SHORE PLATFORM OBSERVATION AT TATAPOURI AND MAHIA PENINSULA, NEW ZEALAND

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Murray Te Aho

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Abstract

Measuring the shore platform width might be an effective way to measure the rate of coastal retreat. The processes controlling shore platforms are a highly debated topic throughout the coastal science community. Some researchers believe that marine processes control them and other researchers believe that physical weathering is responsible.

This study determined the relationship between rock mass classification systems and shore platform widths as a diagnostic tool to predict the rate of recession. Testing took place along the Mahia Peninsula and Tatapouri on the East Coast of New Zealand. A Garmin eTrex hand-held GPS unit was used to map both the cliff base position and the edge boundary of the shore platform.

Data analysis for Mahia Peninsula showed a linear relationship with a r^2 value of 68% with a negative regression line. The data for Tatapouri showed that there was no linear relationship, but has an r^2 value of 68% when a polynomial fit to the 2nd order was apply to the data (appendix). The estimated rate of erosion, ranges from 0.61 to 17.8 $\pm$ 0.06 mm y^{-1} for Mahia Peninsula and 1.32 to 16.45 ± 0.08 mm y^{-1} for Tatapouri.

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CHAPTER ONE

INTRODUCTION TO THESIS

1.1 INTRODUCTION

The loss of coastal cliffs is a concern in countries like Denmark, Germany, Russia, Japan, New Zealand, Canada, UK, and in the USA where on average cliff recession rates in excess of 1 m per year are experienced at some coastal sites (Sunamura 1992 cited in Hall *et al.* 2002)). It is not clear cut and sometimes impossible to measure cliff erosion or predict cliff recession due to physical variations such as wave action, weathering mechanics, cliff strength, and spatial effects (Hall *et al.* 2002, Fairbridge, 2004). For example, extreme storm events, sea level rise, storm surges, tsunamis, tectonic upheaval, landslides, accelerated erosion caused by human development, all impact on short and long – term erosion rates (Hall *et al.* 2002, Finkl 2004).

These processes and complex interactions have been shaping the Earth for millions of years. Most previous investigations of sea-cliff erosion have used sequential aerial photography, historic maps, and / or ground surveys to develop cliff position time series and magnitudes of cliff retreat (e.g. Jones and Williams, 1991; Kirk, 1975; Lajoie and Mathieson, 1985; Carter and Guy, 1988; Sunamura and Horikawa, 1972; and Hampton and Dingler, 1998).

Recession of coastal cliffs is essential for platform development. Based on previous research by Challinor in 1949, Trenhaile in 1974, stated that the entire shore platform migrates landward at a rate controlled by the retreat of the associated coastal cliffs (Moon and de Lange, 2005). Conversely, Sunamura in 1983 and Trenhaile in 2000 and 2001, stated and argued that the seaward margin

of the shore platform remains relatively fixed, so that platform width increases over time (Moon and de Lange, 2005).

So the question must be asked on the relative importance of wave and weathering processes in the formation of shore platforms? The literature on this issue has debated this question for more than half a century (Wentworth 1938, 1939, Bird and Dent 1966, Healy 1968, Trenhaile 1971, Sunamura 1978, 1978; Stephenson 2000).

Many different authors have tended to emphasise one over the other, assigning either weathering to a secondary role as stated by Bartrum and Turner in 1928 and Bartrum in 1935, or waves to a secondary role stated by Wentworth, 1939; and Healy, 1968 (Stephenson 2000).

Kirk in 1977 has proposed that both sub-aerial weathering and erosive marine processes are equally important (Stephenson 2000). Stephenson (2000) identifies four themes in shore platform research:

1. The role of marine and sub-aerial processes in platform development;
2. morphology of shore platforms;
3. modelling platform development and;
4. measuring rates of erosion.

Moon & de Lange (2005) propose that measuring the width of the shore platform may be a simpler and easier way of assessing the nature of possible causes for cliff recession rates within the coastal environment. The rate of retreat varies based on geology and rock mass characteristics.

So the question must be asked, which is more dominant in New Zealand environment; sub-aerial weathering or wave erosion? Does the orientation of the coast increase or decrease platform development? Does tectonic uplift have any influence as well?

For this thesis two locations were chosen in the North Island of New Zealand based on geographical location these are Tatapouri (field area A, figure 1.1) and Mahia Peninsula (field area B figure 1.2). These locations were used to answer some of the question proposed above.

1.2 AIM AND OBJECTIVES

The aim of this research is to collect a variety of information on coastal cliff lithology, geology and their associated shore platform widths, with the aim of determining erosion rates from the platform widths and relating these to rock structure. This study has been primarily field-based, requiring geomorphological and geological data. The specific objectives to be achieved include:

1. to construct a map identifying the main geological units and shore platform widths;

2. to obtain strength data from geological units by incorporating several different rock mass classification systems;

3. to compare the results with rock mass classification systems against shore platform widths to estimate the geological controls on the rate of erosion.

1.2 STUDY AREA

1.3.1 STUDY AREA A –TATAPOURI

Tatapouri is approximately 12 km North East from Gisborne City. Tatapouri Headland is a spectacular environment with a very wide planar shore platform

formed due to the nature of the country rock which easily disintegrates causing rapid coastal erosion and retreat of the high sea cliffs (Gill 1950).

Most of the area is underlain by massive mudstone but there are also extensive areas of sandstone and alternating mudstone and sandstone (McLeod *et al.* 1999). The study area extents from the end of Makorori Beach to Tatapouri (figure 1.1).
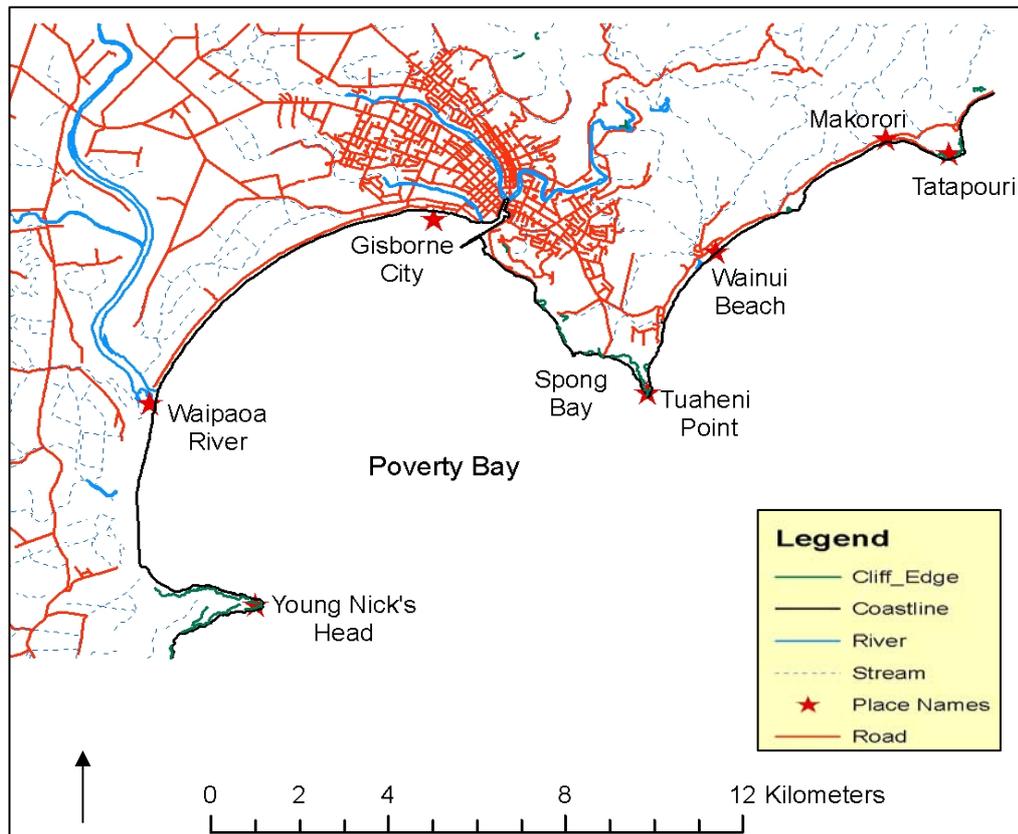
Figure1.1 This map shows a simple map of Poverty Bay Coastline. The Black arrow (left hand corner) is pointing north.

1.3.2 STUDY AREA B – MAHIA PENINSULA

Mahia Peninsula forms a prominent, roughly triangular-shaped promontory at the North-east limit of Hawke's Bay at 39° 10' south, and 177° 511 East (Berryman 1988). The mainland is separated from Mahia peninsula by an extensive tombolo feature, which is about 4-km long, and 3 km wide (Berryman 1988). The

peninsula is covered by NZMS 260 map sheets X19, Y19, X20, and Y20. My field location falls in the NZMS 260 map sheet Y19 (figure 1.2).
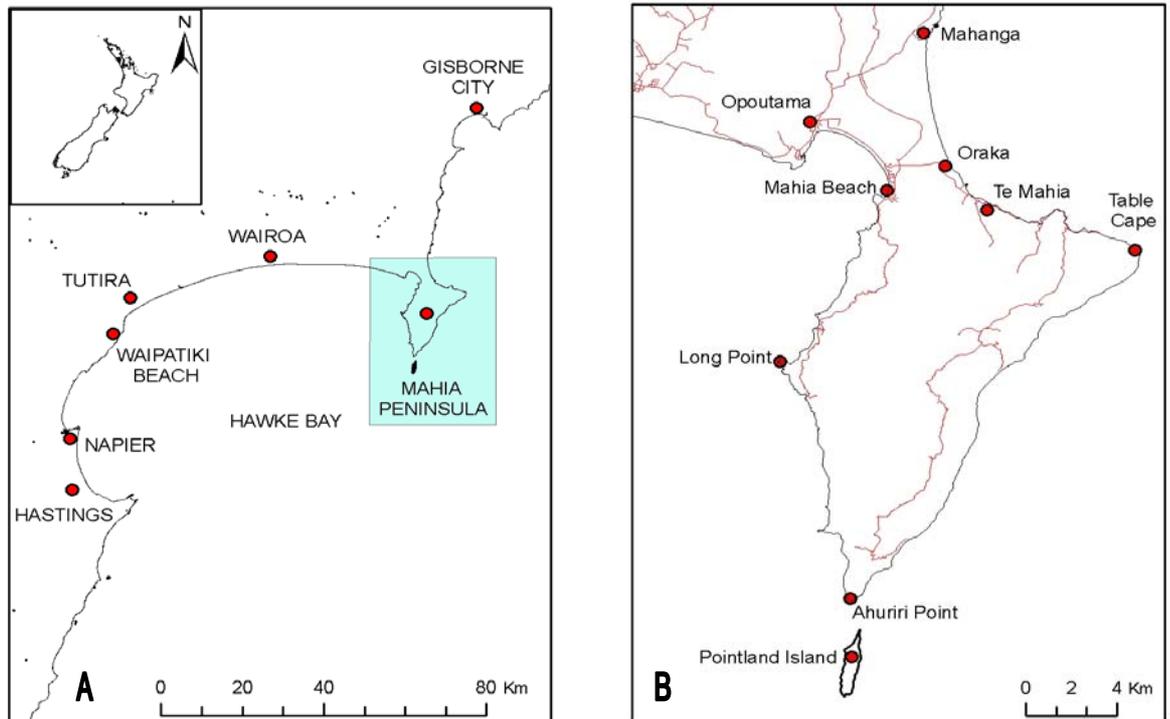
Figure 1.2 Map 'A' shows a simple regional map of the Hawke's Bay Coastline. The blue spots represent lakes with in the region. Map 'B' shows a more detail map of Mahia Peninsula.

The field area (figure 1.2) extends from Oraka to Te Mahia. Berryman (1988) identifies key sub-horizontal marine terrace surfaces ranging from late Pleistocene in age (40 to 212 thousand years) to Holocene coastal plains (younger than 6.5 thousand years old). Mahia Peninsula is composed of steep, dissected hill country, because of rapid rates of tectonic uplift. The highest parts of the peninsula attain over 350 m elevation, yet no part of the peninsula is more than 4.5 km from the sea (Berryman, 1988). Estuaries are common in the area, with a large number of streams and rivers running into the sea.

1.4   RESEARCH OUTLINE

This thesis is concerned with shore platforms and their associated responses to coastal cliff recession rates with emphasis on rock mass strength and the width of the shore platform (if any). The research outline is listed below.

Chapter 2: This chapter outlines the standard literature review, covering topics from: geological and tectonic setting, east coast weather and to the differences between RMS, RMR, and the GSI criterion.

Chapter 3: This chapter outlines the methodology used in this study.

Chapter 4: This chapter describes the rock mass in the field and summarises the rock mass classification in more detail.

Chapter 5: This chapter summarises graphs and statistical data obtained

Chapter 6: In this chapter, results from chapters 4 & 5 are discussed in more detail. This is followed by an overall conclusion, limitations of research, and possibilities for further research to be undertaken.

CHAPTER 2   LITERATURE REVIEW

2.1 INTRODUCTION

This chapter outlines existing literature relating to:

1. the geological and tectonic settings of the study areas;
2. the weather of the East Coast of the North Island, NZ;
3. rock mass classification systems applied in this study;
4. erosion processes; and
5. shore platform research in New Zealand.

2.2 GEOLOGICAL AND TECTONIC SETTING

2.2.1 TATAPOURI

Early geological work by Henderson and Ongley in 1920 recognized that faulting, and not folding, controls the structure of the Gisborne region (Dunn 2001). This was followed up by work from Stoneley (1962) who produced a regional tectonic map; active faulting from this map is included on figure 2.2.

Tatapouri geology is part of the Tuaheni Point Formation, which belongs to the lower part of the Tolaga Group (Neef & Bottrill 1992). The Tuaheni Point Formation is composed of characteristic Bouma sequences (basal intervals of Ta, Tb, Tc) (Neef & Bottrill 1992).

The Bouma sequence, is a 'graphic approach to facies interpretation' deposited by turbidity currents (Shanmugam 1997). The classic Bouma sequence (figure 2.1) is broken down into intervals. Each interval (i.e. Ta, Tb, Tc, Td, and Te) of the entire sequence is a product of turbidity currents (Shanmugam 1997).
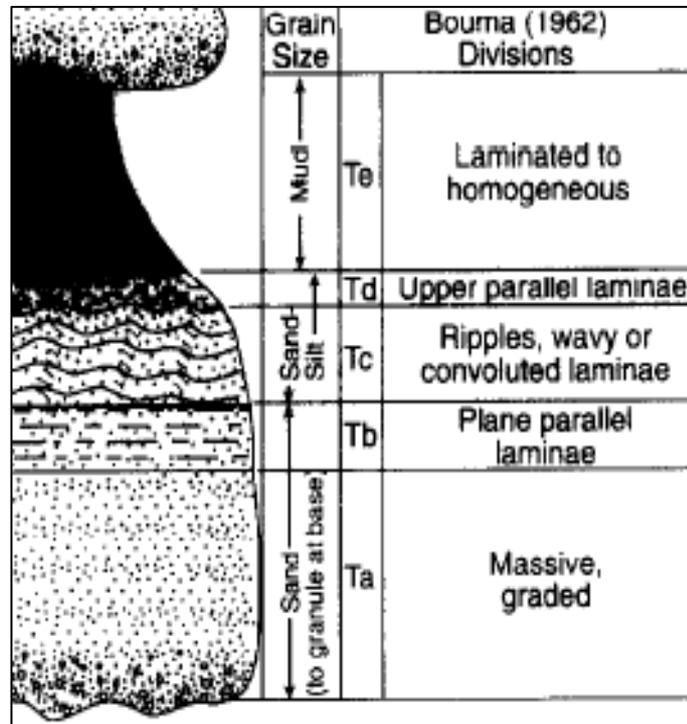
Figure 2.1 A Bouma sequence (Shanmugam 1997).

The intervals Ta or Tb in the Tuaheni Point Formation represent a 'fine to medium grained, calcite-cemented sandstone' (Neef & Bottrill 1992). The Tc interval of events sequences having a basal 'Ta interval commonly are carbonaceous, and locally show convoluted lamminae' (Neef & Bottrill 1992).

2.2.1 MAHIA PENINSULA

The geology of Mahia Peninsula was first mapped by Shell B.P. and Todd Petroleum Co. geologists and reported by Ongley in 1927 and 1930 cited in (Webb 1979). Miocene age marine sediments of the Otunua (mid Miocene) and Onenui (mid Miocene) Formations dominate the Mahia Peninsula figure 2.3.

The Otunua Formation is a very thick sequence of generally massive, light – grey muddy siltstone, with rare pumiceous sandstone Webb (1979). The Onenui (mid Miocene) Formation is a dominantly massive medium blue-grey mudstone, with subordinate flysch facies.

The Auroa Member which was described and named by Webb (1979) is a very thick sequence consisting of pumice - rich flysch packets, separated by thick mudstone. The member is underlain by the Onenui Formation. The Onenui Formation occurs within the study area, but is not exposed on the section of the coastline studied. Late Quaternary deposits of gravel, sand, loess, and tephra rest on marine terraces that fringe the peninsula and mantle hill slopes (Berryman 1988).
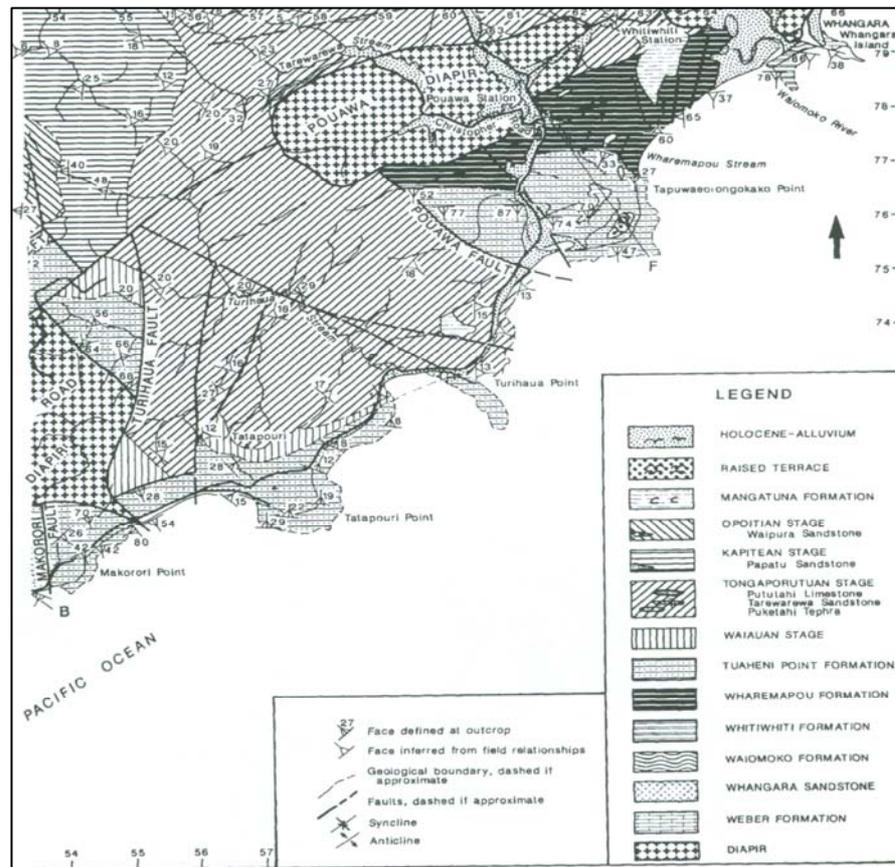
Figure 2.2 Cenozoic geology of Tatapouri and active fault systems. Neff & Bottrill (1992).
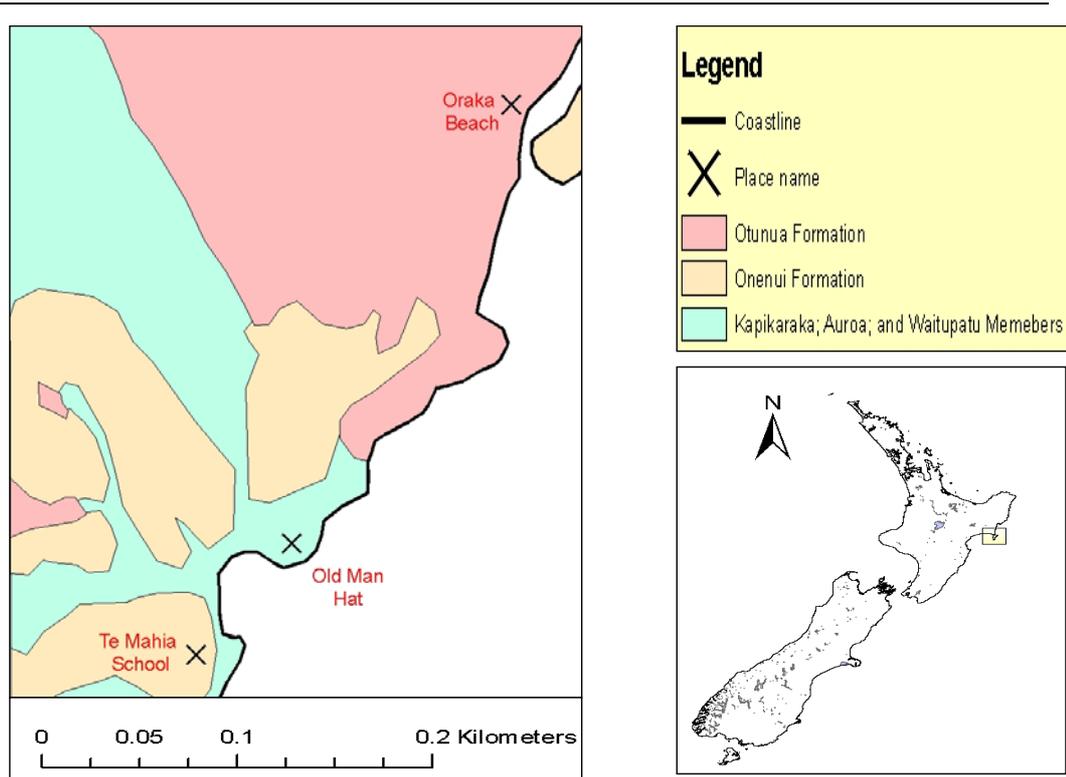
Figure 2.3 Geology of Mahia peninsula Adapted from Webb (1979). The total distance for the study area is approximately 1.3 km. Note the Kapikaraka and the Waitupatu Members are not exposed along the section of coastline within the field and is outside the scope of this thesis.

2.2.2 NEW ZEALAND TECTONIC SETTING

The Hikurangi Trough is located approximately 80 km East from the Mahia Peninsula where the Pacific Plate is being subducted beneath the Australian Plate (figure 2.4). The Pacific Plate is moving towards the Australian plate in the Gisborne region at a rate of 45-50 mm/yr^{-1} (Walcott, 1987; Aitken, 1999) cited in Dunn (2001). The rate of movement for Mahia Peninsula shows a similar rate to the Gisborne region. Most of the soft sediments are coming from off shore sediment sources.
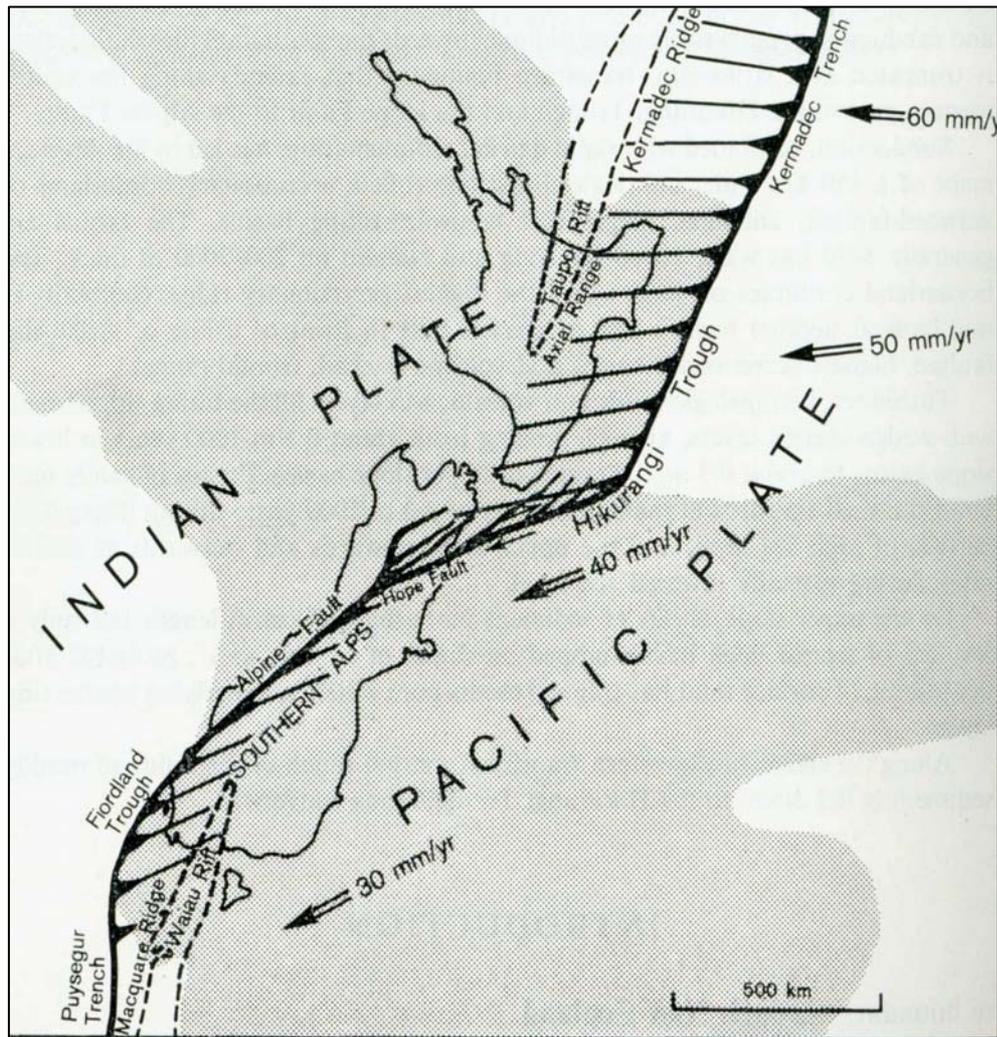
Figure 2.4 Major elements of the Indian – Pacific Plate boundary in the New Zealand Region. Note: Stippling represents continental crust and arrows show relative motion of Pacific Plate with respect to the Indian Plate. Lines represent direction of motion of underthrusting plate. (Adapted from Walcott, 1978a, b) cited in Lewis, (1980).

2.3   CLIMATE REGIME AND SEA -LEVEL

Weather is defined as a collection of dynamic atmospheric processes, and climate is defined as "average weather" (e.g. mean temperature, rainfall, sunshine hours etc.) changes over long or short time scales (Sturman and Tapper 1996).

2.3.1 TATAPOURI

Tatapouri is located on the East Coast, of New Zealand and is sheltered by the Raukumara Range which plays a dominant role in determining rainfall and temperature patterns. 'With W to NW winds Gisborne experiences low rainfall and high temperature' (Dunn 2001). From the NE to S, Gisborne experiences heavy rain and strong onshore winds which bring rolling seas (Dunn 2001). Collected data from the Gisborne Airport shows that over a period of 43 years the average annual rainfall was estimated at 1058 mm/yr for the region (Hessell 1980; New Zealand Meteorological Service 1980) cited in Foster and Carter (1997). This value does not show marked differences that occur on a monthly scale (Foster and Carter 1997). A northwest wind tends to be predominant, but it often weakens in the afternoon and is replaced by sea breezes generated from the southeast (Foster and Carter 1997).

2.3.2 MAHIA PENINSULA

Mahia Peninsula is located at the most northern limits of Hawkes Bay. The climate has maximum air temperatures ranging from 22°C to 28°C, but sometimes exceeds 30°C (Sturman and Tapper 1996). Heavy rainfall can occur from the east or southeast. Westerly winds prevail. Sea breezes often occur in coastal areas on warm summer days (Sturman and Tapper 1996). Figure 2.5 shows mean annual temperature for the entire New Zealand.
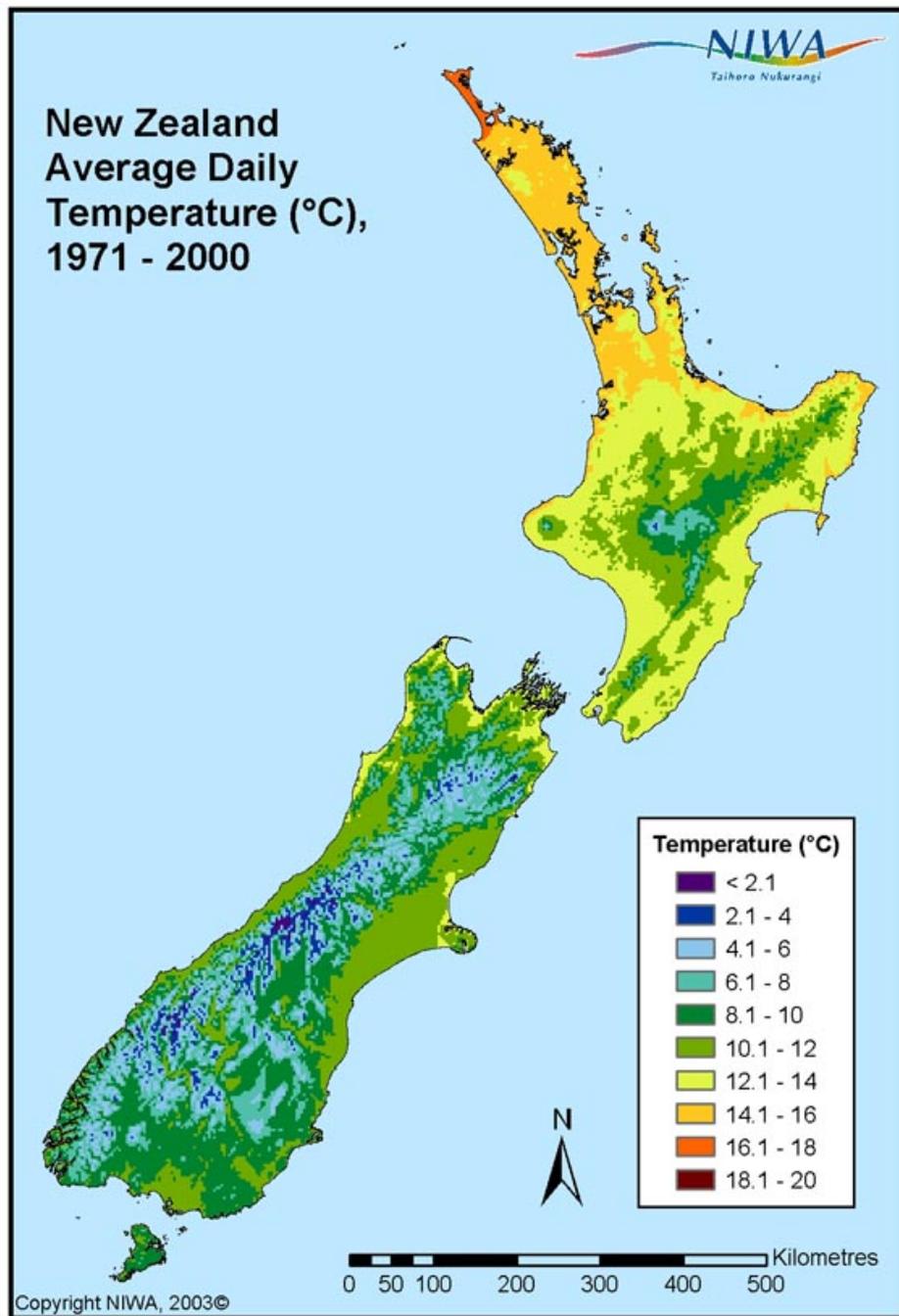
Figure 2.5 Map of New Zealand showing the average daily temperature.

(Source) http://www.niwascience.co.nz/ncc/

2.3.3 EL NINO AND NINA

Both field areas are subjected to extreme weather events such as El Nino and La Nina. South westerly winds dominate during an El Nino event, which produces a ridge of high pressure over the far north of the country while the West coast receives more rain then normal. To simplify, this weather phenomenon means during La Nina, frequent and stronger westerly (easterly) winds in summer, and irregular southerly (northerly) flows in the winter and SW winds in the spring and autumn (Gordon, 1985) cited in Dunn (2001). Note: El Nino and La Nina events are extremely complex and only a simple explanation is used in this thesis.

2.3.3 SEA-LEVEL CURVES

Many studies of the geomorphology and stratigraphy of Holocene coastal features provide evidence for relative sea-level change, even if that was not their focus. Gibb in 1986 produced and compiled a regional 'eustatic' sea-level curve, which is still regarded as the standard curve for New Zealand (Stephenson 2000). Gibb's curve indicates that in common with much of Australia, sea level reached the present datum about 6500 y BP and since that time has fluctuated above and below that value by no more than about 0.5 m. However, Holocene shorelines have been tectonically uplifted on many New Zealand coasts (Stephenson 2000).

2.3.3 MARINE TERRACES

Pleistocene and Holocene marine terraces of the Mahia Peninsula, only approximately 20 km to the southeast of the study area show that uplift rates between 0.7 mm/y and 2.5 mm/y are occurring (Berryman, 1993). Berryman demonstrated that the pattern of co-seismic uplift at Mahia Peninsula in Holocene times is consistent with the continuing development of Pleistocene structures such as the Lachlan Anticline. He also provided estimates of the ages of the palaeoseismic uplift events.

2.3 ROCK MASS CLASSIFICATION

The following sections outline the characteristics of several rock mass classification systems used in this study:

- Geomorphic Rock Mass Strength (RMS) (Selby 1980 1993);
- Rock Mass Rating (RMR) (Bieniawski 1989);
- Geological Strength Index (GSI) (Hoek *et al.* 1995); and
- a modified version of the Geological Strength Index (GSI) for heterogeneous rock masses such as flysch (Marinos *et al.* 2001).

To distinguish between the two GSI classification systems, I will denote that GSI (a) refers to the Hoek *et al.* (1995) classification system, and GSI (b) refers to the Marinos *et al.* (2001) classification system.

These classification systems were used in conjunction with descriptive field data to estimate the rock mass strength. The focus of this study is based on the application and use of the different rock mass classification systems in the coastal environment, and how they apply to shore platform width as a measurement of coastal cliff retreat.

2.4.1 ROCK MASS STREGTH (RMS)

Numerous classifications of rock mass strength have been proposed for engineering purposes (Muller 1958; Pacher 1958; Deere and Miller 1966; Piteau 1971, 1973; Robertson 1971; Wickham *et al.* 1972; Bieniawski 1973, 1989; stated in Selby 1993). The RMS of Selby (1980) is a rating scheme designed specifically for use by geomorphologists and relies upon empirical ratings to develop a mass strength number. Each parameter of the classification is given a rating value, and rock mass strength is indicated by the sum of the ratings.

These final numbers are merely classification numbers, and are dimensionless. Seven parameters are used in the scheme, and the ratings for each category of each parameter are obtained from tables (Selby 1980; Gardiner *et al.*1984). Parameters used in the RMS system are listed below and summarized in figure 2.6:

1. intact rock strength;
2. degree of weathering;
3. spacing of joints;
4. orientation of joints with respect to cut slope;
5. width of joints;
6. continuity of joints;
7. outflow of groundwater.

	Very Strong	Strong	Moderate	Weak	Very Weak
Intact rock strength (N-type Schmidt Hammer 'R')	100–60 r:20	60–50 r:18	50–40 r:14	40–35 r:10	35–10 r:5
Weathering	Unweathered r:10	Slightly weathered r:9	Moderately weathered r:7	Highly weathered r:5	Completely weathered r:3
Spacing of joints	>3 m r:30	3–1 m r:28	1–0.3 m r:21	300–50 mm r:15	<50 mm r:8
Joint orientations	Very favourable. Steep dips into slope, cross joints interlock r:20	Favourable. Moderate dips into slope r:18	Fair. Horizontal dips, or nearly vertical (hard rocks only) r:14	Unfavourable. Moderate dips out of slope r:9	Very unfavourable. Steep dips out of slope r:5
Width of joints	<0.1 mm r:7	0.1–1 mm r:6	1–5 mm r:5	5–20 mm r:4	>20 mm r:2
Continuity of joints	None continuous r:7	Few continuous r:6	Continuous, no infill r:5	Continuous, thin infill r:4	Continuous, thick infill r:1
Outflow of groundwater	None r:6	Trace r:5	Slight <25 l/min/10 m² r:4	Moderate 25–125 l/min/10 m² r:3	Great >125 l/min/10 m² r:1
TOTAL RATING	100–91	90–71	70–51	50–26	<26

Figure 2.6 Geomorphic rock mass strength classification and ratings according to Selby (1980).

In the field each parameter of the RMS is assessed and ranked on a five-fold scale:

- 1 is the best (very strong = high mass strength);
- 5 is the worst (very weak = low mass strength).

Note that these are merely rankings, and do not imply a linear difference between strength at each level.

2.4.2 ROCK MASS RATING (RMR)

The RMR system (or Geomechanics Classification) (figure 2.7), was primarily designed for underground excavation Hoek *et al.* (2001). In applying this classification system, the "rock mass is divided into a number of structural regions and each region is classified separately". This is primarily based on faults and changes in rock type (Bieniawski 1989).

The RMR system uses the following six parameters whose ratings are added to obtain a total RMR-value:

1. uniaxial compressive strength of intact rock material;
2. rock quality designation (RQD);
3. spacing of discontinuities;
4. condition of discontinuities;
5. groundwater conditions;
6. orientation of discontinuities.

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

Parameter		Range of values				
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa / 1 - 5 MPa / < 1 MPa
		Rating	15	12	7	4	2 / 1 / 0
2	Drill core Quality RQD		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%
	Rating		20	17	13	8	3
3	Spacing of discontinuities		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm
	Rating		20	15	10	8	5
4	Condition of discontinuities (See E)		Very rough surfaces / Not continuous / No separation / Unweathered wall rock	Slightly rough surfaces / Separation < 1 mm / Slightly weathered walls	Slightly rough surfaces / Separation < 1 mm / Highly weathered walls	Slickensided surfaces / or / Gouge < 5 mm thick / or / Separation 1-5 mm / Continuous	Soft gouge >5 mm thick / or / Separation > 5 mm / Continuous
	Rating		30	25	20	10	0
5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125
		(Joint water press)/ (Major principal σ)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing
	Rating		15	10	7	4	0

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

Discontinuity length (persistence) Rating	< 1 m / 6	1 - 3 m / 4	3 - 10 m / 2	10 - 20 m / 1	> 20 m / 0
Separation (aperture) Rating	None / 6	< 0.1 mm / 5	0.1 - 1.0 mm / 4	1 - 5 mm / 1	> 5 mm / 0
Roughness Rating	Very rough / 6	Rough / 5	Slightly rough / 3	Smooth / 1	Slickensided / 0
Infilling (gouge) Rating	None / 6	Hard filling < 5 mm / 4	Hard filling > 5 mm / 2	Soft filling < 5 mm / 2	Soft filling > 5 mm / 0
Weathering Ratings	Unweathered / 6	Slightly weathered / 5	Moderately weathered / 3	Highly weathered / 1	Decomposed / 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING*

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	Fair	

* Some conditions are mutually exclusive . For example, if infilling is present, the roughness of the surface will be overshadowed by the influence of the gouge. In such cases use A.4 directly.
** Modified after Wickham et al (1972).

Figure 2.7 Rock Mass Rating System (After Bieniawski 1989).

The strength of the RMR system is that it is very simple to use and adaptable to many different situations (i.e. coal mining, slope stability etc. (Bieniawski 1989)). The RMR classification system method tends to be rather conservative, which can lead to over design of support systems (Bieniawski 1989).

2.4.3 ROCK QUALITY DESIGNATION (RQD)

The RQD is simply a way of assessing rock quality by using pieces of drill core log that are 100 mm or greater in length (Bieniawski 1989). This method has been widely used to identify low-quality rock zones (Bieniawski 1989). For RQD determination, the "International Society for Rock Mechanics recommends a core size of at least NX diameter (54.7 mm) with double-tube core barrels" (Bieniawski 1989). Deere in 1968 (cited in Bieniawski 1989) proposed the relationship between RQD index and the engineering quality of the rock given in Table 2.1.

RQD (%)	Rock Quality
<25	Very poor
25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

Table 2.1   RQD Index (Bieniawski 1989).

The correct method used to measure RQD is illustrated in figure 2.8. Unfortunately no drill core data was available so Equation 2.1 (Priest & Hudson, 1979) was used to work out RQD.
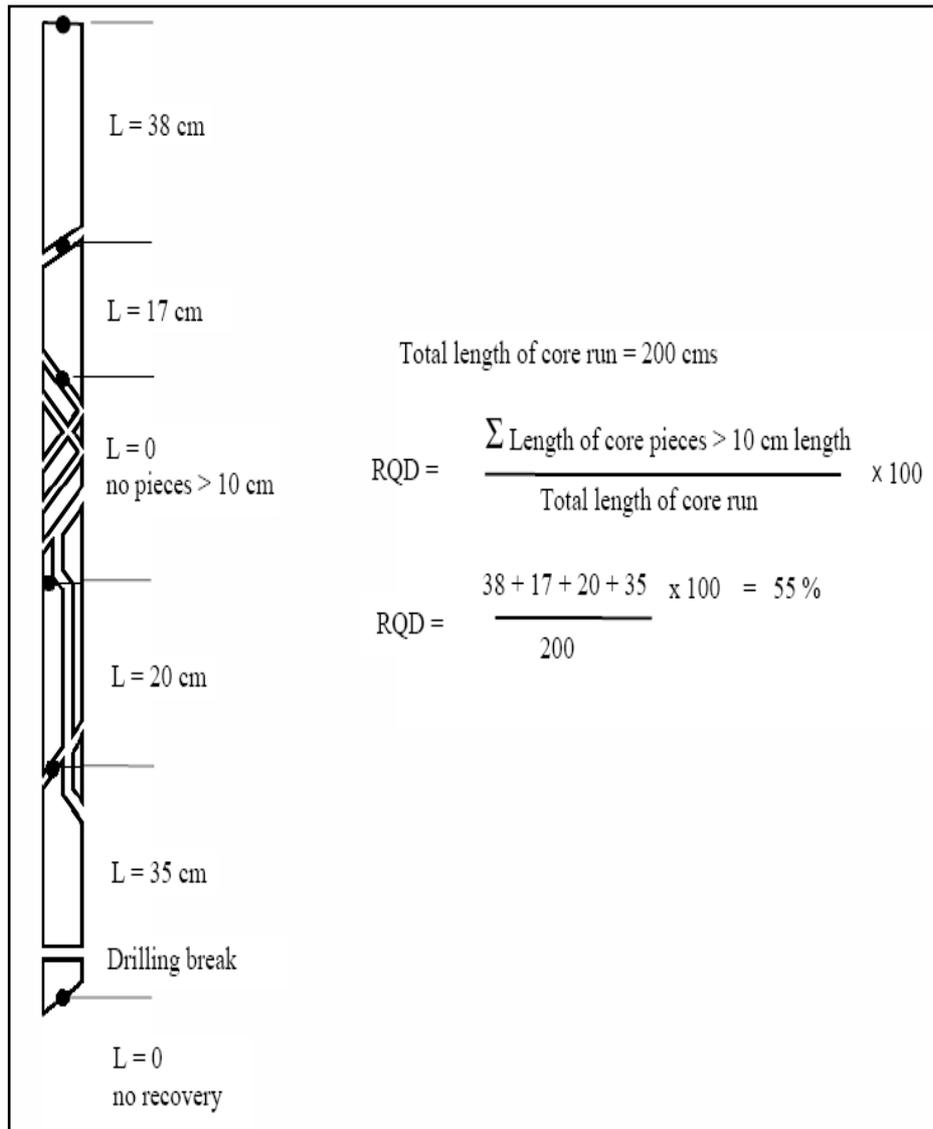
Figure 2.8 Procedure for measurement and calculation of RQD (Deere *et al.* 1989).

Some problems associated with RQD range from, clay in fills, the distances between continuous joints; and the borehole orientation relative to the geology structure (Edelbro 2003). Deere & Deere (1988) recognised that highly weathered, soft, fractured, sheared and jointed rock mass is a problem.

To work out RQD from scanline data the following equation was used:

$$RQD^* = 100e^{-0.1\lambda}(0.1\lambda+1)\ldots\ldots\ldots\ldots\text{ (Equation 2.1)}$$

RQD* = Estimated RQD, λ = Discontinuity frequency per meter (After Priest and Hudson 1976).

2.4.4 GEOLOGICAL STRENGTH INDEX (GSI)

The GSI estimates the reduction in strength of a rock mass based on different geological conditions and relies on field descriptions for assigning a rating number (Hoek *et al.* 1998). Figure 2.9 shows five 'surface conditions' ranging from 'very good' through to 'very poor' and four 'structure categories' ranging from blocky through to disintegrated (Hoek *et al.*1998).

Sonmez and Ulusay (1999) improved on the GSI system by introducing new parameters and ratings, such as surface condition rating (based upon a volumetric joint count), and structure rating (based on joint roughness, infilling and weathering), and their interaction on the modified GSI table can be used to assign the GSI value with greater precision (Sonmez and Ulusay 1999).

Hoek *et al.* (1998) and Hoek 1999 cited in (Bradshaw 2004) introduced two additional rock mass categories called foliated/laminated rock mass structure and massive or intact rock into the GSI system. Due to the anisotropic and heterogeneous nature of the foliated/laminated rock mass structure category, Marinos and Hoek (2001) also proposed a special GSI chart only for the classification of the heterogeneous rock masses such as flysch (figure 2.10).

GEOLOGICAL STRENGTH INDEX

From the letter codes describing the structure and surface conditions of the rock mass (from Table 4), pick the appropriate box in this chart. Estimate the average value of the Geological Strength Index (GSI) from the contours. Do not attempt to be too precise. Quoting a range of GSI from 36 to 42 is more realistic than stating that GSI = 38.

SURFACE CONDITIONS

VERY GOOD
Very rough, fresh unweathered surfaces

GOOD
Rough, slightly weathered, iron stained surfaces

FAIR
Smooth, moderately weathered or altered surfaces

POOR
Slickensided, highly weathered surfaces with compact coatings or fillings of angular fragments

VERY POOR
Slickensided, highly weathered surfaces with soft clay coatings or fillings

STRUCTURE

DECREASING SURFACE QUALITY ⇨

DECREASING INTERLOCKING OF ROCK PIECES ⇩

BLOCKY - very well interlocked undisturbed rock mass consisting of cubical blocks formed by three orthogonal discontinuity sets

VERY BLOCKY - interlocked, partially disturbed rock mass with multifaceted angular blocks formed by four or more discontinuity sets

BLOCKY/DISTURBED- folded and/or faulted with angular blocks formed by many intersecting discontinuity sets

DISINTEGRATED - poorly inter-locked, heavily broken rock mass with a mixture or angular and rounded rock pieces

80
70
60
50
40
30
20
10

Figure 2.9 Estimation of GSI (Hoek *et al.* 1997). Marinos & Hoek (2001, page 154).
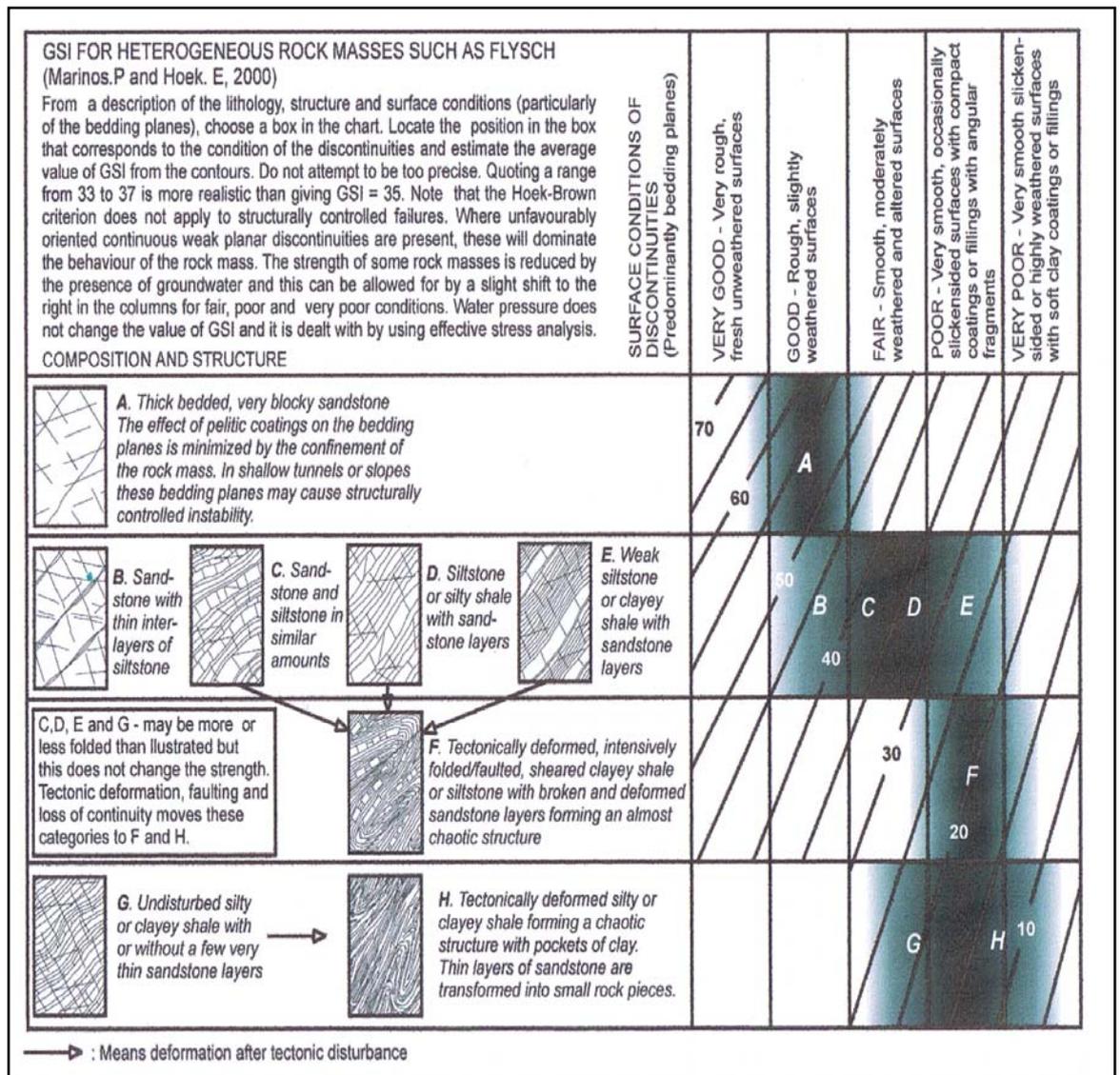
Figure 2.10 GSI estimates for heterogeneous rock masses such as Flysch (Marinos *et al.,* 2001). Marinos & Hoek (2001, page 9).

2.5   LITERATURE REVIEW OF EROSION PROCESSES

2.5.1 MASS WASTING

Selby (1993) states, "Mass wasting is the down slope movement of soil or rock material under the influence of gravity, without the direct aid of other media like

water, air, or ice. The influence of water and ice are frequently involved in mass wasting by reducing the strength of the rock and soil, and by contributing to plastic and fluid behaviour of soils".

Many different classification criteria are in use for describing mass wasting, ranging from the earliest classification from Sharpe 1938, to more recent work from Varnes in 1958 and 1975, Hutchinson in 1988 and Sassa in 1989 (Selby, 1993). Ten types of mass wasting process that may occur in the field are summarized in figure 2.11. Based on classification of Varnes in 1975 in both study areas, the main mass wasting processes are slides (block, and planar), wedge failure, and rock fall.
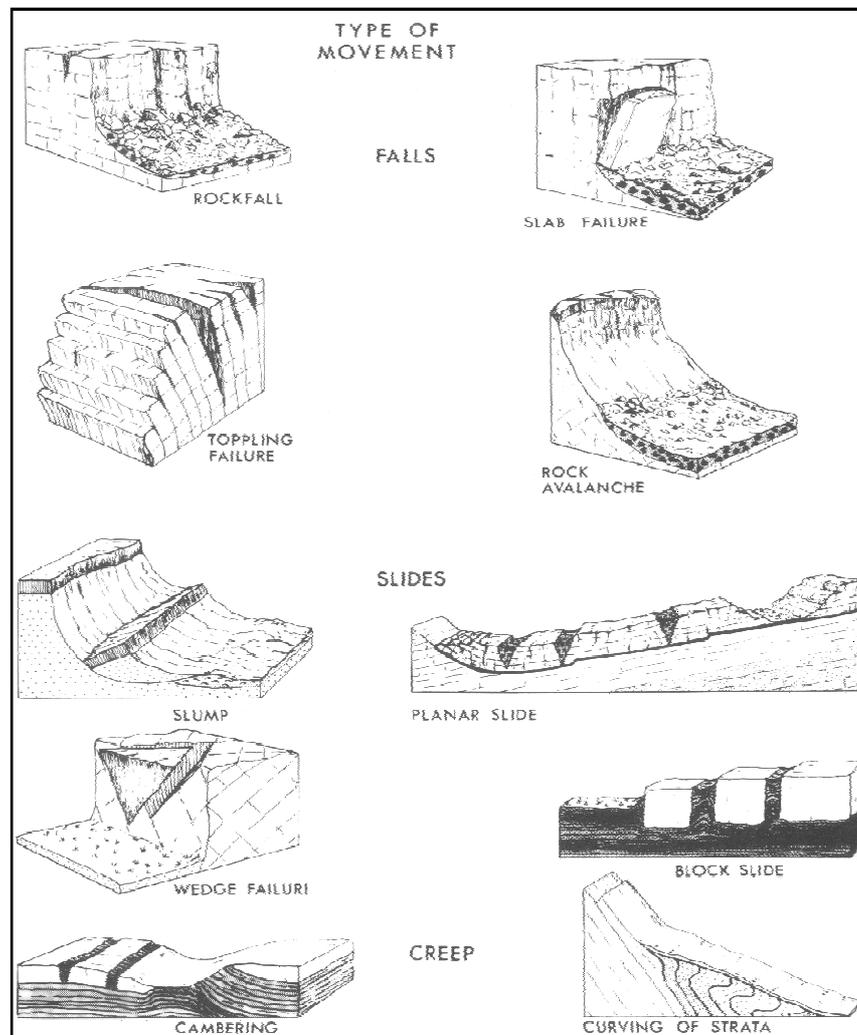
Figure 2.12 Different forms of slope mass failure (Selby, 1993).

2.5.2 COASTAL EROSION PROCESSES

Section 2.5.2 outlines erosion processes recognised in the coastal environment. The identification of the dominant processes at work at the base of a cliff allows only a simplistic identification of either marine or sub-aerial erosion. Blair (1998) recognised that marine erosion is an outside influence on the rock mass. This is normal and specific to the coastal environment, such as the physical action of waves. Sub-aerial erosion refers to the processes that would be acting on a rock at any site. In the case of coastal cliffs sub-aerial processes may be amplified by a marine setting, but the mechanisms of failure are not changed (Blair 1998).

2.5.2.1   BIOEROSION

Bioerosion is sometimes overlooked and difficult to assess (Andrews and Williams 2000). Andrews and Williams (2000) investigated and described a series of experiments that focused on the erosional role of a single organism, the common limpet (*Patella vulgata*), on soft, fine-grained chalk on the coast of Sussex (southeast England). In their paper they pointed out that limpets greatly influence the distributions of other organisms on shore platforms, these in their turn also affect erosion rates.

2.5.2.2   WAVE EROSION

Trenhaile in 1987 stated that mechanical erosion by waves at the base of a cliff is the dominant form of erosion in many coastal areas (Blair 1998). Trenhaile in 1987 and Sunamura in 1992 recognised that there are three different types of waves arriving at the cliff base that contribute to the process of erosion: standing, breaking, and broken waves. Secondary erosional effects include hydraulic action and abrasion.

2.5.2.3   NOTCHES

A clear indicator of cliff erosion is the presence of a notch (figure 2.12), a laterally extending hollow at the base of the cliff with width being greater than depth (Sunamura 1992). Beach material can aid as an abrasive tool which plays an important role in notch development (Sunamura 1992). The rate of notch growth depends on: the strength of the cliff-forming rocks; the energy level of waves arriving at the cliff base; and the amount of abrasive material set in motion by waves (Sunamura 1992).

Figure 2.12 This photo is looking at a cliff notch located on the Mahia Peninsula. The arrows are pointing at notable water seepage coming out of the cliff face.

2.6 SHORE PLATFORM STUDIES

There is a large amount of literature on the subject pertaining to shore platform research. Some of the authors include: Bartrum (1916); Bradley (1958); Trenhaile (1971; 1978; 1980; 1983); Sunamura (1992); Carr *et al.* (1982) and (Bird (1993) stated that the present features of cliffs and shore platforms are largely a consequence of the long phase of relatively stable sea level around much of the world's coastline during the past 6000 years.

On such cliffs, a rising sea level is likely to increase marine erosion; reducing and eventually suppressing the features developed by sub-aerial processes, as undercutting of the cliff base produces a steeper or vertical cliff. Bird (1993), Kirk in 1998 and Stephenson (1998) concluded that sub-aerial weathering, particularly in the form of wetting and drying and salt weathering, is the primary mode of platform lowering.

Recent works from Berryman *et al.* (1992) focused his research on 'Holocene coastal evolution under the influence of episodic tectonic uplift: examples from New Zealand and Japan'. In this paper he outlined shore platform development. He stated that "shore platform development results from the interplay of many factors including bedrock characteristics (i.e. lithology; hardness; chemical composition; jointing; bedding and attitude may strongly influence many aspects of shore platform morphology); wave energy; tidal range; sea level fluctuation; and tectonic uplift and subsidence".

Stephenson *et al.* (2005) give a comprehensive review of Australian rock coasts (except carbonate reefs) which includes shore platform studies. Figure 2.13 shows some New Zealand examples of shore platform research. The general approach in shore platform research in New Zealand has ranged from mathematical models, general field observations and direct measurement from bioerosion, sub-aerial and marine processes, to thorough field surveys with GPS and general field observations of morphology.

Year	Author	Location	Mode of platform formation \ Conclusion	Measurements
1849	Dana	N.Z. & New Holland	Wave cut	General observation
1916	Bartrum	Bay of Islands, N.Z.	Weathering down to saturation level.	General observation
1967	McLean J.F	Northeast Coast, South Island, N.Z.	Genetic model of development, wave energy important.	Levelled profiles, air photos
1968	Healy	Whangaparaoa Peninsula, N.Z.	Contribution of bioerosion.	Observation of morphology
1968	McLean R.F & Davidsion	Gisborne, N.Z.	Wave energy was not a control on morphologic dimension.	Air photo analysis, field survey, wave refraction diagram
1977	Kirk	Kaikoura, N.Z.	Combination of processes subaerial and marine.	Surveyed profiles, MEM measurement, observation of morphology
1981	Trenhaile & Layzell	East Canada, Australia, N.Z. & U.K.	Wave cut	Mathematical modelling
1996	Stephenson & Kirk	Kaikoura, N.Z.	MEM measurement.	MEM measurement Surveyed profiles, geomechanical rock
1998	Stephenson & Kirk	Kaikoura, N.Z.	Comparison of long	
2000a	Stephenson & Kirk	Kaikoura, N.Z.	and short term	testing, direct measurement
2000b	Stephenson & Kirk	Kaikoura, N.Z.		of wave on platform
2001	Stephenson	Kaikoura, N.Z.		
2001	Stephenson & Kirk	Kaikoura, N.Z.		
2005	Kennedy & Beban	Miramar Peninsula, Wellington, N.Z	Active coast uplift	Surveyed using an electronic distance metre
2006	Moon & de Lange	Tipau Point to Waiake Beach, Millon Bay to Prospect Bay, N.Z.		Field survey with GPS

Figure 2.13 Shore platform research.

2.7 SUMMARY

This chapter summarises the geological and tectonic setting, the climate of both field areas, and the use of rock mass classification criteria / systems. The geology for Tatapouri and Mahia Peninsula shows similar patterns with slight differences in the beds. The tectonic setting shows local and regional faulting within the area. The RMS and RMR, uses set parameters to work out the overall rock mass rating. Both GSI classification systems relied on field description to assess the general geological condition of the rock mass from set tables from different authors. Evidence of coastal erosion ranges from localised mass wasting; sea notches; bioerosion; climate; sea wave and the presence of shore platforms.

CHAPTER THREE

METHODOLOGY

3.1 INTRODUCTION

This chapter describes the methods applied in the field and in the laboratory. Software used in the study, ArcMap 9.1.TM (developed by ESRI), MATLAB 7.0.1; RocLab 1.0; and Microsoft Excel 2003, is also described.

3.2 COASTAL EVALUATION

To evaluate coastal cliff conditions and shore platform width a general survey was undertaken on 05 December 2004 at Mahia Peninsula, and 12 October 2005 at Tatapouri. The survey was split into three parts: mapping exercise; rock mass assessment; and a field survey.

3.2.1 MAPPING METHODS

The mapping exercise consisted initially of a general "walkover". One advantage of a general walkover is that it helps to get the general layout of the land and it helps to identify key areas such as changes in geology, lithology, bedding thickness, orientation of the beds, localised mass movement, and faulting. With the aid of a field map and colouring pencils it was a simple matter of drawing in what was seen in the field onto the field map.

The second part of the mapping exercise followed the methods defined by de Lange & Moon (2005) where a Garmin eTrex hand-held GPS (Global Positioning System, best accuracy ± 5m) unit was used to map both the cliff base position and the edge boundary of the shore platform. The waypoints were stored to mark significant locations like streams, outcrops dip, strike, orientation of joints measurements, Schmidt hammer tests, noticeable geology changes, field description notes and location.

Talus deposits at the bottom of the cliff were merely walked over as close as possible to the cliff face. This ensures the best possible representation of the position of the base of the cliff. It was also necessary to change the GPS co-ordinate systems from longitude/latitude through to New Zealand Map Grid (NZGM) To perform this task GPS Utility (4.04.2) was used and the new co-ordinates were saved as both text and shape files.

3.2.2 ROCK MASS ASSESSMENT

3.2.2.1 ROCK MASS DESCRIPTION

For rock mass assessment in the field, the method used in this study was outlined by Wyllie & Mah (2004), which gives descriptive steps and details for describing rock masses. Wyllie & Mah (2004) provide a number of summary tables to estimate the overall rock mass conditions. The rock mass features described were intact rock strength; weathering; discontinuity types; roughness; aperture; infilling and width; spacing; persistence; number of sets; block size and shape.

It was easy to adapt descriptions and Wyllie & Mah's (2004) methods to suit the rock mass classification systems of Selby (RMS), Bieniawski (RMR) and both GSI criteria. It must be pointed out that Wyllie & Mah (2004) is based on previous work from Geological Society Engineering Group Working Party (1977).

3.2.2.2 SCANLINE INFORMATION

Scanlines were employed to estimate Rock Quality Designation (RQD). This involves stretching a tape measure (50 meters in length) over the face of the rock surface (figure 3.1), and measuring the distance between each individual discontinuity along the scanline (Priest and Hudson 1976). RQD was then estimated by using equation 2.1

Figure 3.1 The photo below shows a typical flysch sequence at Tatapouri (Scanline 2). The colour of the rock is darker than normal because it was raining at the time when this picture was taken. The scanline (the white measuring tape) covered a distance of 50 meters in length.

3.2.3 APPLICATION SOFTWARE

3.2.3.1 ArcGIS

Aerial photographs numbers (SN 2637 C/1 and SN 2637 C/2) were used to identify coastal features for Mahia Peninsula. These aerial photographs were provided by New Zealand Aerial Mapping Limited. Tatapouri aerial photographs (photo numbers y18b_fy_00_01) were obtained from the GIS data provided from the University of Waikato Server.

To estimate the shore platform width from the GPS survey data a number of steps were undertaken. The first step was to load the aerial photographs and GPS survey data into ArcGIS. Once loaded it was imported to make sure that all the shape files and images were using the same spatial co-ordinate systems. The NZMG projection was used for this thesis and to complete this task, for the aerial photos Arc catalogue toolbox was used. All maps were done in ArcMap 9.1.TM.

The next step was to divide the aerial photos into 'sections' based on field observations. To work out the shore platform distance for each section the ruler tool was used in GIS. This method involved measuring from the GPS points at the base of the cliff to the shore platform edge. A total of eight measurements from each section were used to work out the average shore platform width for each section.

3.2.3.2 MATLAB 7

MATLAB 7.0.1 is mathematical computing software, which can be applied over a wide range of subjects (such as physics, engineering, and earth sciences). To use this programme it was necessary to use a MATLAB routine programme developed and supplied by de Lange (2005). The GPS survey data from the track logs was manipulated in Microsoft Excel. The GPS survey data was incorporated

into two separate files containing data from the base of the cliff and the other containing GPS survey data from the edge of the shore platform. These two files were loaded into MATLAB by a line of code in the routine programme.

The code in the MATLAB routine programme, works out a series of multiple strikes, at right angles, based on the number of matching GPS coordinates from the base of the cliff to the edge of the shore platform. The end results from MATLAB entail a series of shore platform widths for each set of GPS locations. The extracted data from MATLAB were graphed in Microsoft Excel. The graphs in chapter five used a personalized routine programme modified by the author.

Relative sea-level position had fluctuated around Gibb's curve (6500 y BP) and since that time has fluctuated above and below that value by no more than about 0.5 m (Stephenson 2000). However, Holocene shorelines have been tectonically uplifted on many New Zealand coasts Stephenson (2000). To work out recession rates the following equation expression was used:

Shore platform widths (mm) ÷ long term erosion rate (mm).......(Equation 3.1)

For Tatapouri the episodic uplift age for Holocene marine terraces used in this study was dated at 7590 ± 80 (Ota *et al*. 1992) and for Mahia Peninsula 7100 ± 70 from dated radiocarbon sea shells (Berryman 1998). For the sole purpose of working out the erosion rates the extracted shore platform widths from MATLAB 7.0.1 was used.

3.2.3.3 ROCKLAB 1.0

RocLab 1.0 was used to work out the Hoek-Brown classification parameters (i.e. sigci, GSI, mi, and D) by selecting build-in charts and tables, based on rock type and geological conditions. The programme itself is intuitive and self explainable and it heavily relied on field description. To work out sigci, it was a matter of reading the examples given by the table. For Tatapouri and Mahia sandstone gave a sigci strength range from 50 – 100 MPa. A conservative value of 75MPa was

used. And for GSI, mi, and D, it was a simple matter of selecting the right table and estimating where you think your data should lie on the table based on field observation and field description. The next step was to copy and past the values in Microsoft Excel. These results were graphed as a series of data points for each rock type that corresponded to an average shore platform width. The disturbance factor D application setting was set to slope and a D value of 0.7 and the failure envelope range was set to general (2002 Rocscience Inc).

3.2.3.4 STATISTICAL ANALYSIS

Statistical analysis was carried out in Microsoft Excel. For this study the average; median; standard deviation; standard error; minimum; and maximum were used to quantify the overall rock mass.

3.3 SUMMARY

This chapter outlined and described the processes used in this study including field observations; mapping techniques; and the application of several rock mass classification systems described in chapter 2. To complete this study additional information was needed. This was obtained from the use of computer software (e.g. ArcMap 9.1.TM.; MATLAB 7; RocLab 1.0).

4.1 INTRODUCTION

This chapter examines results from rock mass assessments, RocLab 1.0, MATLab 7, and ArcMap 9.1

4.2 ROCK MASS DESCRIPTION

4.2.1 TATAPOURI

The rocks at Tatapouri can be described as a flysch sequence. This sequence is made up of alternating sandstone and siltstone. The strata dips shoreward at approximately 25° to 30° degrees, and is dipping towards the NE. The whole flysch sequence obviously shows signs of faulting and breaking of beds (figure 4.1) with convoluted patterns within some sandstone (figure 4.2). Large mass movements are common within the field area with large talus deposits near the base of the cliff. A general observation that was made in the field (under dry condition) was that if the bed shows no sign of frittering, crushing, or heavy fracturing the beds are relatively strong, and if they do show the symptoms above, then the beds tend to be weaker. Under sub-aerial conditions the rock rapidly disintegrates when exposed to the air (especially under wet conditions where you could see that the water was oozing out of every pore of the rock). It was noticed on a windy day (sea breeze) there was a constant soft rattle of small pieces of rock, dislodged by the wind.
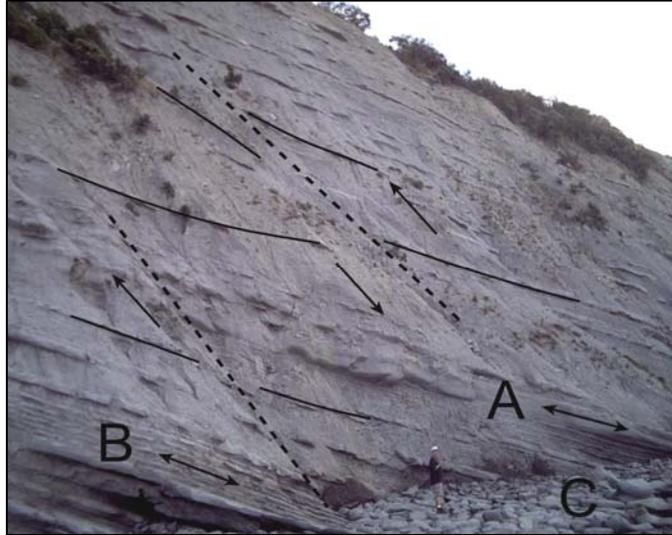
Figure 4.1 The dashed lines represent regions of known faulting. The solid line represents the bedding that has been uplifted and the arrows show the direction of movement. A & B shows the same flysch units, note the thickness difference. C) Rockfall debris. The person in this photo's is approximately 1.79 meters tall.
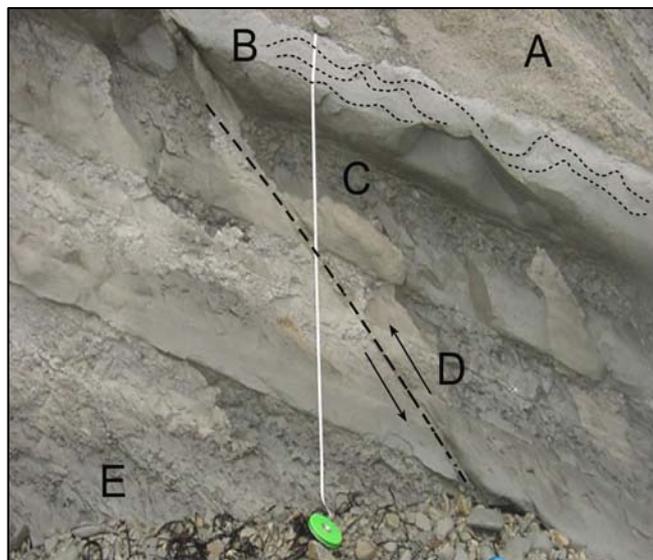
Figure 4.2 Shows complex geology setting for Tatapouri. (A) Shows convolute lamination, dish and flame structures. B) Alternating thick sandstone. C) Crushed alternating siltstone. D) Field evidence of localised displacement. E) Highly convoluted siltstone. Measure tape in the picture covers a distance of 1.75 meters.

4.1.1.1 TATAPOURI SANDSTONE

The grains within the sandstone beds range between 0.25 to 0.5 mm in size, and are classified as medium sand by the Wentworth (1922) classification system. When wet, the colour of the sandstone beds is dark whitish grey and for dry rock it is a whitish grey in colour. The sorting of the grains ranges from moderately sorted to poorly sorted (Gardiner and Dackombe 1983). Tables from Powers (1953) show the grain roundness ranges between sub-rounded to rounded. The sediment strength of the sandstone was assessed as indurated (coarse-grained sediment, broken only with sharp pick blow) based on the classification system of Geological Society Engineering Group Working Party (GSEWP 1977).

Assessment of Tatapouri sandstone relies heavily on field description and tables from Wylllie and Mah (2004). By applying tables from Wylllie and Mah (2004) in the field shows that the sandstone rock requires more than one firm blow from a geological hammer to fracture the rock, which has a corresponding Uniaxial Compressive Strength (UCS) ranging from 50 to 100 (MPa). Due to the UCS range a conservative estimate UCS value of ~75 MPa was assigned to the Tatapouri sandstone and is classified as strong rock (Wylllie and Mah 2004).

Previous work from GSEWP (1977), New Zealand Geomechanics Society, Selby (1980), Wyllie & Mah (2004) have provided tables which quantify different grades of rock mass from unweathered fresh rock through to residual soil. To sum up the weathered sandstone at Tatapouri it is important to give a "quote" range because the conditions of the rock continues to change throughout the day. The quote range used in this study ranges from slight to moderate weathering (Table 4.1).

Table 4.1   Rock-mass weathering grades (NZGS, 1988).

GRADE	CLASS	DESCRIPTION
I	Fresh (unweathered)	Rock material shows no discolouration, loss of strength or any other effects due to weathering. There may be slight discolouration on major discontinuity surfaces.
II	Slightly weathered	Rock material may be slightly discoloured. Discontinuities have discoloured surfaces and may not be open. The rock material is not significantly weaker than the fresh rock material.
III	Moderately weathered	Rock material is discoloured and discontinuity surfaces will have a greater discolouration which also penetrates slightly into the rock material. The rock material is significantly weaker than the fresh rock and part of the rock mass may have been changed to a soil.
IV	Highly weathered	Rock material is discoloured and more than half the rock mass is changed to a soil. Weathering adjacent to discontinuities penetrates deeply into the rock material but lithorelicts or core stones of fresh or slightly weathered rock may still be present.
V	Extremely (completely weathered)	All the rock mass is decomposed and externally changed to a soil, but the original rock fabric is mainly preserved.
VI	Residual weathered (residual soil)	Rock is completely changed to a soil with the original fabric completely destroyed but the resulting soil is not significantly transported.

The Tatapouri sandstones are bedded (figure 4.3) with an range of thickness from (0.03 - 0.8 m). The spacing of adjacent discontinuities is extremely close spacing (< 20mm), with very tight apertures and very low persistence (< 1m). The exposed joint surfaces were covered in rock fragments and grit from the erosion of overlying rock material at the time of field work. The discontinuities were dry at the time of the field survey, but showed evidence of water flow (rust staining). Traces of Fe stains were also noticed on the face of the sandstone and between the cracks.

A thin clay infill (2 - 4 mm) separates the contacts between the sandstone and siltstone. The filling material was damp and sticky to the touch. The bottom contact between the shore platform and the base of the cliff alternated from sandstone to siltstone. This is dominantly caused by the orientation and the dip of the beds.

Figure 4.3 In this picture it shows a person standing on top of a thick sandstone bed at Tatapouri. The person in this photo is approximately 1.79 meters tall.

4.1.1.2 TATAPOURI SILTSTONE

The siltstone beds at Tatapouri are crumbly, loose, friable blocky / disturbed beds, with fSu (fine sand upper limit) based on the size grade scales of Wentworth (1922). The grain roundness ranges between well rounded to rounded, according to Powers (1953) classification system. The sorting of the siltstone grains ranged form very well sorted to well sorted (adapted from Gardiner and Dackombe 1983). The colour of the siltstone beds when wet was dark greyish grey and for dry siltstone it was a whitish grey colour (figure 4.4). The sediment strength of the siltstone was assessed as "hard" (fine-grained sediments, brittle or tough) based on tables from GSEWP (1977).

Figure 4.4   In this picture it shows frittering siltstone beds at Tatapouri.

The siltstone are mostly bedded with an range of thickness from (0.03 - 0.5 m). The beds show very low persistence. Tables from Wylllie and Mah (2004) show that the siltstone rock wasn't able to be scraped or peeled by a pocket knife and the intact rock fractures when hit with a single blow with a geological hammer. The UCS value that best describes Tatapouri siltstone has a range from 25 to 50 (MPa). Due to the UCS range a conservative estimated UCS value of ~35 MPa was assigned to the Tatapouri siltstone.

4.1.2 MAHIA

The rocks at Mahia Peninsula can best be described as a flysch sequence. The field area itself can by split into two different Formations (e.g. Auroa and Otunua). The Auroa Formation is composed of tuffaceous sandstone and siltstone (figure 4.5). At multiple points along the coastline from Oraka Beach to the bottom cliff of Te Mahia School, signs of water staining and water seepage from the cliffs were observed (figure 4.6).

Figure 4.5   This photo is looking at a section of coastline in Auroa Formation where water is seeping out of the cliff face along a distinct discontinuity boundary zone. This photo was taken at Mahia Peninsula.

Figure 4.6   This photo is looking toward Oraka Beach, located on the Mahia Peninsula. A zone of water pooling along a discontinuity produces water staining within the sandstone and muddy siltstone sequence. The iron rust stain shows the boundary of the discontinuity along this section of the coastline.

The whole area has been uplifted, resulting in intense folding structures in several locations (figure 4.7). Figure 4.8 shows water seeping out along a discontinuity zone. This may create a potential weak zone within the cliff and may result in failure. Signs of mass wasting were also visible. It was noticed that the upper parts of the cliff face were more prone to erosion and slips than the bottom section of the cliff.

The water normally flows along discontinuities. Evidence of discolouration and the wetness of the surface rock within the discontinuity indicate some type of chemical weathering process. Rock falls were common on the steepest part of the cliff where the rock mass was highly weathered and fractured.

Figure 4.7   This photo is looking at spectacular geological structures caused by tectonic uplift. This photo is located near Old Man Hat on the Mahia Peninsula. Note a loss of beach sediment in this section of coastline.

Figure 4.8 This photo is looking at a section of coastline where water is seeping out of the cliff face along a distinct discontinuity boundary zone. This photo was taken at Mahia Peninsula.

4.1.2.1 MAHIA PENINSULA SANDSTONE

The sandstone units within the study area are a part of the Auroa Formation (Web 1979). It is composed of tuffaceous sandstone (figure 4.9). The main feature of this rock unit is the presence of lapilli grains. It can be described as light greyish brown in colour. The sorting of the grains ranged moderately sorted to poorly sorted (Gardiner and Dackombe 1983) from mSL (medium sand, lower limit) to mSU (medium sand, upper limit) grains according to the size grade scales of Wentworth (1922). The sediment strength of the sandstone was assessed as "indurated" (coarse-grained sediment, broken only with sharp pick blow), (GSEWP 1977).

Figure 4.9   This photo shows a thick tuffaceous sandstone which belongs to the Auroa Formation (Web 1979). The geological hammer in this picture is about 30 cm long.

Assessment of Mahia Peninsula sandstone used tables from Wylllie and Mah (2004), show the sandstone rock requires more than one firm blow from a geological hammer to fractures the rock, which has a corresponding Uniaxial Compressive Strength (UCS), range from 50 to 100 (MPa). Due to the UCS ranges a conservative estimated UCS value of ~75 MPa was assigned to the Tatapouri sandstone and can be classified as strong rock (Wylllie and Mah 2004).

The rock itself shows signs of being slightly to moderately weathered based on the New Zealand Geomechanics Society guideline (Table 4.1). Adjacent discontinuities in the sandstone are extremely closely spaced (< 20mm), with very tight apertures and very low persistence. The exposed joints are slightly rough with an assigned JRC value of 6 (Joint Roughness Coefficient, where JRC, 1 represents a smooth surface and JRC, 10 represent a rough surface).

4.1.2.2 MAHIA PENINSULA SILTSTONE

The Mahia Peninsula siltstone beds have very similar characteristics as those siltstone beds at Tatapouri. The beds are crumbly, loose, and friable with fSu (fine sand upper limit) based on the size grade scales of Wentworth (1922). The grain roundness ranges between well rounded to rounded, according to Powers (1953) classification system. The sorting of the siltstone grains ranged very well sorted to well sorted (Gardiner and Dackombe 1983). The sediment strength of the siltstone was assessed as "hard" (fine-grained sediments, brittle or tough) based on tables from (GSEWP 1977).

The siltstone is mostly bedded with an range of thickness from (0.03 - 0.5 m). The beds show very low persistence. Tables from Wylllie and Mah (2004) show that the siltstone rock wasn't able to be scraped or peeled by a pocket knife and the rock fractures when hit with a single blow with a geological hammer. The UCS value which best describes Mahia Peninsula siltstone has a range from 25 to 50 (MPa). Due to the UCS range a conservative estimated UCS value of ~35 MPa was assigned to the Mahia siltstone. The exposed joints are rough with an assigned JRC value of 9.

4.2 ROCK MASS CLASSIFICATION

This section summarises the rock mass classification results from Selby (1980) RMS, Bieniawski (1989) RMR, and both GSI variants by Hoek *et al.* in (1995), and Marinos *et al.* (2001). One of the key requirements for a rock-mass classification is to measure the intact rock strength and the overall rock mass. To work out intact rock strength for RMS and the uniaxial compressive strength for RMR, relies on the use of tables from Selby (1980), Bieniawski (1989), Hoek *et al.* in (1995), and Marinos *et al.* (2001).

By matching the appropriate boxes (structure and surface) in the chart it was easy to assign a GSI number for that particular rock mass. The RMS and RMR has similar criteria, so the same method was used to work out the degree of weathering; spacing of joints; orientation of joints with respect to cut slope; width of joints; continuity of joints; outflow of groundwater. These tables heavily relied on visual observation to sum up the rock mass.

The only difference between RMS and RMR is that RMR requires additional information such as RQD. To calculate RQD without a log core (due to the highly crumbly, loose, disturbed beds), it was necessary to employ the equation 2.1 (Priest and Hudson 1976) (section 2.4.3). The 'scanline surveys' were used to measure the distance / space to each discontinuity along the measuring tape. Scanline surveys were done at known locations based on changes in bed thickness, discontinuity density. The mean RQD value was used in this study and is expressed as a percentage in Table 4.2. The 'scanline surveys' data are presented in appendix 4.

Table 4.2   Statistical discontinuity spacing results for each scanline surveys used in this study.

Location	Tatapouri 1. G.R. E2957833 N6270760	Tatapouri 2. G.R. E2957707 N6270597	Tatapouri 3. G.R. E2951504 N6270513	Mahia P. 4. G.R. E2934608 N6224610	Mahia P. 5. G.R. E2934847 N6224039	Mahia P. 6. G.R. E2935083 N62223764
Mean (m)	0.52	0.15	0.27	0.26	0.06	0.06
Median (m)	0.40	0.05	0.17	0.17	0.04	0.03
Min (m)	0.01	0.01	0.04	0.04	0.00	0.01
Max (m)	1.82	3.07	2.17	1.92	0.38	0.20
Sample Sizes (N)	50.00	50.00	77.00	77.00	26.00	32.00
RQD	**98.36%**	**86.16%**	**94.74%**	**94.25%**	**50.37%**	**49.49%**

Note: G.R. = Grid References is based on the 1949 NZMG.
        E = Easting
        N = Northing

Table 4.2 show the mean spacings for Tatapouri are higher then those for Mahia Peninsula. Tatapouri 3 and Mahia Peninsula 4 shows very similar results. Sample sizes range from 77 for Tatapouri 3 and 26 for Mahia Peninsula 5.

4.3.1 RMS

Table 4.3 Show RMS results for Tatapouri and Mahia Peninsula. These sites were chosen due to the accessibility to the cliff and the change in the condition of the beds. In general the RMS ranges from 62 to 57 for Tatapouri Ss, and 58 to 55 for Tatapouri Sz. The results for Mahia Peninsula Ss and Sz RMS ranges from 55 to 46 Ss and 50 to 42 Sz. The qualitative rock strength ranges from moderate for Tatapouri and ranges from moderate to weak for Mahia Peninsula.

4.3.2 RMR

The RMR results (table 4.4) for Tatapouri ranges from 64 to 59 for Tatapouri Ss, and 58 to 55 for Tatapouri Sz. The results for Mahia Peninsula Ss and Sz ranges from 55 to 49 (Ss) and 50 to 42 (Sz).

4.3.2 GSI (a) and GSI (b)

Table 4.5 and table 4.6 show the GSI (a) and GSI (b) estimates for Tatapouri (Ss & Sz) and Mahia Peninsula (Ss & Sz). The GSI (a) range for both (Ss & Sz) ranges from 45 to 40 and for both units for GSI (b) has a range from 30 to 35.

Table 4.3 Summary tables for Rock Mass Strength Rating for Tatapouri and Mahia Peninsula Sandstone (Ss) + Siltstone (Sz). For full descriptions, see appendix 1.

Site No:	Rock Type	Total RMS Rating	Qualitative rock strength
Tatapouri 1	Ss	60	moderate
Tatapouri 1	Sz	58	moderate
Tatapouri 2	Ss	60	moderate
Tatapouri 2	Sz	58	moderate
Tatapouri 3	Ss	59	moderate
Tatapouri 3	Sz	56	moderate
Tatapouri 4	Ss	57	moderate
Tatapouri 4	Sz	55	moderate
Tatapouri 5	Ss	60	moderate
Tatapouri 5	Sz	56	moderate
Tatapouri 6	Ss	58	moderate
Tatapouri 6	Sz	56	moderate
Tatapouri 7	Ss	58	moderate
Tatapouri 7	Sz	56	moderate
Tatapouri 8	Ss	58	moderate
Tatapouri 8	Sz	56	moderate
Tatapouri 9	Ss	62	moderate
Tatapouri 9	Sz	60	moderate
Tatapouri 10	Ss	58	moderate
Tatapouri 10	Sz	58	moderate

Site No:	Rock Type	Total RMS Rating	Qualitative rock strength
Mahia 3	Sz	49	weak
Mahia 4	Sz	49	weak
Mahia 5	Sz	50	weak
Mahia 6a	Ss	55	moderate
Mahia 6b	Sz	49	weak
Mahia 7a	Sz	48	weak
Mahia 7b	Ss	52	moderate
Mahia 7c	Sz	47	weak
Mahia 8a	Ss	47	weak
Mahia 8b	Sz	49	weak
Mahia 8c	Sz	46	weak
Mahia 9a	Ss	49	weak
Mahia 9b	Sz	47	weak
Mahia 10a	Ss	49	weak
Mahia 10b	Sz	46	weak
Mahia 11a	Ss	51	moderate
Mahia 11b	Sz	46	weak
Mahia 12a	Sz	46	weak
Mahia 12b	Ss	51	moderate
Mahia 12c	Sz	45	weak
Mahia 12d	Ss	51	moderate
Mahia 13a	Ss	51	moderate
Mahia 13b	Ss	48	weak
Mahia 13c	Sz	43	weak
Mahia 14a	Ss	46	weak
Mahia 14b	Ss	49	weak
Mahia 14c	Ss	42	weak

Table 4.4 Summary tables for Rock Mass Rating for Tatapouri and Mahia Peninsula Sandstone (Ss) + Siltstone (Sz). For full descriptions, see appendix 1.

Site No:	Rock Type	Total RMR Rating	Qualitative rock strength
Tatapouri 1	Ss	59	fair rock
Tatapouri 1	Sz	57	fair rock
Tatapouri 2	Ss	64	good rock
Tatapouri 2	Sz	57	fair rock
Tatapouri 3	Ss	64	good rock
Tatapouri 3	Sz	59	fair rock
Tatapouri 4	Ss	64	good rock
Tatapouri 4	Sz	54	fair rock
Tatapouri 5	Ss	61	good rock
Tatapouri 5	Sz	51	fair rock
Tatapouri 6	Ss	61	good rock
Tatapouri 6	Sz	51	fair rock
Tatapouri 7	Ss	61	good rock
Tatapouri 7	Sz	51	fair rock
Tatapouri 8	Ss	64	fair rock
Tatapouri 8	Sz	51	fair rock
Tatapouri 9	Ss	64	good rock
Tatapouri 9	Sz	51	fair rock
Tatapouri 10	Ss	64	good rock
Tatapouri 10	Sz	51	fair rock

Site No:	Rock Type	Total RMR Rating	Qualitative rock strength
Mahia 3	Sz	54	fair rock
Mahia 4	Sz	54	fair rock
Mahia 5	Sz	62	good rock
Mahia 6a	Ss	59	fair rock
Mahia 6b	Sz	54	fair rock
Mahia 7a	Sz	59	fair rock
Mahia 7b	Ss	56	fair rock
Mahia 7c	Sz	54	fair rock
Mahia 8a	Ss	56	fair rock
Mahia 8b	Sz	51	fair rock
Mahia 8c	Sz	45	fair rock
Mahia 9a	Ss	51	fair rock
Mahia 9b	Sz	51	fair rock
Mahia 10a	Ss	54	fair rock
Mahia 10b	Sz	59	fair rock
Mahia 11a	Ss	56	fair rock
Mahia 11b	Sz	50	fair rock
Mahia 12a	Sz	55	fair rock
Mahia 12b	Ss	56	fair rock
Mahia 12c	Sz	47	fair rock
Mahia 12d	Ss	57	fair rock
Mahia 13a	Ss	50	fair rock
Mahia 13b	Ss	55	fair rock
Mahia 13c	Sz	50	fair rock
Mahia 14a	Ss	56	fair rock
Mahia 14b	Ss	50	fair rock
Mahia 14c	Ss	47	fair rock

Table 4.5 Summary tables for the GSI (a) and GSI (b) for Mahia Peninsula sandstone and siltstone. For full field description see appendix 1

Site No / Units (Ss)	Structure	Surface Condition	GSI(a) Estimates	Used in Study
Mahia 6a	b/d	fair	40-45	45
Mahia 7b	b/d	fair	40-45	45
Mahia 8a	b/d	fair	40-45	42
Mahia 9a	b/d	fair	40-45	42
Mahia 10a	b/d	fair	40-45	41
Mahia 11a	b/d	fair	40-45	41
Mahia 12b	b/d	fair	40-45	42
Mahia 12d	b/d	fair	40-45	41
Mahia 13a	b/d	fair	40-45	41
Mahia 13b	b/d	fair	40-46	42
Mahia 14a	b/d	fair	40-47	42
Mahia 14b	b/d	fair	40-45	40

Site No / Units (Ss)	Structure	Surface Condition	GSI(b) Estimates	Used in Study
Mahia 6a	disintegrated	fair	30-35	35
Mahia 7b	disintegrated	fair	30-35	34
Mahia 8a	disintegrated	fair	30-35	31
Mahia 9a	disintegrated	fair	30-35	31
Mahia 10a	disintegrated	fair	30-35	30
Mahia 11a	disintegrated	fair	30-35	30
Mahia 12b	disintegrated	fair	30-35	31
Mahia 12d	disintegrated	fair	30-35	30
Mahia 13a	disintegrated	fair	30-35	30
Mahia 13b	disintegrated	fair	30-35	31
Mahia 14a	disintegrated	fair	30-35	31
Mahia 14b	disintegrated	fair	30-35	30

Site No / Units (Sz)	Structure	Surface Condition	GSI(a) Estimates	Used in Study
Mahia 3	b/d	fair	40-45	45
Mahia 4	b/d	fair	40-45	42
Mahia 5	b/d	fair	40-45	42
Mahia 6b	b/d	fair	40-45	42
Mahia 7a	b/d	fair	40-45	45
Mahia 7c	b/d	fair	40-45	41
Mahia 8b	b/d	fair	40-45	41
Mahia 8c	b/d	fair	40-45	41
Mahia 9b	b/d	fair	40-45	41
Mahia 10b	b/d	fair	40-46	44
Mahia 11b	b/d	fair	40-47	45
Mahia 12a	b/d	fair	40-45	40
Mahia 12c	b/d	fair	40-45	42
Mahia 13c	b/d	fair	40-45	40
Mahia 14c	b/d	fair	40-45	42

Site No / Units (Sz)	Structure	Surface Condition	GSI(b) Estimates	Used in Study
Mahia 3	disintegrated	fair	30-35	34
Mahia 4	disintegrated	fair	30-35	34
Mahia 5	disintegrated	fair	30-35	35
Mahia 6b	disintegrated	fair	30-35	35
Mahia 7a	disintegrated	fair	30-35	33
Mahia 7c	disintegrated	fair	30-35	33
Mahia 8c	disintegrated	fair	30-35	31
Mahia 9b	disintegrated	fair	30-35	30
Mahia 10b	disintegrated	fair	30-35	31
Mahia 11b	disintegrated	fair	30-35	31
Mahia 12c	disintegrated	fair	30-35	30
Mahia 13c	disintegrated	fair	30-35	32
Mahia 14c	disintegrated	fair	30-35	30
Mahia 14d	disintegrated	fair	30-35	30

Note: b/d = Blocky / Disturbed, d = Siltstone or silty shale with sandstone layers

Table 4.6 Summary tables for the GSI (a) and GSI (b) for Mahia Peninsula sandstone and siltstone. For full field description see appendix 1

Site No / Units (Ss)	Structure	Surface Condition	GSI(a) Estimates	Used in Study
Tatapouri 1	b/d	fair	40-45	40
Tatapouri 2	b/d	fair	40-45	41
Tatapouri 3	b/d	fair	40-45	40
Tatapouri 4	b/d	fair	40-45	43
Tatapouri 5	b/d	fair	40-45	42
Tatapouri 6	b/d	fair	40-45	44
Tatapouri 7	b/d	fair	40-45	44
Tatapouri 8	b/d	fair	40-45	45
Tatapouri 9	b/d	fair	40-45	42
Tatapouri 10	b/d	fair	40-45	45

Site No / Units (Ss)	Structure	Surface Condition	GSI(b) Estimates	Used in Study
Tatapouri 1	d	fair	30-35	30
Tatapouri 2	d	fair	30-35	31
Tatapouri 3	d	fair	30-35	31
Tatapouri 4	d	fair	30-35	35
Tatapouri 5	d	fair	30-35	34
Tatapouri 6	d	fair	30-35	35
Tatapouri 7	d	fair	30-35	34
Tatapouri 8	d	fair	30-35	34
Tatapouri 9	d	fair	30-35	33
Tatapouri 10	d	fair	30-35	35

Site No / Units (Ss)	Structure	Surface Condition	GSI(b) Estimates	Used in Study
Tatapouri 1	d	fair	30-35	30
Tatapouri 2	d	fair	30-35	30
Tatapouri 3	d	fair	30-35	30
Tatapouri 4	d	fair	30-35	33
Tatapouri 5	d	fair	30-35	33
Tatapouri 6	d	fair	30-35	35
Tatapouri 7	d	fair	30-35	34
Tatapouri 8	d	fair	30-35	35
Tatapouri 9	d	fair	30-35	32
Tatapouri 10	d	fair	30-35	35

Site No / Units (Sz)	Structure	Surface Condition	GSI(a) Estimates	Used in Study
Tatapouri 1	b/d	fair	40-45	40
Tatapouri 2	b/d	fair	40-45	41
Tatapouri 3	b/d	fair	40-45	41
Tatapouri 4	b/d	fair	40-45	43
Tatapouri 5	b/d	fair	40-45	42
Tatapouri 6	b/d	fair	40-45	44
Tatapouri 7	b/d	fair	40-45	44
Tatapouri 8	b/d	fair	40-45	45
Tatapouri 9	b/d	fair	40-45	42
Tatapouri 10	b/d	fair	40-45	45

Note: b/d = Blocky / Disturbed, d = Siltstone or silty shale with sandstone layers

4.1   STATISTICS SUMMARY

Table 4.7 show that their very little variation between RMS, RMR, GIS (a) except for GIS (b).

Table 4.7   Summary statistics for RMS, RMR, GSI (a) and GSI (b) for Tatapouri and Mahia Peninsula.

Units	RMS	RMR	GSI (a)	GSI (b)
Sandstone	54 ± 1.5 **(23)**	58 ± 1.6 **(21)**	42.27 ± 1.4 **(23)**	32.09± 1.2 **(24)**
Siltstone	51 ± 1.4 **(23)**	53 ± 1.5 **(25)**	42.52 ± 1.3 **(24)**	23.35± 1.2 **(25)**

Note: () = Number of Observation

4.2   SHORE PLATFORM WIDTH

Table 4.8 and table 4.9 show the shore platform widths measured in ArcMap 9.1. Table 4.10 and 4.11 show the shore platform width used with in conjunction with sandstone and siltstone result for RMS, RMR, GSI (a) and GSI (b).

Table 4.8   GIS summary statistics for Shore platform widths for Mahia Peninsula.

MAHIA PENINSULA SHORE PLATFORM WIDTHS	
Mean width	21.6 m
Median width	16.76 m
Standard Deviation	10.48 m
Minimum width	8.47 m
Maximum width	38.89 m

Table 4.9   GIS summary statistics for Shore platform widths for Tatapouri.

TATAPOURI SHORE PLATFORM WIDTHS	
Mean width	230.33 m
Median width	237.5 m
Standard Deviation	21.42 m
Minimum width	195 m
Maximum width	256 m

Table 4.10 Shore platform widths for Mahia Peninsula from MATLAB 7.

Distance (m)	Width (m)	Width (mm)	Erosion (mm.yr^{-1})
69.37	72.51	72507.00	10.21
81.91	79.71	79707.00	11.23
90.35	93.94	93941.00	13.23
93.37	114.01	114010.00	16.06
111.33	80.94	80944.00	11.40
126.90	50.32	50319.00	7.09
159.73	106.08	106080.00	14.94
158.87	101.99	101990.00	14.36
178.06	126.46	126460.00	17.81
193.40	125.93	125930.00	17.74
205.47	124.25	124250.00	17.50
207.64	123.31	123310.00	17.37
235.89	79.15	79151.00	11.15
259.80	81.99	81986.00	11.55
282.40	71.47	71468.00	10.07
292.30	83.34	83337.00	11.74
315.98	52.76	52763.00	7.43
340.51	77.52	77517.00	10.92
356.22	84.09	84092.00	11.84
363.57	57.19	57187.00	8.05
394.61	38.89	38892.00	5.48
545.40	84.46	84464.00	11.90
631.68	73.21	73209.00	10.31
644.84	74.15	74146.00	10.44
654.13	65.91	65910.00	9.28
672.00	61.18	61184.00	8.62
735.16	45.59	45589.00	6.42
996.30	13.19	13187.00	1.86
1028.60	34.03	34031.00	4.79
1150.70	39.74	39739.00	5.60
1419.00	31.79	31791.00	4.48
1437.80	12.95	12945.00	1.82
1435.80	10.78	10784.00	1.52
1435.00	7.55	7552.70	1.06
1434.20	4.31	4311.50	0.61
1457.70	30.71	30705.00	4.32
1457.70	30.71	30705.00	4.32
1459.90	29.00	28998.00	4.08

Table 4.11 Shore platform widths for Tatapouri from MATLAB 7.

Distance (m)	Width (m)	Width (mm)	Erosion (m.yr^{-1})
30.16	10.02	10020.30	1.32
66.60	27.70	27696.30	3.65
66.40	29.69	29686.60	3.91
70.88	35.15	35154.90	4.63
74.86	35.55	35549.00	4.68
99.67	69.16	69157.00	9.11
138.10	87.03	87030.10	11.47
162.08	88.40	88399.60	11.65
164.77	91.68	91680.60	12.08
170.35	96.25	96252.30	12.68
185.48	105.79	105789.90	13.94
218.61	106.06	106055.90	13.97
230.87	124.35	124352.60	16.38
268.38	121.03	121032.20	15.95
287.18	113.85	113849.60	15.00
329.45	92.91	92912.40	12.24
348.74	80.75	80754.00	10.64
370.83	80.93	80931.40	10.66
402.48	86.07	86074.60	11.34
431.81	63.86	63856.50	8.41
441.46	57.78	57777.40	7.61
459.37	59.55	59550.90	7.85
498.97	55.43	55432.40	7.30
535.57	40.97	40968.60	5.40
542.33	33.60	33598.70	4.43
560.23	25.32	25322.30	3.34
574.95	18.74	18740.60	2.47

4.3   SUMMARY

This chapter describes the flysch sequences in some detail. It shows that the lithologies are very similar to each other. This is supported by the results from RMS, RMR, GSI (a) and GSI (b).

CHAPTER FIVE

GRAPHS AND STATISTICAL DATA

5.1 INTRODUCTION

This chapter show the relationship between shore platform widths and assigned rock mass classification system.

5.2 TATAPOURI SANDSTONE GRAPHS

The graphs below show (figure 5.1) R^2 values, which compare the predicted rock mass strength for Tatapouri sandstone with the estimated shore platform width. Note both that RMS and RMR (Graphs A & B) produce poor R^2 values while both GSI (a) and GSI (b) (C & D) produce good r^2 values.

Graph A shows that as RMS increases, the shore platform width decreases, conversely, Graph B, C, and D show the opposite; where RMR, GSI (a) and GSI (b) increase so too does the width of shore platform. Thus, these suggest that as the rock mass strength increases the shore platform erodes more rapidly. Note, however, the RMR graph suggests a very weak relationship.

GRAPHS AND STATISTICAL DATA
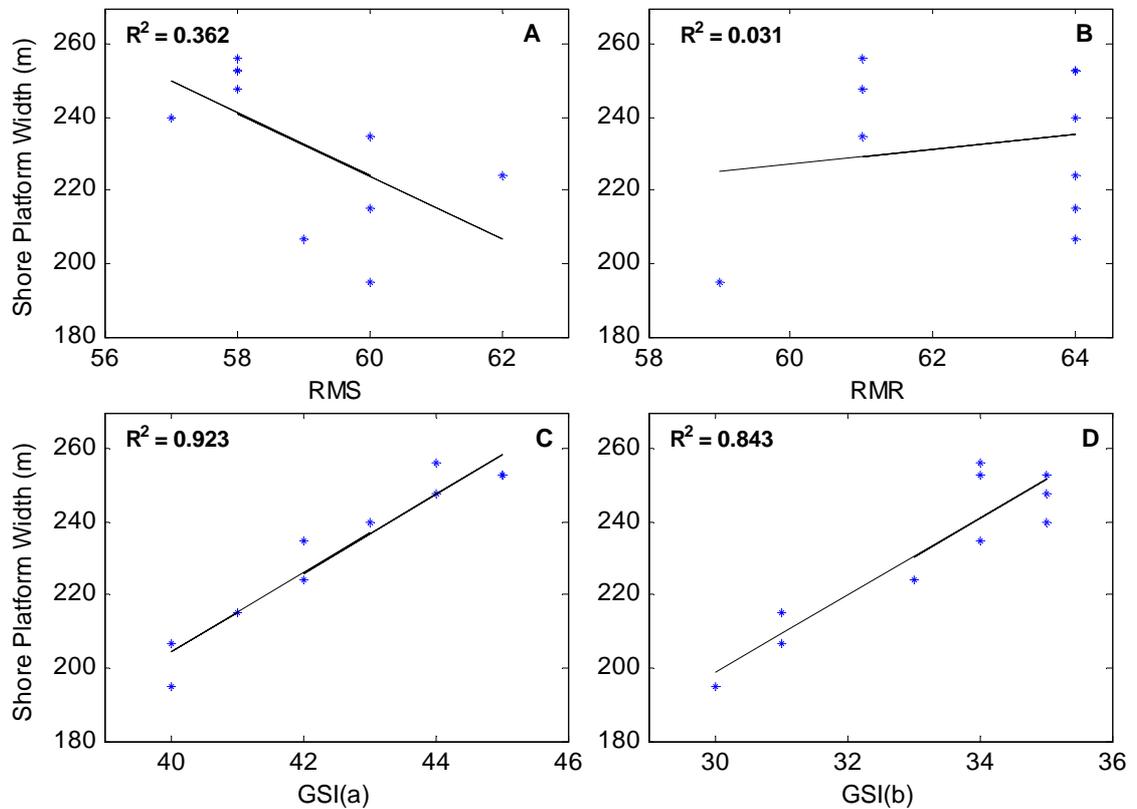
Figure 5.1 Graphs A - D show different rock mass classification systems plotted against shore platform width for Tatapouri sandstone.

5.2.1 TATAPOURI SILTSTONE GRAPHS

The graphs below (figure 5.2) plot rock mass classification versus shore platform width for siltstone from Tatapouri. These show R^2 values from 0.14 for RMS, to 0.92 for GSI (a). Graphs A & B suggest a negative gradient and graphs C & D show a positive gradient. Graphs A & B shows that as RMS & RMR increase the shore platform width decreases. For RMS this is in keeping with sandstone results but in both cases the R^2 is very low. Graphs C & D show that as GSI (a) & GSI (b) increase, the shore platform width increases for Tatapouri siltstone. Both graph C & D have good R^2 values, indicating a good fit of the line to the data.
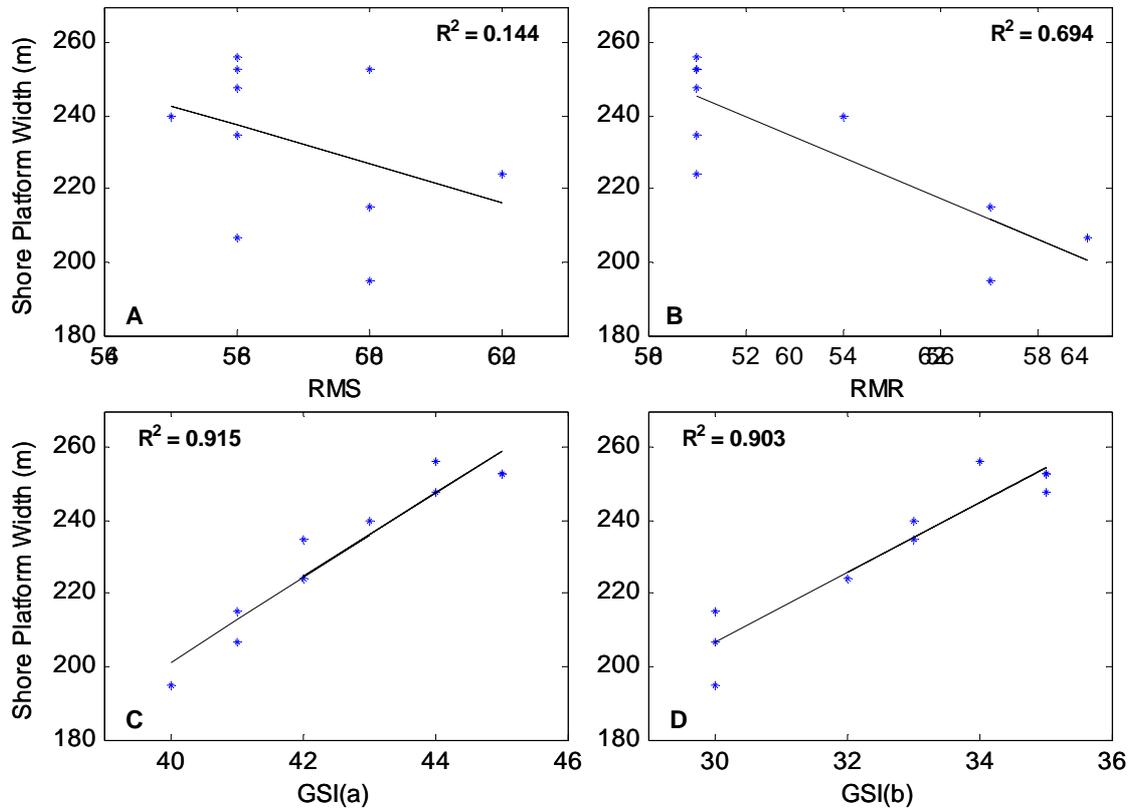
Figure 5.2   Graphs A - D show different rock mass classification systems plotted against shore platform width for Tatapouri siltstone.

5.3   MAHIA PENINSULA SANDSTONE GRAPHS

Figure 5.3 plots rock mass classification versus shore platform width for Mahia Peninsula sandstone graphs. This shows R^2 values from 0.38 for RMR, to 0.93 for GSI (b). All graphs show increases in platform width with increased rock mass strength. Graphs C & D show that the GSI (a) and GSI (b) classification system seem to produce better R^2 results than RMS & RMR.
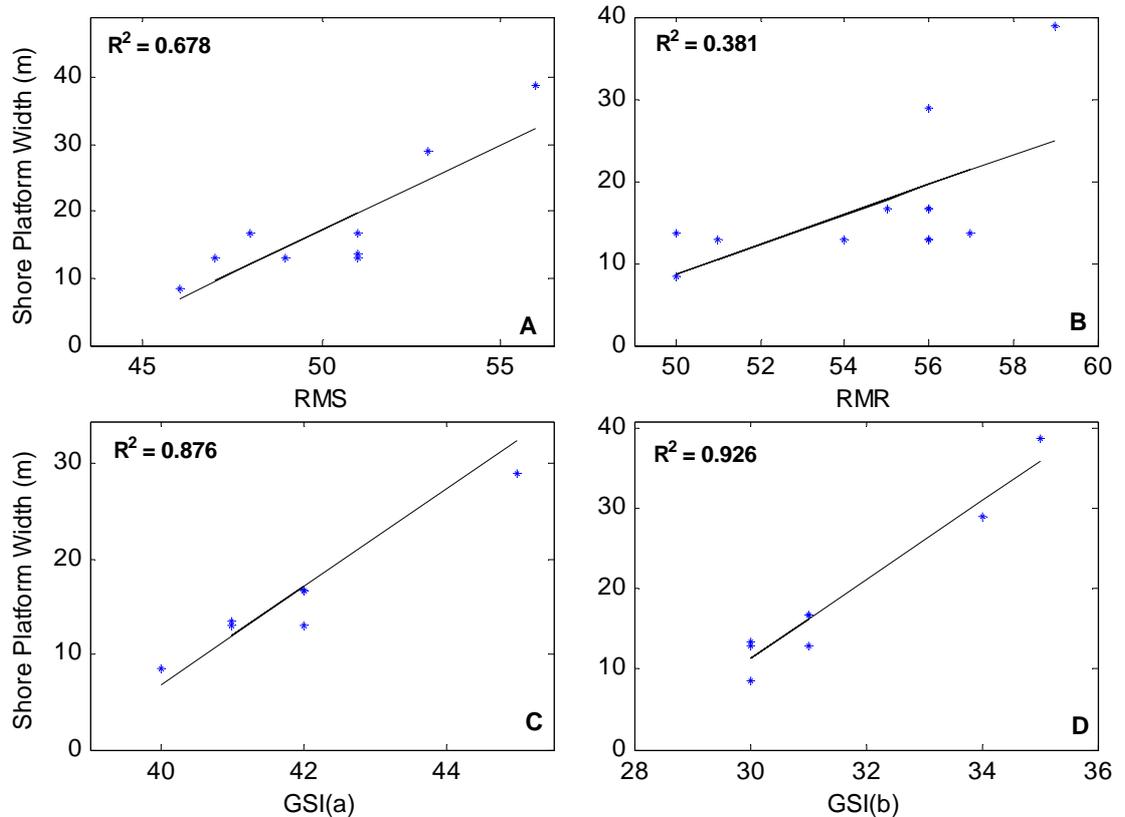
Figure 5.3 Graphs of rock mass classification vs shore platform width for Mahia Peninsula sandstone.

5.3.1 MAHIA PENINSULA SILTSTONE GRAPHS

Figure 5.4 plots rock mass classification versus shore platform width for Mahia Peninsula siltstone graphs. This shows R^2 values from 0.06 for GSI (a), to 0.89 for GSI (b). The graphs for Mahia Peninsula siltstone show similar trends as for the sandstone, that is, as RMS, RMR, GSI (a) and GSI (b) increase; so too does the width of shore platform. However, the GSI (a) shows a very poor relationship.
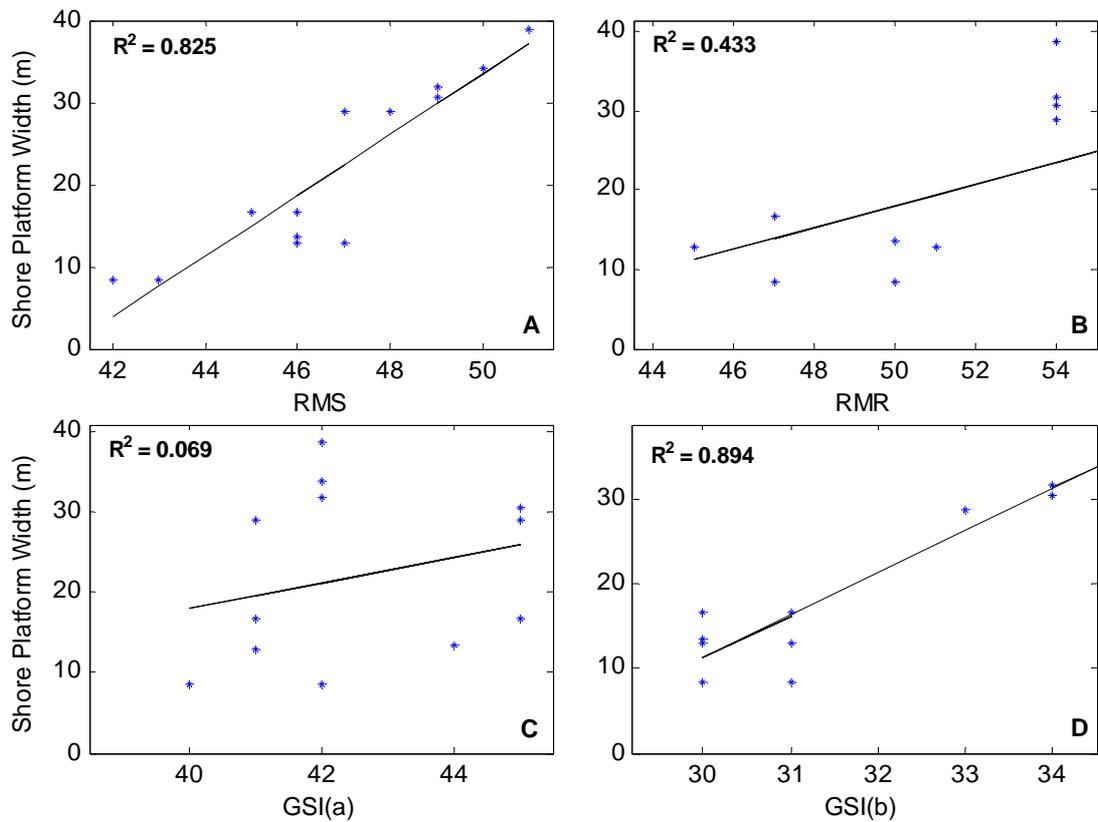
Figure 5.4 The graphs above for Mahia siltstone shows a low R-square results for GSI (a) and RMR while over all good results for GSI (b) and RMS.

5.4 COMPARISON BETWEEN TATAPOURI AND MAHIA PENINSULA SANDSTONE & SILTSTONE GRAPHS

Figure 5.5 shows Tatapouri and Mahia Peninsula sandstone (graph A - D) & siltstone (graph E- H) are plotted together.
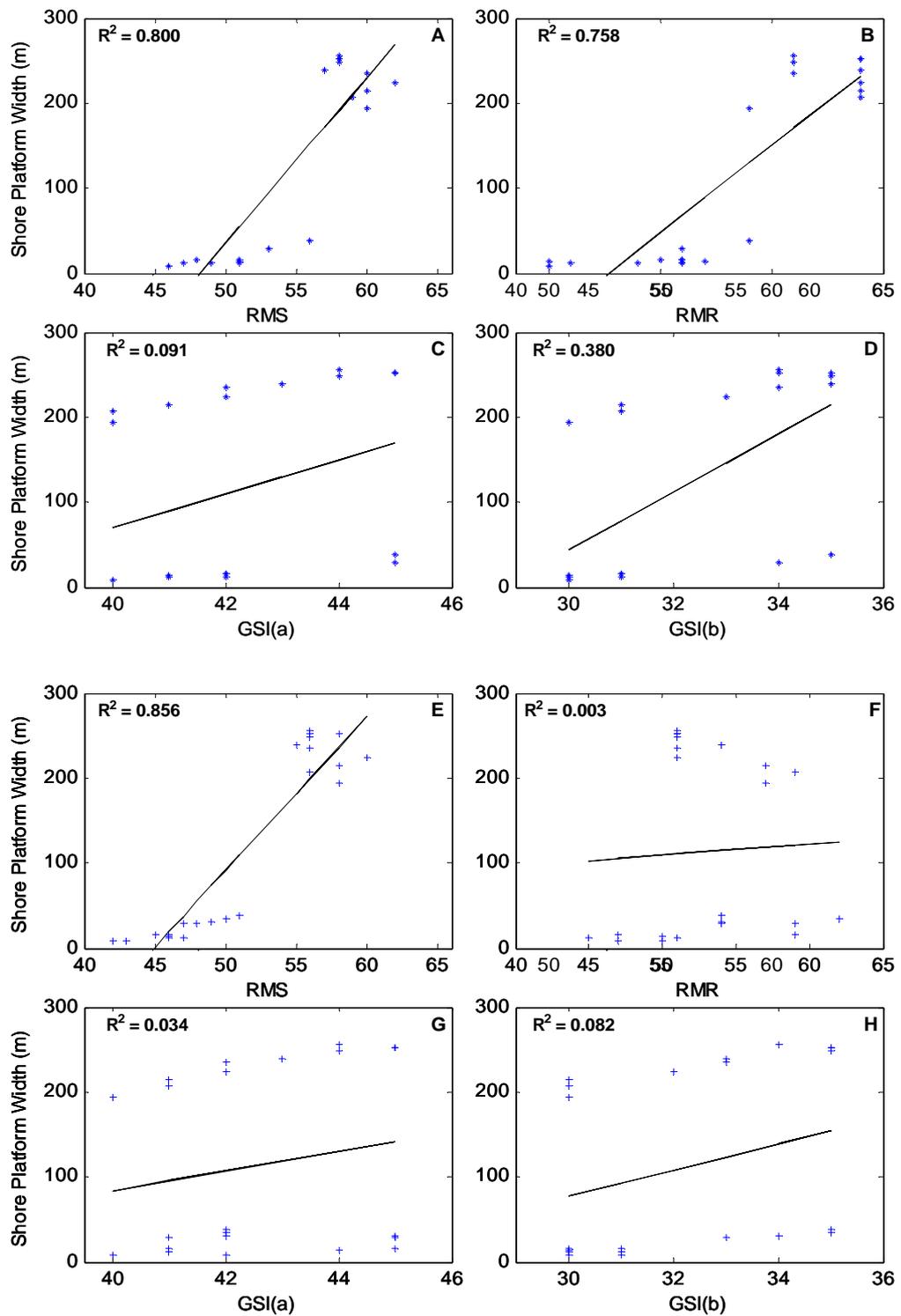
Figure 5.5 Graphs of rock mass classification vs shore platform width Graphs A – D are results for Tatapouri and Mahia Peninsula sandstone. Graphs E – H are results for Tatapouri and Mahia Peninsula siltstone.

The RMS, RMR sandstone graphs (A, B) and RMS siltstone graph (E) show two distinct clusters with no common trends while RMR siltstone graph (F) shows two clusters, but overlap in RMR values with no common trends. The GSI (a) and GSI (b) graphs (C, D, G, H) show the same strength ranges but also show difference shore platform widths and parallel trends. These graphs illustrate that the GSI results show slight differences between graphs (C, D, G, & H). GSI (a) of Tatapouri and Mahia Peninsula sandstone & siltstone cover the same range and GSI (b) also follow the same trend as GSI (a) for both Tatapouri and Mahia Peninsula Sandstone & Siltstone.

The reason for this is that the rock mass classification systems used, i.e. GSI (a) and GSI (b), are very similar as a result of how it works out its rock mass value based on the Hoek–Brown Classifications & Criteria. Graph (A, B, E, & F) show that the data separates into two distinct cluster groups. This is based on the difference in the RMS and RMR classification. It should be noted that the data is strongly influenced by the difference in shore platform width for both Tatapouri and Mahia Peninsula. This may suggest that lithology is not controlling the width of the shore platform but it may be controlled by geography or by wave climate instead.

5.5   MATLAB 7

MATLab 7 was used to calculate shore platform width rates versus distance along the cliff at Tatapouri and Mahia Peninsula (figures 5.7. -5.8). These were used to calculate erosion rates (equation 3.1) which are plotted against distance along cliff in figures 5.9 and 5.10. The data for Mahia Peninsula showed an r^2 value of 0.69 with a negative regression line, and Tatapouri has an r^2 value of 0.0149. There is no linear relationship between shore platform widths and erosion rate for the Tatapouri data. A polynomial fit was applied to the data and it shows an r^2 value of 0.69 for Mahia Peninsula and a r^2 value of 0.86 for Tatapouri, showing a overall negative regression line. The MATLab 7 shore platform width varied between 4.31 to 126.46 m, with a mean width of 65.13 ±1.6 m for Mahia

Peninsula and for Tatapouri have a shore platform width range between 10.02 to 124.35 m, with a mean of 68.06 ±0.21 m. The estimated rate of erosion, ranged from 0.61 to 17.8 ± 0.06 mm y^{-1} for Mahia Peninsula and 1.32 to 16.45 ±0.08 mm y^{-1} for Tatapouri. Table a (appendix) show estimated erosion rates (mm ^{-1}y) at 100 metres along the cliff.
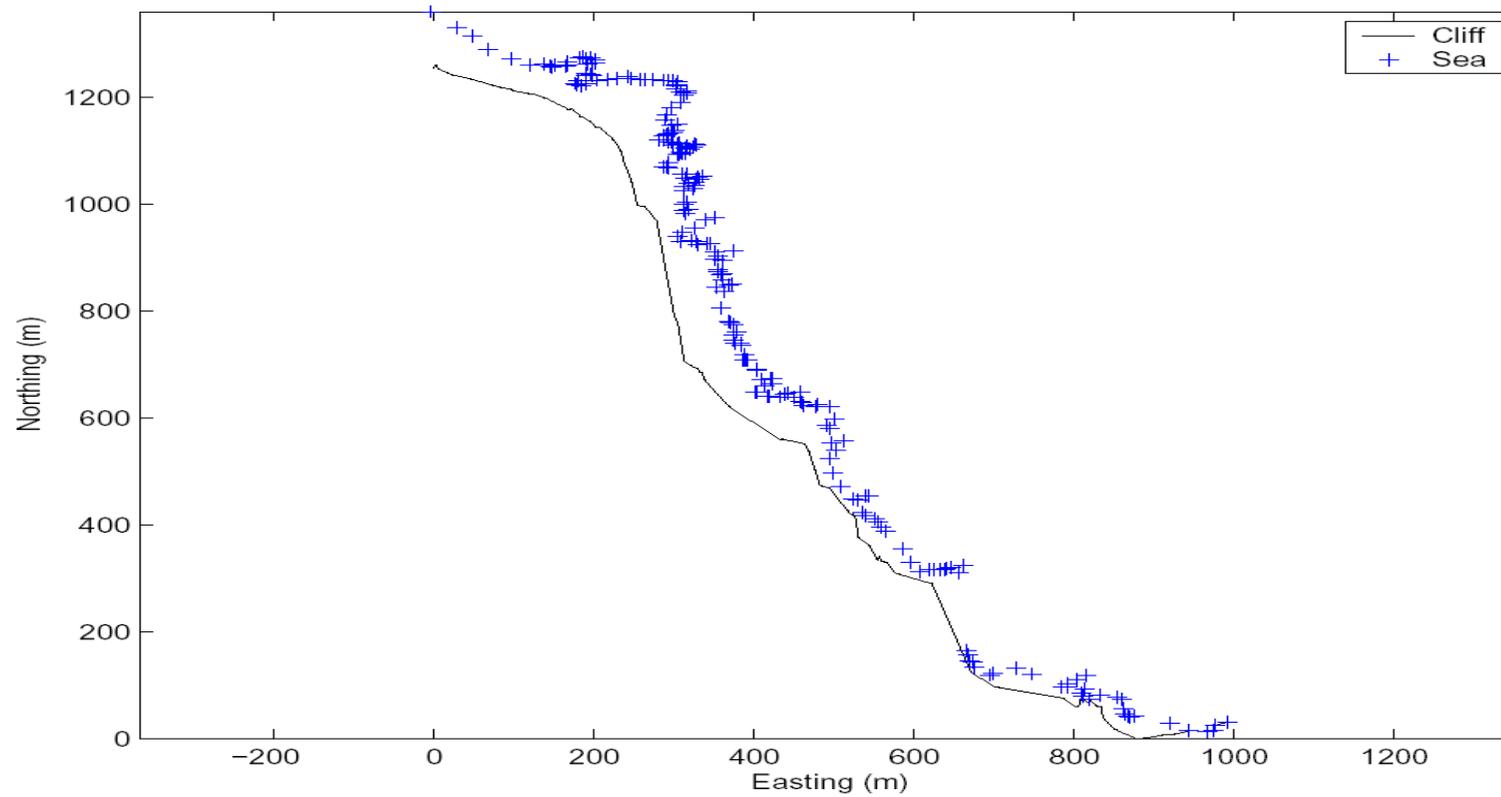
Figure 5.7   GPS data showing the location of the cliff base at Mahia Peninsula, represented by the black line, and the width of the shore platform edge, represented by the blue crosses.
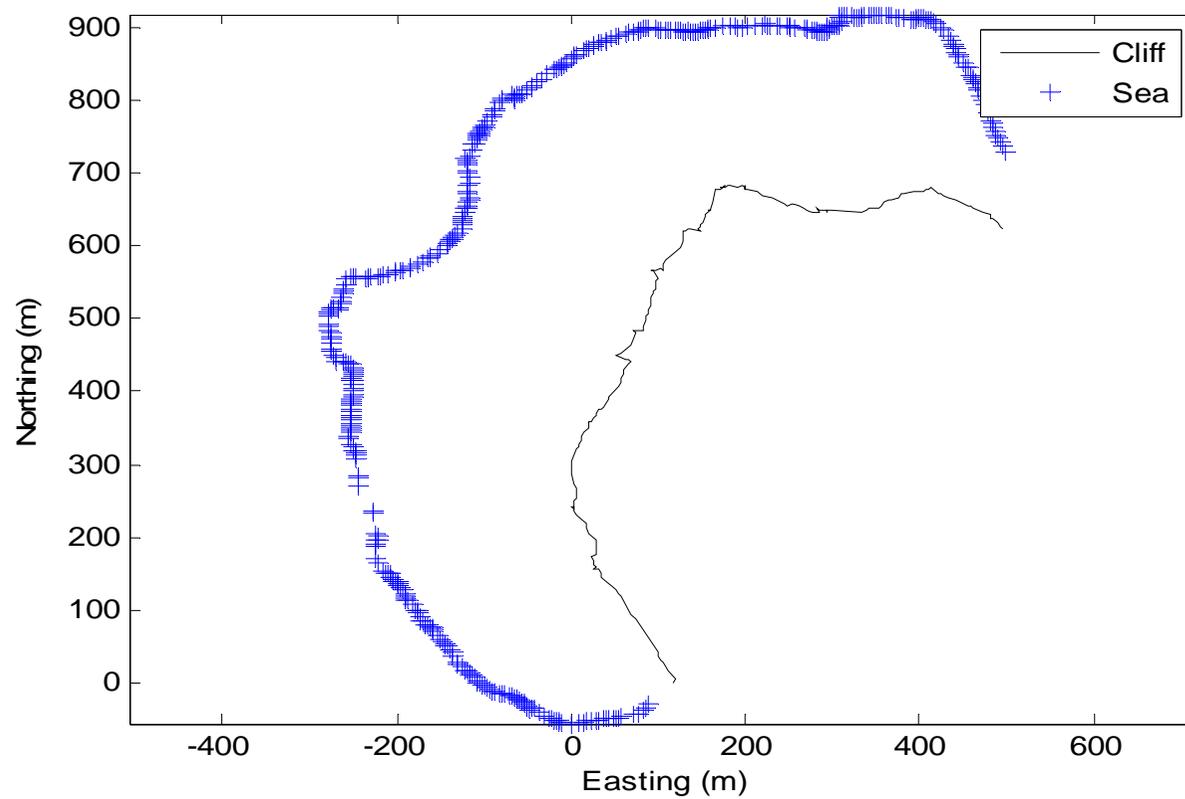
Figure 5.8 GPS data showing the location of the cliff base at Tatapouri, represented by the black line, and the width of the shore platform edge, represented by the blue crosses.
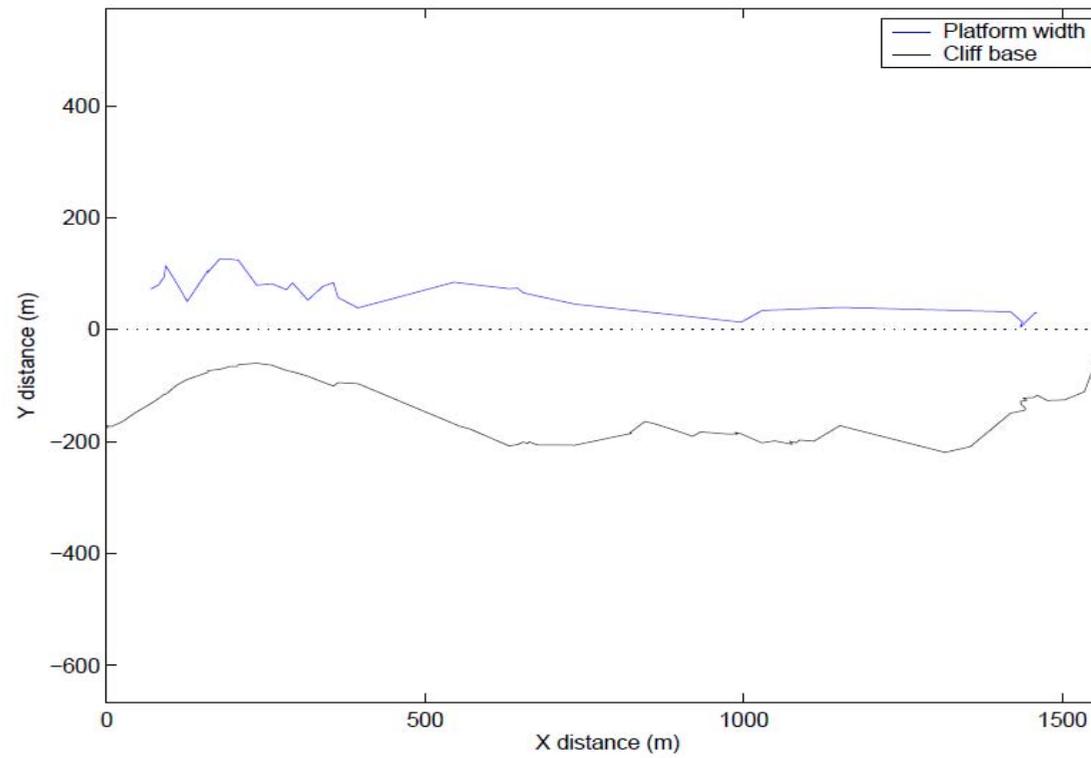
Figure 5.9 Transformed data showing platform width compared to the base of the cliff for Mahia Peninsula.
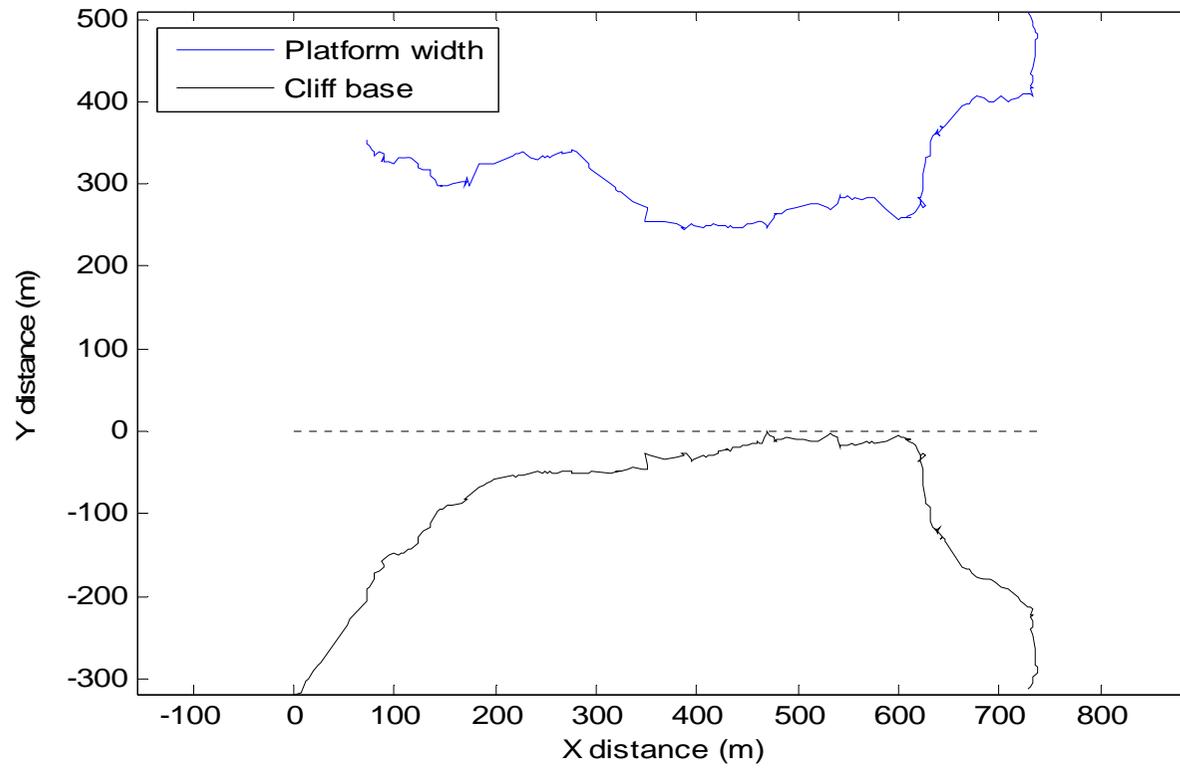
Figure 5.10 Transformed data showing platform width compared to the base of the cliff for Tatapouri.
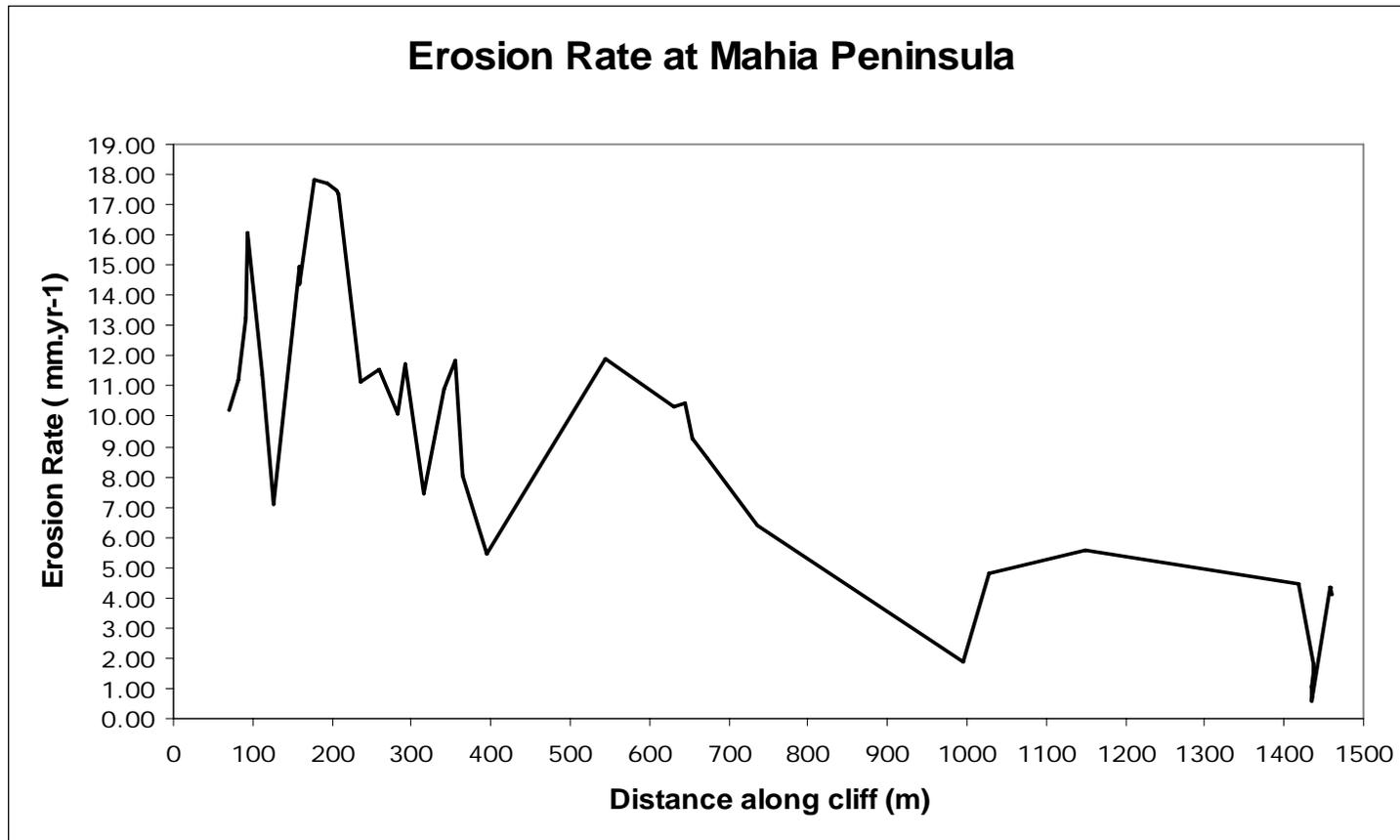
Figure 5.11 Transformed data from Easting and Northing to erosion rates versus distance along the cliff at Mahia Peninsula.
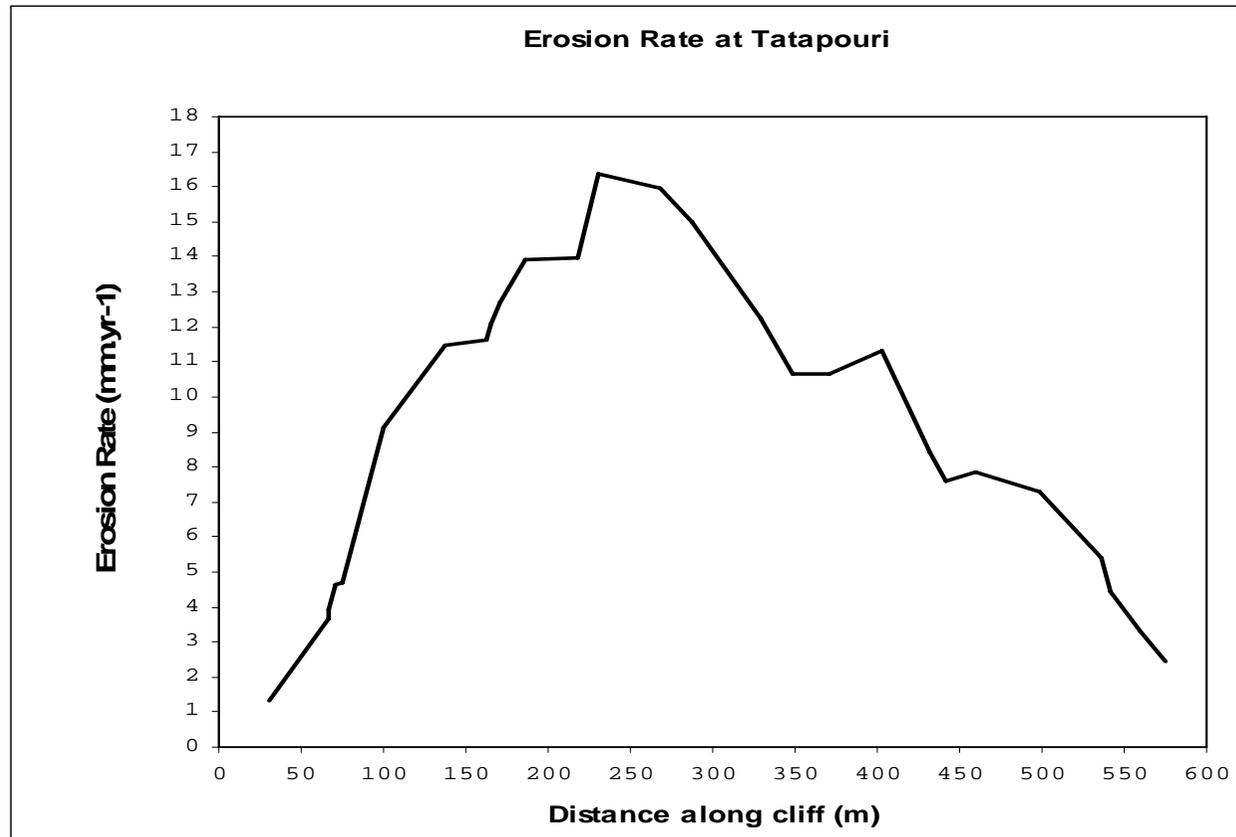
Figure 5.12 Transformed data from Easting and Northing to erosion rates versus distance along the cliff at Tatapouri.

5.2 SUMMARY

This chapter summarises the relationship between plot rock mass classification versus shore platform width. The graphs for Tatapouri and Mahia Peninsula show similar trends where rock mass classification increase; so too does the width of shore platform.

CHAPTER SIX

DISCUSION & CONCLUSION

6.1 INTRODUCTION

This thesis tries to make some sense of the large volume of literature and presents research methods pertaining to shore platform studies and rates of erosion. This research took a new direction by assigning a rock mass classification system to the surrounding cliff face based on field descriptions. It will be recalled that this work was undertaken with the following question and objectives as stated in Chapter 1.

1). which is more dominant in New Zealand environment; sub-aerial weathering or wave erosion?

2). does the orientation of the coast increase or decrease platform development?

3). does tectonic uplift have annoying influence as well?

4). to construct a map identifying the main geological units and shore platform widths;

5). to obtain strength data from geological units by incorporating several of rock mass classification system;

6). to compare the results with rock mass classification systems against shore platform widths to estimate the geological controls on the rate of erosion.

Conclusions have been reached in relation to these three questions and objectives and will be discussed later on in this chapter. The main method used in this study was to map the cliff based boundary and edge of the shore platform with the use of an e-Trax GPS unit. The next part of this study was to map and describe the lithology where a rock mass classification system was applied to the rock type. This was achieved by set tables prepared by the different authors, which was followed and used in the field. Additional information was needed to work out RQD for the RMR rockmass classification system, normally borehole logs is used which was not available at the time of this study so a scanline was employed.

All of the data where collaborated, formatted, and processes with the appropriate computer software programme. ArcGIS was used to display aerial photos and GPS survey data. Based on field descriptions it was a simple matter to divide the photos into 'sections'. Within these 'sections' a total of eight measurements were used to work out the average shore platform width for that 'section'. The advantage of this method was that it was easy to identify field locations and measure the distance from the base of the cliff to the edge of the shore platform. The disadvantage of this method is that it is very random which GPS points to choose which may over or under estimate the shore platform.

The shore platform width was used in conjunction with rockmass rating numbers and also with RockLab results. A MATLAB routine programme, was used to work out shore platform width by calculating a series of multiples strikes, at right angles based on the number of matching GPS coordinates from the base of the cliff to the edge of the shore platform. The end results from MATLAB entail a series of shore platform widths for each set of GPS locations. The advantage of this method was that it gave a multiple of shore platform widths along the stretch of coastline. The disadvantage of this method is that the programme itself skips GPS survey points until two matching points are found, leading to a possibly false representation of the shore platform compared to the real shape.

6.1   SUMMARY OF RESEARCH AIMS & METHODS

6.3.1   GPS

The main method used in this study was to map the cliff based boundary and edge of the shore platform with the use of an e-Trax GPS unit. ArcGIS was used to display aerials photos and GPS survey data. Based on field descriptions it was a simple matter to divide the photos into 'sections'. Within theses 'sections' a total of eight measurements was used to work out the average shore platform width for that 'section'.

The advantaged of this method was that it was easy to identify field locations and measure the distance from the base of the cliff to the edge of the shore platform. The disadvantage of this method is that it is very random which GPS points to choose which may over or under estimate the shore platform. The shore platform width was used in congonation with rockmass rating numbers and also with RockLab results. The limitation of the eTrex hand-held GPS unit is that it was only accurate to ± 5 metres near the edge of the shore platform and gradually worsened when you moved closer to the base of the cliff (accurate to ± 15 metres).

6.3.2   ROCK MASS DESCRIPTION

Tatapouri and Mahia Peninsula have similar rock mass characteristics. The rocks were classified as medium weak rock (sandstone) through to very weak rock (siltstone) according to the classification system of Wyllie & Mah (2004). Sedimentary structures such as planar or low angle laminations, current ripple-forms, and flame and slump structures were observed which closely follow the Bouma Sequence model. The beds of the cliff were dipping into the cliff at both sites. Signs of rust stains between the discontinuities indicated the present of water movement.

6.3.3   RQD

Priest and Hudson (1976) method was used to calculate the RQD. In general Tatapouri shows a RQD range from 98% to 86% and Mahia Peninsula shows a RQD range from 94% to 49%. To put these percentages into some kind of context the results tell us that Tatapouri rock quality is rated as excellent to good and for Mahia Peninsula rock quality is rated as excellent to poor according to Bieniawski 1989 RQD index. The difference between sites may be explained by outside influences such as localized faulting, spaces between discontinuities due to weathering effects, type of clay in the rock.

The RQD results in chapter 4, section 4.2.1 reveal that the condition of the surrounding cliff (flysch deposit) at Tatapouri shows that the cliff has a strong rock mass rating. At Mahia Peninsula the strength of the cliff varies from place to place. From Oraka Beach (scanline 4) to the bottom of Te Mahia School (scanline 6) shows that the rock mass strength decreases. The noticeable reduction in rock strength could be explained by the localized faulting or the influence of lithology. The photo (Photo 1) shows the general application on how to work out RQD value based on the distance between each discontinuity. Weathering can often alter the physical appearances and strength of the rock mass and can increase or decrease the space between discontinuities affecting the strength of the rock (i.e. sinking and swell clays and pore water pressure) within. The general physical characteristics of the rock can also alter the RQD value when wet or dry.

6.3.4   ROCK MASS CLASSIFICATION SYSTEMS

This section summarised the rock mass classification results from Selby (1980) RMS, Bieniawski (1989) RMR, and both GSI prospers by Hoek *et al.* in (1995), and Marinos *et al.* (2001). All classification systems in this thesis were easy to use and self explainable. Each system had a set number of categories and parameters to work out a total rating number which corresponds to a rock mass strength.

Tatapouri sandstone has an RMS range from 62 to 57 and Tatapouri siltstone has an RMS range from 58 to 55. The rock mass strength for both Tatapouri sandstone and siltstone has a moderate rock mass strength according to Selby (1980) classification system. The RMS results for Mahia Peninsula sandstone has an RMS range from 55 to 46 and Mahia Peninsula siltstone has an RMS range from 50 to 42. The rock mass strength for Mahia Peninsula rocks has a moderate to weak rock mass strength according to Selby (1980) classification system.

The RMR results for Tatapouri sandstone have a range form 64 to 59 and for Tatapouri siltstone has a range from 58 to 55. According to Bieniawski (1989) rock mass rating both rock types can by assessed as fair rock. The RMR results for Mahia Peninsula sandstone have a range form 55 to 49 and for Mahia Peninsula siltstone has a range from 50 to 42. According to Bieniawski (1989) rock mass rating for both rock types can by assessed as fair rock. The GSI (a) and GSI (b) results for Tatapouri and Mahia Peninsula sandstone & siltstone have a range from 45 to 40 (Ss) and a range from 35 to 30 (Sz). This means that for GSI (a) Ss is regarded as good rock mass and for Sz is regarded as fair rock mass. For GSI (b) has a range from 30 to 35 for both field locations. The sandstone and siltstone is considered to be rated as fair rock mass.

6.3.5 GRAPH INTERPRETATION

To summarise the RMS for Tatapouri and Mahia Peninsula sandstone and siltstone showed that Mahia Peninsula have a better rock mass strength ranging from 0.83 Ss – 0.63 Sz. This shows that a link exists between increases in platform width with increased rock mass strength. The results for Tatapouri sandstone and siltstone show a range from 0.36 Ss – 0.14 Sz. This shows as platform width decreases, the rock mass strength also decreases.

To summarise the RMR for Tatapouri and Mahia Peninsula sandstone and siltstone showed that Mahia Peninsula RMR ranges from 0.38 Ss – 0.43 Sz. As shore platform width increased so does the rock mass strength. The results for

Tatapouri sandstone and siltstone show a range from 0.03 Ss – 0.69 Sz. This shows as platform width decreases, the rock mass strength also decreases. Tatapouri sandstone shows that the data points are grouped into two separate areas with an outlier point. The trend line is relatively flat due to the influence of the cluster data point.

The results for Tatapouri sandstone and siltstone show a range from 0.03 Ss – 0.69 Sz. This shows as platform width decreases, the rock mass strength also decreases. Tatapouri sandstone shows that the data points are grouped into two separate areas with an outlier point. The trend line is relatively flat due to the influence of the cluster data point.

The GSI (a) results for Tatapouri and Mahia Peninsula sandstone / siltstone showed that Mahia Peninsula GSI (a) ranged from 0.88 Ss – 0.07 Sz and the Tatapouri GSI (a) results shows a range from 0.92 Ss – 0.92 Sz. The GSI (b) for Tatapouri and Mahia Peninsula sandstone and siltstone showed that Mahia Peninsula GSI (b) ranged from 0.93 Ss – 0.89 Sz and the Tatapouri results show a range from 0.84 Ss – 0.90 Sz. As shore platform width increased so does the GSI (a) and GSI (b) rock mass strength. This may suggest that the lithology is controlling the width of the shore platform. As more fresh rock is exposed and eroded the talus deposits at the base of the cliff are acting as a buffer reducing the erosional effects of the sea.

All graphs in (chapter 4) show R^2 values, which compares the predicted rock mass strength with the estimated shore platform width. Figure 5.1 show Tatapouri and Mahia Peninsula sandstone and siltstone are plotted together. A noticeable pattern emerged from these graphs, where the data points are divided and separated into discrete clusters / groups. These graphs clearly show that the sandstone and siltstone data are independent from each other and strongly influenced by the width of the shore platform.

The graph data for Mahia Peninsula showed an r^2 value of 0.687 with a negative regression line, and Tatapouri has an r^2 value of 0.0149. There is no linear

relationship between shore platform widths and erosion rate for the Tatapouri data. A polynomial fit was applied to the data and it shows a r^2 value of 0.6908 for Mahia Peninsula and a r^2 value of 0.8567 for Tatapouri shows an overall negative regression line.

6.3.5.1   MATLAB 7

The MATLab 7 shore platform width varied between 4.31 to 126.46 m, with a mean width of 72. ±1.6 m for Mahia Peninsula. Tatapouri has a shore platform width range between 10.02 to 124.35 m, with a mean of 68.06 ±0.21 m. The estimated rate of erosion, ranges from 0.61 to 17.8 ± 0.06 mm y^{-1} for Mahia Peninsula and 1.32 to 16.45 ±0.08 mm y^{-1} for Tatapouri.

Figure 5.9 shows a reasonable range in platform widths for Mahia Peninsula. Figure 5.10 results are suggesting that the maximum shore platform width is 500 metres, which is incorrect from field observations. To make some sense out of the data everything greater than 230 metres was removed from the dataset. The problem may lie within the Matlab code itself. The main difference between the individual sties is that Tatapouri is more exposed to the open sea and is generally one big headland. Mahia Peninsula shows both headland features and sheltered embayment due to the coastline orientation.

To put these graph results into some kind of context the different parts of the cliff were eroding at a faster rate than other parts of the coast. Based on Gibb (1978) calculated erosion rates of 0.02 (m.y^{-1}) for Wainui Beach. This shows that Tatapouri and Mahia Peninsula has a lower erosion rate than the Gibb (1978) calculated erosion rate.

6.4 FUTURE INVESTIGATION

This research has highlighted the potential uses in coast cliff erosion. This research could be used as a standard approach where the local and regional Councils could use to their advantage. As such, there is further work which could provide a comparison, and investigate areas not covered in this study. These include:

a) Future investigation in the development of a new rock mass classification system would be helpful.

b) Investigation into the influence of approaching waves. This could be achieved by video imaging techniques.

c) The development of a coastal database system could help to monitor gradual or large changes along the coast with the aid of LIDAR data.

d) Existing bathymetric charts and aerial photography should be up-dated frequently.

The above recommendations are helpful suggestion which may improve the overall research.

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APPENDIX 1

APPENDIX – Mahia RMS

Site No.	Rock type	Intact rock strength	Weathering	Spacing of joints	Joint orientation	Width of joints	Continuity of joints	Outflow of groundwater	Total Rating	Qualitative rock strength
	Siltstone	Weak	Slightly	<50 mm scanline	Moderate dips out of slope	1 - 5mm	Continuous, no infill	Slight	-	-
Mahia 3	Total RMS	(10*)	9	8	9	5	5	4	50	(Weak)
	Rock Description	Siltstone; light greyish blue; weak rock; well sorted; moderate to highly weathered rock; well to extremely (fSL) ; bedding; may have experienced shear / folding during uplift; rough; stepped; (JRC 8); moderated wide; close spacing very low persistence; four or more joint sets; crushed.								
	Siltstone	Weak	moderate	<50 mm scanline	Moderate dips out of slope	1 - 5mm	Continuous, no infill	Slight		
Mahia 4	Total RMS	(10*)	7	8	9	5	5	4	48	(Weak)
	Rock Description	Siltstone; light greyish grey; weak rock; well sorted; slightly to moderately weathered rock; well to extremely sorted; bedding; may have experienced shear / folding during uplift rough; stepped; (JRC 9); moderated wide; extremely close spacing very low persistence; four or more joint sets; irregular.								
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips out of slope	1 - 5mm	None continuous	Slight		
Mahia 5	Total RMS	(10*)	5	8	9	5	7	4	48	(Weak)
	Rock Description	Siltstone; light greyish grey; weak rock; well sorted; slightly to moderately weathered rock; well to extremely sorted; fSL; bedding; may have experienced; shear / folding during uplift rough; stepped; (JRC 8); moderated wide; extremely close spacing very low persistence; massive; occasional random joints irregular.								
	Sandstone	Weak	Slightly	<50 mm scanline	Moderate dips out of slope	<0.1mm	Continuous, no infill	None		
Mahia 6a	Total RMS	(11*)	9	8	9	7	5	6	55	(Moderate)
	Rock Description	Sandstone; greyish white; medium weak rocks; slightly to moderately weathered rock; moderate to well sorted grains; mSL to mSU; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC 4); very tight; extremely close spacing very low persistence; massive; occasional random joint; massive.								
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips out of slope	1 - 5mm	Continuous, no infill	Slight		
Mahia 6b	Total RMS	(10*)	5	8	9	5	5	4	46	(Weak)
	Rock Description	Siltstone; light greyish blue; weak rock; well sorted; moderate to highly weathered rock; well to extremely sorted; fSL; bedding; may have experienced; shear / folding during uplift; rough; stepped; (JRC 8); moderated wide; close spacing very low persistence; four or more joint sets; crushed.								
	Siltstone	Weak	moderate	<50 mm scanline	Moderate dips out of slope	1 - 5mm	Continuous, no infill	Slight		
Mahia 7a	Total RMS	(10*)	7	8	9	5	5	4	48	(Weak)
	Rock Description	Siltstone; white greyish grey; weak rock; well sorted; slightly to moderately weathered rock; well to extremely fSL to fSU; bedding; may have experienced; shear / folding during uplift; smooth; stepped; (JRC8); partly open moderated wide; close spacing very low persistence; four or more joint sets; irregular.								
	Sandstone	Weak	Slightly	<50 mm scanline	Moderate dips out of slope	1 - 5mm	Continuous, no infill	Trace		
Mahia 7b	Total RMS	(11*)	9	8	9	5	5	5	52	(Moderate)
	Rock Description	Sandstone; brownish grey; medium weak rocks; slightly to moderately weathered rock; moderate to well sorted grains; mSL to mSU; lapilli <5mm; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC8); moderated wide; extremely close spacing very low persistence; occasional random joint; massive.								

Site No.	Rock type	Intact rock strength	Weath-ering	Spacing of joints	Joint orientation	Width of joints	Continuity of joints	Outflow of groundwater	Total Rating	Qualitative rock strength
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips out of slope	1 - 5mm	Continuous, no infill	Slight		
Mahia 7c	Total RMS	(10*)	5	8	9	5	5	4	46	(Weak)
	Rock Description	Siltstone; dark greyish blue; weak rock; well sorted; moderate to highly weathered rock; well to extremely sorted; fSL to fSU; bedding; may have experienced; shear /folding during uplift; smooth; stepped; (JRC7); moderated wide; close spacing very low persistence; four or more joint sets; irregular.								
	Sandstone	Weak	moderate	<50 mm scanline	Moderate dips out of slope	5-20mm	Continuous, no infill	Trace		
Mahia 8a	Total RMS	(10*)	7	8	9	4	5	5	48	(Weak)
	Rock Description	Sandstone; greyish white; medium weak rocks; moderate to highly weathered rock; moderate to well sorted grains; mSL to mSU; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC 6); moderated wide; extremely close spacing very low persistence; four or more joint sets joint; blocky.								
	Siltstone	Weak	moderate	<50 mm scanline	Moderate dips out of slope	1 - 5mm	Continuous, no infill	Trace		
Mahia 8b	Total RMS	(10*)	7	8	9	5	5	5	49	(Weak)
	Rock Description	Sandstone / Volcanic material; dark brownish brown; medium weak rocks; moderate to highly weathered rock; moderate to well sorted grains; mSL to mSU; lapilli < 5mm; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC 8); moderated wide; extremely close spacing very low persistence; massive; occasional random joint; massive.								
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips out of slope	0.1-1mm	Continuous, no infill	Slight		
Mahia 8c	Total RMS	(10*)	5	8	9	6	5	4	47	(Weak)
	Rock Description	Siltstone; light greyish blue; weak rock; well sorted; moderate to highly weathered rock; well to extremely sorted; fSL to fSU; bedding; may have experienced; shear /folding during uplift; smooth; stepped; (JRC7); tight; close spacing very low persistence; four or more joint sets; irregular.								
	Sandstone	Weak	moderate	<50 mm scanline	Moderate dips out of slope	1 - 5mm	Continuous, no infill	Trace		
Mahia 9a	Total RMS	(10*)	7	8	9	5	5	5	49	(Weak)
	Rock Description	Sandstone / Volcanic material; dark brownish brown; medium weak rocks; moderate to highly weathered rock; moderate to well sorted grains; mSL to mSU; lapilli < 5mm; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC 8); moderated wide; extremely close spacing very low persistence; massive; occasional random joint; massive.								
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips out of slope	0.1-1mm	Continuous, no infill	Trace		
Mahia 9b	Total RMS	(10*)	5	8	9	6	5	5	48	(Weak)
	Rock Description	Siltstone; light greyish blue; weak rock; well sorted; moderate to highly weathered rock; well to extremely sorted; fSL to fSU; bedding; may have experienced; shear / folding during uplift; smooth; stepped; (JRC 7); tight; close spacing very low persistence; four or more joint sets; irregular.								
	Sandstone	Weak	moderate	<50 mm scanline	Moderate dips out of slope	1 - 5mm	Continuous, no infill	Trace		
Mahia 10a	Total RMS	(10*)	7	8	9	5	5	5	49	(Weak)
	Rock Description	Sandstone / Volcanic material; dark brownish brown; medium weak rocks; moderate to highly weathered rock; moderate to well sorted grains; mSL to mSU; lapilli < 5mm; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC 8); moderated wide; extremely close spacing very low persistence; massive; occasional random joint; massive.								

Site No.	Rock type	Intact rock strength	Weath-ering	Spacing of joints	Joint orientation	Width of joints	Continuity of joints	Outflow of groundwater	Total Rating	Qualitative rock strength
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips out of slope	0.1-1mm	Continuous, no infill	Slight		
Mahia 10b	Total RMS	(10*)	5	8	9	6	5	4	47	(Weak)
	Rock Description	Siltstone; light greyish white; weak rock; well sorted; moderate to highly weathered rock; well to extremely sorted; fSL to fSU; bedding; may have experienced; shear /folding during uplift; smooth; stepped; (JRC 7); moderated wide; close spacing very low persistence; four or more joint sets; crushed.								
	Sandstone	Weak	moderate	<50 mm scanline	Moderate dips out of slope	< 0.1mm	Continuous, no infill	Trace		
Mahia 11a	Total RMS	(10*)	7	8	9	7	5	5	51	(Moderate)
	Rock Description	Sandstone; brownish grey; medium weak rocks; moderate to highly weathered rock; moderate to well sorted grains; mSL to mSU; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC 8); very tight; extremely close spacing very low persistence; massive; occasional random joint; massive.								
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips out of slope	0.1-1mm	Continuous, no infill	Slight		
Mahia 11b	Total RMS	(10*)	5	8	9	6	5	4	47	(Weak)
	Rock Description	Siltstone; light greyish white; weak rock; well sorted; moderate to highly weathered rock; well to extremely sorted; fSL to fSU; bedding; may have experienced; shear /folding during uplift; smooth; stepped; (JRC 7); moderated wide; close spacing very low persistence; four or more joint sets; crushed.								
	Siltstone	Weak	moderate	<50 mm scanline	Moderate dips out of slope	1 - 5mm	Continuous, thick infill	Slight		
Mahia 12a	Total RMS	(10*)	7	8	9	5	1	4	44	(Weak)
	Rock Description	Mud stone; dark brownish brown; weak rock; well sorted; moderate to highly weathered rock; well to extremely sorted; fSL to fSU; bedding; may have experienced; shear /folding during uplift; smooth; planar; (JRC 4); moderated wide; close spacing very low persistence; four or more joint sets; crushed.								
	Sandstone	Weak	moderate	<50 mm scanline	Moderate dips out of slope	< 0.1mm	Continuous, no infill	Trace		
Mahia 12b	Total RMS	(10*)	7	8	9	7	5	5	51	(Moderate)
	Rock Description	Sandstone; greyish white; medium weak rocks; moderate to highly weathered rock; moderate to well sorted grains; mSL to mSU; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC 4); tight; extremely close spacing very low persistence; massive; occasional random joints; massive.								
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips out of slope	1 - 5mm	Continuous, no infill	Slight		
Mahia 12c	Total RMS	(9*)	5	8	9	5	5	4	45	(Weak)
	Rock Description	Siltstone; light greyish brown; weak rock; moderate to highly weathered rock poorly sorted grains; highly weathered rock bedding; may have experienced shear / folding during uplift; rough; undulating; (JRC 9); moderated wide; extremely close spacing; very low persistence; crushed rock; earth-like.								
	Sandstone	Weak	moderate	<50 mm scanline	Moderate dips out of slope	< 0.1mm	Continuous, no infill	Trace		
Mahia 12d	Total RMS	(10*)	7	8	9	7	5	5	51	(Moderate)
	Rock Description	Sandstone / Volcanic material; dark grey; medium weak rocks; moderate to highly weathered rock; poorly to moderated sorted; mSL to mSU; lapilli > 5mm; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC 6); very tight; moderated wide; extremely close spacing very low persistence; massive; occasional random joint; massive.								

Site No.	Rock type	Intact rock strength	Weath-ering	Spacing of joints	Joint orientation	Width of joints	Continuity of joints	Outflow of groundwater	Total Rating	Qualitative rock stregth
	Sandstone	Weak	moderate	<50 mm scanline	Moderate dips out of slope	< 0.1mm	Continuous, no infill	Trace		
Mahia 13a	Total RMS	(10*)	7	8	9	7	5	5	51	(Moderate)
	Rock Description	Sandstone / Volcanic material; dark grey; medium weak rocks; moderate to highly weathered rock; poorly to moderated sorted; mSL to mSU; lapilli > 5mm; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC6); very tight; moderated wide; extremely close spacing very low persistence; massive; occasional random joint; massive.								
	Sandstone	Very weak	moderate	<50 mm scanline	Moderate dips out of slope	< 0.1mm	None Continuous	Trace		
Mahia 13b	Total RMS	(5)*	7	8	9	7	7	5	48	(Weak)
	Rock Description	Sandstone; Dark black; Schmidt hammer result (25.2) ; very weak; moderate to highly weathered rock; extremely fine bedding planes; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC7 close spacing; very low persistence; massive; occasional random; crushed.								
	Siltstone	Very weak	Highly	<50 mm scanline	Moderate dips out of slope	1 - 5mm	None Continuous	Slight		
Mahia 13c	Total RMS	5	5	8	9	5	7	4	43	(Weak)
	Rock Description	Siltstone; Dark black; Schmidt hammer result (11.75); very weak; moderate to highly weathered rock; extremely fine bedding planes; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC 7); close spacing; very low persistence; massive; occasional random; crushed.								
	Sandstone	Very weak	moderate	<50 mm scanline	Moderate dips out of slope	1 - 5mm	None Continuous	Trace		
Mahia 14a	Total RMS	(5)*	7	8	9	5	7	5	46	(Weak)
	Rock Description	Sandstone; Dark black; Schmidt hammer result (11.75); very weak; moderate to highly weathered rock; extremely fine bedding planes; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC7); close spacing; very low persistence; massive; occasional random; crushed.								
	Sandstone	Weak	moderate	<50 mm scanline	Moderate dips out of slope	1 - 5mm	Continuous, no infill	Trace		
Mahia 14b	Total RMS	(10)*	7	8	9	5	5	5	49	(Weak)
	Rock Description	Sandstone; brownish grey; medium weak rocks; moderate to highly weathered rock; moderate to well sorted grains; mSL to mSU; lapilli <5mm; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC8); moderated wide; extremely close spacing very low persistence; massive; occasional random joint.								
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips out of slope	1 - 5mm	Continuous, thick infill	Slight		
Mahia 14c	Total RMS	(9*)	5	8	9	5	1	4	41	(Weak)
	Rock Description	Siltstone; dark greyish blue; weak rock; well sorted; moderate to highly weathered rock; well to extremely sorted; fSL to fSU; bedding; may have experienced; shear / folding during uplift; smooth; stepped; (JRC7); moderated wide; close spacing very low persistence; four or more joint sets; irregular.								
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips out of slope	1 - 5mm	Continuous, thick infill	Slight		
Mahia 14d	Total RMS	(10*)	5	8	9	5	1	4	42	(Weak)
	Rock Description	Siltstone; dark greyish blue; weak rock; well sorted; moderate to highly weathered rock; well to extremely sorted; fSL to fSU; bedding; may have experienced; shear / folding during uplift; smooth; stepped; (JRC7); moderated wide; close spacing very low persistence; four or more joint sets; irregular.								

APPENDIX – Mahia RMR

Site No.	Rock type	UCS	(RQD)	Spacing of discontinuities	Condition of discontinuities	groundwater condtions	Total Rating	Qualitative rock stregth
	Siltstone	5 - 25 MPa	90% - 100%	<60mm	slightly rough surfaces, separation <1mm, highly weathering walls	Wet		
Mahia 3	Total RMR	(2*)	20	5	20	7	54	FAIR ROCK
	Siltstone	5 - 25 MPa	90% - 100%	<60mm	slightly rough surfaces, separation <1mm, highly weathering walls	Wet		
Mahia 4	Total RMR	(2*)	20	5	20	7	54	FAIR ROCK
	Siltstone	5 - 25 MPa	90% - 100%	<60mm	slightly rough surfaces, separation <1mm, highly weathering walls	Completely dry		
Mahia 5	Total RMR	(2*)	20	5	20	15	62	GOOD ROCK
	Sandstone	25 - 50 MPa	90% - 100%	<60mm	slightly rough surfaces, separation <1mm, highly weathering walls	Damp		
Mahia 6a	Total RMR	(4*)	20	5	20	10	59	FAIR ROCK
	Siltstone	5 - 25 MPa	90% - 100%	<60mm	slightly rough surfaces, separation <1mm, highly weathering walls	Wet		
Mahia 6b	Total RMR	(2*)	20	5	20	7	54	FAIR ROCK
	Siltstone	5 - 25 MPa	75% - 90%	<60mm	slightly rough surfaces, separation <1mm, highly weathering walls	Completely dry		
Mahia 7a	Total RMR	(2*)	17	5	20	15	59	FAIR ROCK
	Sandstone	25 - 50 MPa	75% - 90%	<60mm	slightly rough surfaces, separation <1mm, highly weathering walls	Damp		
Mahia 7b	Total RMR	(4*)	17	5	20	10	56	FAIR ROCK
	Siltstone	5 - 25 MPa	75% - 90%	<60mm	slightly rough surfaces, separation <1mm, highly weathering walls	Damp		
Mahia 7c	Total RMR	(2*)	17	5	20	10	54	FAIR ROCK
	Sandstone	25 - 50 MPa	75% - 90%	<60mm	slightly rough surfaces, separation <1mm, highly weathering walls	Damp		
Mahia 8a	Total RMR	(4*)	17	5	20	10	56	FAIR ROCK
	Sandstone	25 - 50 MPa	75% - 90%	<60mm	slightly rough surfaces, separation <1mm, highly weathering walls	Wet		
Mahia 8b	Total RMR	(2*)	17	5	20	7	51	FAIR ROCK
	Siltstone	5 - 25 MPa	75% - 90%	<60mm	slightly rough surfaces, separation <1mm, highly weathering walls	Wet		
Mahia 8c	Total RMR	(2*)	17	5	20	7	51	FAIR ROCK
	Sandstone	25 - 50 MPa	75% - 90%	<60mm	slightly rough surfaces, separation <1mm, highly weathering walls	Damp		
Mahia 9a	Total RMR	(2*)	17	5	20	10	54	FAIR ROCK
	Siltstone	5 - 25 MPa	75% - 90%	<60mm	slightly rough surfaces, separation <1mm, highly weathering walls	Wet		
Mahia 9b	Total RMR	(2*)	17	5	20	7	51	FAIR ROCK
	Sandstone	25 - 50 MPa	75% - 90%	<60mm	slightly rough surfaces, separation <1mm, highly weathering walls	Damp		
Mahia 10a	Total RMR	(4*)	17	5	20	10	56	FAIR ROCK

Site No.	Rock type	UCS	(RQD)	Spacing of discontinuities	Condition of discontinuities	groundwater conditions	Total Rating	Qualitative rock stregth
	Siltstone	5 - 25 MPa	75% - 90%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Damp		
Mahia 10b	Total RMS	(2*)	17	5	20	10	54	FAIR ROCK
	Sandstone	25 - 50 MPa	75% - 90%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Damp		
Mahia 11a	Total RMS	(4*)	17	5	20	10	56	FAIR ROCK
	Siltstone	5 - 25 MPa	75% - 90%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Wet		
Mahia 11b	Total RMS	(2*)	17	5	20	7	51	FAIR ROCK
	Siltstone	25 - 50 MPa	90% - 100%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Damp		
Mahia 12a	Total RMS	(4*)	20	5	20	10	59	FAIR ROCK
	Sandstone	25 - 50 MPa	50% - 75%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Completely dry		
Mahia 12b	Total RMS	(4*)	13	5	20	15	57	FAIR ROCK
	Siltstone	5 - 25 MPa	50% - 75%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Damp		
Mahia 12c	Total RMS	(2*)	13	5	20	10	50	FAIR ROCK
	Sandstone	5 - 25 MPa	50% - 75%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Damp		
Mahia 12d	Total RMS	(2*)	13	5	20	10	50	FAIR ROCK
	Sandstone	5 - 25 MPa	50% - 75%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Completely dry		
Mahia 13a	Total RMS	(2*)	13	5	20	15	55	FAIR ROCK
	Sandstone	25 - 50 MPa	50% - 75%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Completely dry		
Mahia 13b	Total RMS	(3*)	13	5	20	15	56	FAIR ROCK
	Siltstone	5 - 25 MPa	50% - 75%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Completely dry		
Mahia 13c	Total RMS	(2*)	13	5	20	15	55	FAIR ROCK
	Sandstone	5 - 25 MPa	50% - 75%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Damp		
Mahia 14a	Total RMS	(2*)	13	5	20	10	50	FAIR ROCK
	Sandstone	25 - 50 MPa	50% - 75%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Damp		
Mahia 14b	Total RMS	(4*)	13	5	20	10	52	FAIR ROCK
	Siltstone	5 - 25 MPa	50% - 75%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Wet		
Mahia 14c	Total RMS	(2*)	13	5	20	7	47	FAIR ROCK
	Siltstone	5 - 25 MPa	50% - 75%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Damp		
Mahia 14d	Total RMS	(2*)	13	5	20	10	50	FAIR ROCK

APPENDIX – TATAPOURI RMS

Site No.	Rock type	Intact rock strength	Weath-ering	Spacing of joints	Joint orientation	Width of joints	Continuity of joints	Outflow of groundwater	Total Rating	Qualitative rock stregth
	Sandstone	Weak	Slightly	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Trace		
1	Total RMS	(10*)	9	8	18	5	5	5	60	(Moderate)
	Rock Description	Sandstone; white greyish brown; medium weak rocks; slightly weathered rock; moderate to well sorted grains; mSu to crs SL; clastic 1mm to 2mm; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC, 8) moderate wide; extremely close spacing; very low persistence; massive; random joints; irregular.									
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips in slope	< 0.1mm	None Continuous	Slight		
1	Total RMS	(10*)	5	8	18	7	7	4	59	(Moderate)
	Rock Description	Siltstone; light greyish blue; weak rock; moderate to highly weathered rock; well to extremely well sorted; fSL; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC, 6); very tight; extremely close spacing; very low persistence; massive; crushed rock; irregular.									
	Siltstone	Weak	Slightly	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Trace		
2	Total RMS	(10*)	9	8	18	5	5	5	60	(Moderate)
	Rock Description	Sandstone; light greyish brown; Schmidt hammer result (35.5); medium weak rocks; slight to moderate weathered rock; well sorted grains; fSU to mSU; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC 4); moderate wide; extremely close spacing; very low persistence; massive; occasional random joints; massive.									
	Siltstone	Weak	moderate	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Trace		
2	Total RMS	(10*)	7	8	18	5	5	5	58	(Moderate)
	Rock Description	Siltstone; light greyish grey; weak rock; very well sorted; moderate to highly weathered rock; well to extremely sorted; fSL; bedding; may have experienced; shear / folding during uplift smooth; planar; (JRC2); moderate wide; extremely close spacing very low persistence; massive; occasional random joints; massive.									
	Siltstone	Weak	moderate	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	None		
3	Total RMS	(10*)	7	8	18	5	5	6	59	(Moderate)
	Rock Description	Sandstone; greyish white; Schmidt hammer result (38); medium weak rock; slight to moderate weathered rock; well sorted grains; fUS; bedding; may have experienced shear / folding during uplift; smooth; planar; (JRC3); moderate wide; extremely close spacing; very low persistence; massive; occasional random joints; massive.									
	Siltstone	Weak	moderate	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Trace		
3	Total RMS	(12*)	7	8	18	5	5	5	60	(Moderate)
	Rock Description	Siltstone; light greyish grey; weak rock; very well sorted grains; moderate to highly weathered rock; well to extremely sorted; fSL; bedding; may have experienced; shear / folding during uplift; Rough; stepped; (JRC 5); moderate wide; close spacing very low persistence; four or more joint sets; crushed.									
	Siltstone	Weak	moderate	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Slight		
4	Total RMS	(10*)	7	8	18	5	5	4	57	(Moderate)
	Rock Description	Sandstone; light greyish grey; Schmidt hammer result (34.5); medium weak rocks; slight to moderate weathered rock; moderate to well sorted beds; bedding; may have experienced shear / folding during uplift; rough; undulating; (JRC 5); moderate wide; extremely close spacing; very low persistence; massive; occasional random joints; massive.									
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Slight		
4	Total RMS	(10*)	5	8	18	5	5	4	55	(Moderate)
	Rock Description	Siltstone; light greyish brown; weak rock; moderate to highly weathered rock; moderate to poorly sorted grains; rounded to angular grains <20 mm; bedding; may have experienced shear / folding during uplift; rough; undulating; (JRC 7); moderately wide; extremely close spacing; very low persistence; crushed rock; earth-like.									

Site No.	Rock type	Intact rock strength	Weath-ering	Spacing of joints	Joint orientation	Width of joints	Continuity of joints	Outflow of groundwater	Total Rating	Qualitative rock stregth
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Slight		
5	Total RMS	(10*)	5	8	18	5	5	4	55	(Moderate)
	Rock Description	Sandstone; greyish white; medium weak rock; slight to moderate weathered rock; well sorted; mSu to crs SL; may have experienced shear; / folding during uplift; smooth; planar; (JRC 3); moderate wide; extremely close spacing; very low persistence; massive; occasional random joints; massive.								
	Siltstone	Weak	Slightly	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Trace		
5	Total RMS	(10*)	9	8	18	5	5	5	60	(Moderate)
	Rock Description	Siltstone; dark greyish grey; weak rock; Very well sorted; moderate to highly weathered rock; well to extremely sorted grains; fSL; bedding; may have experienced; shear / folding during uplift smooth; planar; (JRC 2); moderate wide; extremely close spacing very low persistence; massive; occasional random joints; massive.								
	Siltstone	Weak	moderate	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Trace		
6	Total RMS	(10*)	7	8	18	5	5	5	58	(Moderate)
	Rock Description	Sandstone; dark greyish grey; medium weak rocks; moderate to highly weathered rock; moderate to well sorted grains; mSu to crs SL; bedded; may have experienced shear / folding during uplift; smooth; planar; (JRC 5); moderate wide; extremely close spacing; very low persistence; massive; occasional random joints; massive.								
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Trace		
6	Total RMS	(10*)	5	8	18	5	5	5	56	(Moderate)
	Rock Description	Siltstones; dark greyish black; Schmidt hammer result (22.5); weak rock; moderately sorted grains; moderate to highly weathered rock; beded; may have experienced shear / folding during uplift; rough stepped; (JRC 2); moderate wide; extremely close spacing; very low persistence; crushed rock; earth-like.								
	Siltstone	Weak	moderate	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Trace		
7	Total RMS	(10*)	7	8	18	5	5	5	58	(Moderate)
	Rock Description	Sandstone; greyish white; medium weak rocks; moderate to highly weathered rock; moderate to well sorted grains; msL to mSu; beded; may have experienced shear / folding during uplift; smooth; planar; (JRC4); moderate wide; extremely close spacing; very low persistence; massive; occasional random joints; massive.								
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Trace		
7	Total RMS	(10*)	5	8	18	5	5	5	56	(Moderate)
	Rock Description	Siltstone; light greyish grey; weak rock; very well sorted grains; slight to moderate weathered rock; well to extremely sorted grains; fSL; beded; may have experienced; shear / folding during uplift; rough; stepped; (JRC 6); moderate wide; close spacing very low persistence; crushed rock; earth-like crushed.								
	Siltstone	Weak	moderate	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Trace		
8	Total RMS	(10*)	7	8	18	5	5	5	58	(Moderate)
	Rock Description	Sandstone; greyish white; medium weak rocks; moderate to highly weathered rock; moderate to well sorted grains; mSL to mSU; bedded; may have experienced shear / folding during uplift; smooth; planar; (JRC4); moderate wide; extremely close spacing very low persistence; massive; occasional random joints; massive.								
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Trace		
8	Total RMS	(10*)	5	8	18	5	5	5	56	(Moderate)
	Rock Description	Siltstone; dark greyish grey; very weak rock; moderate sorted grains; moderate to highly weathered rock; beded; may have experienced shear / folding during uplift; rough; undulating; (JRC 7); moderate wide; extremely close spacing; very low persistence; crushed rock; earth-like.								

Site No.	Rock type	Intact rock strength	Weath-ering	Spacing of joints	Joint orientation	Width of joints	Continuity of joints	Outflow of groundwater	Total Rating	Qualitative rock stregth
	Siltstone	Weak	moderate	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Trace		
9	Total RMS	(12*)	7	8	18	5	5	5	60	(Moderate)
	Rock Description	Sandstone; greyish white; medium weak rocks; moderate to highly weathered rock; moderate to well sorted grains; mSL to mSU; bedded; may have experienced shear / folding during uplift; smooth; planar; (JRC 4); moderate wide; extremely close spacing very low persistence; massive; occasional random joints; massive.								
	Siltstone	Weak	Highly	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Trace		
9	Total RMS	(12*)	5	8	18	5	5	5	58	(Moderate)
	Rock Description	Siltstone; light greyish brown; very weak to weak rock; slight to moderately weathered rock; poorly sorted grains; bedded; may have experienced shear / folding during uplift; rough; undulating; (JRC 9); moderate wide; extremely close spacing; very low persistence; crushed rock; earth-like.								
	Siltstone	Weak	moderate	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Trace		
10	Total RMS	(10*)	7	8	18	5	5	5	58	(Moderate)
	Rock Description	Sandstone; dark greyish brown; medium weak rocks; slightly weathered; moderate to well sorted grians; bedded; may have experienced shear / folding during uplift; smooth planar (JRC 8); moderate wide; extremely close spacing; very low persistence; massive; occasional random joints.								
	Siltstone	Weak	moderate	<50 mm scanline	Moderate dips in slope	1 - 5mm	Continuous, no infill	Trace		
10	Total RMS	(10*)	7	8	18	5	5	5	58	(Moderate)
	Rock Description	Siltstone; light greyish brown; weak rock; slight to moderately weathered poorly sorted grains; highly weathered; bedded may have experienced shear / folding during uplift; rough; undulating; (JRC 9); moderate wide; extremely close spacing; very low persistence; crushed rock; earth-like.								

APPENDIX –TATAPOURI RMR

Site No.	Rock type	UCS	(RQD)	Spacing of discontinuities	Condition of discontinuities	ground water conditions	Total Rating	Qualitative rock stregth
	Sandstone	25 - 50 MPa	90% - 100%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Damp		
1	Total RMR	(4*)	20	5	20	10	59	FAIR ROCK
	Siltstone	5 - 25 MPa	90% - 100%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Damp		
1	Total RMR	(2*)	20	5	20	10	57	FAIR ROCK
	Sandstone	25 - 50 MPa	90% - 100%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Completely dry		
2	Total RMR	(4*)	20	5	20	15	64	GOOD ROCK
	Siltstone	5 - 25 MPa	90% - 100%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Damp		
2	Total RMR	(2*)	20	5	20	10	57	FAIR ROCK
	Sandstone	25 - 50 MPa	90% - 100%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Completely dry		
3	Total RMR	(4*)	20	5	20	15	64	GOOD ROCK
	Siltstone	25 - 50 MPa	90% - 100%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Damp		
3	Total RMR	(4*)	20	5	20	10	59	FAIR ROCK
	Sandstone	25 - 50 MPa	90% - 100%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Completely dry		
4	Total RMR	(4*)	20	5	20	15	64	GOOD ROCK
	Siltstone	5 - 25 MPa	90% - 100%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Wet		
4	Total RMR	(2*)	20	5	20	7	54	FAIR ROCK
	Sandstone	25 - 50 MPa	75% - 90%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Completely dry		
5	Total RMR	(4*)	17	5	20	15	61	GOOD ROCK
	Siltstone	5 - 25 MPa	75% - 90%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Wet		
5	Total RMR	(2*)	17	5	20	7	51	FAIR ROCK
	Sandstone	25 - 50 MPa	75% - 90%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Completely dry		
6	Total RMR	(4*)	17	5	20	15	61	GOOD ROCK
	Siltstone	5 - 25 MPa	75% - 90%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Wet		
6	Total RMR	(2*)	17	5	20	7	51	FAIR ROCK
	Sandstone	25 - 50 MPa	75% - 90%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Completely dry		
7	Total RMR	(4*)	17	5	20	15	61	GOOD ROCK
	Siltstone	5 - 25 MPa	75% - 90%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Wet		
7	Total RMR	(2*)	17	5	20	7	51	FAIR ROCK
	Siltstone	5 - 25 MPa	90% - 100%	< 60 mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Wet		
8	Total RMR	(2*)	20	5	20	7	54	FAIR ROCK

| Site No.	Rock type	UCS	(RQD)	Spacing of discontinuities	Condition of discontinuities	groundwater conditions	Total Rating	Qualitative rock stregth
	Sandstone	25 - 50 MPa	90% - 100%	<60mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Completely dry		
8	Total RMR	(4*)	20	5	20	15	64	GOOD ROCK
	Siltstone	25 - 50 MPa	90% - 100%	<60mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Completely dry		
9	Total RMR	(4*)	20	5	20	15	64	GOOD ROCK
	Sandstone	25 - 50 MPa	90% - 100%	<60mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Damp		
9	Total RMR	(4*)	20	5	20	10	59	FAIR ROCK
	Sandstone	25 - 50 MPa	90% - 100%	<60mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Completely dry		
10	Total RMR	(4*)	20	5	20	15	64	GOOD ROCK
	Siltstone	5 - 25 MPa	75% - 90%	<60mm	slightly rough surfaces, separation < 1mm, highly weathering walls	Wet		
10	Total RMR	(2*)	17	5	20	7	51	FAIR ROCK

APPENDIX – GRAPHS

Table shows calculated erosion rates for graphs A and graph B.
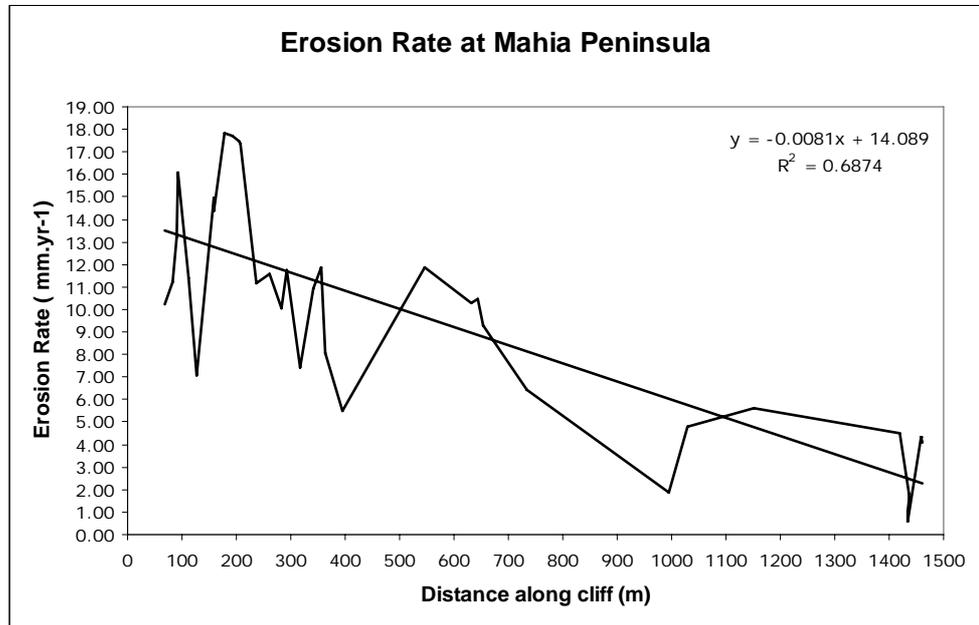
Graph A show erosion rate at Mahia Peninsual
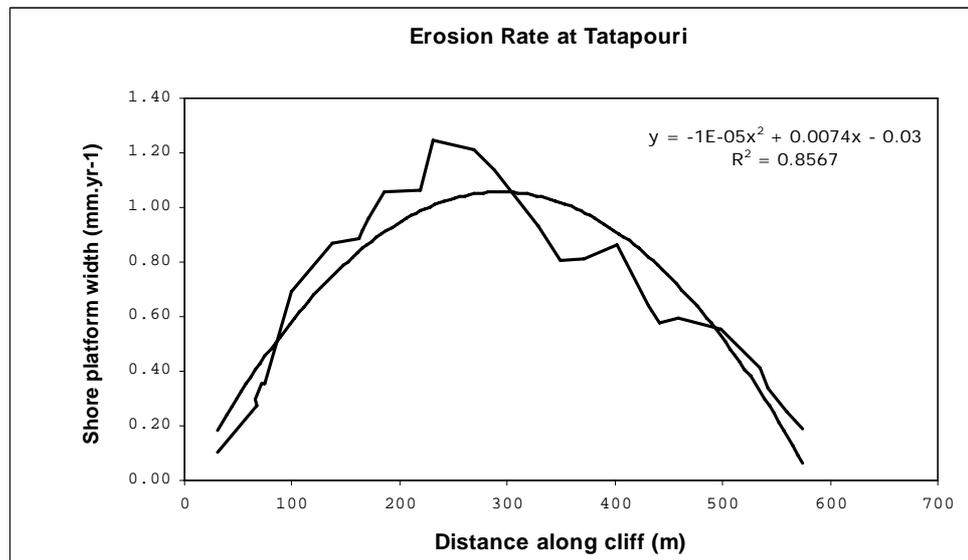
Graph B show erosion rate at Tatapouri