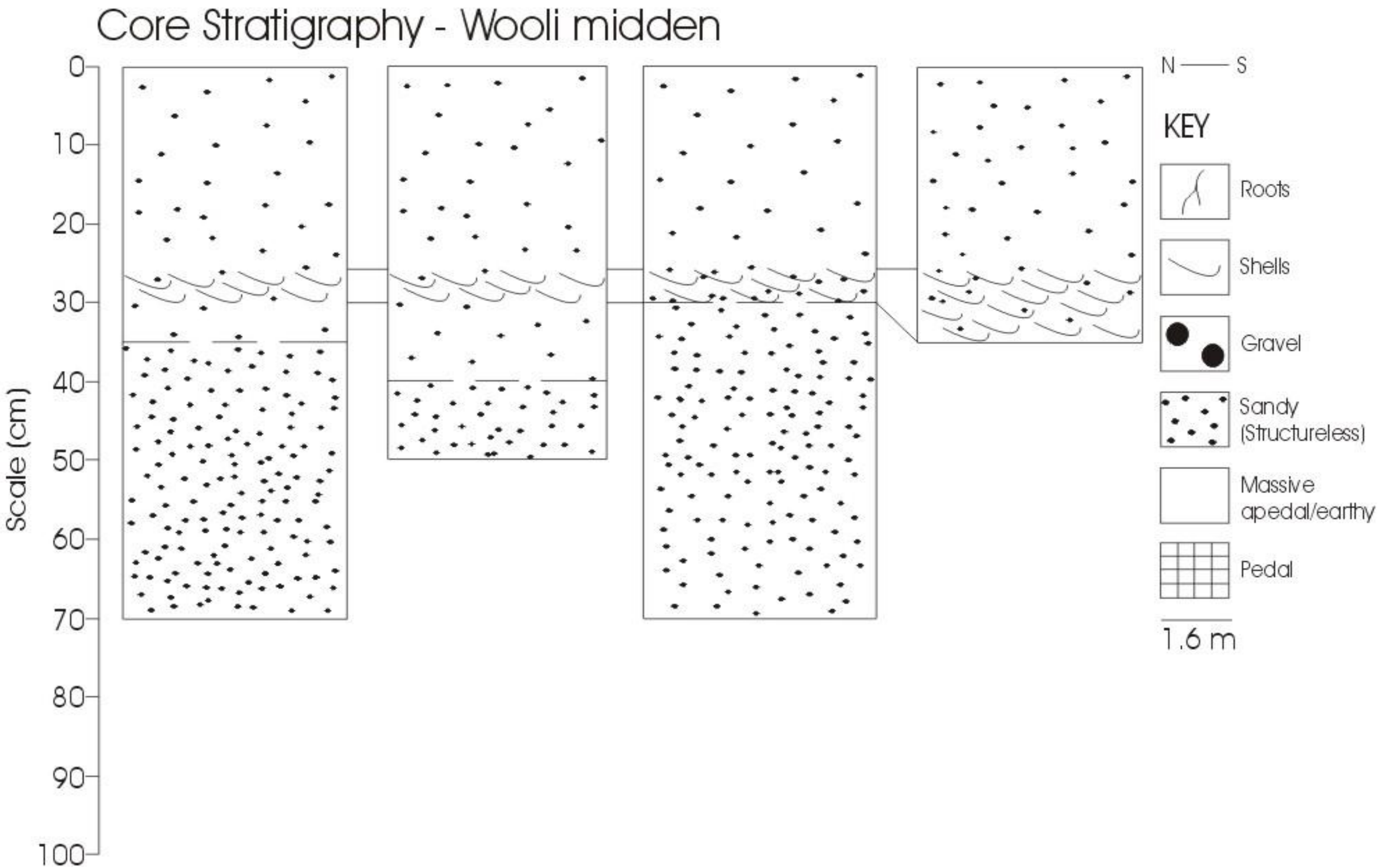
10WL
HC, MC
FSCL, SiCL, CL
SCL, SiL, Lfsy, L
SCL-, FSL, SL
CS, LS, S
0
10
20
30
40
50
60
70
80
90
100
Scale (Cm)
Ah
LS
Al
S

Core Stratigraphy - Wooli midden eastern extent



Core Stratigraphy - Wooli midden western extent




Core Stratigraphy - Wooli midden
Scale (cm)
0
10
20
30
40
50
60
70
80
90
100
N — S
KEY
Roots
Shells
Gravel
Sandy (Structureless)
Massive apedal/earthy
Pedal
1.6 m

APPENDIX 2

RESULTS OF SEDIMENT ANALYSES AS USED IN THE GIS EROSION HAZARD ASSESSMENT MODEL

FID	SITE ID	SAMPLE NO.	MGA ZONE	MGA EASTING	MGA NORTHING	DEPTH CM	MUNS. COLOUR	MUNSELL DESCRIPTION	FIELD TEXT	PSA TEXT	DOM TEXT	PC SAND	PC SILT	PC CLAY	PSA RISK	PSA RISK NUM	TOC PC	TOC DEFN	TOC RISK	TOC RISK NUM	EMAG NO.	EM_AG NO. RISK
0	WA	1A0	56	528570	6751431	0	2.5Y6/1	Grey	LS	SAND	SAND	100	0	0	Low	1	4.672	Moderate	Moderate	2	7	0
1	WA	1A22	56	528570	6751431	22	2.5Y4/1	Dark grey	SL	SAND	SAND	100	0	0	Low	1	1.979	Low	High	3	7	0
2	WA	1A60	56	528570	6751431	60	2.5Y2/2, lens 5Y3/2	Black	LS	SAND	SAND	100	0	0	Low	1	0.642	Low	High	3	N/A	
3	WA	1A90	56	528570	6751431	90	2.5Y7/1	Light grey	S	SAND	SAND	100	0	0	Low	1	0.15	Low	High	3	N/A	
4	WA	2A0	56	528547	6751322	0	10YR2/2	Very dark brown	Lfsy	SAND	SAND	94.7188	4.88	0.4012	Low	1	9.626	High	Low	1	7	0
5	WA	2A24	56	528547	6751322	24	10YR4/3	Brown	SL	SAND	SAND	100	0	0	Low	1	2.67	Low	High	3	2(1)	3
6	WA	2A40	56	528547	6751322	40	10YR6/4	Light yellowish brown	LS	SAND	SAND	99.1578	0.8422	0	Low	1	0.956	Low	High	3	N/A	
7	WA	2A86	56	528547	6751322	86	10YR7/2	Light grey	S	SAND	SAND	100	0	0	Low	1	0.42	Low	High	3	N/A	
8	WA	3A0	56	528514	6751304	0	2.5Y3/2	Very dark greyish brown	SL	SAND	SAND	100	0	0	Low	1	7.35	Low	High	3	7	2
9	WA	3A45	56	528514	6751304	45	2.5Y4/2	Dark greyish brown	SL	SAND	SAND	100	0	0	Low	1	0.951	Low	High	3	7	2
10	WA	3A93	56	528514	6751304	93	2.5Y5/2	Greyish brown	S	SAND	SAND	98.5549	1.4451	0	Low	1	0.239	Low	High	3	N/A	
11	WA	4A0	56	528417	6751147	0	5Y3/1	Very dark grey	LS	SAND	SAND	100	0	0	Low	1	7.177	Moderate	Moderate	2	2(1)	3
12	WA	5A0	56	528355	6751140	0	5Y6/2	Light olive grey	N/A	N/A	N/A	N/A	N/A	N/A			N/A				N/A	
13	WA	5A13	56	528355	6751140	13	5Y7/1	Light grey	S	N/A	SAND	N/A	N/A	N/A	Low	1	N/A				N/A	

14	WA	5A38	56	528355	6751140	38	5Y5/2	Olive grey	S	N/A	SAND	N/A	N/A	N/A	Low	1	N/A				N/A	
15	WA	5A44	56	528355	6751140	44	10YR3/2	Very dark greyish brown	N/A	N/A	N/A	N/A	N/A	N/A			N/A				N/A	
16	WB	1B0	56	527971	6751318	0	10YR2/2	Very dark brown	SL	SAND	SAND	100	0	0	Low	1	9.041	High	Low	1	3 (4)	2
17	WB	2B0	56	528065	6751390	0	7.5YR3/3	Dark brown	CL	SANDY LOAM	MIXED	71.5432	22.9826	5.4742	Moderate	2	4.421	Moderate	Moderate	2	2(1)	3
18	WB	2B24	56	528065	6751390	24	2.5Y5/6	Light olive brown	LS	SAND	SAND	95.2911	4.046	0.663	Low	1	0.957	Low	High	3	N/A	
19	WB	2B50	56	528065	6751390	50	2.5Y7/3	Pale yellow	S	SAND	SAND	100	0	0	Low	1	0.337	Low	High	3	N/A	
20	WB	3B0	56	528070	6751440	0	5YR3/3	Dark reddish brown	FSCL	CLAY LOAM	SILT	37.1023	51.7448	11.1528	High	3	7.348	Moderate	Moderate	2	2(2)	3
21	WB	3B69	56	528070	6751440	69	7.5YR5/6	Strong brown	SC	SAND	SAND	91.8977	7.7329	0.3695	Low	1	1.027	Low	High	3	2(3)	3
22	WB	4B0	56	528029	6751217	0	5YR3/3	Dark reddish brown	FSCL	CLAY LOAM	MIXED	55.1601	38.8927	5.9472	Moderate	2	6.539	Moderate	Moderate	2	2(2)	3
23	WB	4B18	56	528029	6751217	18	2.5Y5/2	Greyish brown	SC	SANDY LOAM	MIXED	72.0488	23.4268	4.5243	Moderate	2	3.818	Low	High	3	1	3
24	WB	4B32	56	528029	6751217	32	2.5Y5/2	Greyish brown	SC	SANDY LOAM	MIXED	74.6771	22.4308	2.8921	Moderate	2	N/A				N/A	
25	WB	4B50	56	528029	6751217	50	10YR5/4	Yellowish brown	CS	SAND	SAND	87.1317	9.5915	3.2768	Low	1	1.352	Low	High	3	N/A	
26	WB	5B0	56	528013	6751228	0	10YR3/2	Very dark greyish brown	LC	SANDY SILT LOAM	SILT	20.8018	68.3626	10.8357	High	3	6.947	Moderate	Moderate	2	2(1)	3
27	SI	1S0	56	531405	6746390	0	10YR2/2	Very dark greyish brown	CL	SANDY SILT LOAM	SILT	27.4881	62.2512	10.2607	High	3	21.698	High	Low	1	3(4)	2

28	SI	1S4	56	531405	6746390	4	10YR4/3	Brown	CL	SANDY SILT LOAM	SILT	25.2483	65.0104	9.7412	High	3	11.972	High	Low	1	2(1)	3
29	SI	1S26	56	531405	6746390	26	7.5YR3/3, 5YR4/6 inclusions	Dark brown	LC	SILT LOAM	SILT	14.3337	74.9856	10.6808	High	3	5.777	Moderate	Moderate	2	N/A	
30	SI	1S47	56	531405	6746390	47	2.5Y3/2	Very dark greyish brown	HC	SILT LOAM	SILT	11.0138	72.7329	16.2533	High	3	7.378	Moderate	Moderate	2	N/A	
31	SI	1S75	56	531405	6746390	75	2.5Y3/1	Very dark grey	SC	LOAMY SAND	MIXED	75.8445	20.396	3.7595	Moderate	2	9.162	High	Low	1	N/A	
32	SI	2S0	56	531558	6746528	0	7.5YR3/3, 5YR4/6 inclusions	Dark brown	LC	SANDY LOAM	MIXED	52.3308	42.2725	5.3967	Moderate	2	8.525	High	Low	1	2(1)	3
33	SI	2S12	56	531558	6746528	12	2.5Y3/2	Very dark greyish brown	HC	SANDY SILT LOAM	SILT	26.6518	62.0162	11.3321	High	3	7.992	High	Low	1	2(2)	3
34	SI	2S27	56	531558	6746528	27	2.5Y3/2	Very dark greyish brown	HC	SILT LOAM	SILT	11.1217	73.9181	14.9603	High	3	16.302	High	Low	1	N/A	
35	SI	2S65	56	531558	6746528	65	2.5Y3/1	Very dark grey	SC	SANDY SILT LOAM	SILT	38.9143	51.0901	9.9956	High	3	5.839	Moderate	Moderate	2	N/A	
36	SI	3S0	56	531594	6746622	0	10YR3/3	Dark brown	CL	SANDY SILT LOAM	SILT	47.0125	47.2201	5.7674	High	3	13.048	High	Low	1	2(1)	3
37	SI	3S7	56	531594	6746622	7	7.5YR3/3, 5YR4/6 inclusions	Dark brown	LC	SANDY SILT LOAM	SILT	27.2296	62.6789	10.0915	High	3	8.653	High	Low	1	2(2)	3

38	SI	3S13	56	531594	6746622	13	2.5Y3/2	Very dark greyish brown	HC	SILT LOAM	SILT	12.0158	73.3481	14.636	High	3	8.641	High	Low	1	N/A	
39	SI	3S70	56	531594	6746622	70	2.5Y3/1	Very dark grey	SC	SILT LOAM	SILT	6.3696	79.1973	14.4331	High	3	7.069	Moderate	Moderate	2	N/A	
40	SI	4S0	56	531648	6746674	0	10YR4/3	Brown	CL	SANDY SILT LOAM	SILT	41.8379	47.7574	10.4047	High	3	6.95	Moderate	Moderate	2	7	0
41	SI	4S29	56	531648	6746674	29	7.5YR3/3, 5YR4/6 inclusions	Dark brown	LC	SANDY LOAM	MIXED	55.9556	37.2236	6.8209	Moderate	2	7.242	Moderate	Moderate	2	2(2)	3
42	SI	4S46	56	531648	6746674	46	10YR3/2	Very dark greyish brown	LC	SILT LOAM	SILT	6.7614	76.0739	17.1647	High	3	7.848	High	Low	1	N/A	
43	PI	1P0	56	531954	6717489	0	5Y3/1	Very dark grey	LS	LOAMY SAND	SAND	84.87854	12.83266	2.288801	Low	1	4.124	Moderate	Moderate	2	7	0
44	PI	1P52	56	531954	6717489	52	10YR6/6	Brownish yellow	SC	SANDY SILT LOAM	MIXED	43.56214	40.5747	15.86316	Moderate	2	2.683	Low	High	3	2(2)	3
45	WL	1WL0	56	525571	6695080	0	2.5Y4/1	Dark grey	LS	SAND	SAND	100	0	0	Low	1	1.42	Low	High	3	N/A	
46	WL	2WL0	56	525567	6695082	0	2.5Y4/1	Dark grey	LS	SAND	SAND	100	0	0	Low	1	2.04	Low	High	3	N/A	
47	WL	2WL40	56	525567	6695082	40	2.5Y4/2	Dark greyish brown	S	SAND	SAND	100	0	0	Low	1	0.38	Low	High	3	N/A	
48	WL	3WL0	56	525575	6695082	0	2.5Y4/1	Dark grey	LS	SAND	SAND	100	0	0	Low	1	3.93	Low	High	3	N/A	
49	WL	3WL25	56	525575	6695082	25	2.5Y4/2	Dark greyish brown	S	SAND	SAND	100	0	0	Low	1	0.97	Low	High	3	N/A	
50	WL	4WL0	56	525576	6695060	0	2.5Y4/1	Dark grey	LS	SAND	SAND	100	0	0	Low	1	5.88	Moderate	Moderate	2	N/A	
51	WL	4WL40	56	525576	6695060	40	2.5Y4/2	Dark greyish	S	SAND	SAND	100	0	0	Low	1	0.67	Low	High	3	N/A	

								brown														
52	WL	5WL0	56	525583	6695064	0	2.5Y4/1	Dark grey	LS	SAND	SAND	100	0	0	Low	1	3.2	Low	High	3	N/A	
53	WL	5WL35	56	525583	6695064	35	2.5Y4/2	Dark greyish brown	S	SAND	SAND	100	0	0	Low	1	1.22	Low	High	3	N/A	
54	WL	6WL0	56	525573	6695086	0	2.5Y4/1	Dark grey	LS	SAND	SAND	100	0	0	Low	1	5.33	Moderate	Moderate	2	N/A	
55	WL	6WL30	56	525573	6695086	30	2.5Y4/2	Dark greyish brown	S	SAND	SAND	100	0	0	Low	1	0.6	Low	High	3	N/A	
56	WL	7WL0	56	525562	6695092	0	2.5Y3/1	Very dark grey	LS	SAND	SAND	100	0	0	Low	1	2.96	Low	High	3	N/A	
57	WL	8WL0	56	525570	6695093	0	2.5Y3/1	Very dark grey	LS	SAND	SAND	100	0	0	Low	1	3.71	Low	High	3	N/A	
58	WL	9WL0	56	525578	6695055	0	2.5Y4/1	Dark grey	LS	SAND	SAND	100	0	0	Low	1	5.49	Moderate	Moderate	2	N/A	
59	WL	9WL40	56	525578	6695055	40	2.5Y4/2	Dark greyish brown	S	SAND	SAND	100	0	0	Low	1	1.19	Low	High	3	N/A	
60	WL	10WL0	56	525587	6695055	0	2.5Y4/1	Dark grey	LS	SAND	SAND	100	0	0	Low	1	3.88	Low	High	3	N/A	
61	WL	10WL35	56	525587	6695055	35	2.5Y4/2	Dark greyish brown	S	SAND	SAND	100	0	0	Low	1	1.29	Low	High	3	N/A	
62	MW	1MW0	56	528677	6707238	0	2.5Y3/1	Very dark grey	LS	LOAMY SAND	SAND	100	0	0	Low	1	3.75	Low	High	3	N/A	
63	MW	1MW100	56	528677	6707238	100	2.5Y5/3	Light olive brown	S	SANDY SILT LOAM	SAND	100	0	0	Low	1	1.35	Low	High	3	N/A	
64	MW	1MW380	56	528677	6707238	380	2.5Y5/3	Light olive brown	S	SANDY LOAM	SAND	100	0	0	Low	1	1.12	Low	High	3	N/A	
65	MW	2MW0	56	528685	6707250	0	2.5Y3/1	Very dark grey	LS	LOAMY SAND	SAND	100	0	0	Low	1	7.85	High	Low	1	N/A	
66	MW	2MW100	56	528685	6707250	100	2.5Y5/3	Light olive brown	S	SANDY SILT	SAND	100	0	0	Low	1	1.46	Low	High	3	N/A	

										LOAM												
67	MW	2MW380	56	528685	6707250	380	2.5Y4/2	Dark greyish brown	S	SANDY LOAM	SAND	100	0	0	Low	1	1.19	Low	High	3	N/A	
68	MW	3MW0	56	528741	6707252	0	10YR3/1	Very dark grey	LS	LOAMY SAND	SAND	85.24439	13.40362	1.351989	Low	1	3.94	Low	High	3	7	0
69	MW	3MW25	56	528741	6707252	25	2.5Y5/4	Light olive brown	FSCL	SANDY SILT LOAM	SILT	24.27157	58.27564	17.45279	High	3	2.35	Low	High	3	2(1)	3
70	MW	3MW380	56	528741	6707252	380	2.5Y4/3	Olive brown	S	SANDY LOAM	SAND	100	0	0	Low	1	1.7	Low	High	3	N/A	
71	MW	4MW0	56	528756	6707250	0	10YR3/1	Very dark grey	LS	LOAMY SAND	SAND	85.06466	12.73112	2.20422	Low	1	3.65	Low	High	3	7	0
72	MW	4MW25	56	528756	6707250	25	2.5Y5/4	Light olive brown	SC	SANDY SILT LOAM	MIXED	47.66696	41.73712	10.59593	Moderate	2	6.08	Moderate	Moderate	2	2(2)	3
73	MW	4MW380	56	528756	6707250	380	5Y5/2	Olive grey	SCL-	SANDY LOAM	MIXED	55.5308	35.50607	8.963126	Moderate	2	4.03	Low	High	3	N/A	

FID=GIS field ID/site number
SITE ID=Study site name
SAMPLE NO.=Core number and depth of sediment sample
MGA ZONE=MGA Zone
MGA EASTING=Easting
MGA NORTHING=Northing
DEPTH CM=Sediment sample depth
MUNS. COLOUR=Munsell Colour
MUNSELL DESCRIPTION=Munsell colour description

FIELD TEXT=Field texture
PSA TEXT=Texture result from Malvern Mastersizer analysis
PC SAND/PC SILT/PC CLAY=% sand/silt/clay from Malvern Mastersizer analysis
PSA RISK=Erosion risk according to the particle size analysis results
PSA RISK NUM=Numeric representation of erosion risk according to the particle size analysis results
TOC PC=% organic content
TOC DEFN=Amount (category) of organic matter in the sample
TOC RISK=Erosion risk according to organic content
TOC RISK NUM= Numeric representation of erosion risk according to organic content
EM AG NO.=Emerson Aggregate Number
EM_AG NO. RISK=Numeric representation of erosion risk according to the Emerson Aggregate Number

APPENDIX 3

HANDBOOK FOR USE WITH THE EROSION HAZARD PRO FORMA

MACQUARIE UNIVERSITY

HANDBOOK FOR USE WITH THE EROSION HAZARD PRO FORMA

INCLUDING RECOMMENDATIONS FOR MAINTENANCE AND CONSERVATION OF ABORIGINAL SHELL MIDDEN SITES BASED ON THE EROSION HAZARD INDEX

Hannah Nair

2011

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Following is a step-by-step guide to filling out the Erosion Hazard Pro Forma. A copy of the Erosion Hazard Pro Forma can be found in Appendix 1.

Location
Record the name of the town or property in which the site is located.

Date
Record the date you are assessing the site.

Recorder
Write your name here.

Grid Reference/GPS Reading (GDA/MGA)
You can use a hand held GPS unit in the field to record the coordinates of the site. Instructions for individual units will vary so you will need to refer to the instructions for your unit. It is important to turn on the GPS unit some time before you plan to take a measurement as this will increase the accuracy of the reading.

If a hand held GPS unit is not available it is possible to read the site location from a topographic map. This is called a grid reference. Either GDA (newer maps) or MGA (older maps) is written on every topographic map. Circle the correct one on the pro forma. To obtain a grid reference from a topographic map follow the steps outlined below:

There are two sets of lines on a topographic map. The numbers on the set which runs west to east (right to left) are called eastings. The numbers on the set which runs south to north (down and up the map) are called northings. Eastings and northings make up a grid reference.

To calculate the grid reference of a point on a topographic map find the number on the easting line which is west (left) of the point. These three numbers make up the first half of the easting. Next, divide the distance between this number and the number to the right of it into ten equal parts – use a ruler and mark on the map with a pencil. Then, moving right, count the number of marks from the first part of the easting to your map point. If you count seven marks then the next three numbers of your easting will be 700. If you count two marks the next three numbers will be 200 and so on.

To find the northing find the number on the northing line which is directly south of your map point. This is a four digit number and makes up the first part of the northing. Next, divide the distance between this number and the number to the north of it into ten equal parts – use a ruler and mark on the map with a pencil. Then, moving north, count the number of marks from the first part of the northing to your map point. If you count six marks then the next three numbers of your northing will be 600. If you count four marks the next three numbers will be 400 and so on. See Figure 1 for an example of how to calculate a grid reference from a topographic map.

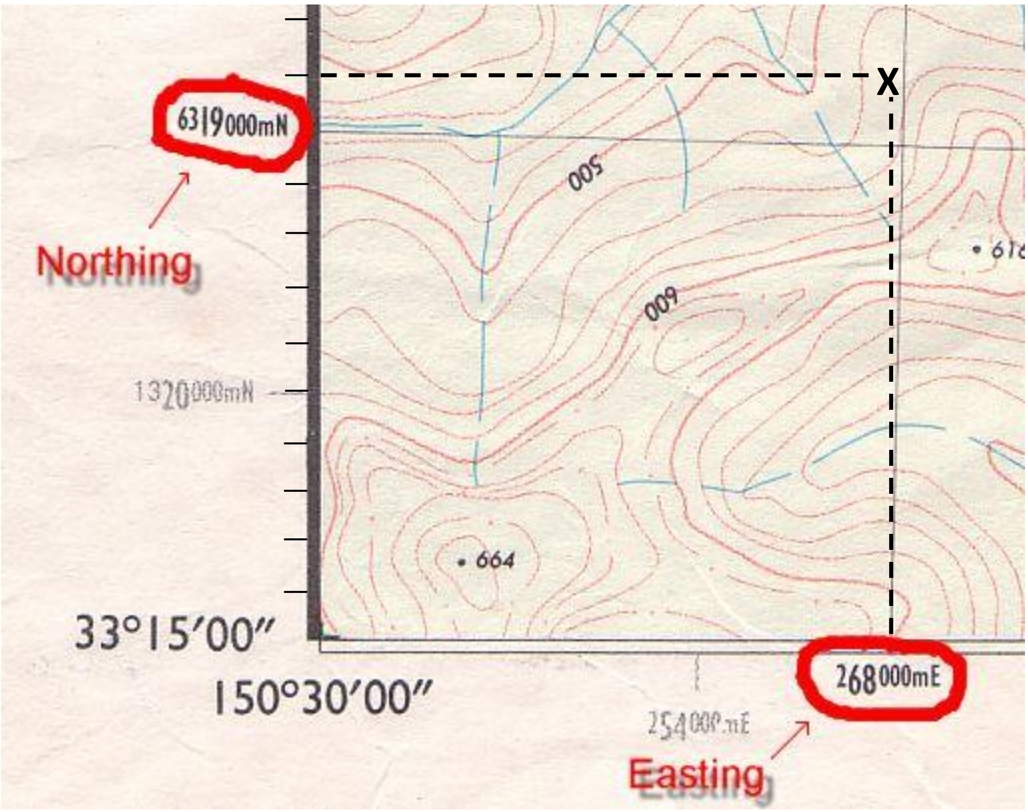


Figure 1: An example of a topographic map showing the grid reference at the point X. The grid reference at point X is 268000E, 6319100N. The northing square to the left is divided into ten parts using a ruler and pencil. The X is located directly above an easting measurement which is already printed on the map so the easting reference is 268000. The X is located on the *first* northing line above the 6319 line so adding *100* onto the end of this number gives a northing reference of 6319100. Image modified after http://adunk.ozehosting.com/MapsAndDatums.html

Site Type

Describe the site type here. For example open site shell midden with artifacts, open site shell midden without artifacts, open site stone quarry, closed site shelter/cave.

Site Features

Features of the site can be selected from the list below:

Aboriginal Ceremony and Dreaming
Aboriginal Resources and Gathering
Art
Artifact
Burial
Ceremonial Ring
Conflict
Earth Mound
Fish Trap
Grinding Groove
Habitation (housing) structure
Hearth
Non-human Bone and Organic Material
Ochre Quarry
Potential Archaeological Deposit
Stone Quarry

Shell
Stone Arrangement
Modified Tree
Water Hole

Further details such as the type of art, artifacts, stone quarried or shell species can be recorded if known. The aim is to record the most information possible at each site.

Current Land Use
In this section you need to record the current land use. There are a number of options to choose from and more than one can be ticked, for example farming – crops and domestic/residential. You also need to record the type of crops, livestock or recreational activities if those boxes have been ticked.

Terrain (surrounding area)
There are four types of terrain to select from in this section and they are all easily identified in the field. Aboriginal shell middens are often found in coastal locations. An estuary is the mouth of a river where it broadens into the sea and is usually tidal (Whittow, 1984). Shell middens can also be found along the banks of rivers or in sheltered, hilly locations near the coast. Select one terrain type only.

Landform (at site)
There are a number of landforms which occur in each type of terrain and you need to circle one which corresponds with the terrain type you have selected. A coastal site may be situated on the beach, a headland, or within a swamp or sand dune. An estuarine site may be found in a riverbank or swamp. Estuarine sites can also be found along a river's floodplain, the relatively flat area next to a river which can flood as river levels rise. A similar set of landforms can be found in riverine areas. Several common landforms are associated with hills and mountains. The upper slope is the area near the top of the hill or mountain and the footslope is the area towards the bottom. Aboriginal cultural sites may also be found within stream banks or rock shelters in hilly or mountainous terrain.

Vegetation
Type: Vegetation type can be identified in the field and a general description is all that is needed here. Record any exotic (non-native) species and weeds you see. Then record any native species. Common names can be recorded if the scientific name is not known. If the vegetation cannot be identified photographs of the leaves, flowers and fruit can be taken to assist in later identification. The titles of some useful books for identifying vegetation are included in Appendix 2. You may also be able to collect specimens, however if the land is protected, such as a National Park, permission may be required before collection. You also need to record the native vegetation formation and class, if possible, as outlined below:

Dry Sclerophyll Forests (shrub/grass sub-formation) – contains plants with hard, short and often spiky leaves, such as eucalypts, banksias and wattles. This sub-formation consists of a grassy understorey (ground layer) with patches of shrubs. The *Clarence Dry Sclerophyll Forests Vegetation Class* is found in the Clarence River valley and the Richmond valley and foothills below 600 m. It is a dry open eucalypt forest with trees up to 30 m tall and an open subcanopy containing casuarinas. The subcanopy is the area just below the canopy; a canopy is the top layer of the forest where the leaves of the tallest trees reach the sun light. The understorey contains patchy shrubs and a continuous grassy groundcover. See Appendix 2 for species list and selected pictures.

Dry Sclerophyll Forests (shrubby sub-formation) – contains plants with hard, short and often spiky leaves, such as eucalypts, banksias and wattles. This sub-formation consists of a sparse ground cover of sedges (grass-like plants with solid stems). Grasses are rare. Shrubs include banksias, pea-flowers, tea-trees, waratahs and wattles. The *North Coast Dry Sclerophyll Forests Vegetation Class* is found on the plateaux around Grafton and the western parts of Bundjalung and Yuraygir National Parks. It is an open eucalypt forest with trees up to 25 m tall with many sclerophyll shrubs (hard, thick-skinned leaves) and an open grassy groundcover.

The *Coastal Dune Dry Sclerophyll Forests Vegetation Class* is found along the coastal dunefields from north of Jervis Bay into south-east Queensland. Locally, this vegetation class extends throughout coastal reserves within the Yuraygir and Bundjalung National Parks. Straight-trunked eucalyptus growing up to 35 m are found on younger (Holocene) dunes closer to the coast, while the older (Pleistocene) dunes contain a woodland of shorter trees, reaching a maximum height of 10 m. Sclerophyll shrubs are also present, along with an open understorey of sedges and scattered grasses. See Appendix 2 for species list and selected pictures.

Grassy Woodlands Vegetation Formation – open canopy dominated by box and red gum eucalypts and a ground cover of tussock grasses (grasses growing in tuft-like clumps). Few shrubs. The *Coastal Valley Grassy Woodlands Vegetation Class* is found locally in the Clarence valley. Open forests and woodlands with trees growing 20-35 m in height, scattered woody shrubs and dense groundcover characterise this vegetation class. See Appendix 2 for species list and selected pictures.

Heathlands Vegetation Formation – dominated by heaths (closely spaced shrubs generally less than 2 m tall) with rare grasses and trees. The *Coastal Headland Heaths Vegetation Class* can be found locally from Woolgoolga to Iluka. Can include dense scrub with grassy groundcover in between or open grasslands with scattered heaths. Trees are generally absent. See Appendix 2 for species list and selected pictures.

Rainforests Vegetation Formation – characterised by a closed and continuous canopy (the top of the trees) of soft, horizontal leaves. Broad-leaved evergreen trees dominate and eucalypts are rare. A local example of the *Littoral Rainforests Vegetation Class* is found at Iluka. Littoral Rainforests range from thickets a few metres tall found on exposed headlands to a canopy above 20 m in height at sheltered locations. The understorey includes vines and non-woody shrubs but growth is not dense.

The *Subtropical Rainforests Vegetation Class* is found locally around Yamba and Iluka. Closed forest with an uneven canopy. Trees are generally 20-40 m tall with a wide range of leaf sizes. Shrubs are present, including palms. Groundcover is patchy and includes ferns and much leaf litter can be found on the ground. See Appendix 2 for species list and selected pictures.

Wet Sclerophyll Forests (grassy sub-formation) – tall, open tree canopy containing plants with hard, short and often spiky leaves and an understorey of soft-leaved shrubs and ferns. The *Northern Hinterland Wet Sclerophyll Forests Vegetation Class* is found on coastal foothills and plateaux. This vegetation class consists of open eucalypt forests growing to 40 m high, an open shrubby understorey and a continuous grassy groundcover. Appendix 2 for species list and selected pictures.

Wet Sclerophyll Forests (shrubby sub-formation) – tall, open tree canopy containing plants with hard, short and often spiky leaves and an understorey of soft-leaved shrubs and ferns. This sub-formation contains more shrubs than the grassy sub-formation and occurs in slightly moister places. The *North Coast Wet Sclerophyll Forests Vegetation Class* consists of tall dense eucalypt forests 30-

60 m tall with small trees and tall shrubs up to 15 m in height. Continuous groundcover includes ferns. Vines grow over shrubs and small trees. See Appendix 2 for species list and selected pictures.

Forested Wetlands Vegetation Formation – contains similar trees to the dry sclerophyll forests (eucalypts, paper-barks, she-oaks and tea-trees) with an understorey of water-loving grasses, sedges and/or rushes. The *Coastal Floodplain Wetlands Vegetation Class* is found along river corridors and the coastal floodplains which are found next to these. Can consist of open eucalypt forests with trees over 40 m in height or denser *Casuarina* or *Melaleuca* forests with trees growing up to 20 m tall.

The *Coastal Swamp Forests Vegetation Class* is found along coastal lowlands from Port Stephens into south-east Queensland. Locally, this vegetation class extends along the sandy coastal lowlands of Yuraygir and Bundjalung National Parks. A mixed forest of low density eucalypts and paperbarks with a dense grass understorey.

The *Eastern Riverine Forests Vegetation Class* is found locally at Wooli and commonly consists of an open *Casuarina* forest with trees ranging in height from 10-40 m, with non-woody shrubs and patchy groundcover. See Appendix 2 for species list and selected pictures.

Freshwater Wetlands Vegetation Formation – areas which are permanently or temporarily inundated by fresh water. Dominated by shrubs and sedges. The *Coastal Freshwater Lagoons Vegetation Class* is made up of areas of sedges, aquatic vegetation and open water. There are no trees or shrubs. It is found locally around Wooli and Lawrence and includes the Clarence Broadwater.

The *Coastal Heath Swamps Vegetation Class* is found scattered along the New South Wales coastline including the Northern Rivers region. Dense sedgeland and open patches of woody shrubs characterise this vegetation class. Trees are not present. See Appendix 2 for species list and selected pictures.

Saline (salty) Wetlands Vegetation Formation – occur around saline lake shores and coastal mudflats. Vegetation is generally low growing and trees are dominant only in mangrove swamps. The *Mangrove Swamps Vegetation Class* is found in mudflats and coastal estuaries scattered along the New South Wales coastline. It is a low forest 2-8 m in height with either no groundcover or patches of non-woody flowering plants.

The *Saltmarshes Vegetation Class* is scattered along the New South Wales coastline and found locally from Iluka to Wooli. It consists of closed or open herbland (a group of low growing, non-woody, non-grasslike plants) and grassland with occasional shrubs. See Appendix 2 for species list and selected pictures.

Highly Disturbed Areas with none or Limited Native Vegetation – may occur in areas such as roads and road verges, ploughed paddocks public parks or recreation areas, areas which are currently, or have been, quarried or mined and urban and residential areas.

Source and further information:
http://www.threatenedspecies.environment.nsw.gov.au/tsprofile/home_vegetation.aspx

% Ground Cover: You will need to estimate the amount of the ground surface at the site which is covered by grasses and other ground covering plants. This can be done in a few different ways. If the midden is relatively small (the whole area of the midden can be seen when standing near it) the percentage ground cover can be estimated by looking at the area. If the midden is larger the percentage ground cover can be measured by using a frame with sides approximately 1 m long. The frame can be made by tying together sticks or PVC pipe, or by using lengths of wood which have been hammered together. Alternatively, an adult size hula hoop or similar sized ring can be used. Mark out the edges of the midden with coloured tent pegs, tape, paint or any other item which can be seen easily. Starting in one corner of the marked area, place the frame on the ground and estimate the percentage ground cover inside it. Write this down. Walk five paces and repeat. Keep repeating this process until you reach the other end of the midden. If the area of the midden is large enough take two paces towards the centre of the marked area and repeat the process until you reach the other side. If you have not covered the whole marked area repeat this process pacing in lines until you have sampled the whole area. To calculate the average percentage ground cover for the midden site add together all your estimates and then divide that number by the number of estimates you have made. An example is given below:

Ground coverage estimates (from inside frame): 40%, 25%, 30%, 45%, 30%.
40 + 25 + 30 + 45 + 30 = 170
170 ÷ 5 = 34%
The average ground coverage at the midden site is 34%.

% Tree and Shrub Cover: You will also need to estimate the amount of the ground surface at the site which is covered by the base of trees and shrubs. If the midden is relatively small (the whole area of the midden can be seen when standing near it) the percentage tree and shrub cover can be estimated by looking at the area. If the base of the shrubs cannot be seen directly, move away the leaves to estimate the amount of the ground surface covered by the shrubs. For larger middens divide the area you have marked out to measure the percentage ground cover into smaller areas and make an estimate for each area. Then calculate the average percentage tree and shrub cover as demonstrated for percentage ground cover. Figure 2 provides a guide for estimating percentage vegetation coverage.

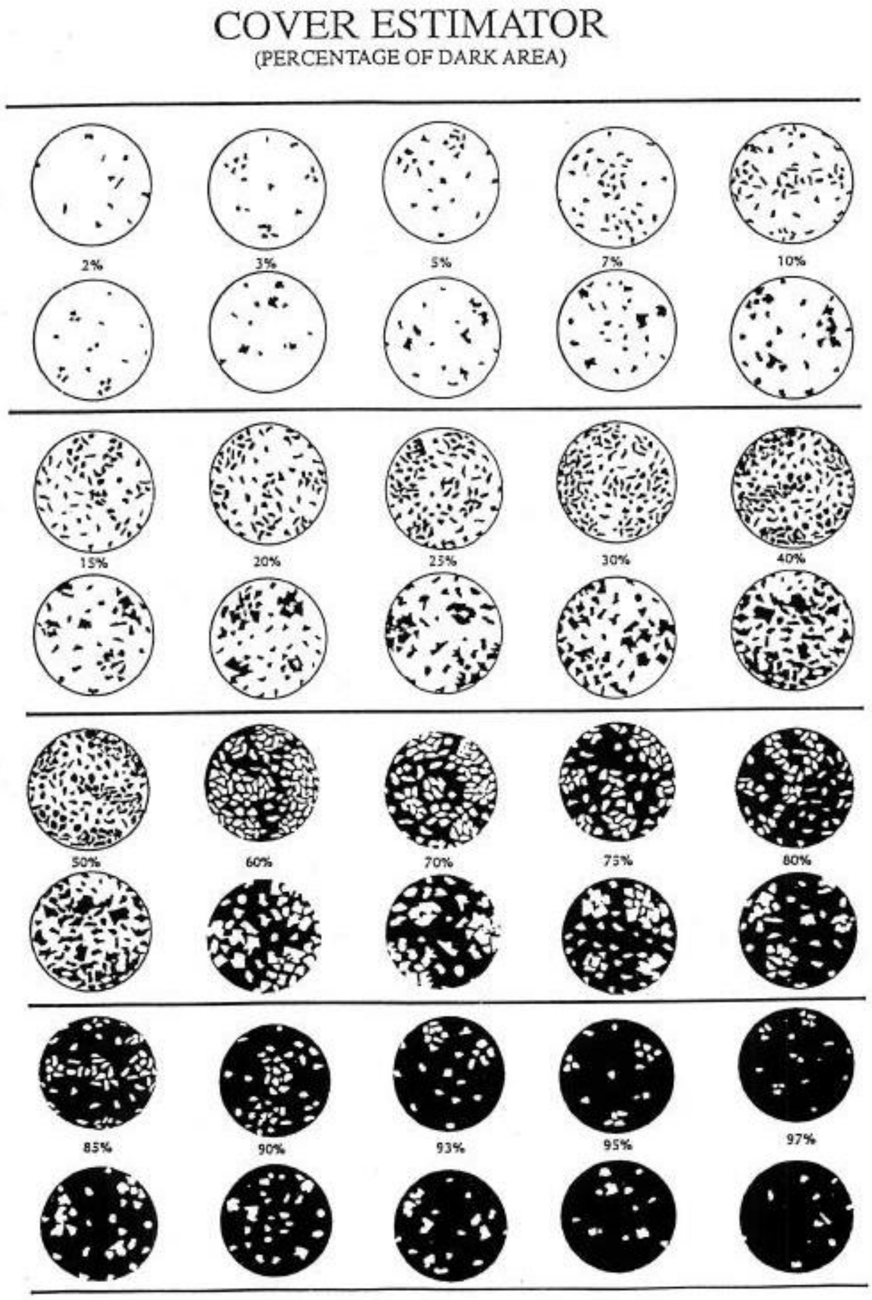


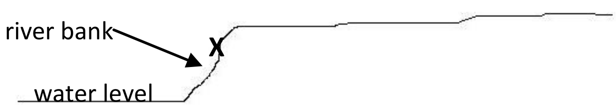
Figure 2: Guide to estimating vegetation coverage. Source: Sheila Barry (http://animalscience.ucdavis.edu/extension/FactSheets/RangelandResources/pdfs/Veg_Cover_Monitoring2.PDF)

Tidal Activity
You need to note whether or not the midden sits above the high tide level. The upper limit of tidal activity is included in topographic maps. Tide prediction charts and local knowledge will also provide useful information on the location, timing and heights of tides if you need to check for tidal activity.

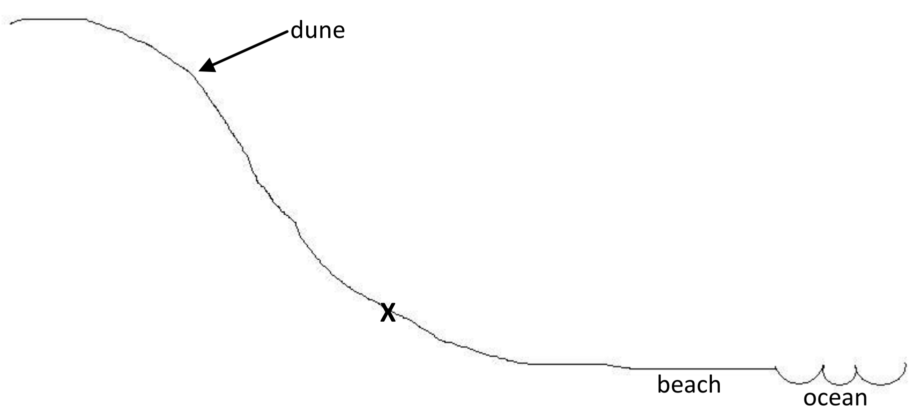
Orientation of Midden
This refers to the way in which the midden sits with reference to the compass points of north, south, east and west and can be measured by using a compass or looking at the sun. There are four options provided on the pro forma and you need to circle one. The options are north-south, east-west, northeast-southwest and northwest-southeast. Stand at one end of the midden and face towards the other end. If using a compass, hold it up in front of you. The hands will show the directions of north and south and you should then be able to see which way the midden deposit sits in relation to the compass hands. If you are using the sun as a guide stand at one end of the midden and face towards the other end. As the sun moves east-west you will be able to see which way the midden sits in relation to the position of the sun.

Slope
Degrees: The slope of a riverbank, floodplain, headland or other midden deposit can affect the amount of erosion at the site. Slope is measured by a simple instrument called a clinometer which has degrees marked on its face. To measure the slope at a site using a clinometer place the clinometer upright on its side on the ground surface to be measured. The face of the clinometer should be facing the side, not upwards. Similar to a compass, you will see a measurement line which runs through the face of the instrument. Record this measurement in the section titled 'Degrees' on the Erosion Hazard Pro Forma.

Shape: You will need to draw the shape of the land around the midden deposit as if you have cut a slice through the middle of the midden (a cross section). Draw an X at the point where the midden is located. For example, if the midden is in a steep river bank it may look like this:



If the midden is in a beach dune it may look like this:



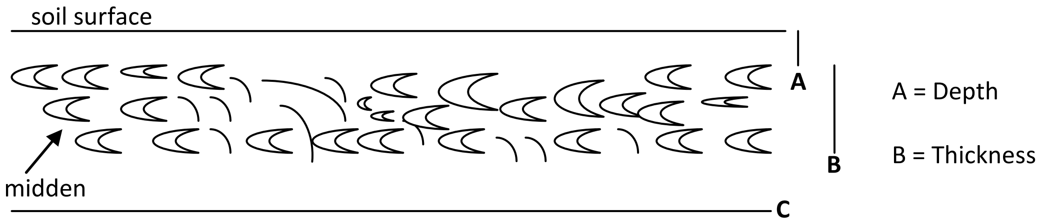
Soil

Field Texture: This is a way of measuring the size of soil particles in the midden. First, you need to take a handful of soil in the palm of your hand and wet it. You then need to work it around in your hands until it all sticks together and all the lumps have broken down. You should also pick out any rocks or sticks. Some soils will stick together better than others. Once you have done this, press the soils with your thumb, over your forefinger until a section breaks off. Measure this section with a ruler. This is the ribbon length of the sample. Repeat the procedure to make sure you get a similar measurement the second time. Looking at the chart below (Figure 3), match the ribbon length with its texture grade and write this in the space provided on the Pro Forma.

FIELD TEXTURE GROUPS	RIBBON LENGTH (mm)	COHERENCE	FEEL	OTHER FEATURES	TEXTURE GRADE	APPROX. CLAY %
1 *The Sands*	Nil	Nil	Sandy	Single sand grains adhere to fingers	1 **Sand (S)**	Commonly <5
	5	Slight	Sandy	Discolours fingers with an organic stain	2 **Loamy Sand(LS)**	5–10
	5–15	Slight	Sticky	Sand grains stick to fingers and discolour with a clay stain	3 **Clayey Sand (CS)**	5–10
2 *The Sandy Loams*	15–25	Just Coherent	Very Sandy	Medium Sand readily visible	4 **Sandy Loam(SL)**	10–20
	15–25	Just Coherent	Very Sandy	Fine Sand may be heard	5 **Fine Sandy Loam (FSL)**	10–20
	20–25	Strong	Sandy	Medium sand easily visible	6 **Light Sandy Clay Loam (SCL-)**	15–20
3 *The Loams*	about 25	Coherent	Spongy and Greasy	No obvious sandiness	7 **Loam(L)**	25
	about 25	coherent	slightly spongy	Fine sand	8 **Loam Fine Sandy (LFsy)**	25
	about 25	coherent	Smooth	Silky; very smooth when manipulated	9 **Silt Loam (SiL)**	25 (>25% Silt)
	25–40	Strong	Sandy	Medium sand in fine matrix	10 **Sandy Clay Loam (SCL)**	20–30
4 *The Clay Loams*	40–50	Strong	Smooth	No obvious sand grains	11 **Clay Loam (CL)**	30–35
	40–50	Coherent	Smooth	Silky feeling	12 **Silty Clay Loam (SiCL)**	30–35 (>25% Silt)
	40–50	Coherent	Smooth & Sandy	Fine sand can be felt and heard	13 **Fine Sandy Clay Loam (FSCL)**	30–35
5 *The Light Clays*	50–75	Coherent	Plastic	Fine to medium sand	14 **Sandy Clay (SC)**	35–40
	50–75	Coherent	Plastic	Smooth and silky	15 **Silty Clay (SiC)**	35–40 (>25% Silt)
	50–75	Coherent	Plastic	Smooth with slight resistance to shearing	16 **Light Clay (LC)**	35–40
	>75	Coherent	Plastic	Smooth with a little resistance to shearing	17 **Light Medium Clay (LMC)**	40–45
6 *The Medium & Heavy Clays*	>75	Coherent	Plastic	Fair resistance to shearing	18 **Medium Clay (MC)**	45–55
	>75	Coherent	Plastic	Firm resistance to shearing	19 **Heavy Clay (HC)**	>50

Figure 3: Australian Soil Identification Spreadsheet (ASIS) soil texture identification chart. Source: Mazaheri *et al.,* 1995 (ASIS Manual Version 1.1).

Midden Depth from Soil Surface, Midden Thickness and Midden Length: Measure the depth of the midden. Using a ruler or measuring tape measure the distance between the soil surface and the top of the midden (A). Write this measurement next to 'Midden Depth from Soil Surface' on the Pro Forma. To measure the midden thickness (B) place a tape measure or ruler at the top of the midden and measure to the deepest shell you can see. Write this measurement next to 'Thickness' on the Pro Forma. Measure the length of the midden (C) by rolling a tape measure from one end of the midden to the other. Write this measurement next to 'Length' on the Pro Forma.



Emerson Class Number: You will need to take some small soil samples to complete this test away from the field. If the soil is very sandy and will not stick together when it is wet you do not need to do this test. You will need three ten cent piece sized balls of soil so collect about three times this amount in case the test needs to be repeated. Place the sample in a snap-lock bag or similar and label it clearly with the date and location. For instructions on how to complete the aggregate stability test, see Appendix 3.

Appearance of shells in the midden
Draw an X on the line to show the amount of shell material you can see *in situ* (*within* the midden, see example below). If the Indigenous community wishes, a small trench can be dug through the midden to see if the amount of shell material remains the same in different areas. However, of you are non-Indigenous you must obtain the relevant permission before this is undertaken. The midden does not need to be disturbed to take this measurement, you can simply look at the area which is already visible. Figure 4 will help you make this estimate.

100% |————————**X**————————| 0%

The X in the middle shows that approximately 50% of the midden shells remain in the midden and the other 50% have fallen out and can be seen at the base of the midden.

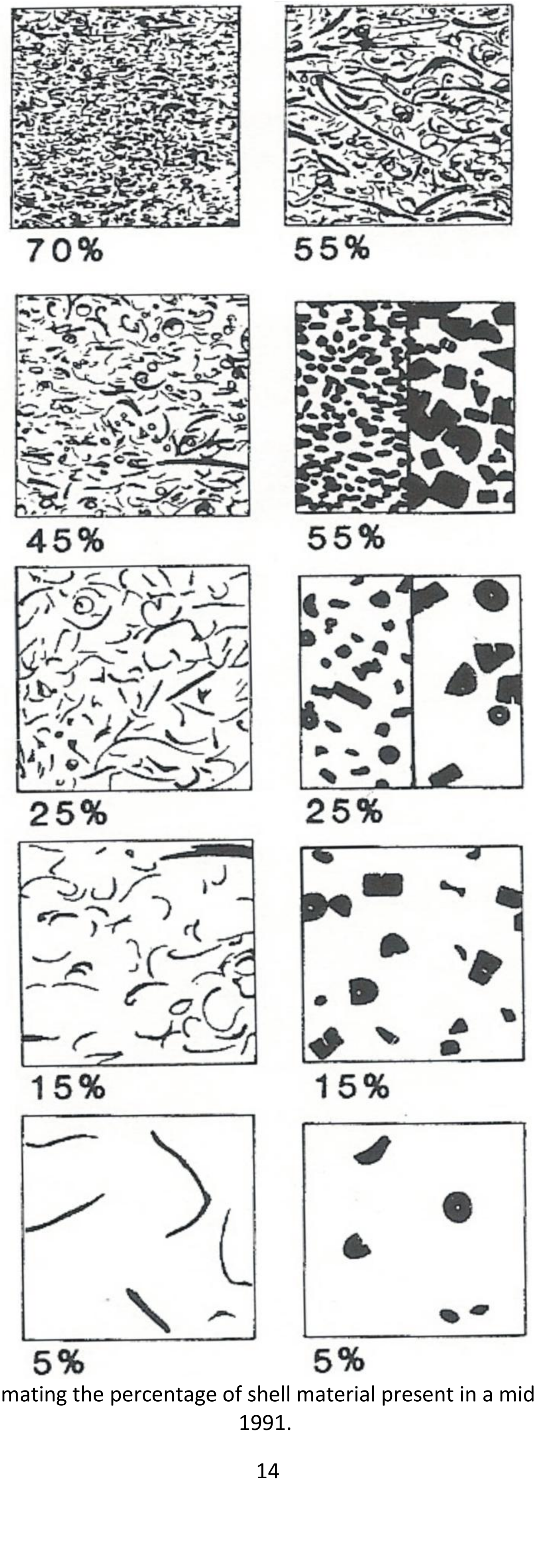


Figure 4: Guide to estimating the percentage of shell material present in a midden. Source: Kidwell, 1991.

Condition of Shells: In this section you will look at three characteristics of the midden shells – whether or not they are worn, have a chalky appearance or are broken. Worn shells will appear polished or rounded with no sharp edges (Figure 5). Chalky shells will look very white like chalk (Figure 6). When you touch them some fine white powder may come off onto your hands. Chalky shells can also be brittle. Next, look at the visible shells *within* the midden to see whether they are mostly broken or mostly whole. Use the scale lines on the Pro Forma to show the amount of shell material which appears worn, chalky and broken, as illustrated below:

Worn (Rounded Edges) ---X---- Not Worn (Sharp Edges)
Chalky Appearance ---X------ Not Chalky
Shells Mostly Broken ---X-- Shells Mostly Whole

The above example shows shells in the midden are in relatively good condition – most are whole shells which are not worn or chalky in appearance.

Figure 5: Some examples of rounded shells. Scale bars = 1 cm.

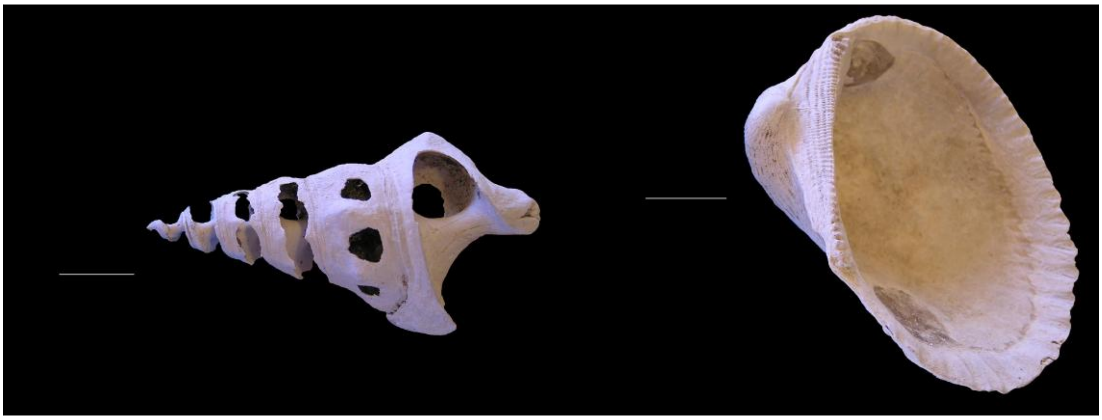


Figure 6: Some examples of chalky shells. Scale bars = 1 cm.

Erosion – Field Forms

Exposed Tree Roots/Fence Posts/Other Structures: Exposure of structures which were once buried is a sign of erosion. Figure 7 shows loss of soil around tree roots on Sleeper Island. If exposed tree roots, fence posts or other structures can be seen at a site circle one of the options in this section of the Pro Forma.

Soil Pedestals: These are small columns of soil occurring underneath materials such as stones or plant roots (Stocking and Murnaghan, 2001). The soil underneath these materials is protected, whereas the soil around them is exposed to erosion. Figure 8 shows a sketch of a soil pedestal and Figure 9 shows an example of a soil pedestal in the field. If soil pedestals can be seen at a site their height will need to be measured. To measure the height of a soil pedestal place a ruler on the ground next to the pedestal and measure to the top of the soil column (not including the stone or other material on top of the soil column). This is labelled as the depth of soil lost in Figure 8. Write this measurement in the space provided on the Pro Forma.

Rills: These are small channels which form when flowing water drains across the land, removing soil. Rills can be up to approximately 30 cm deep. Figure 10 shows some examples of rills. If rills can be seen at a site their depth will need to be measured. To measure the depth of a rill place a ruler or tape measure at the lowest point and measure up to the soil surface. Write this measurement in the space provided on the Pro Forma.

Gullies: A gully is similar to a rill, only deeper (more than 30 cm). If gullies can be seen at a site circle this option on the Pro Forma. Figure 11 shows some examples of gullies.

Soil Build-up Behind Trees/Fence Posts/Other Structures: As water moves soil across the landscape this soil may become stuck behind trees, fence posts or other structures. This build-up shows that soil has moved across the landscape. If soil build-up can be seen at a site circle one of the options in this section of the Pro Forma. An example of soil build-up behind a fence can be seen in Figure 12.

Figure 7: Tree root exposure on Sleeper Island.

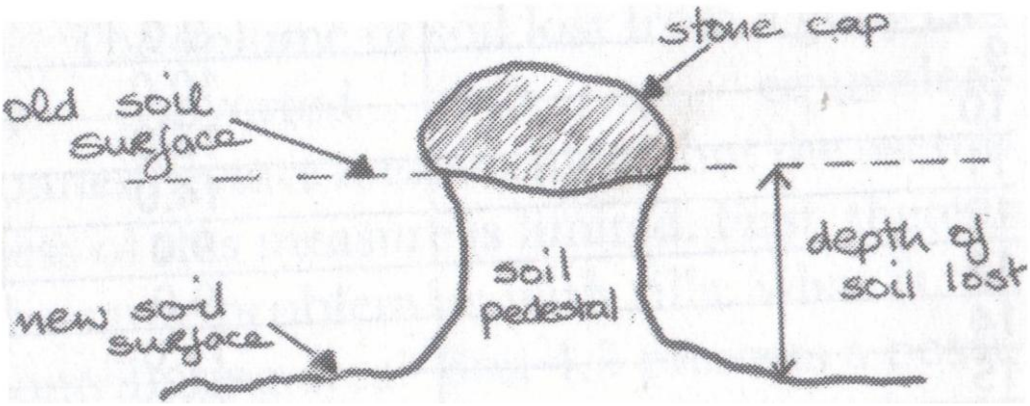


Figure 8: Sketch of a soil pedestal. Source: Stocking and Murnaghan, 2001.

Figure 9: Soil pedestal capped by a stone (dashed box). Source: www.northern.cma.nsw.gov.au/images/publications_pdf.php?id=21

Figure 10: Examples of rill erosion. Sources:
http://cobweb.ecn.purdue.edu/~engelb/agen526/Erosion/Index.html
http://www.fs.fed.us/GRAIP/gallery/Cutslope%20rilling.JPG

Figure 11: An example of gully erosion. Source:
http://plantandsoil.unl.edu/croptechnology2005/UserFiles/Image/siteImages/GullyErosionPasture-NRCS-LG.jpg

Figure 12: Soil build-up behind a fence. Source: www.northern.cma.nsw.gov.au/images/publications_pdf.php?id=21

CALCULATING THE EROSION HAZARD SCORE

You will need to use some of the information recorded in the Erosion Hazard Pro Forma to calculate a score which will indicate the severity of erosion at a site (the erosion hazard index). Table 1 uses information from the vegetation coverage and field forms sections of the Pro Forma. Matching the descriptions on the right side of the table with the measurements recorded in the Pro Forma will give a score of the severity of erosion at the site between 0 and 3.

TABLE 1

DEGREE	SCORE	CHARACTERISTICS OF FIELD FORMS & VEGETATION
NONE	0	No tree root/structure exposure. No soil build-up behind trees/structures. No rills, gullies or pedestals. 60-100% vegetation cover.
SLIGHT	1	Slight root/structure exposure. Slight soil build-up behind trees/structures. Shallow (<100 mm) rills affecting <5% of the surface area. No pedestals or gullies. 50-60% vegetation cover.
MODERATE	2	Root/structure exposure. Soil build-up behind trees/structures. Pedestals up to 500 mm high. Rills 100-200 mm deep and/or affecting 5-25% of the surface area. No gullies. 25-40% vegetation cover.
SEVERE	3	Extensive root/structure exposure and soil build-up behind trees/structures. Pedestals >500 mm high. Rills >200 mm deep and/or affecting >25% of the surface area. Gullies present. Subsoil horizons exposed at or close to the soil surface. Bare soil. <20% vegetation cover.
SCORE		

Table 1: Scores for the severity of erosion based on characteristics of field forms and vegetation.

Information on the appearance of shells in the midden is used in Table 2 . If the midden shells are worn write a 1 in the score column on the right side of the table. If they are not worn write a 0 in this column. If the midden shells are chalky write a 1 in the score column on the right side of the table. If they are not chalky write a 0 in this column. If the midden shells are mostly broken write a 1 in the score column on the right side of the table. If they are mostly whole write a 0 in this column. Then add these three scores together and write the total (between 0 and 3) in the total score box.

TABLE 2

APPEARANCE OF SHELLS IN MIDDEN	SCORE (0-1)
Wear (shells mostly worn=1, shells mostly not worn=0)	
Chalkiness (shells mostly chalky=1, shells mostly not chalky=0)	
Breakage (shells mostly broken=1, shells mostly whole=0)	
Degree (0=none, 1=slight, 2=moderate, 3=severe):	**Total Score:**

Table 2: Scores for the severity of shell wear based on taphonomic characteristics in the Erosion Hazard Pro Forma.

You will need to add the Emerson aggregate score to Table 3. If this test was not performed because the soil was too sandy then do not fill in this table. Write the depth the soil sample was taken from in the column with the heading 'DEPTH FROM SURFACE' and circle the Emerson Class Number in the next column. Then circle the number next to this number in the 'SCORE' column.

TABLE 3

DEPTH FROM SURFACE	EMERSON CLASS NUMBER	SCORE (CIRCLE)
	1	3
	2	3
	3	2
	4	1
	5	1
	6	1
	7	0
	8	0

Table 3: Template for recording the Emerson Class Number of soil in a shell midden.

To answer the question in Table 4 copy your answer from the 'Tidal Activity' section of the Pro Forma. Circle Yes or No and write the corresponding score, either 0 or 3, in the blank box underneath.

TABLE 4

Is the midden above the high tide level?	No=3 Yes=0
Score	

Table 4: Tidal activity score.

Erosion Hazard Index

Table 1 score	
Table 2 score	
Table 3 score	
Table 4 score	
Total score	
EROSION HAZARD INDEX	

Table 5: Erosion Hazard Index.

Next, fill in the summary table, 'Erosion Hazard Index' on the back of the Pro Forma. Add together the four scores you have calculated and write this number in the 'Total Score' box. Divide the total score by four. This will give you the Erosion Hazard Index. For example, if you had scores of 3, 3, 2 and 1:

3 + 3 + 2 + 1 = 9
9 ÷ 4 = 2.25
The Erosion Hazard Index is 2.25 for this site.

If you do not have an Emerson aggregate score, simply add the other three scores together and divide by three. This will give you the Erosion Hazard Index. For example, if there are scores of 2, 2 and 1:

2 + 2 + 1 = 5
5 ÷ 3 = 1.7
The Erosion Hazard Index is 1.7 for this site.

RECOMMENDATIONS FOR MAINTENANCE AND CONSERVATION OF ABORIGINAL SHELL MIDDEN SITES BASED ON THE EROSION HAZARD INDEX

INDEX	CATEGORY	RECOMMENDATIONS
0-0.9	1	Very low erosion hazard. Visiting these sites every two years is recommended. Fill in an Erosion Hazard Pro Forma each time the site is visited to monitor any changes in vegetation, shell condition, tidal activity and land use.
1-1.9	2	Low erosion hazard. Visiting these sites every one to two years is recommended. Fill in an Erosion Hazard Pro Forma each time the site is visited to monitor any changes in vegetation, shell condition, tidal activity and land use.
2-2.5	3	Moderate erosion hazard. Yearly visits to these sites are recommended. Fill in an Erosion Hazard Pro Forma each time the site is visited to monitor any changes in vegetation, shell condition, tidal activity and land use. Encouraging vegetation growth will help stabilise these sites and reduce erosion. If the type of land use at a site appears to be causing further erosion contact local council, the Department of Environment, Climate Change and Water Aboriginal Heritage Section or the National Parks and Wildlife Service to discuss your concerns.
2.6-3	4	High erosion hazard. Sites need to be visited at least once every six months. Fill in an Erosion Hazard Pro Forma each time the site is visited to monitor any changes in vegetation, shell condition, tidal activity and land use. Encouraging vegetation growth will help stabilise these sites and reduce erosion. If the type of land use at a site appears to be causing further erosion contact local council, the Department of Environment, Climate Change and Water Aboriginal Heritage Section or the National Parks and Wildlife Service to discuss your concerns.

The above table outlines recommendations for maintenance and conservation of Aboriginal shell midden sites based on the Erosion Hazard Index. These are general guidelines only. Information on site-specific processes can be collected by the authorities using the information collected in the Erosion Hazard Pro Formas as a starting point for further study.

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www.northern.cma.nsw.gov.au/images/publications_pdf.php?id=21

http://plantandsoil.unl.edu/croptechnology2005/UserFiles/Image/siteImages/GullyErosionPasture-NRCS-LG.jpg

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EROSION HAZARD PRO FORMA

Location:	**Grid Reference / GPS Reading (GDA/MGA):**
Date:	**Site Type:**
Recorder:	**Site Contents/Features:**

Current Land Use (Tick All That Apply) (p. 5)

☐ **Farming – Livestock (Type: ______________________)**	☐ **National Park / Crown Land / Council Land / State Forest**
☐ **Farming – Crops (Type: ______________________)**	
☐ **Tourism / Recreational Activities (Type: _______________)**	☐ **Domestic / Residential**

Terrain (Surrounding Area)	**Land Form at Site (Circle One) (p. 5)**			
☐ **Coastal**	**Beach**	**Swamp**	**Headland**	**Dune**
☐ **Estuary**	**Riverbank**	**Floodplain**	**Swamp/Mangroves**	
☐ **River**	**Riverbank**	**Floodplain**	**Swamp/Mangroves**	
☐ **Hills / Mountains**	**Upper Slope**	**Foot Slope**	**Stream Bank**	**Rock Shelter**

Vegetation (p. 6)

Vegetation Type:	
% Ground Cover:	**% Tree and Shrub Cover:**

Tidal Activity (p. 11)

Is the midden above the high tide level: **Yes / No**

Orientation of Midden (p. 11)

N-S	**E-W**	**NE-SW**	**NW-SE**

Slope (p. 11)

Degrees:	**Shape:**

Soil (p. 12)

Field Texture (Texture Grade):	**Emerson Class Number:**

Midden Depth from Soil Surface: **Thickness:** **Length:**

Appearance of Shells in Midden (p. 13)

Draw a X on the line to show the amount of shell material remaining *in situ* (within the midden)

100% |————————————————————| **0%**

Condition of Shells (draw an X on the lines to show the amount of shells in each condition):

Worn (Rounded Edges) -- Not Worn (Sharp Edges)

Chalky Appearance -- Not Chalky

Shells Mostly Broken --- Shells Mostly Whole

Erosion – Field Forms Around Midden Area (Tick if Present) (p. 16)

☐ **Exposed Tree Roots / Fence Posts / Other Structures**	
☐ **Soil Pedestals (Height:___________________)**	☐ **Rills (Depth: ___________________)**
☐ **Soil Build up behind Trees / Fences / Other Structures**	☐ **Gullies**

TABLE 1

DEGREE	SCORE	CHARACTERISTICS OF FIELD FORMS & VEGETATION
NONE	0	No tree root/structure exposure. No soil build-up behind trees/structures. No rills, gullies or pedestals. 60-100% vegetation cover.
SLIGHT	1	Slight root/structure exposure. Slight soil build-up behind trees/structures. Shallow (<100 mm) rills affecting <5% of the surface area. No pedestals or gullies. 50-60% vegetation cover.
MODERATE	2	Root/structure exposure. Soil build-up behind trees/structures. Pedestals up to 500 mm high. Rills 100-200 mm deep and/or affecting 5-25% of the surface area. No gullies. 25-40% vegetation cover.
SEVERE	3	Extensive root/structure exposure and soil build-up behind trees/structures. Pedestals >500 mm high. Rills >200 mm deep and/or affecting >25% of the surface area. Gullies present. Subsoil horizons exposed at or close to the soil surface. Bare soil. <20% vegetation cover.
SCORE		

TABLE 2

APPEARANCE OF SHELLS IN MIDDEN	SCORE (0-1)
Wear (worn=1, not worn=0)	
Chalkiness (chalky=1, not chalky=0)	
Breakage (shells mostly broken=1, shells mostly whole=0)	
Degree (0=none, 1=slight, 2=moderate, 3=severe):	**Total Score:**

TABLE 3

DEPTH FROM SURFACE	EMERSON CLASS NUMBER	SCORE (CIRCLE)
	1	8
	2	7
	3	6
	4	5
	5	4
	6	3
	7	2
	8	1

TABLE 4

Is the midden above the high tide level?	No=1 Yes=0
Score	

Erosion Hazard Index

Table 1 score	
Table 2 score	
Table 3 score	
Table 4 score	
Total score	
EROSION HAZARD INDEX	

NOTES:

APPENDIX 2

List of vegetation associations and common plant species found on the north coast of New South Wales and list of useful plant identification field guides

VEGETATION ASSOCIATION	SPECIES – SCIENTIFIC NAME	SPECIES – COMMON NAME
Dry Sclerophyll Forest	*Corymbia gummifera*	red bloodwood
	C. henryi	large-leaved spotted gum
	C. intermedia	pink bloodwood
	Eucalyptus baileyi	Baileys stringbark
	E. carnea	thick-leaved mahogany
	E. moluccana	grey box
	E. pilularis	blackbutt
	E. planchoniana	bastard tallowood
	E. propinqua	grey gum
	E. siderophloia	grey ironbark
	E. signata	scribbly gum
	E. variegate	spotted gum
	Angophora costata	Sydney red gum
	Banksia oblongifolia	
	B. serrata	old man banksia
	Macrozamia communis	burrawang
	Monotoca elliptica	tree broom-heath
	Syncarpia glomulifera	turpentine
	Allocasuarina torulosa	forest oak
	Alphitonia excelsa	red ash
	Ricinocarpos pinifolius	wedding bush
		coffee bush

	Breynia oblongifolia *Pteridium esculentum* *Jacksonia scoparia* *Dianella caerulea* *Pratia purpurascens* *Leucopogon lanceolatus* *Persoonia stradbrokensis* *Gompholobium pinnatum* *Leptospermum trinervium* *Cymbopogon refractus* *Entolasia stricta* *Imperata cylindrica* var. *major* *Themeda australis* *Xanthorrhoea latifolia* *Lomandra longifolia*	bracken dogwood blue flax lily white root pinnate wedge pea flaky-barked teatree barbed wire grass wiry panic blady grass kangaroo grass grass tree spiny-headed mat-rush

VEGETATION ASSOCIATION	SPECIES – SCIENTIFIC NAME	SPECIES – COMMON NAME
Wet Sclerophyll Forest	*Eucalyptus acmenioides*	White Mahogany
	E. carnea	Thick-leaved mahogany
	E. grandis	Flooded Gum
	E. microcorys	Tallowwood
	E. pilularis	Blackbutt
	E. propinqua	Grey Gum
	E. saligna	Sydney Blue Gum
	E. siderophloia	Grey Ironbark
	Lophostemon confertus	Brush Box
	Syncarpia glomulifera	Turpentine
	Angophora subvelutina	Broad-leaved Apple
	Corymbia intermedia	Pink Bloodwood
	Allocasuarina torulosa	Forest Oak
	Breynia oblongifolia	Coffee Bush
	Jacksonia scoparia	Dogwood
	Leucopogon lanceolatus	
	Maytenus sylvestris	Narrow-leaved Orange Bark
	Notelaea longifolia	Large Mock-Olive
	Ozothamnus diosmifolius	White Dogwood
	Persoonia linearis	Narrow-leaved Geebung
	Pittosporum revolutum	Yellow Pittosporum
	Podolobium ilicifolium	Prickly Shaggy Pea
	Polyscias sambucifolia	Elderberry Panax
	Trochocarpa laurin	Tree Heath
	Cissus hypoglauca	Giant Water Vine
	Hibbertia sp.	Climbing Guinea Flower
	Pandorea pandorana	Wonga Wonga Vine
	Smilax australis	Sarsparilla
	Amperea xiphoclada var. *xiphoclada*	Broome Spurge
	Breynia cernua	
	Eupomatia laurina	Bolwarra
	Elaeocarpus reticulatus	Blueberry Ash
	Diospyros australis	Black Plum
	Rapanea variabilis	Muttonwood
	Guioa semiglauca	Wild Quince
	Synoum glandulosum	Scentless Rosewood
	Cryptocarya rigida	Forest Maple
	Desmodium sp.	Tick-trefoil
	Cordyline stricta	Narrow-leaved Palm Lily
	Dianella caerulea	Blue Flax Lily
	Geitonoplesium cymosum	Scrambling Lily
	Wilkiea huegeliana	Veiny Wilkiea
	Hibbertia sp.	Guinea Flower
	Cissus sp.	Giant Water Vine
	Dioscorea transversa	Native Yam
	Geranium homeanum	
	Pratia purpurascens	White Root

	Pteridium esculentum	Bracken
	Imperata cylindrica var. *major*	Blady Grass
	Lomandra longifolia	Spiny-headed Mat-rush
	Entolasia stricta (wiry panic)*,*	Wiry Panic
	Lepidosperma sp.	
	Oplismenus sp.	
	Themeda australis	Kangaroo Grass
	Blechnum cartilagineum	Gristle Fern
	Calochlaena dubia	Common Ground Fern
	Cyathea australis	Rough Tree Fern
	Doodia aspera	Prickly Rasp Fern
	Hypolepis glandulifera	Downy Ground Fern
	Lastreopsis decomposita	Trim Shield Fern

VEGETATION ASSOCIATION	SPECIES – SCIENTIFIC NAME	SPECIES – COMMON NAME
Grassy Woodland	*Angophora floribunda*	Forest Red Gum
	Eucalyptus crebra	Narrow-leaved Ironbark
	E. eugenioides	Narrow-leaved Stringy Bark
	E. moluccana	Grey Box
	E. tereticornis	Rough-barked Apple
	Corymbia maculate	Spotted Gum
	Bursaria spinosa	Blackthorn
	Acacia implexa	Hickory Wattle
	A. *mearnsii*	Black Wattle
	Daviesia ulicifolia	Gorse Bitter Pea
	Dillwynia sieberi	Egg and Bacon Pea
	Jacksonia scoparia	Dogwood
	Leucopogon juniperinus	Prickly Beard-heath
	Ozothamnus diosmifolius	White Dogwood
	Alphitonia excelsa	Red Ash
	Eustrephus latifolius	Wombat Berry
	Glycine sp.	
	Desmodium sp.	Tick-trefoil
	Dichondra repens	Kidney Weed
	Geranium solanderi	Native Geranium
	Hydrocotyle laxiflora	Stinking Pennywort
	Oxalis perennans	
	Pratia purpurascens	White Root
	Asperula conferta	Common Woodruff
	Brunoniella australis	Blue Trumpet
	Wahlenbergia gracilis	Australian Bluebell
	Cheilanthes sieberi subsp. *Sieberi*	Poison Rock Fern
	Aristida ramose	Purple Wiregrass
	A. *vagans*	Threeawn Speargrass
	Cymbopogon refractus	Barbed Wire Grass
	Eragrostis leptostachya	Paddock Lovegrass
	Themeda australis	Kangaroo Grass
	Carex inversa	Knob Sedge
	Dichelachne micrantha	Plumegrass
	Microlaena stipoides var. *stipoides*	Weeping Grass

VEGETATION ASSOCIATION	SPECIES – SCIENTIFIC NAME	SPECIES – COMMON NAME
Heathland	*Leptospermum laevigatum* *Melaleuca armillaris* subsp. *armillaris* *Acacia myrtifolia* A. *suaveolens* *Allocasuarina distyla* *Banksia integrifolia* subsp. *Integrifolia* *B. oblongifolia* *Hakea laevipes* subsp. *Laevipes* *Lambertia Formosa* *Pultenaea maritime* *Westringia fruticosa* *Pandanus tectorius* var. *australianus* *Dianella caerulea* *Gonocarpus teucrioides* *Hydrocotyle peduncularis* *Mirbelia rubiifolia* *Patersonia sericea* *Polymeria calycina* *Lindsaea linearis* *Entolasia stricta* *Isolepis nodosa* *Lomandra longifolia*	Coast Teatree Red-stemmed Wattle Sweet Wattle Scrub Sheoak Coast Banksia Mountain Devil Coastal Rosemary Screw Pine Blue Flax Lily Raspwort Silky Purple-Flag Screw Fern Wiry Panic

	L. oblique *Oplismenus imbecillus* *Poa poiformis* *Ptilothrix deust* *Themeda australis*	Knobby Club-rush Spiny-headed Mat-rush Twisted Mat-rush Kangaroo Grass

VEGETATION ASSOCIATION	SPECIES – SCIENTIFIC NAME	SPECIES – COMMON NAME
Rainforest	*Acmena* sp., *Syzygium* sp.	Lilly Pilly
	Banksia integrifolia subsp. *Integrifolia*	Coast Banksia
	Cupaniopsis anacardioides	Tuckeroo
	Drypetes deplanchei subsp. *Deplanchei*	Yellow Tulipwood
	Euroschinus falcata var. *falcate*	Ribbonwood
	Ficus macrophylla subsp. *Macrophylla*	Moreton Bay Fig
	F. oblique	Small-leaved Fig
	Glochidion ferdinandi	Cheese Tree
	Pisonia umbellifera	Birdlime Tree
	Polyscias elegans	Celerywood
	Podocarpus elatus	Plum Pine
	Breynia oblongifolia	Coffee Bush
	Hibbertia scandens	Climbing Guinea Flower
	Pandorea pandorana	Wonga Wonga Vine
Subtropical Rainforest (Yamba and Iluka)	*Araucaria cunninghamii*	Hoop Pine
	Ficus macrophylla subsp. *Macrophylla*	Moreton Bay Fig
	F. oblique	
	F. coronata	Creek Sandpaper Fig
	Toona ciliate	Red Cedar
	Acmena ingens	Red Apple
	Syzygium crebrinerve	Purple Cherry
	Syzygium corynanthum	Sour Cherry
	Akania lucens	Turnipwood
	Baloghia inophylla	Brush Bloodwood
	Brachychiton acerifolius	Illawarra Flame Tree
	Caldcluvia paniculosa	Soft Corkwood
	Castanospermum australe	Black Bean

	Cryptocarya erythroxylon	Pidgeonberry Ash
	C. obovata	Pepperberry
	Dendrocnide excelsa	Stinging Tre
	Diploglottis australis	Native Tamarind
	Doryphora sassafras	Sassafras
	Dysoxylon fraserianum	Dysoxylon fraserianum
	Elaeocarpus grandis	Blue Quandong
	Flindersia australis	Crows Ash
	Geissois benthamiana	Red Carabeen
	Sloanea woollsii	Yellow Carabeen
	Gmelina leichhardtii	White Beech
	Heritiera actinophylla	Black Booyong
	H. trifoliolata	White Booyong
	Lophostemon confertus	Brush Box
	Orites excelsa	Prickly Ash
	Archontophoenix cunninghamiana	Bangalow Palm
	Citriobatus pauciflorus	Orange Thorn
	Cordyline stricta	Narrow-leaved Palm Lily
	Linospadix monostachya	Walking Stick Palm
	Neolitsea dealbata	White Bolly Gum
	Polyosma cunninghamii	Featherwood
	Ripogonum discolour	Prickly Supplejack
	Sarcopteryx stipata	Steelwood
	Wilkiea huegeliana	Veiny Wilkiea
	Cissus Antarctica	Water Vine
	Morinda jasminoides	
	Piper novae-hollandiae	Giant Pepper Vine
	Trophis scandens subsp. *Scandens*	Burny Vine
	Dendrobium gracilicaule	Rats Tail Orchid
	Asplenium australasicum	Birds Nest Fern
	Platycerium bifurcatum	Elkhorn

	Pyrrosia confluens var. *confluens*	Horseshoe Felt Vine
	Pseuderanthemum variabile	Pastel Flower
	Dioscoea transversa	Native Yam
	Alocasia brisbanesis	Cunjevoi
	Adiantum formosum	Giant Maidenhair
	Blechnum patersonii subsp. *Patersonii*	Strap Water Fern
	Cyathea leichhardtiana	Prickly Tree Fern
	Lastreopsis munita	Naked Shield Fern
	Gymnostachys anceps	Settlers Flax
	Lomandra spicata	

VEGETATION ASSOCIATION	SPECIES – SCIENTIFIC NAME	SPECIES – COMMON NAME
Forested Wetland – Coastal Floodplain (river corridors and coastal floodplains)	*Angophora floribunda*	Rough-barked Apple
	A. subvelutina	Broad-leaved Apple
	Eucalyptus amplifolia	Cabbage Gum
	E. grandis	Flooded Gum
	E. robusta	Swamp Mahogany
	E. saligna	Sydney Blue Gum
	E. tereticornis	Forest Red Gum
	Casuarina glauca	Swamp Oak
	Lophostemon suaveolens	Swamp Mahogany
	Ficus macrophylla	Moreton Bay Fig
	Livistona australis	Cabbage Palm
	Melaleuca ericifolia	Swamp Paperbark
	Melaleuca styphelioides	Teatree
	Glochidion ferdinandi	Cheese Tree
	Parsonsia straminea	Common Silkpod
	Alternanthera denticulate	Lesser Joyweed
	Commelina cyanea	Scurvy Weed
	Dichondra repens	Kidney Weed
	Lobelia alata	Angled Lobelia
	Persicaria decipiens	Slender Knotweed
	Pratia purpurascens	White Root
	Solanum pungetium	Eastern Nightshade
	Viola hederacea	Ivy-leaved Violet
	Baumea juncea	Bare Twig-rush
	Carex appressa	Tussock Sedge
	Cynodon dactylon	Couch
	Zoysia macrantha	Prickly Couch
Coastal Swamp (Yuraygir and Bundjalung National Parks)	*Echinopogon ovatus*	Forest Hedgehog Grass
	Entolasia marginata	Bordered Panic
	Gahnia clarkei	Tall Saw-sedge
	Imperata cylindrica var. *major*	Blady Grass
	Juncus kraussii subsp.	Sea Rush

Eastern Riverine Forests (Wooli)	*Australiensis* *J. usitatus* (common rush)*,* *Lomandra longifolia* *Microlaena stipoides* var. *stipoides* *Phragmites australis* *Callistemon salignus* *Eucalyptus robusta* *Melaleuca quinquenervia* *M. nodosa* *M. sieberi* *Casuarina glauca* *Banksia oblongifolia* *Callistemon linearis* *Leptospermum juniperinum* *Xanthorrhoea fulva* *Gonocarpus micranthus* *Blechnum camfieldii* *B. cartilagineum* *B. indicum* *Hypolepis muelleri* *Baloskion tetraphyllus* subsp. *meiostachyus* *Baumea arthrophylla* *B. rubiginosa* *Empodisma minus* *Gahnia clarkei* *Schoenus brevifolius* *Casuarina cunninghamiana* *Acacia floribunda* *Acacia mearnsii*	 Common Rush Spiny-headed Mat-rush Weeping Grass Common Reed Sweet Willow Bottlebrush Swamp Mahogany Broad-leaved Paperbark Swamp Oak Narrow-leaved Bottlebrush Prickly Teatree Creeping Raspwort Gristle Fern Swamp Water Fern Harsh Ground Fern Tassel Rush Soft Twig-rush Spreading Rope-rush Tall Saw-sedge Short-leaf/Zig-zag Bog-rush River Oak White Sally Black Wattle

	Glochidion ferdinandi *Hymenanthera dentate* *Tristaniopsis laurina* *Hydrocotyle tripartite* *Persicaria hydropiper* *Carex appressa* *Entolasia marginata* *Lomandra longifolia* *Microlaena stipoides* var. *stipoides* *Oplismenus aemulus.*	Cheese Tree Tree Violet Water Gum Pennywort Water Pepper Tussock Sedge Bordered Panic Spiny-headed Mat-rush Weeping Grass

VEGETATION ASSOCIATION	SPECIES – SCIENTIFIC NAME	SPECIES – COMMON NAME
Freshwater Wetland – Coastal Freshwater Lagoons (Wooli, Lawrence and Clarence Broadwater)	*Lepironia articulata*	Twig Rush
	Eleocharis sphacelata	Giant Spike Rush
	Baumea sp.	Twig Rush
	Isachne globosa	Marsh Millet
	Lepidosperma longitudinale	Pithy Saw Sedge
	Villarsia exaltata	Erect Marsh Flower
	Ludwigia peploides ssp. *Montevidensis*	Water Primrose
	Alisma plantago-aquatica	Water Plantain
Coastal Heath Swamps (Northern Rivers Region)	*Leptospermum* sp.	Teatree
	Melaleuca squarrosa	Scented Paperbark
	Callistemon citrinus	Crimson Bottlebrush
	Epacris paludosa	Swamp Heath
	E. obtusifolia	Blunt-leaf Heath
	Sprengelia incarnata	Pink Swamp Heath
	Banksia sp.	
	Hakea teretifolia	Dagger Hakea
	Bauera sp.	
	Dillwynia floribunda	Parrot Pea
	Symphionema paludosum	
	Empodisma minus	Spreading Rope Rush
	Leptocarpus tenax	Seeded Rush
	Lepyrodia sp.	
	Eurychorda complanatus	Flat Stemmed Cord Rush
	Schoenus brevifolius	Short-leaf/Zig-zag Bog-rush
	Lepidosperma limicola	Razor Sedge
	L. neesii	Stiff Rapier Sedge
	Ptilothrix deusta	Fluke Bog-rush
	Baumea sp.	Twig Rush
	Chorizandra sphaerocephala	Roundhead Bristle Rush
	Gymnoschoenus sphaerocephalus	Button Grass

	Gahnia sieberiana	Saw-sedge
	Entolasia stricta	Wiry Panic
	Tetrarrhena turfosa	Smooth Rice Grass
	Selaginella uliginosa	Swamp Clubmoss
	Gleichenia dicarpa	Pouched Coral Fern
	Drosera spathulata	Sundew
	D. binata	Forked Sundew
	Xanthorrhoea sp.	Grass Tree
	Blandfordia grandiflora	Christmas Bells
	Burchardia umbellata	Milkmaid
	Sowerbaea juncea	Vanilla Lily/Rush Lily
	Thysanotus juncifolius	Rush Fringe Lily
	Xyris operculata	Tall Yellow-eye
	Dampiera stricta	Glasshouse Glory

VEGETATION ASSOCIATION	SPECIES – SCIENTIFIC NAME	SPECIES – COMMON NAME
Saline Wetland – Mangrove Swamps (mudflats and coastal estuaries)	*Avicennia marina*	Grey Mangrove
	Aegiceras corniculatum	Goat's Horn Mangrove
	Bruguiera gymnorrhiza	Large-leaved Orange Mangrove
	Rhizophora stylosa	Spotted-leaved Red Mangrove
	Excoecaria agallocha	Blind-your-eye Mangrove
	Samolus repens	Creeping Brookweed
Saltmarshes (Iluka to Wooli)	*Suaeda australis*	Seablite
	Sarcocornia quinqueflora ssp. *quinqueflora*	Beaded Glasswort
	Sclerostegia arbuscula	Shrubby Glasswort
	Sarcocornia quinqueflora ssp. quinqueflora	Beaded Glasswort
	Avicennia marina	Grey Mangrove
	Juncus kraussii	Sea Rush
	Sporobolus virginicus	Salt Couch
	Samolus repens	Creeping Brookweed
	Austrostipa stipoides	Coast Spear Grass
	Suaeda australis	Seablite
	Apium prostratum	Fine-leaved Apium
	Baumea sp.	Twig Rush
	Limonium australe	Sea Lavender
	Selliera radicans	Swamp Weed
	Zoysia macrantha	Prickly Couch
	Gahnia filum	Chaffy Saw-sedge
	Wilsonia backhousei	Narrow-leaf Wilsonia
	Phragmites australis	Common Reed
	Triglochin striata	Streaked Arrow-grass
	Disphyma crassifolium ssp. *clavellatum*	Rounded Moon Flower

List of useful plant identification field guides:

Aquatic and Wetland Plants: A Field Guide for Non-tropical Australia, Nick Romanowski.
Australian Rainforests in New South Wales, Alexander G Floyd.
Beach Plants of South Eastern Australia, Roger Carolin and Peter Clarke.
Coastal Dune Vegetation of New South Wales, Peter Clarke.
Field Guide to Native Plants of Australia, compiled by the editors and writers of The Living Australia magazine.
Grassland Plants of South-Eastern Australia: A Field Guide to Native Grassland and Grassy Woodland Plants of South-Eastern Australia, Neil and Jane Marriott.
Weeds of the South-east: An Identification Guide for Australia, F. J. Richardson, R. G. Richardson and R. C. H. Shepherd.

APPENDIX 3

How to perform the Emerson Aggregate Test of soil stability (Emerson, 1967)

Equipment:

- Clear 250 ml container (for example, a glass or similar)
- Bottle of deionised or rain water
- Mixing bowl
- Small spoon or similar

Method:
(also see the following flow chart, Figure 13, and glossary)

- Select three air-dry clumps of soil (aggregates) measuring 5-10 mm across.
- Place 75 ml water in a clear container. Place the 3 aggregates in the container
- of water, spaced equally around the side. Do not stir.
- Record the time the aggregates were placed in the water.
- After 2 hours and 20 hours, record whether **slaking** has occurred (see Figure 14). If there has been slaking, note the degree of **dispersion**: complete dispersion (this is a class 1 aggregate; see Figure 16), some dispersion (this is a class 2 aggregate; see Figure 15) or no dispersion (this is a class 7 aggregate).
- If there has been no slaking, record if there has been any **swelling** of the aggregate. If there has been swelling, this is a class 7 aggregate. If there has been no swelling, this is a class 8 aggregate.
- If there is slaking but no dispersion after 20 hours (class 7 aggregates), place about 2 mm of the soil in a mixing bowl. Add enough water so that the soil can be molded and mix with a spoon for 30 seconds.
- Make a 5 mm ball of this soil using the spoon. Place this ball into another clear container filled with water. Do not stir.
- After 2 and 20 hours, if there is no dispersion the aggregate is still in class 7. If there is dispersion the aggregate is class 3.
- If there is no dispersion, the soil will require further testing in a laboratory.

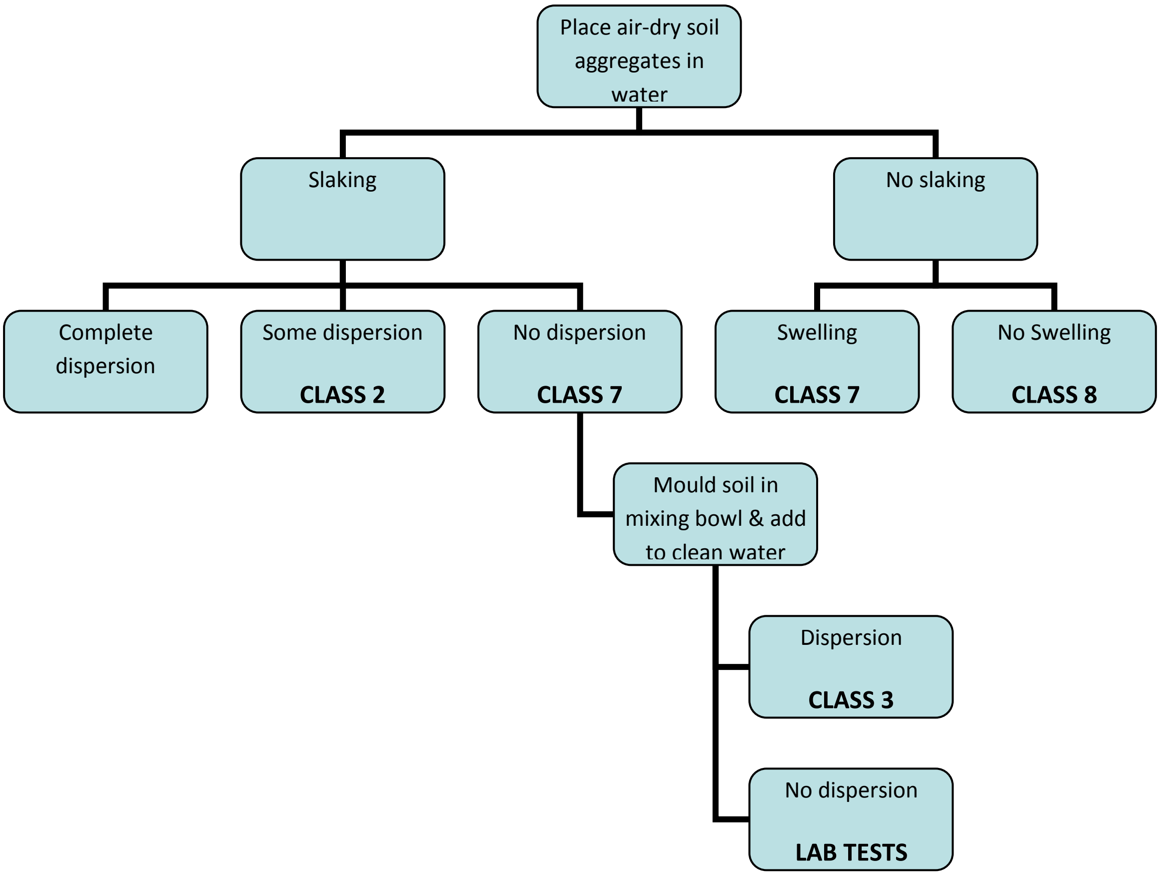

Figure 13: Flow chart for the Emerson Aggregate Test.

Glossary and pictures:
Dispersion occurs when soil separates into single particles (see Figures 15 and 16).
Slaking occurs when wet soil breaks down into smaller pieces. This happens when clay swells and the air trapped inside bursts out (see Figure 14).
Swelling – when a soil aggregate becomes wet the air trapped inside it causes swelling. The aggregate will appear larger but not broken down into smaller pieces (slaked).

Figure 14: Slaking of a soil aggregate. Slight dispersion can be seen as milkiness of water around the aggregate (arrow). Source: http://www.dpi.nsw.gov.au/agriculture/horticulture/vegetables/soil/soilpak/soil-testing/Slaking-and-dispersion.pdf

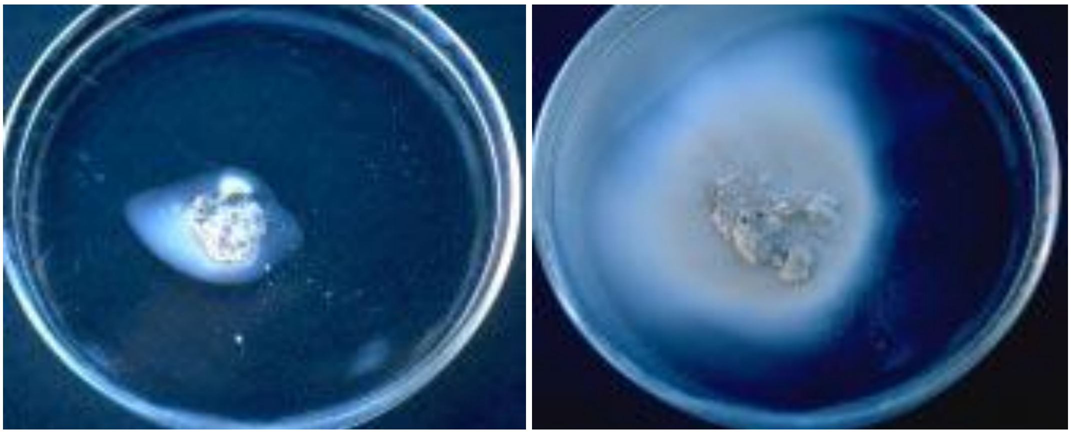

Figure 15: Partly dispersed soil aggregates. Source: http://www.dpi.nsw.gov.au/agriculture/horticulture/vegetables/soil/soilpak/soil-testing/Slaking-and-dispersion.pdf

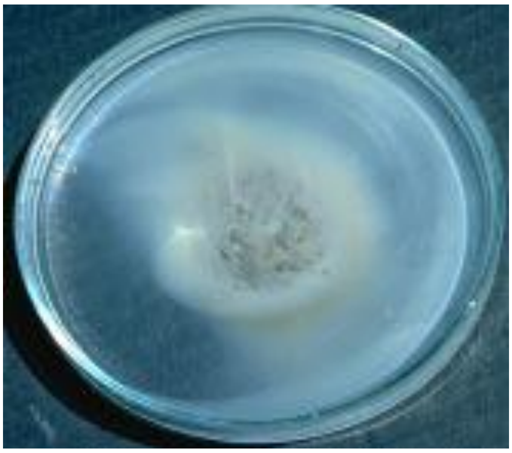

Figure 16: Complete dispersion of a soil aggregate. The water is very milky and only sand grains are left at the bottom of the container. Source: http://www.dpi.nsw.gov.au/agriculture/horticulture/vegetables/soil/soilpak/soil-testing/Slaking-and-dispersion.pdf

APPENDIX 4

HISTORIC FLOOD AND TIDE DATA

Data pertaining to flood peak levels and return periods has been collected by the Clarence Valley Council Floodplain Services and Manly Hydraulics Laboratory at the Maclean and Palmer's Channel flood gauges. These data are presented in Appendix 4 along with a frequency distribution table of flood flows used by Manly Hydraulics Laboratory to calculate the inundation classes refered to in the text. A summary table of relevant study sites and their corresponding inundation classes is also included on page A4-3.

GAUGE	**YEAR**	**PEAK LEVEL (m AHD)**	**ARI (period - yr)**
MACLEAN	1945	2.654	6.1
	1946	2.474	5
	1948	2.904	9.4
	1950	3.154	15.2
	1954	2.994	9.7
	1956	2.544	4.9
	1959	2.464	5
	1963	3.054	15
	1967	3.314	>20
	1974	3.364	>20
	1976	2.724	5.3
	1988	2.754	5.3
	1989	2.674	6.2
	1990	1.05	2.4
	1995	1.04	2.2
	1996	2.994	9.7
	1997	0.95	1.5
	1999	0.98	1.6
	2001	3.214	19.5
	2006	1.1	2.8
	2008	1.53	3.9
PALMER'S CHANNEL			
	1945	2.3	
	1946	2.2	
	1948	2.4	
	1959	2.13	
	1962	2.13	
	1963	2.55	
	1964	1.4	

	1965	1.12	
	1967	2.57	
	1968	1.82	
	1971	1.26	
	1974	1.44	
	1980	2	
	2007	2.67	[18.9]*

*Manly Hydraulics data. All other data from Clarence Valley Council Floodplain Services.

INUNDATION CLASS	LEVEL (mIPD)		Freq.
4	2.3		4
4	2.2		9
3	2.1		49
2	2		214
2	1.9		716
1	1.8		1674
1	1.7		3275
1	1.6		5439
1	1.5		7836
1	1.4		9855
1	1.3		11524
1	1.2		12565
1	1.1		12672
1	1		12813
1	0.9		12424
1	0.8		12773
1	0.7		13492
1	0.6		13816
1	0.5		12495
1	0.4		9655
1	0.3		5880
1	0.2		2727
2	0.1		932
3	0		150
3	-0.1		26
4	-0.2		7
4	-0.3		5
5	-0.4		1

IPD=Iluka Port Datum.

SITE	**LEVEL (mLAT/IPD)**	**INUNDATION CLASS**
Woombah A	1.93	2
Woombah B	2.25	4
Sleeper Island	1.92	2
Wooli^	1.86	above tidal range

^Wooli tidal inundation classes used for this site.

APPENDIX 5

RESULTS OBTAINED USING THE THREE EROSION HAZARD ASSESSMENT TECHNIQUES OUTLINED IN THE TEXT

Method 1

SITE	DISTURBANCE PROCESS(ES)	FACTORS CONSIDERED	OUTCOME	SITE HAZARD RANKING
Sleeper Island	Bank erosion	Bank stability	Veg cover=100% (grass), 20% (shrubs and trees) - floodplain. Veg cover=0% (grass, shrubs and trees) - bank.	
		Tidal inundation	Elevation 1.92m: Inundation Class 2	
		Wave height	Fetch=25m	
		Bank position in channel	Exposed - outside meander bend=erosion	
		Human activity multiplier	sustained use (3) X affected factors (2)=6	
	Cultivation	Human activity	Riverbank: slope=90° floodplain: slope=<2°	
			Distance of crops from riverbank=N/A	
			years farmed= special licences issued between 1915 and 1958, possibly longer. Leased for dairy and agriculture from at least 1915 to 1929, no current farming activity	
				MAJOR
Woombah Riverbank A	Bank erosion	Bank stability	Veg cover= 100% (grass), 25% (shrubs and trees) - floodplain. Veg cover=0% (grass), 40% (shrubs and trees) - bank.	
		Tidal inundation	Elevation 1.93m: Inundation Class 2	
		Wave height	Fetch=125m	
		Bank position in channel	Narrow channel of North Arm adjacent to Yargai Island=sheltered/protected	
		Human activity multiplier	minimal use (1) X affected factors (2)=2	
	Cultivation	Human activity	Creekbank: slope=60°, floodplain: slope=<2°	
			Distance of crops from riverbank=N/A	
			years farmed= 1/8X3/4 mile lots subdivided pre-1912, no record of ownership between 1912 and 1931, no current farming activity	

				MODERATE
Woombah Creek bank B	Excavation	Human activity	*in situ* material estimate=4.84%	
			Current disturbance=0, historic disturbance=2005 (illegal excavation for a residential development), earlier (collection of shells for lime)	
			325m south of sealed road to Iluka, 150m south of unsealed residential access public road	
			Zones 1(a) rural (agricultural protection) and 1(r) rural (residential).	
	Cultivation	Human activity	Riverbank: slope=90°, floodplain: slope=<2°	
			Distance of crops from riverbank=N/A	
			years farmed= 1/8X3/4 mile lots subdivided pre-1912, no record of ownership between 1912 and 1931, no current farming activity	
				MINOR
Plover Island	Wind erosion	Deposit stability	Veg cover (surface scatter)=60% (grass), 0% (shrubs and trees), veg cover (*in situ* exposure)=20% (grass), 10% (shrubs and trees)	
		Exposure to prevailing winds	*in situ*=50% (morning SW), surface scatter=100% (morning SW, afternoon NE)	
		Human activity multiplier	seasonal use (2) X affected factors (1)=2	
	Wave erosion	Ocean swell	Elevation^=6.4mAPSL (*in situ*), 7.1mAPSL (surface scatter)	
			Storm surge deposits=absent	
			Cliffing=absent at *in situ* and surface scatter elevations	
				MODERATE
Minnie Water	Wind erosion	Deposit stability	Veg cover=20% (grass), 5% (shrubs and trees)	
		Exposure to prevailing winds	100% (morning S and SW, afternoon S, SE and E)	
		Human activity multiplier	seasonal use (2) X affected factors (1)=2	
	Wave erosion	Ocean swell	Elevation^=2.0mAPSL (1.1mLAT)	
			Storm surge deposits=present (the deposit itself is a reworked midden)	
			Cliffing=present	

				MAJOR
Wooli	Excavation	Human activity	Current disturbance=0 (proposed walkway will be elevated and go around midden site) , historic disturbance=0 (parish maps from 1898 - 1955 indicate the land 'for licence and lease generally noted 26/06/1907 for public recreation'. The Parish of Wooli Wooli declared a bird and animal sanctuary 05/07/1940.	
			50m west of sealed Wooli Road	
			Zone 6(a) (open space)	
		Bioturbation	*in situ* material estimate=99.98% (ie. 0.02% disturbed)	
				MINOR

^Elevation for coastal sites measured as mAPSL, for estuarine sites measured as mLAT.

Method 2

RESEARCHER'S RESULTS				**GROUP 1 RESULTS**				**GROUP 2 RESULTS**				**GROUP 3 RESULTS**			**GROUP 4 RESULTS**	
SITE	COMPONENT	SCORE		SITE	COMPONENT	SCORE		SITE	COMPONENT	SCORE		COMPONENT	SCORE		COMPONENT	SCORE
WA	Field forms & veg.	1		WA	Field forms & veg.	1		WA	Field forms & veg.	1		Field forms & veg.	1		Field forms & veg.	2
	Taphonomy	1			Taphonomy	1			Taphonomy	1		Taphonomy	1		Taphonomy	1
	Aggregate stability	3			Aggregate stability	3			Aggregate stability	3		Aggregate stability	3		Aggregate stability	3
	Tidal activity	3			Tidal activity	3			Tidal activity	3		Tidal activity	3		Tidal activity	3
	TOTAL	8			TOTAL	8			TOTAL	8		TOTAL	8		TOTAL	9
	EROSION HAZARD INDEX	**2**			EROSION HAZARD INDEX	2			EROSION HAZARD INDEX	2		EROSION HAZARD INDEX	2		EROSION HAZARD INDEX	2.25
	RECOMMENDATION CATEGORY	**3**			RECOMMENDATION CATEGORY	3			RECOMMENDATION CATEGORY	3		RECOMMENDATION CATEGORY	3		RECOMMENDATION CATEGORY	3
WB	Field forms & veg.	1		WB	Field forms & veg.	1		WB	Field forms & veg.	1		Field forms & veg.	0		Field forms & veg.	0
	Taphonomy	1			Taphonomy	1			Taphonomy	1		Taphonomy	2		Taphonomy	2
	Aggregate stability	2			Aggregate stability	2			Aggregate stability	2		Aggregate stability	2		Aggregate stability	2
	Tidal activity	3			Tidal activity	3			Tidal activity	3		Tidal activity	3		Tidal activity	3
	TOTAL	7			TOTAL	7			TOTAL	7		TOTAL	7		TOTAL	7
	EROSION HAZARD INDEX	**1.75**			EROSION HAZARD INDEX	1.75			EROSION HAZARD INDEX	1.75		EROSION HAZARD INDEX	1.75		EROSION HAZARD INDEX	1.75
	RECOMMENDATION CATEGORY	**2**			RECOMMENDATION CATEGORY	2			RECOMMENDATION CATEGORY	2		RECOMMENDATION CATEGORY	2		RECOMMENDATION CATEGORY	2
SI	Field forms & veg.	3		SI	Field forms & veg.			SI	Field forms & veg.	3		Field forms & veg.	3		Field forms & veg.	3
	Taphonomy	2			Taphonomy				Taphonomy	2		Taphonomy	2		Taphonomy	2
	Aggregate stability	3			Aggregate stability				Aggregate stability	3		Aggregate stability	3		Aggregate stability	3
	Tidal activity	3			Tidal activity				Tidal activity	3		Tidal activity	3		Tidal activity	3
	TOTAL	11			TOTAL				TOTAL	11		TOTAL	11		TOTAL	11
	EROSION HAZARD INDEX	**2.75**			EROSION HAZARD INDEX				EROSION HAZARD INDEX	2.75		EROSION HAZARD INDEX	2.75		EROSION HAZARD INDEX	2.75

	RECOMMENDATION CATEGORY	**4**			RECOMMENDATION CATEGORY				RECOMMENDATION CATEGORY	4		RECOMMENDATION CATEGORY	4		RECOMMENDATION CATEGORY	4
MW	Field forms & veg.	2		MW	Field forms & veg.	2		MW	Field forms & veg.	2		Field forms & veg.	2		Field forms & veg.	2
	Taphonomy	3			Taphonomy	3			Taphonomy	3		Taphonomy	3		Taphonomy	3
	Aggregate stability	3			Aggregate stability	3			Aggregate stability	3		Aggregate stability	3		Aggregate stability	3
	Tidal activity	3			Tidal activity	3			Tidal activity	3		Tidal activity	3		Tidal activity	3
	TOTAL	11			TOTAL	11			TOTAL	11		TOTAL	11		TOTAL	11
	EROSION HAZARD INDEX	**2.75**			EROSION HAZARD INDEX	2.75			EROSION HAZARD INDEX	2.75		EROSION HAZARD INDEX	2.75		EROSION HAZARD INDEX	2.75
	RECOMMENDATION CATEGORY	**4**			RECOMMENDATION CATEGORY	4			RECOMMENDATION CATEGORY	4		RECOMMENDATION CATEGORY	4		RECOMMENDATION CATEGORY	4
WL	Field forms & veg.	0		WL	Field forms & veg.	0		WL	Field forms & veg.	0		Field forms & veg.	0		Field forms & veg.	0
	Taphonomy	1			Taphonomy	1			Taphonomy	1		Taphonomy	1		Taphonomy	1
	Aggregate stability	N/A			Aggregate stability	N/A			Aggregate stability	N/A		Aggregate stability	N/A		Aggregate stability	N/A
	Tidal activity	0			Tidal activity	0			Tidal activity	0		Tidal activity	0		Tidal activity	0
	TOTAL	1			TOTAL	1			TOTAL	1		TOTAL	1		TOTAL	1
	EROSION HAZARD INDEX	**0.3**			EROSION HAZARD INDEX	**0.3**			EROSION HAZARD INDEX	**0.3**		EROSION HAZARD INDEX	**0.3**		EROSION HAZARD INDEX	**0.3**
	RECOMMENDATION CATEGORY	**1**			RECOMMENDATION CATEGORY	**1**			RECOMMENDATION CATEGORY	**1**		RECOMMENDATION CATEGORY	**1**		RECOMMENDATION CATEGORY	**1**
PI	Field forms & veg.	2			**GROUP 1:** Yaegl community members lead by an environmental scientist.				**GROUP 2:** Yaegl community members lead by an archaeologist.			**GROUP 3:** Yaegl community members lead by a scientist in an unrelated discipline.			**GROUP 4:** Yaegl community members briefed by the researcher and self-lead.	
	Taphonomy	N/A														
	Aggregate stability	0														
	Tidal activity	0														
	TOTAL	2														
	EROSION HAZARD	**0.67**														

	INDEX															
	RECOMMENDATION CATEGORY	**1**														

Maximum total score=12; Maximum Erosion Hazard Index=3

Method 3

SITE	**LAYER**	**RISK**
WA	Vegetation Coverage	1
	Slope	1
	Soils (texture)	1
	Soils (TOC)	2
	Soils (Emerson)	3
	Surface/subsurface Age/texture	3
	Land Use	2
	Total	13
	AVG	**1.86**
WB	Vegetation Coverage	2
	Slope	1
	Soils (texture)	1
	Soils (TOC)	1
	Soils (Emerson)	2
	Surface/subsurface Age/texture	3
	Land Use	1
	Total	11
	AVG	**1.57**
SI	Vegetation Coverage	3

	Slope	1
	Soils (texture)	3
	Soils (TOC)	1
	Soils (Emerson)	3
	Surface/subsurface Age/texture	3
	Land Use	1
	Total	15
	AVG	**2.14**
MW	Vegetation Coverage	1
	Slope	1
	Soils (texture)	3
	Soils (TOC)	3
	Soils (Emerson)	3
	Surface/subsurface Age/texture	3
	Land Use	0
	Total	14
	AVG	**2**
WL	Vegetation Coverage	1
	Slope	1
	Soils (texture)	1
	Soils (TOC)	2
	Soils (Emerson)	n/a
	Surface/subsurface Age/texture	3
	Land Use	1
	Total	9
	AVG	**1.5**

PI	Vegetation Coverage	2
	Slope	1
	Soils (texture)	1
	Soils (TOC)	3
	Soils (Emerson)	0
	Surface/subsurface Age/texture	3
	Land Use	1
	Total	11
	AVG	**1.57**

RECOMMENDATIONS FOR MAINTENANCE AND CONSERVATION OF ABORIGINAL SHELL MIDDEN SITES BASED ON THE EROSION HAZARD INDEX

INDEX	CATEGORY	RECOMMENDATIONS
0-0.9	1	Very low erosion hazard. Visiting these sites every two years is recommended. Fill in an Erosion Hazard Pro Forma each time the site is visited to monitor any changes in vegetation, shell condition, tidal activity and land use.
1-1.9	2	Low erosion hazard. Visiting these sites every one to two years is recommended. Fill in an Erosion Hazard Pro Forma each time the site is visited to monitor any changes in vegetation, shell condition, tidal activity and land use.
2-2.5	3	Moderate erosion hazard. Yearly visits to these sites are recommended. Fill in an Erosion Hazard Pro Forma each time the site is visited to monitor any changes in vegetation, shell condition, tidal activity and land use. Encouraging vegetation growth will help stabilise these sites and reduce erosion. If the type of land use at a site appears to be causing further erosion contact local council, the Department of Environment, Climate Change and Water Aboriginal Heritage Section or the National Parks and Wildlife Service to discuss your concerns.
2.6-3	4	High erosion hazard. Sites need to be visited at least once every six months. Fill in an Erosion Hazard Pro Forma each time the site is visited to monitor any changes in vegetation, shell condition, tidal activity and land use. Encouraging vegetation growth will help stabilise these sites and reduce erosion. If the type of land use at a site appears to be causing further erosion contact local council, the Department of Environment, Climate Change and Water Aboriginal Heritage Section or the National Parks and Wildlife Service to discuss your concerns.

MACQUARIE
UNIVERSITY ~ SYDNEY

3 May 2007

Ms Hannah Nair
9 Darvall Road
Eastwood NSW 2122

Reference: HE23MAR2007-D05061

Dear Ms Nair

FINAL APPROVAL

Title of project: ***The role of geomorphological processes in the accumulation, degradation, and preservation of Aboriginal Midden sites; northern New South Wales***

Thank you for your recent correspondence. Your responses have satisfactorily addressed the outstanding issues raised by the Committee. You may now proceed with your research.

Please note the following standard requirements of approval:

1. Approval will be for a period of twelve months. At the end of this period, if the project has been completed, abandoned, discontinued or not commenced for any reason, you are required to submit a Final Report on the project. If you complete the work earlier than you had planned you must submit a Final Report as soon as the work is completed. The Final Report is available at http://www.ro.mq.edu.au/ethics/human/forms
2. However, at the end of the 12 month period if the project is still current you should instead submit an application for renewal of the approval if the project has run for less than five (5) years. This form is available at http://www.ro.mq.edu.au/ethics/human/forms. If the project has run for more than five (5) years you cannot renew approval for the project. You will need to complete and submit a Final Report (see Point 1 above) and submit a new application for the project. (The five year limit on renewal of approvals allows the Committee to fully re-review research in an environment where legislation, guidelines and requirements are continually changing, for example, new child protection and privacy laws).
3. Please remember the Committee must be notified of any alteration to the project.
4. You must notify the Committee immediately in the event of any adverse effects on participants or of any unforeseen events that might affect continued ethical acceptability of the project.
5. At all times you are responsible for the ethical conduct of your research in accordance with the guidelines established by the University (http://www.ro.mq.edu.au/ethics/human).

If you will be applying for or have applied for internal or external funding for the above project **it is your responsibility** to provide Macquarie University's Research Grants Officer with a copy of this letter as soon as possible. The Research Grants Officer will not inform external funding agencies that you have final approval for your project and funds will not be released until the Research Grants Officer has received a copy of this final approval letter.

Yours sincerely

p.p

Dr Margaret Stuart
Director of Research Ethics
Chair, Ethics Review Committee [Human Research]
cc. Associate Professor Jim Kohen

HLTR08.2 : CRO File: 07/179 **ETHICS REVIEW COMMITTEE (HUMAN RESEARCH)**
MACQUARIE UNIVERSITY (E11A)
SYDNEY, NSW, 2109 AUSTRALIA
Secretary: Ph: (02) 9850 7850 Fax: (02) 9850 4465 E-mail: ethics.secretariat@vc.mq.edu.au
http://www.ro.mq.edu.au/ethics/human
Portrait (85%)

MACQUARIE
UNIVERSITY ~ SYDNEY

Ms Hannah Nair
9 Darvall Road
Eastwood NSW 2122

1 June 2007

Dear Ms Nair

FINAL APPROVAL

Title of Project: The role of geomorphological processes in the accumulation, degradation and preservation of Aboriginal Midden Sites: Northern New South Wales (Part B)
Reference Number: HE25MAY2007-D05255

Thank you for submitting the above application which was reviewed by the Ethics Review Committee (Human Research) at its meeting on 25 May 2007. It was noted that the first stage of the work in this application for initial contact with the participants on site in northern NSW has previously been approved by the ERC (HE23MAR2007-D05061). The application above is for the fieldwork.

The Committee recommended final approval of this application and requested that you receive congratulations on the submission of a well-structured, clear, exemplary application.

The Committee offers you its best wishes for the conduct of this project.

Please note the following standard requirements of approval:
1. Approval will be for a period of twelve months. At the end of this period, if the project has been completed, abandoned, discontinued or not commenced for any reason, you are required to submit a Final Report on the project. If you complete the work earlier than you had planned you must submit a Final Report as soon as the work is completed. The Final Report is available at http://www.ro.mq.edu.au/ethics/human/forms.
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6. If you will be applying for or have applied for internal or external funding for the above project it is your responsibility to provide Macquarie University's Grants Officer with a copy of this letter as soon as possible. The Grants Officer will not inform external funding agencies that you have final approval for your project and funds will not be released until the Grants Officer has received a copy of this final approval letter.

CRO File: 07/629
ETHICS REVIEW COMMITTEE (HUMAN RESEARCH)
MACQUARIE UNIVERSITY (E11A)
SYDNEY, NSW, 2109 AUSTRALIA
Secretary: Ph: (02) 9850 7854 Fax: (02) 9850 8799 E-mail: kdesilva@vc.mq.edu.au
http://www.ro.mq.edu.au/eth_hum.htm
Portrait (85%

Yours sincerely

[signature]

PP **Dr Margaret Stuart**
Director of Research Ethics
Chair, Ethics Review Committee (Human Research)

ETHICS REVIEW COMMITTEE (HUMAN RESEARCH)
MACQUARIE UNIVERSITY (E11A)
SYDNEY, NSW, 2109 AUSTRALIA
Secretary: Ph: (02) 9850 7854 Fax: (02) 9850 8799 E-mail: kdesilva@vc.mq.edu.au
http://www.ro.mq.edu.au/eth_hum.htm