Contents

Our Dynamic Planet

1 COASTS

Should Coastal Environments Matter?

In this Chapter, you will explore these key questions:

1. How and why are coastal environments different and dynamic?
2. Why are coastal areas valuable?
3. How can we manage coastal areas in a sustainable manner?

CHECK-IN

Every year, many people flock to the coast to enjoy a relaxing holiday by the sea. The London Bridge in Port Campbell National Park in Victoria, Australia, is one such place people flock to. One of its famous tourist attractions, the London Bridge, is located along the 257-kilometre-long Great Ocean Road at Port Campbell.

The London Bridge is a natural landform and was named after the original man-made bridge in London. On 15 January 1990, part of the bridge unexpectedly collapsed, leaving a couple of tourists stranded. They had to be rescued by helicopter.

Figure 1.1a) The London Bridge before the collapse.

Natural processes caused by wave action resulted in the collapse of the bridge over time. This coastal area will continue to change due to natural processes and other portions of the bridge may collapse in time to come.

The London Bridge area in Victoria is not the only place that has undergone change. Changes in coastal areas are taking place all over the world. These changes are caused by natural processes and also human activities. With more than one third of the world's population living within 100 kilometres of a coastline, what impacts will these changes have?

Figure 1.1b) The London Bridge after the collapse.

GATEWAY 1

How and why are coastal environments different and dynamic?

1. Refer to Figures 1.2a) and 1.2b).
   a) What physical feature is shown in the coastal environments?
   b) What is one similarity and one difference between the coastal environments?
2. Which of the four photographs is most similar to Singapore's coastal environment? Explain your answer.
3. Suggest ways in which people can make use of the coasts shown in Figure 1.2.

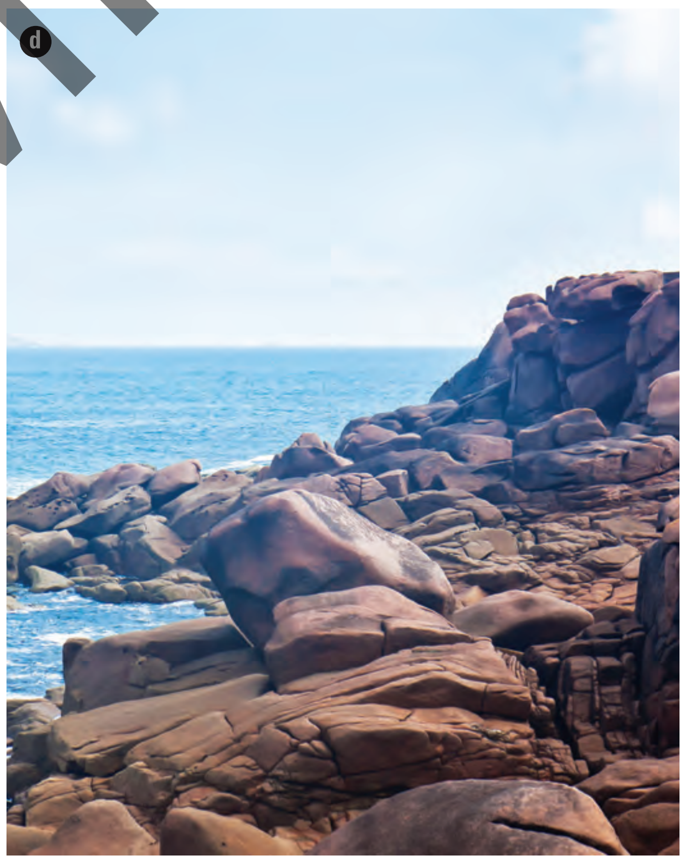


Figure 1.2 Different coastal environments.

What is a coastal environment?

The **coast** is the area where the land meets the sea. It covers the area of land that is affected by waves and tides, and can be divided into zones as shown in Figure 1.3. The coastal environment is the result of interactions between the land (lithosphere), water (hydrosphere), air (atmosphere) and living things (biosphere).

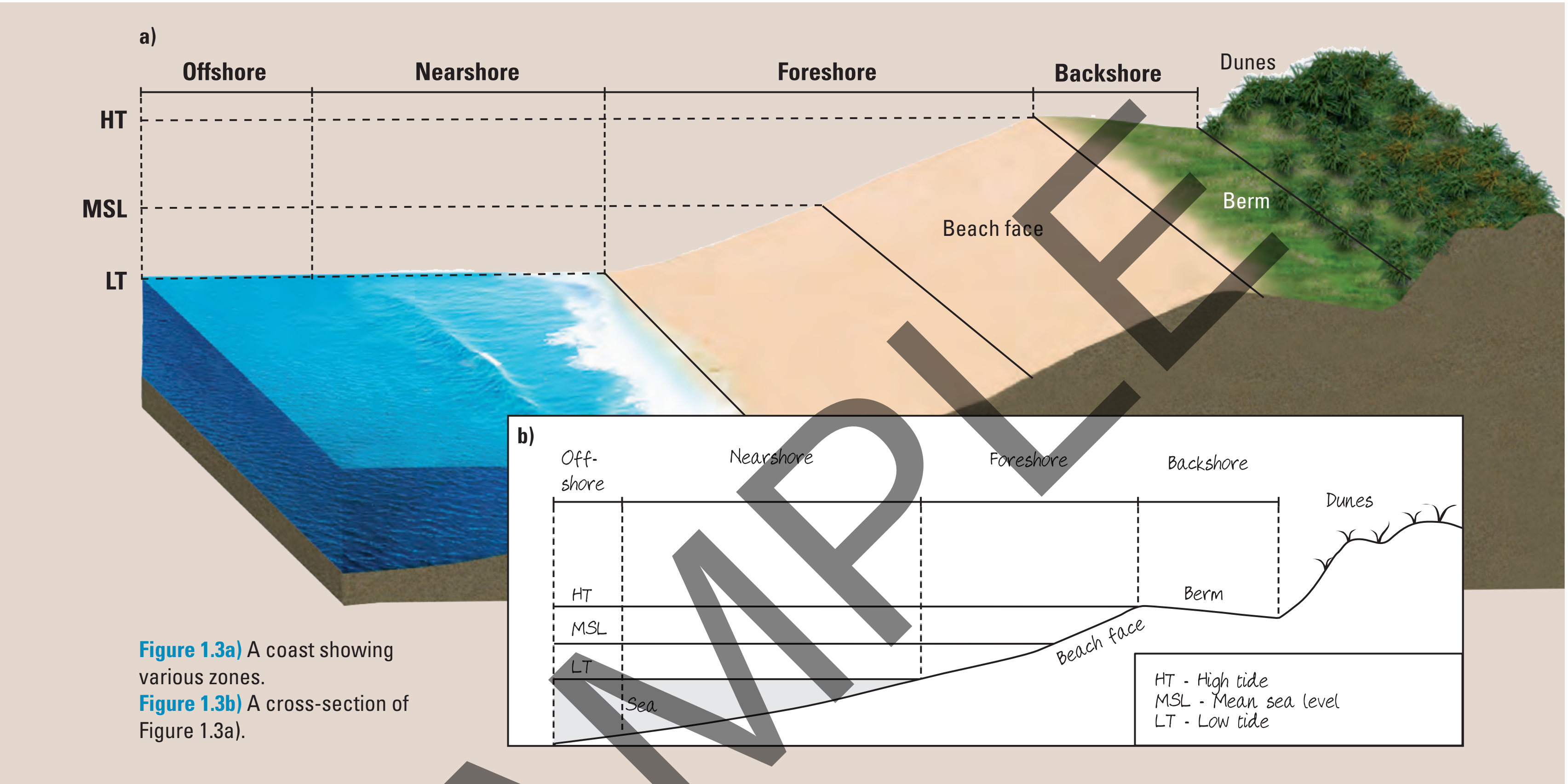


Figure 1.3a) A coast showing various zones.
Figure 1.3b) A cross-section of Figure 1.3a).

How are coastal environments different?

Coastal environments vary from place to place. The variations depend on how much they affect or are affected by natural processes and human activities. Coastal environments can be cliffed, sandy, muddy or rocky. These characteristics, as well as the diverse landforms found in coastal environments, result from many factors and processes interacting with one another. This is why they are described as **dynamic coastal environments**.

Figure 1.4 Coastal environments with different characteristics.

Why are coastal environments dynamic?

Stack collapse leaves 8 Apostles standing

Sea stacks in Victoria, Australia, before July 2005.

Sea stacks in Victoria, Australia, after July 2005.

A pile of rubble is all that remains after the collapse of one of the sea stacks at the '12 Apostles' off Victoria's southwest coast in southern Australia.

At around 9 am, the 50-metre limestone pillar that stood off Victoria's southwest coast crumbled into the water.

In a matter of seconds, all that remained was rubble.

Stunned tourists took photos of the dramatic change in the landscape.

"Reports were it sort of shimmied or shuddered a bit, it fractured and sort of imploded and pretty much slid straight into the ocean," Alex Green from Parks Victoria said.

"We expect from reports of previous collapses like this that that pile of rubble will very quickly be eroded away by the ocean."

The collapse was part of the natural process that has helped shape the popular tourist attraction for centuries.

But it leaves only 8 Apostles still standing.

Note: Despite its name, the '12 Apostles' originally comprised 9 sea stacks.

Figure 1.5 An article on the stack collapse of the 12 Apostles in Victoria, Australia. *Adapted from: ABC News (3 July 2005).*

The collapse of the sea stack in Victoria, Australia, was quick and abrupt after being weakened by erosion for a period of time. Other changes in coastal environments occur more slowly and over a longer period of time. For example, in southern Thailand, the base of the limestone rocks shown in Figure 1.6 has been eroded by seawater over the past 5,000 years.

Changes occur constantly in coastal environments and make these environments dynamic.

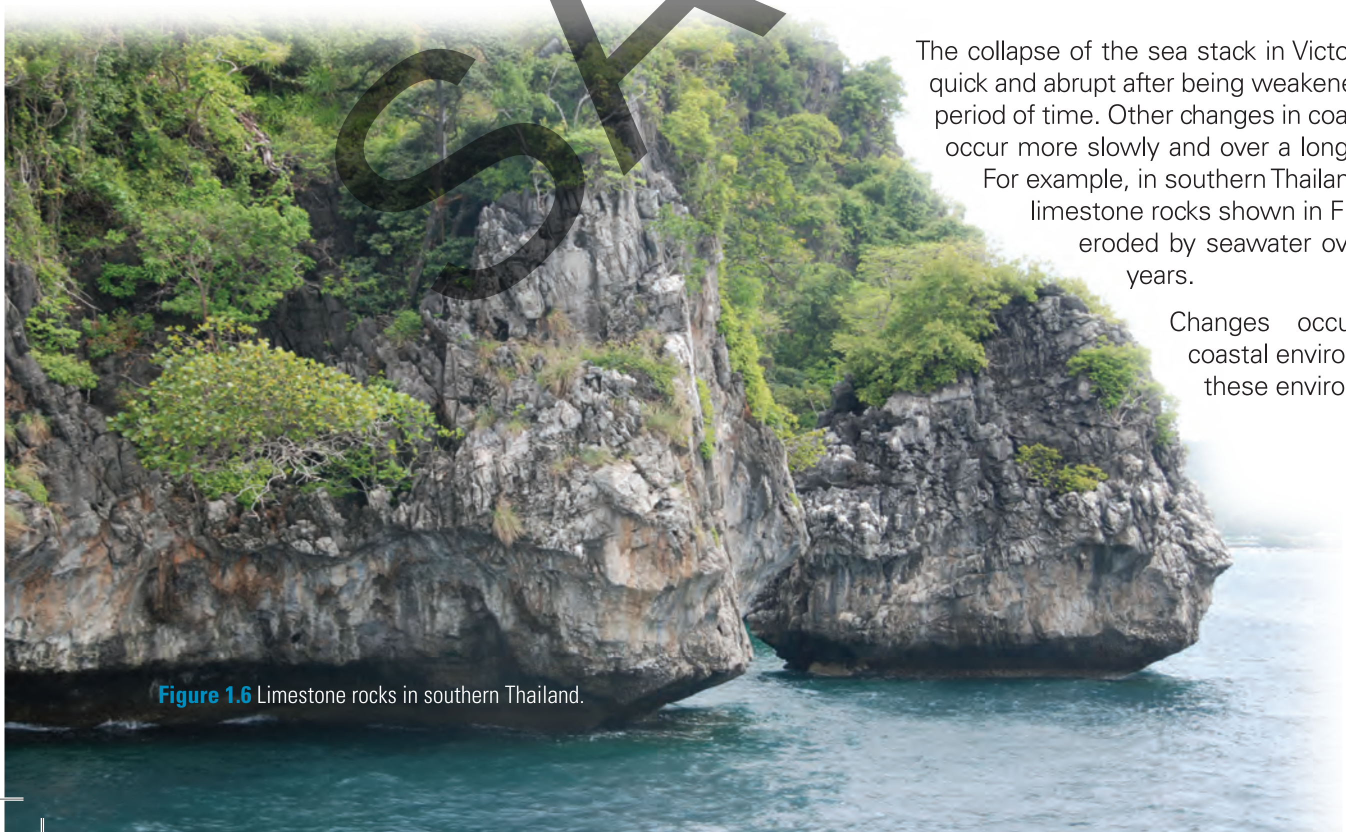


Figure 1.6 Limestone rocks in southern Thailand.

Factors affecting coastal environments

Many factors interact to cause changes within coastal environments. The constant influence of these factors means that coastal environments are changing and dynamic.

Waves

Wave action is the main shaping force of coastal environments. **Waves** are generated when the energy from wind blowing across seas and oceans is transferred to the water surface. This occurs when wind blows across the surface of seas and oceans. Energy from the wind is transferred to the water and it is this wind energy that helps shape coasts when the waves hit land.

Tides

Tides refer to the daily alternate rise and fall in the sea level. They are caused mainly by the effects of the gravitational pull of the moon and sun on the earth. This produces a cycle of alternating low and high tide which changes about every six hours. This means that there is a cycle of two low tides and two high tides every 24 hours.

Tides affect processes such as coastal erosion, sediment transport and sediment deposition. During high tides, waves reach parts of coasts that may not be subjected to wave action at low tides. Hence, at high tides, waves erode and transport more sediments away from larger parts of the coasts than at other times.

Currents

Currents are large-scale, continuous movements of water in seas and oceans. They are driven largely by prevailing winds which generally blow in one direction. Ocean currents play a very important role in distributing sediments and regulating temperatures. Currents carry large amounts of energy and shape coasts through the processes of coastal erosion, sediment transport and sediment deposition. Ocean currents carry cool water away from the North and South Poles towards the Equator and warm water away from the Equator towards the Poles. In this way, ocean currents help create milder climates in coastal environments. Closer to the shore, nearshore currents help to shape the coastline. An example is longshore currents, which flow parallel to the coast.

Geology

Coastal environments are affected by their **geology**, which is the arrangement and composition of rock found in the area. Rocks may be arranged in layers, such as in alternate layers of hard and soft rocks.

Rock composition determines the hardness of rocks and their resistance to erosion, which affects the rate of change along coasts. Harder rocks such as granite and basalt will erode more slowly than softer rocks such as limestone and shale. Yet granite and basalt (well-jointed rocks such as those in Figure 1.2d) are vulnerable to erosion when the joints of these rocks are attacked by waves. Erosion hence weakens the rocks.

Coastal processes that operate on coasts consisting of different types of rock result in coasts with different coastlines. A coastline is the outline or contour of a coast. It is usually seen at the mean sea level, which is the average level between high tide and low tide levels.

IN SG

Before the 1960s, Singapore had four major types of coastal environments:
1. cliff or steep slopes
   e.g. Pasir Laba
2. sandy beaches
   e.g. Changi
3. mangroves
   e.g. Pulau Ubin
4. coral reefs
   e.g. Pulau Hantu

Visit http://www.wildsingapore.com/places/index.html to find out more about these coastal environments.

IT LINK

Learn more about the effects of rising sea levels on coasts. Visit http://climate.nasa.gov/effects.

Connect

Learn more about climate change in Chapter 3, Gateway 2.

IT LINK

Learn more about how geology plays a part in affecting the coastal environment. Visit: http://www.s-cool.co.uk/gcse/geography and type 'coastal erosion features' in the 'Search' box.

Types of ecosystems

In an **ecosystem**, communities of plants and animals interact with each other as well as the environment. Examples of ecosystems in coastal environments include mangroves and coral reefs. They affect the rate of change of coastal environments by reducing the impacts of waves on coasts.

Coral reefs are structures comprising colonies of billions of tiny polyps. They develop on the sea bed slightly below sea level. Coral reefs provide natural barriers that help slow down the speed and impact of waves on the coastline.

Mangroves, with their special aerial roots, help trap sediments and reduce coastal erosion. Over time, the trapped sediments can form small islands and extend the coastline further seawards.

IT LINK

Learn more about organisations dedicated to protecting coral reefs. Visit www.coral.org and www.reefrelief.org. What are some things they do to protect coral reefs?

Human activities

People change coastal environments by living, trading, fishing and engaging in recreational activities in these environments. For example, people alter coastlines when they build marinas and port facilities. People also cause pollution in these environments by dumping waste.

Figure 1.7 This landform is formed by wave erosion.

PITSTOP 1

1. With reference to Figure 1.8 and using the terms you have learnt, decide which zone would be best for the following activities. Explain your decisions.
   a) Sitting in the sun without getting wet
   b) Enjoying the waves lapping at your feet
   c) Swimming safely near the shore
2. a) Draw a sketch of the cross profile of the coast in Figure 1.8. On your sketch, label the various coastal zones. You may refer to Figure 1.3b) to help you.
   b) Which zones are not shown on Figure 1.8? Give possible reasons to explain why.
3. With reference to Figure 1.6, explain how the impact of waves would differ between granite and limestone coasts.
4. Refer to Figure 1.4. What factors caused the differences in the four coastal environments?
5. Refer to Figure 1.7. Using what you have learnt about geology, explain how the coastline has been eroded.

Figure 1.8 Bondi Beach in Sydney, Australia, is a popular tourist spot.

What are waves and how are they generated?

Waves develop when the energy from wind blowing across seas and oceans is transferred to the water surface. The movement of waves is affected by wind direction. Onshore winds push waves towards the coast, resulting in waves crashing onto the shore.

Wave terminology

Figure 1.9 shows the various parts of a wave.

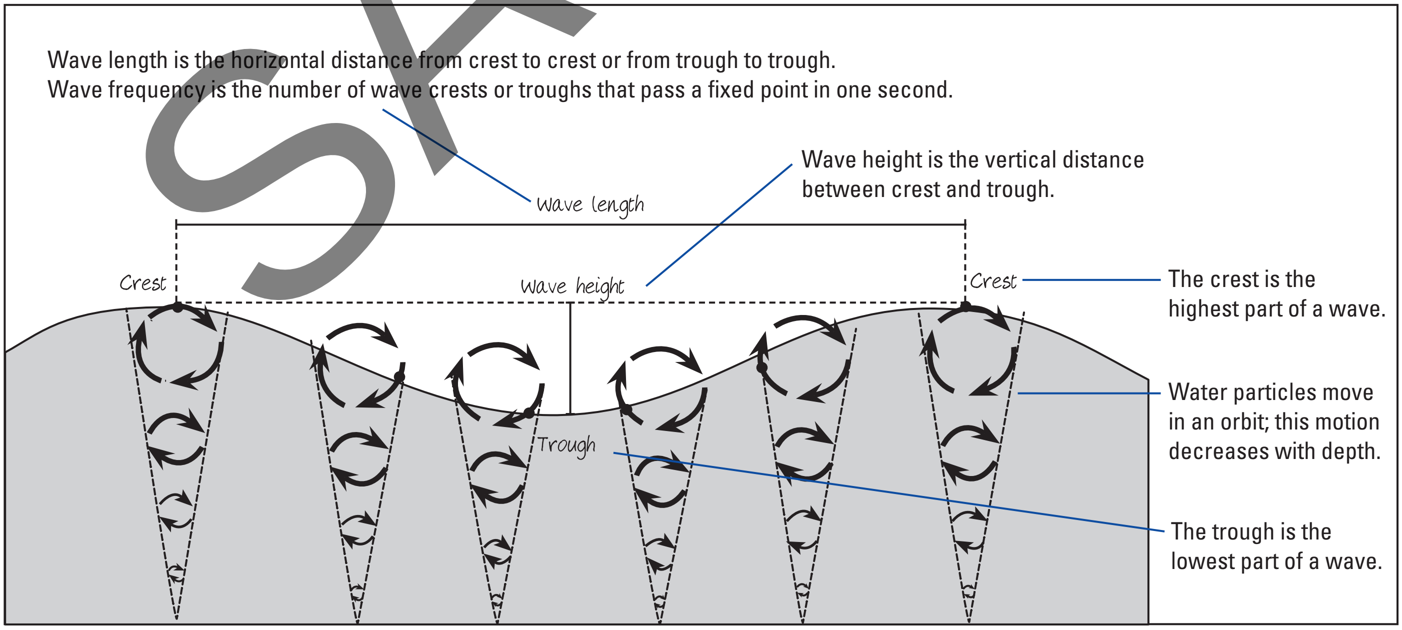


Figure 1.9 Various parts of a wave.

Figure 1.10 Large waves have high energy.

Factors affecting wave energy

Wave energy depends on three factors: the wind speed, wind duration and length of fetch. **Fetch** is the distance the wind has travelled over seas and oceans to form waves. Figure 1.11a) explains how these factors affect the size and energy of waves.

Factor	Size and energy of wave
Wind speed	The faster the wind blows, the greater the wave energy is.
Wind duration	The longer the wind blows, the larger the waves are; resulting in greater wave energy.
Fetch	The greater the fetch, the more energy the waves have (refer to Figure 1.11b).

Figure 1.11a) Wave energy is affected by various factors.

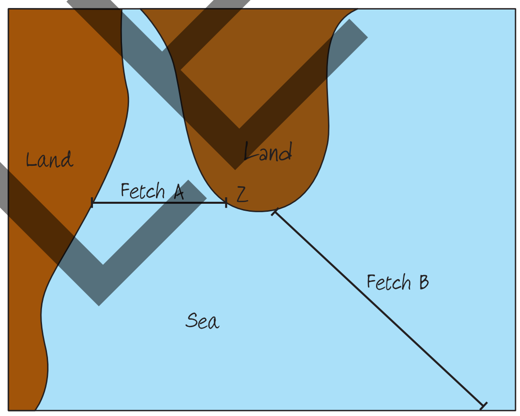


Figure 1.11b) As Fetch B is longer than Fetch A, wind blowing across Fetch B towards Z is able to generate higher energy waves than the wind blowing across Fetch A, all other factors being equal.

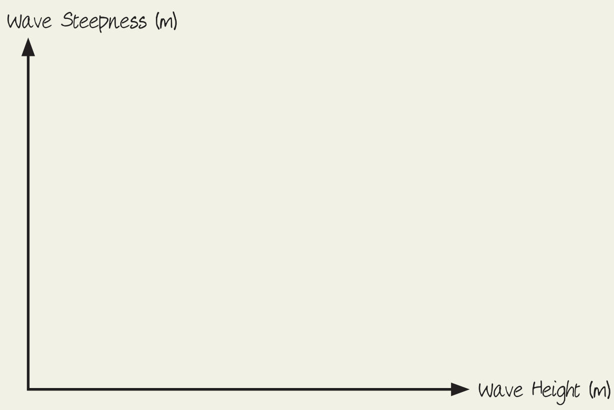
The amount of energy in waves can be seen from the wave steepness and wave period. Wave steepness is the ratio of wave height to wave length; wave period is the time waves take to travel through one wave length. The higher the wave energy is, the steeper the wave and the shorter the wave period becomes.

INVESTIGATE THIS 1

The table shows the reported wave height and wave length for three different coastlines. With the average wave length and wave height data, calculate wave steepness using the formula:

$$\text{Wave steepness (in metres)} = \frac{\text{wave height}}{\text{wave length}}$$

Next, present the data in a simple line graph on graph paper, using the x- and y- axis given. (Refer to Chapter 4, page 246 on how to construct a simple line graph.) Then state the suggested relationship between wave height and wave steepness.



Site	Wave Height in metres (H)	Wave Length in metres (L)	Wave Steepness in metres (H/L)
1	0.2	7.6	
2	1.4	31.5	
3	4.3	75.4	
4	8.1	128	
5	14.6	205.6	

Waves in the open ocean

Waves in the open ocean have a long wave length and a low wave height. Water particles in the ocean move in an orbit (Figure 1.12), a motion that rapidly decreases with depth (refer to Figure 1.9).

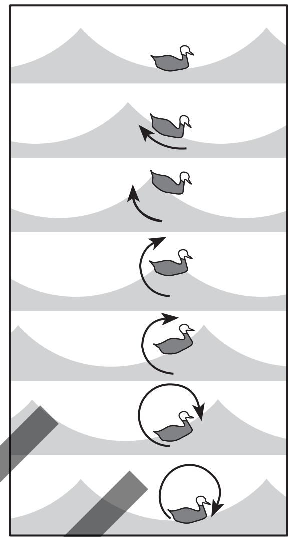


Figure 1.12 The rubber duck moves in an orbit and almost returns to its original position.

Waves close to the coastline

Although water particles in the ocean move in a circular motion, this motion changes as waves approach coastlines (refer to Figure 1.13).

1. **Near the coastline**
The water is shallow and the waves interact with the sea bed. The waves start to change their shape at a depth that is equivalent to about half of their wave length.

2. **Nearer the coastline**
As the waves continue to move in the shallow water, the base of the wave starts to slow down due to friction. This causes the wave height to increase and the wave length to decrease.

3. **Nearest the coastline**
The base of the wave stops but the wave crest becomes steeper and topples over. This causes the wave to break onto the coast, releasing the energy of the wave. Surfers, such as the one in Figure 1.10, ride on these breaking waves.

Figure 1.13 Changes in motion of waves as they approach coastlines.

When energy within a wave is released on the coast, it breaks down rocks along the coastline into smaller particles. These particles are then moved away to other parts of the coast. Waves are key forces of change, creating coastal environments which vary from place to place.

How do waves affect coastal areas?

Have you ever wondered why beaches do not all look the same? The key reason is because the profile of a beach is partly determined by waves. Wave energy differs from place to place, depending on various factors.

Waves on the beach

Swash and backwash

When waves break, water rushes up a beach. We call this **swash**. As swash moves up the beach, it carries sediments with it. Swash loses energy due to gravity and friction with the land, and returns to the sea as **backwash**. The backwash carries sediments from the shore into the sea.

Figure 1.14 Swash and backwash.

Types of waves

Constructive waves

Constructive waves break far from the shore and with little energy. In such low energy wave environments, finer material is deposited, which in turns forms gentle slopes. Constructive waves have a strong swash but a weak backwash.

Landforms such as beaches are 'constructed' by strong swash accompanied by weak backwash. The strong swash deposits sediments on the coasts while the weak backwash removes only some materials. Over time, the coasts are built up by the deposited sediments, forming sandy beaches.

Destructive waves

Destructive waves break violently on the shore with high energy. In such high energy wave environments, finer materials (such as sand) tend to be transported away by the turbulent water, leaving only coarser materials (such as pebbles) which in turn form steeper slopes. Destructive waves produce a weak swash but a strong backwash. Instead of depositing sediments on coasts, destructive waves erode coasts and transport rocks and beach material away.

Constructive waves	Destructive waves
Low gradient, low energy environment	Steep gradient, high energy environment
Small, low waves	Large, high waves
Low wave height	High wave height
Long wave length	Short wave length
Wave frequency: 6 to 8 per minute	Wave frequency: 10 to14 per minute
Swash more powerful than backwash	Backwash more powerful than swash
Occur on gentle coastal slope and sheltered coast	Occur on steep coastal slope and open coast
Deposition process more prominent	Erosion process more prominent

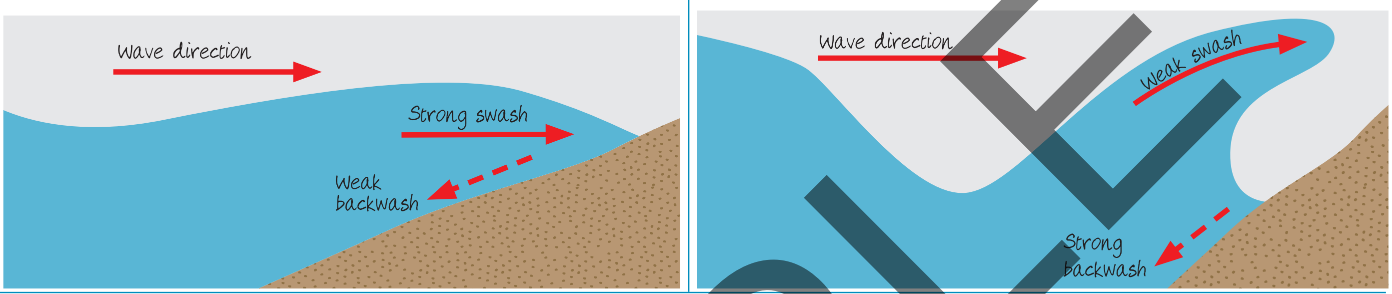


Figure 1.15 Characteristics of constructive and destructive waves.

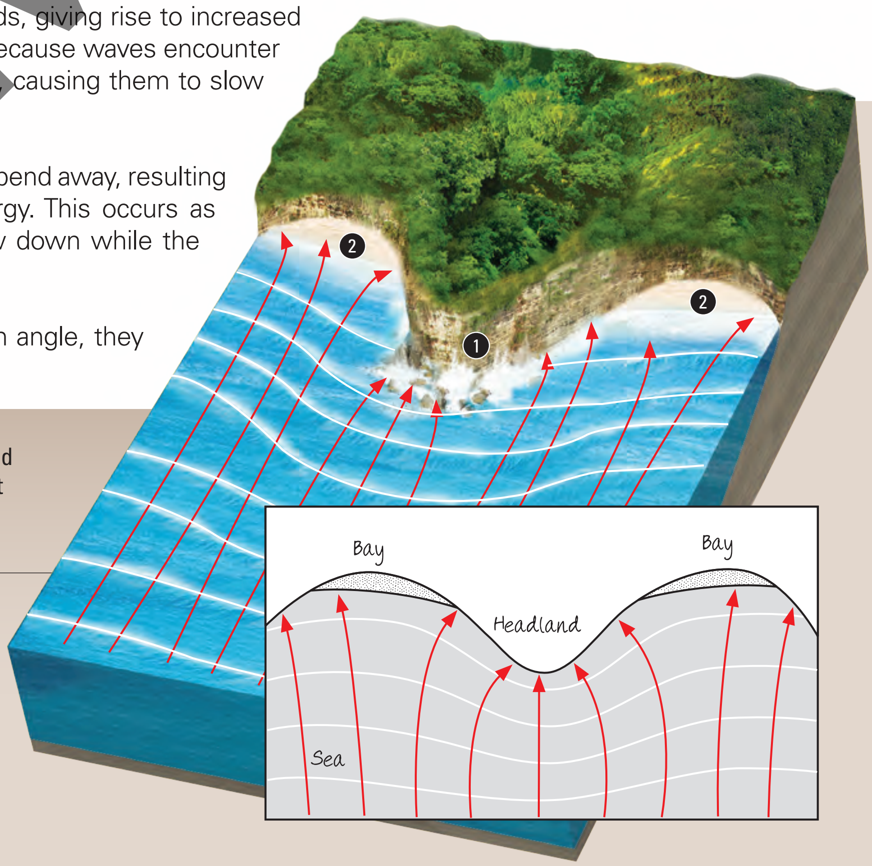
Wave refraction

Wave refraction is the process by which waves change direction as they approach a coast. This occurs as waves slow down due to interaction with the sea bed as they move towards the coast. The impact of wave refraction on the shoreline is uneven. Figure 1.16 explains the uneven impact.

Waves tend to converge on or bend towards headlands, giving rise to increased wave height and greater erosive energy. This occurs because waves encounter friction with the headland as they approach the coast, causing them to slow down and break onto it.

However, when waves approach bays, they diverge or bend away, resulting in decreased wave height and reduced erosive energy. This occurs as parts of the wave that reach shallow water first slow down while the other parts of the wave continue at the same speed.

When waves approach a relatively straight coast at an angle, they are refracted and break almost parallel to the coast.

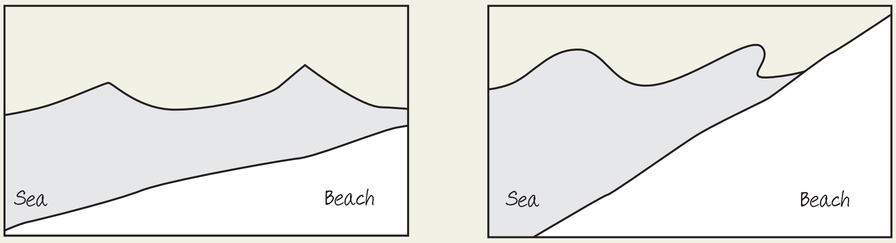


1. Waves approach a headland and bend towards it. More erosion will occur at the headland where wave energy is concentrated.
2. Waves diverge when they reach the adjacent bays. More deposition will occur in bays where wave energy is spread out.

Figure 1.16 Wave refraction at a headland and in bays.

INVESTIGATE THIS 2

Study Figure 1.17 and suggest a hypothesis about the relationship between the types of waves and the beach gradient.



Constructive waves
- Waves that break far from the shore and with little energy.
- Strong swash and weak backwash.

Destructive waves
- Waves that break violently on the shore with high energy.
- Weak swash and strong backwash.

Figure 1.17 Cross-section of beaches showing beach gradient and different types of waves.

PITSTOP 2

1. What is the difference between:
   a) wave trough and wave crest?
   b) wave length and wave height?
2. Explain why waves increase in height as they approach a coastline.
3. a) What is meant by the term 'fetch'?
   b) Explain why surfing is carried out close to the coastline rather than in the open ocean.
   c) What wind conditions and fetch do you think are ideal for surfing?
4. With the aid of the world map at the back of the Textbook, explain which of the following is likely to generate larger waves:
   a) Winds blowing southwest across the Indian Ocean from Madagascar to Sri Lanka; or
   b) Winds blowing northeast across the Indian Ocean from Myanmar to Sri Lanka?

   Give a reason for your answer.
5. What is wave refraction and how does it affect headlands and bays?
6. Imagine you are standing at the edge of a sandy beach. Your feet are becoming wet from the incoming waves and you feel the sand shifting under your feet. Which event do you think is the swash? Which event do you think is the backwash?
7. Describe the characteristics of constructive waves.
8. Suggest what will happen to the shape of the coastline shown in Figure 1.16 after a long period of time.

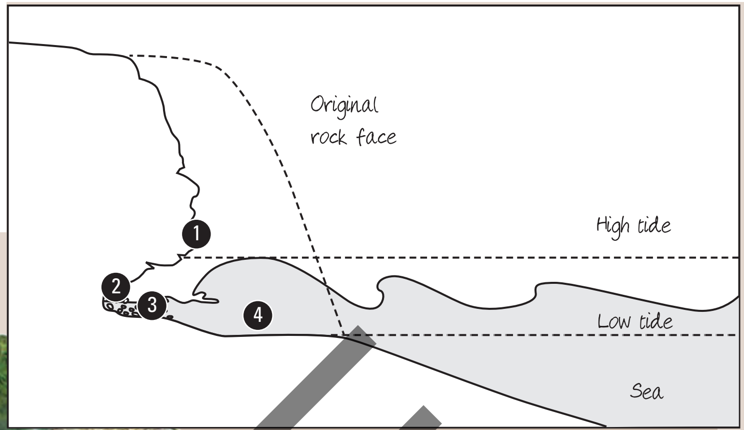
Why do coastal landforms and features vary from place to place?

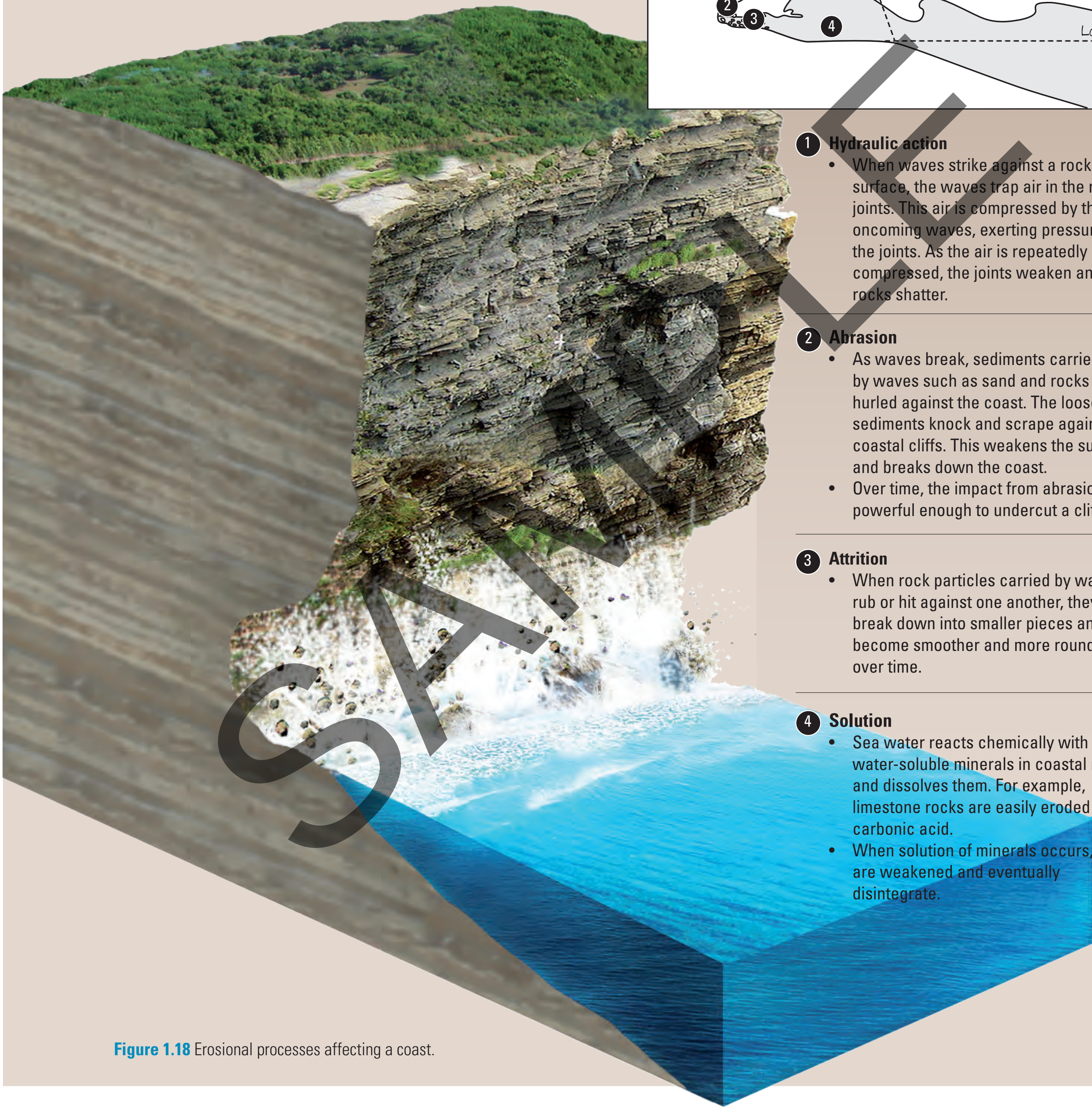
Waves, tides and currents erode coastal rocks, and transport and deposit sediments along coasts. The coastal processes of coastal erosion, transport and deposition operate at varying degrees to produce a variety of coastal landforms and features. In addition, coastal processes cause changes to the landforms and features over time.

Coastal processes

Coastal erosion

Coastal erosion takes place in four main ways. One or more of these erosional processes may take place at the same time at any one coastal location.





1. **Hydraulic action**
   - When waves strike against a rock surface, the waves trap air in the rock joints. This air is compressed by the oncoming waves, exerting pressure on the joints. As the air is repeatedly compressed, the joints weaken and the rocks shatter.

2. **Abrasion**
   - As waves break, sediments carried by waves such as sand and rocks are hurled against the coast. The loosened sediments knock and scrape against the coastal cliffs. This weakens the surface and breaks down the coast.
   - Over time, the impact from abrasion is powerful enough to undercut a cliff.

3. **Attrition**
   - When rock particles carried by waves rub or hit against one another, they break down into smaller pieces and become smoother and more rounded over time.

4. **Solution**
   - Sea water reacts chemically with water-soluble minerals in coastal rocks and dissolves them. For example, limestone rocks are easily eroded by carbonic acid.
   - When solution of minerals occurs, rocks are weakened and eventually disintegrate.

Figure 1.18 Erosional processes affecting a coast.

Sediment transport

Sediments are transported along coasts through two related processes: beach drift and longshore drift. These processes are the result of waves approaching the coast at an angle.

As waves approaching the coast at an angle break on the beach, sediments move up the beach at an angle as swash and move perpendicularly down the beach as backwash. The resultant zigzag movement along the beach is known as beach drift.

When waves approach the coast at an angle, they generate longshore currents in the nearshore zone and move sediments along the shore. **Longshore currents** are ocean currents that flow parallel to a coast.

The combined effect of sediment movement by longshore currents and beach drift is known as **longshore drift**. Longshore drift is most rapid when waves approach a straight coast at an angle of about 30°.

Figure 1.19 Waves approaching the coast at an angle.

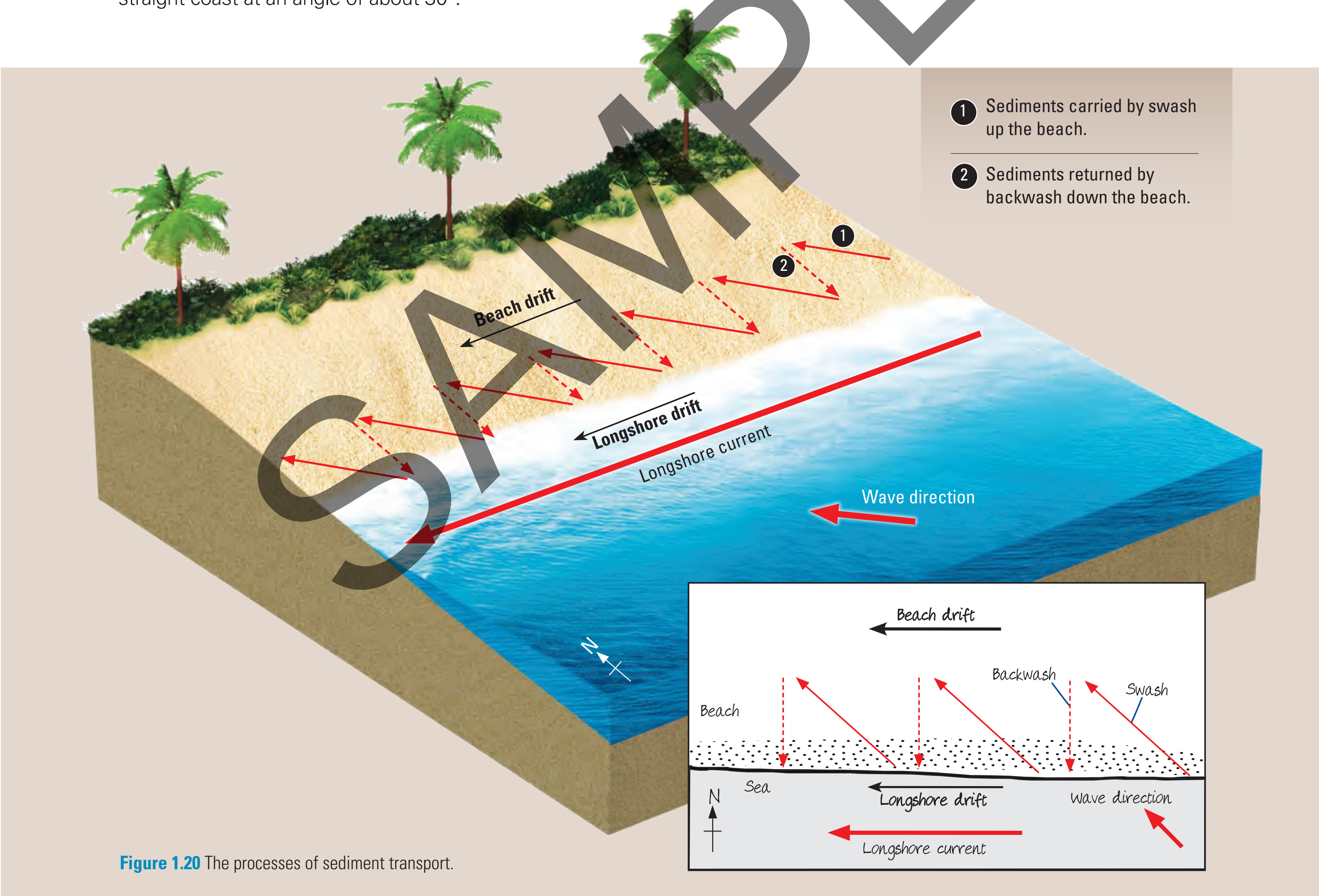


Figure 1.20 The processes of sediment transport.

INVESTIGATE THIS 3

A. Hypothesis

After learning about sediment transport, conduct a fieldwork investigation to test the hypothesis: The direction of sediment movement is influenced by wind direction.

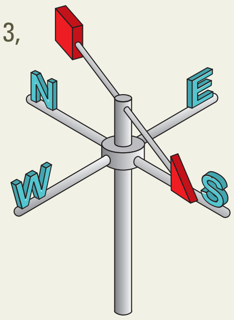
B. Collecting data

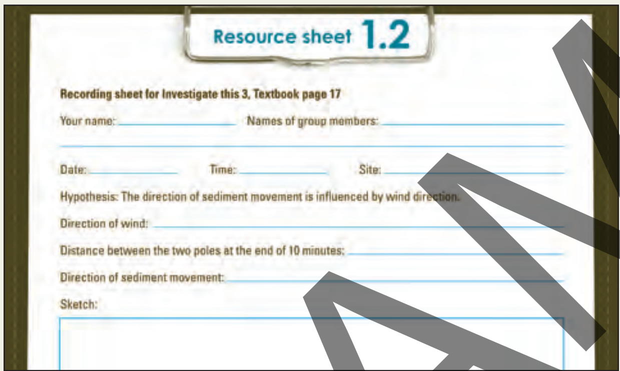
To investigate the hypothesis, you need to:

- Identify wind direction; and
- Identify the direction of sediment movement.

Equipment:

- Wind vane (refer to Chapter 3, page 160)
- Stopwatch
- Five small oranges
- Two poles (approximately 30 cm each)
- Measuring tape
- Recording sheet (Resource sheet 1.2)





Resource sheet 1.2

Recording sheet for Investigate this 3, Textbook page 17

Your name: ____ Names of group members: ____

Date: ____ Time: ____ Site: ____

Hypothesis: The direction of sediment movement is influenced by wind direction.

Direction of wind: ____

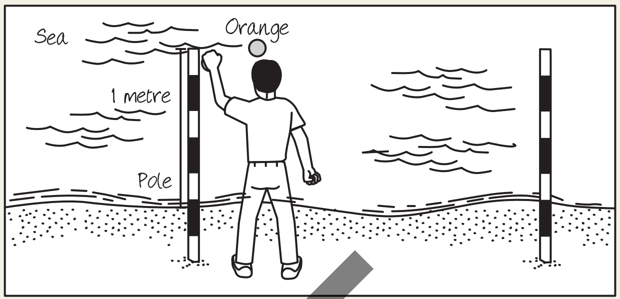
Distance between the two poles at the end of 10 minutes: ____

Direction of sediment movement: ____

Sketch:

Procedure:

1. Find a safe spot where your view of the open sea is not blocked.
2. Use a wind vane to find the direction of the wind. Record the direction of the wind.
3. Near the water's edge, stick the first pole into the sand. At this spot, throw the oranges a metre away from the water's edge.
4. Observe the patterns of the travelling path of the oranges for at least 10 minutes. Then, stick the second pole into the sand where the oranges finally land after being moved by a series of swash and backwash.
5. Use a measuring tape to measure the distance between the two poles. Record the distance. Identify the direction of sediment movement by noting the position of the second pole in relation to the first pole.



C. Analysing data

1. Draw a sketch showing the travelling path of the oranges. Indicate the wind direction in your sketch. Suggest and explain the relationship between wind direction and sediment movement.
2. Note if there are any anomalies and suggest reasons for them. Consider whether there were any conditions that could have affected your results.
3. Observe if your findings agree with what you have learnt about sediment transport. Suggest reasons for the differences, if any.

D. Presenting data

Besides presenting your sketch, provide enough information for your audience to understand your findings. This can be done by including the following:

- Map of the area showing where data was collected; and
- Photographs showing features of the beach and the methods of data collection.

E. Forming a conclusion

1. State whether the hypothesis 'the direction of sediment movement is influenced by wind direction' has been proven or disproven. If proven, accept the hypothesis. Otherwise, reject it.
2. Reflect on the reliability of data collected by taking into account conditions which may have resulted in inaccuracies. Think of ways to minimise or prevent these inaccuracies.
3. Evaluate the data collection methods used by assessing if they were the most appropriate. If they were not, suggest ways to improve the methods.

TIP Further your analysis by predicting if changes in weather and wave conditions over an extended period of time could change the movement of sediments.

Sediment deposition

Sediments eroded from the coast are transported away and deposited elsewhere. When wave energy decreases, the waves are unable to carry these sediments. Large sediments are deposited first, followed by smaller sediments. Deposited sediments vary in type and size, resulting in a variety of beaches. Figure 1.21 shows different types of sediments and their sizes.

The location of coasts influences the deposition of sediments. In areas where coasts are sheltered from strong winds, destructive waves are less common. Fine sediments are deposited along sheltered coasts with calm waters such as mangrove coasts. In deep bays sheltered by headlands, as in Figure 1.22, sandy beaches are common. On the other hand, coarser sediments are likely to settle in more exposed bays where there is higher wave energy to remove the finer sediments.

Sediment type	Sediment size
Clay	less than 0.0039 mm
Silt	0.0039 mm to 0.0625 mm
Fine sand	0.125 mm to 0.25 mm
Medium sand	0.25 mm to 0.5 mm
Coarse sand	0.5 mm to 1 mm
Very coarse sand	1 mm to 2 mm
Pebble	2 mm to 64 mm
Cobble	64 mm to 256 mm
Boulder	more than 256 mm

Figure 1.21 Different sediment types and their sizes.

PITSTOP 3

1. Explain how beach materials are transported along a coast.
2. With reference to Figure 1.21, decide which sediment types are likely to be deposited in:
   a) Sheltered coasts; and
   b) Small bays.

Figure 1.22 A beach forms in this sheltered bay as deposition takes place.

INVESTIGATE THIS 4

A. Hypothesis

After learning about sediment deposition and gradient of beach slope, conduct a fieldwork investigation to test the hypothesis: The steeper the wave, the steeper the beach gradient. Test this hypothesis at two different beaches.

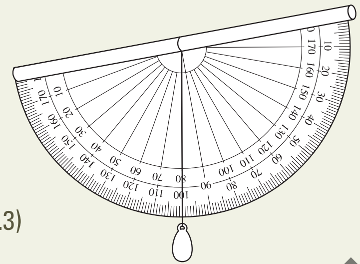
B. Collecting data

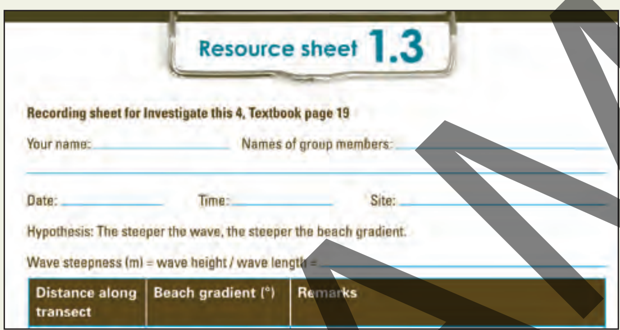
To investigate the hypothesis, you need to:

- Measure beach gradient; and
- Calculate wave steepness.

Equipment:

- Protractor clinometer (refer to Chapter 4, page 265)
- Ranging poles
- Measuring tape
- Metre ruler
- Calculator
- Stopwatch
- Recording sheet (Resource sheet 1.3)





Resource sheet 1.3

Recording sheet for Investigate this 4, Textbook page 19

Your name: Names of group members:

Date: Time: Site:

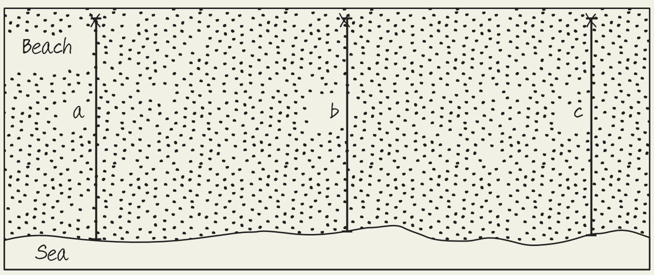
Hypothesis: The steeper the wave, the steeper the beach gradient.

Wave steepness (m) = wave height / wave length =

Distance along transect	Beach gradient (°)	Remarks

Procedure:

1. Before you set out to the beach, practise using the protractor clinometer by measuring the gradient of the slopes in your school compound. Identify the steepest and gentlest slope in your school.
2. At each fieldwork site, identify a line of transect on the beach from the edge of the water heading inland. Note that each group should identify different lines of transect along the beach. The lines of transect (a, b and c) are to be perpendicular to the shoreline.



3. Place the ranging poles along the line of transect.
4. At the seaward end of the transect, measure the beach gradient using the protractor clinometer and record this value. Repeat this along the transect either i) where there is a change in beach gradient or ii) at regular intervals of 2 metres if the beach has a constant gradient. Record the beach gradient values and associated distance along the line of transect. (Refer to Chapter 4, page 266 on how to measure beach gradient.)
5. At the seaward end of the transect, calculate the wave steepness using the steps in 'Investigate this 1'.

C. Analysing data

1. Plot the beach profile for each beach, with the x-axis being the distance from the shoreline and the y-axis being the slope angle. (Refer to Chapter 4, page 266 on how to construct a beach profile). Compare the beach profiles drawn and associated wave steepness readings gathered by all groups.
2. Observe if your findings agree with what you have learnt about wave steepness and beach gradient. Suggest reasons for the differences, if any.

D. Presenting data

Besides presenting your beach profile and wave steepness values, provide enough information for your audience to understand your findings. This can be done by including the following:

- Map of the area showing where data was collected; and
- Photographs showing features of the beach and the methods of data collection.

E. Forming a conclusion

1. State whether the hypothesis 'the steeper the wave, the steeper the beach gradient' has been proven or disproven. If proven, accept the hypothesis. Otherwise, reject it.
2. Reflect on the reliability of data collected by taking into account conditions which may have resulted in inaccuracies. Think of ways to minimise or prevent these inaccuracies.
3. Evaluate the data collection methods used by assessing if they were the most appropriate. If they were not, suggest ways to improve the methods.

In what ways do coastal landforms and features vary from place to place?

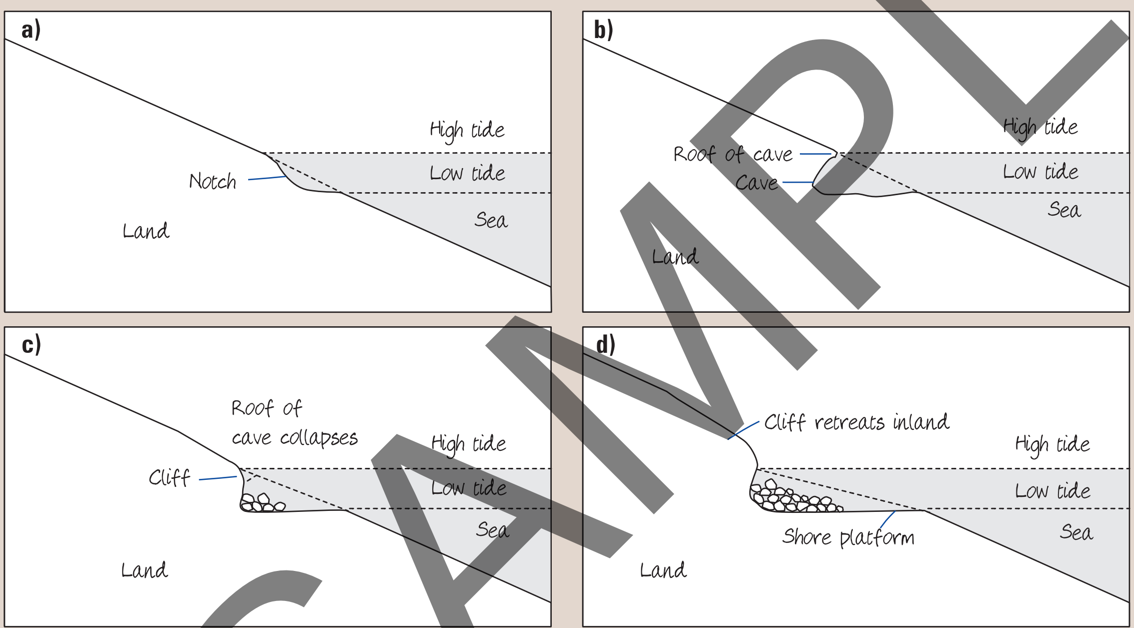
Cliffed coasts or depositional coasts may form depending on the geology of different locations and the action of waves, tides and currents.

Cliffed coasts

These coasts have some of the most dramatic landforms of all coastal environments. The landforms of cliffed coasts include cliffs, shore platforms, headlands, bays, caves, arches and stacks.

Cliffs and shore platforms

A **cliff** refers to a steep and near-vertical rock face found along coasts. It is produced by the action of waves undercutting a steep, rocky coast.



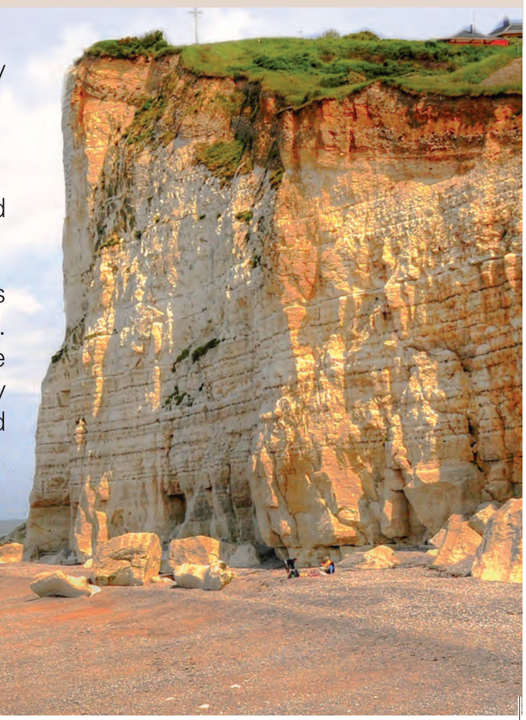
a) Hydraulic action and abrasion may erode a crack or joint on the rock surface, gradually enlarging the crack or joint to form a notch.

b) This notch may be further deepened to produce a bigger hollow space called a cave.

c) Further erosion by the waves eventually causes the roof of the cave to collapse and form a steep cliff.

d) As the process of erosion continues, an overhanging cliff is formed. Eventually, this overhanging cliff will collapse and the materials will be deposited at the foot of the cliff. Some of these materials may be carried by waves and thrown against the base of the cliff, thus causing further erosion. Over time, the cliff will retreat inland and a gently sloping platform appears at the base where the cliff used to be. This platform is called a **shore platform**, which is submerged during high tides.

Figure 1.23 Formation of a cliff and shore platform.



INVESTIGATE THIS 5

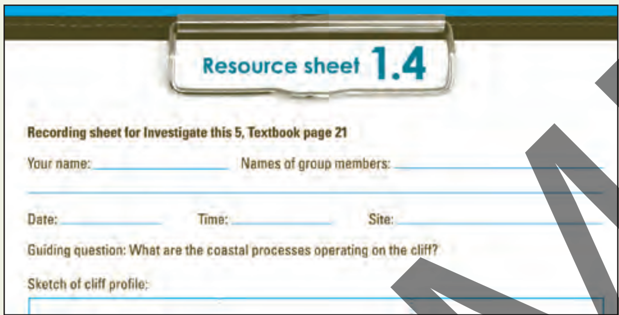
A. Guiding question

After learning about cliffed coasts, conduct a fieldwork investigation using the guiding question: What are the coastal processes operating on a cliff?

B. Collecting data

To answer the guiding question, you need to:
- Sketch the cliff profile;
- Observe and annotate coastal landforms; and
- Calculate wave frequency.

Equipment:
- Clipboard
- A4-sized drawing paper
- Sketching frame (refer to Chapter 4, pages 262–263)
- Pencil
- Eraser
- Stopwatch


Resource sheet 1.4

Recording sheet for Investigate this 5, Textbook page 21

Your name: Names of group members:

Date: Time: Site:

Guiding question: What are the coastal processes operating on the cliff?

Sketch of cliff profile:

Procedure:
1. Look for a spot where you have a clear view of the coastal cliff.
2. Hold up your sketching frame and position it to focus on that area.
3. Using the lines on the border of the frame, imagine nine sections within the frame to help you position your landscape details. Sketch the coast including the cliff on the paper. Keep your sketching simple and neat.
4. Observe the types of sediments you find at the base of the cliff and the materials of the rocks of the cliff.
5. Count the number of waves that break in a minute for 5 minutes. Calculate the average number of waves per minute to get the wave frequency.

C. Analysing data

1. Analyse your cliff profile and the features of the cliff.
2. Examine the wave frequency and suggest if they are constructive (6 to 8 per minute) or destructive (10 to 14 per minute).
3. Suggest and explain the coastal processes operating on the cliff.

D. Presenting data

Write a report on the coastal processes operating on the cliff. Include your sketch and photographs.

TIP Conduct an Internet research to find out more about the coastal processes operating at the cliff you have investigated:
- What did the cliff look like 5 years, 10 years and 20 years ago?
- Are there any newspaper articles on how the cliff has changed over the years?

Headlands and bays

Some coastlines have alternate bands of more resistant and less resistant rock arranged at right angles to the coast, as shown in Figure 1.24. The less resistant rocks will be eroded faster than the more resistant rocks. When the less resistant rocks are eroded away, **bays** are formed. These are wide indented coasts. The remaining more resistant rocks which extend into the sea are known as **headlands**. The south coast of the United Kingdom and the east coast of Johor, Malaysia, are good places to see impressive headlands and bays.

IT LINK

The Jurassic Coast in England has impressive headlands and bays. Visit http://www.jurassiccoast.com to learn more about these coastal features. What are some other coastal features at the Jurassic Coast?

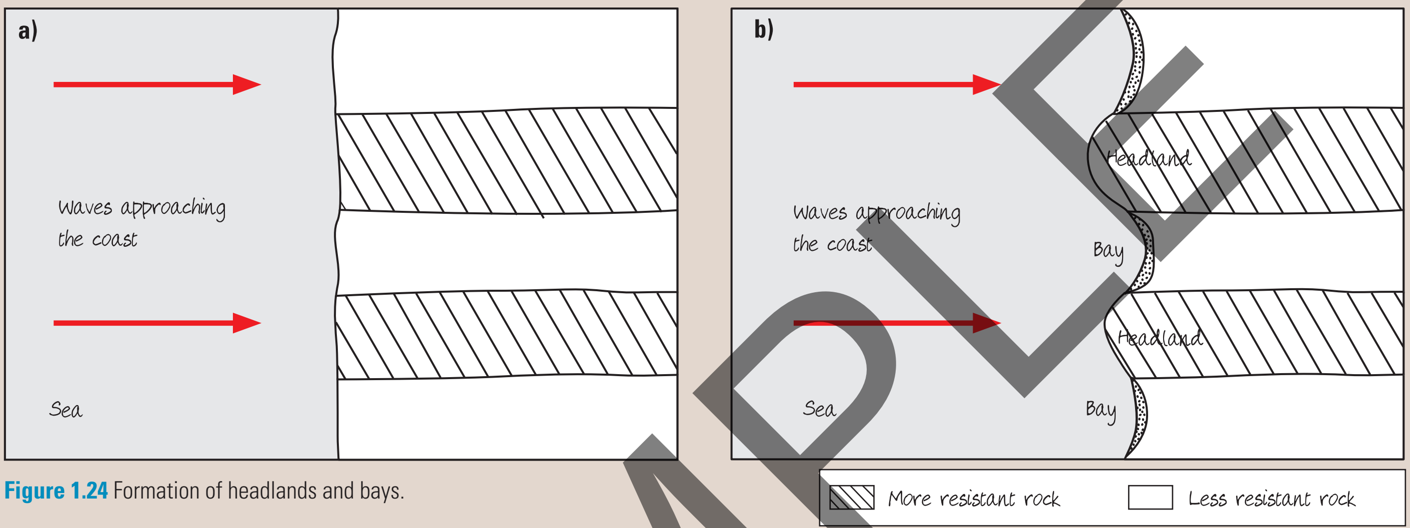


Figure 1.24 Formation of headlands and bays.

Figure 1.25 An irregularly shaped coastline in Phuket, Thailand, with headlands and bays.

Landforms are represented on topographical maps in specific ways. The topographical map below shows the landforms of a cliffed coast.

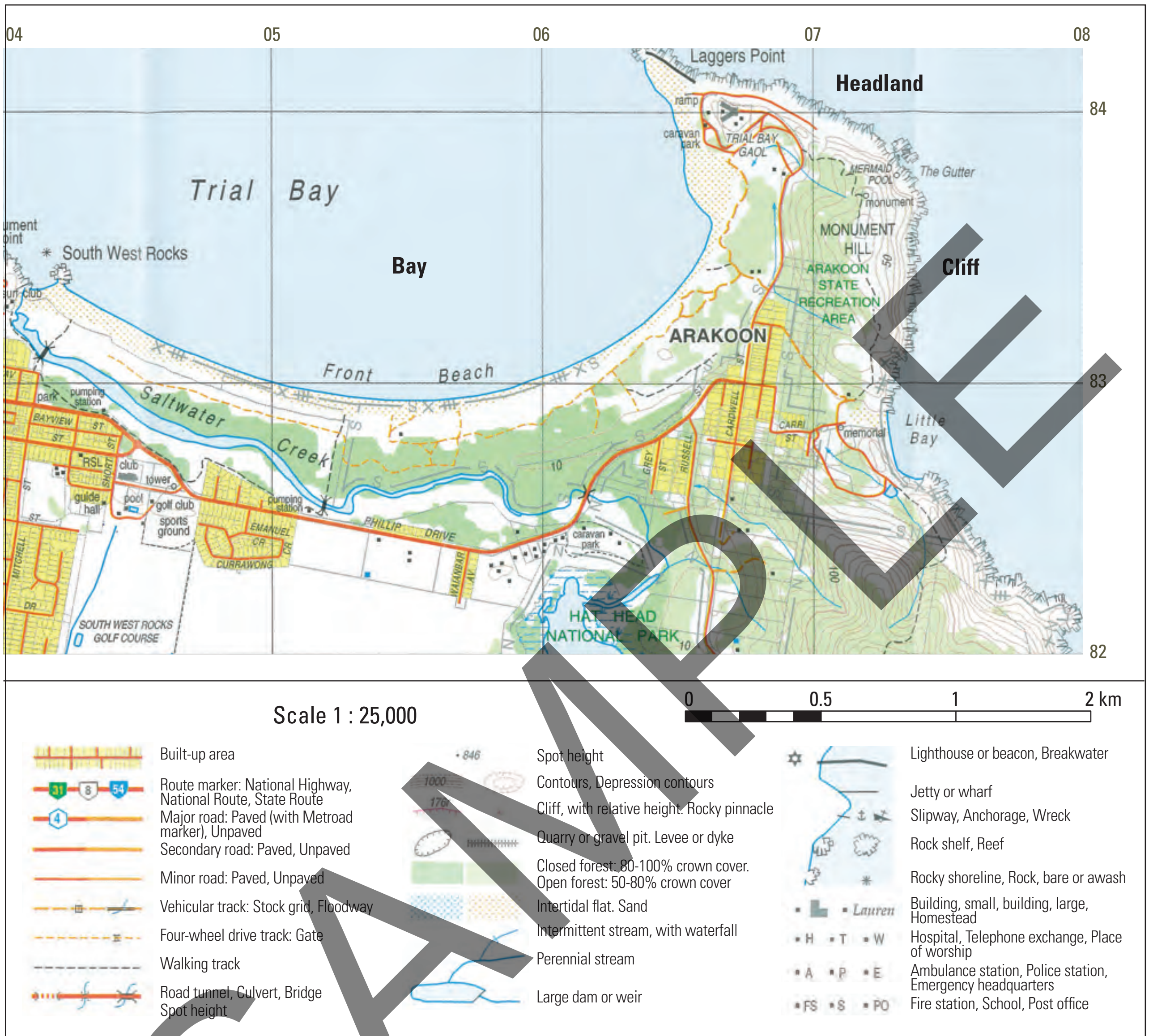


Figure 1.26 Topographical map showing a cliffed coast in South West Rocks, Australia. *Produced with permission from: NSW Department of Finance and Services, Panorama Avenue, Balthrust 2795; www.lpi.nsw.gov.au.*

PITSTOP 4

Refer to Figure 1.26.

a) Identify the coastal feature at each of the following grid references:
i) 072828 ii) 064842

b) What is the direction of South West Rocks (grid square 0483) from Monument Hill (grid square 0783)?

c) What is the distance along the major road of Philip Drive between the caravan park in grid square 0682 and the pumping station at grid reference 051825?

d) Which type of land use is the most widespread along the western edge of the map? (Refer to Chapter 4, pages 232–234 on how to interpret map evidence.)

e) Why are there very few roads along the eastern coast of the map? (Refer to Chapter 4, page 237 on how to explain the relationship between relief and transport and communication.)

f) What leisure facilities are available in the area shown on this map?

Connect

Learn more about topographical map reading skills in Chapter 4, Gateway 1.

Caves, arches and stacks

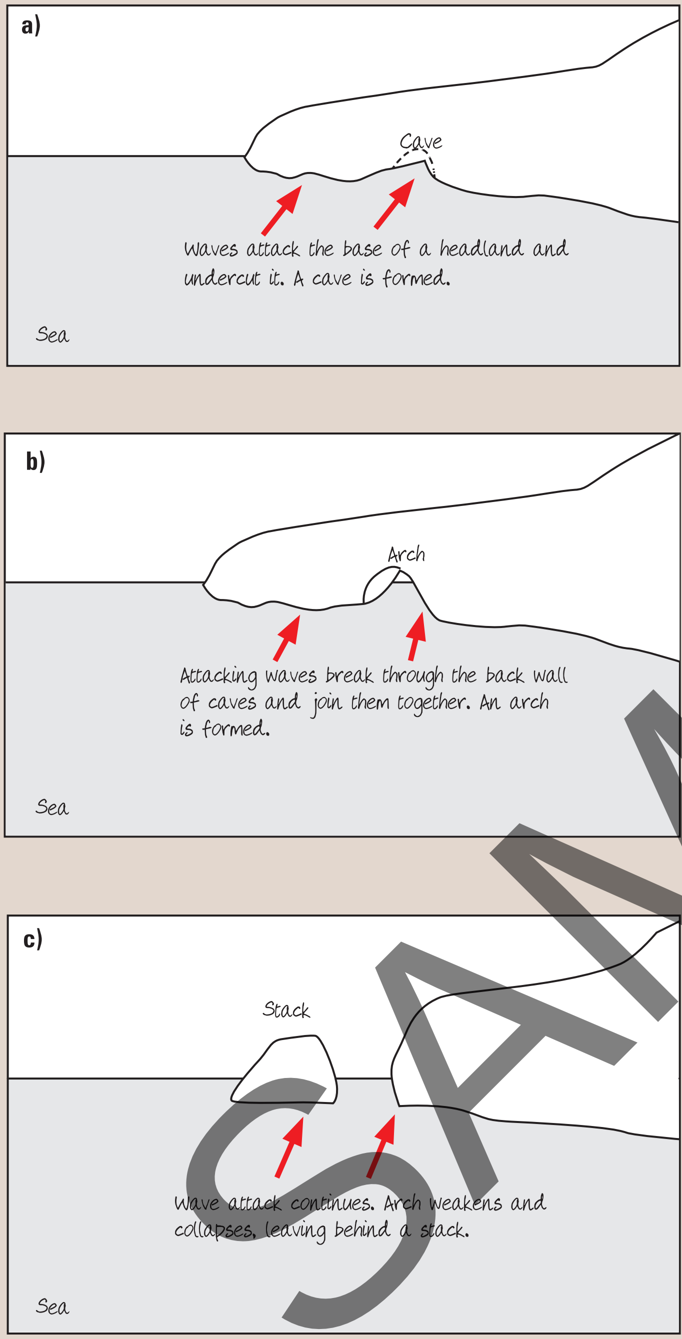


Figure 1.27 Formation of a cave, an arch and a stack.

Figure 1.28 A cave in Hanauma Bay, United States of America.

Figure 1.29 An arch in Port Campbell, Australia.

Figure 1.30 A stack in 'James Bond Island', Thailand.

a) Within headlands, some rocks may be less resistant to erosion than other rocks. These parts of the headlands will be eroded more quickly, especially by hydraulic action and abrasion. Waves attack lines of weakness (e.g. joints and faults) at the base of the headland and undercut it. The continuous action of waves forms a **cave** at the area that is hollowed by wave action.

b) Caves may develop on each side of the headland. Erosion may eventually join caves together, leaving a bridge of rock known as an **arch** above the opening.

c) After a period of time, the roof of the arch may collapse to form a **stack**. A stack is a pillar of rock in the sea left behind after an arch collapses.

Caves, arches and stacks are usually not shown on topographical maps as they cannot be seen at the scale at which most maps are drawn.

Depositional coasts

Along depositional coasts, sediments are deposited more quickly than they are eroded. Landforms such as beaches, spits and tombolos are found along depositional coasts.

Beaches

A **beach** is a zone of sediment deposition, usually formed from loose sand, gravel, pebbles, broken shells and corals, or a mixture of these materials. Figure 1.31 shows a beach formed from pebbles. Beach materials may come from eroded cliffs, river deposits and sediments carried by waves.

The composition and size of the materials on the beach vary greatly. The composition of materials depends on the source of materials. The size of materials may change over time due to changes in wave energy or changes in the source of materials.

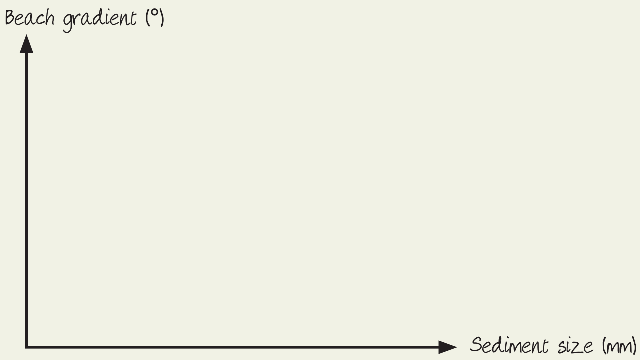
The slope of the beach is determined by grain size. Finer grain sizes tend to result in beaches with a gentle gradient. On the other hand, materials of coarser grains form beaches with a steeper gradient.

Beaches are constantly changing as their shapes are affected daily by waves, tides and currents. For example, during calm weather, constructive waves can help deposit materials on the beach and build it up further. On the other hand, during coastal storms, strong waves will erode and remove materials from the beach.

Figure 1.31 A pebbled beach.

INVESTIGATE THIS 6

The table shows the mean sediment size and beach gradient along a beach. Present the data in a scatter graph on graph paper and draw the line of best fit, using the x- and y- axis given. (Refer to Chapter 4, pages 253 and 254 on how to construct a scatter graph and the line of best fit.) Then state the suggested relationship between sediment size and beach gradient. Suggest reasons for the relationship between the sediment size and beach gradient.



Site	Sediment size (mm)	Beach gradient (°)
1	0.35	3
2	0.6	6
3	0.4	5
4	0.3	4
5	0.25	3
6	0.3	3
7	0.35	3
8	0.4	5

INVESTIGATE THIS 7

A. Hypothesis

After learning about sediment size and beach slope, conduct a fieldwork investigation to test the hypothesis: The bigger the sediment size, the gentler the beach slope.

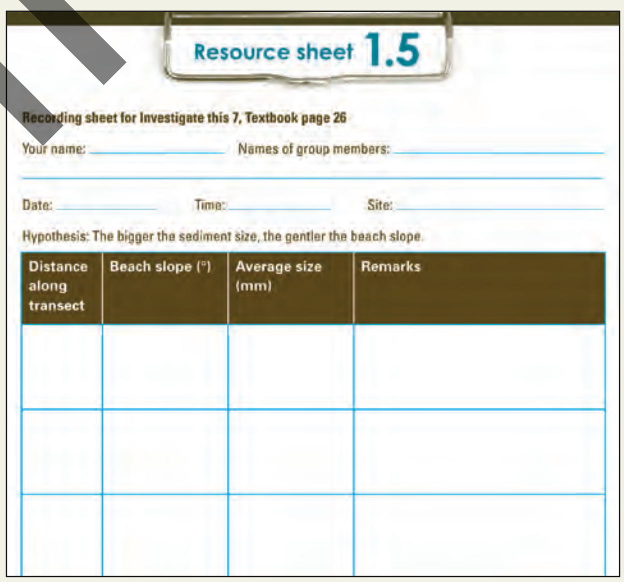
B. Collecting data

To investigate the hypothesis, you need to:

- Collect and analyse beach sediments; and
- Measure beach gradient.

Equipment:

- Vernier caliper (refer to Chapter 4, page 268)
- Measuring tape or ruler
- Magnifying glass
- Sieves (refer to Chapter 4, page 267)
- Recording sheet (Resource sheet 1.5)



Resource sheet 1.5

Recording sheet for Investigate this 7, Textbook page 26

Your name: Names of group members:

Date: Time: Site:

Hypothesis: The bigger the sediment size, the gentler the beach slope.

Distance along transect	Beach slope (°)	Average size (mm)	Remarks

Procedure:

1. Along a selected section of the coast, identify a line of transect.
2. At the seaward end of the transect, measure the beach gradient and collect a sample of sediments. Repeat this at regular intervals along the transect (e.g. every 2 metres) or where there is a change in beach gradient. (Refer to Chapter 4, page 267–268 on how to conduct sampling to collect sediments.)
3. Number the sediment samples and bring them back to your laboratory in school.

4. If the sediments are fine, sort them according to size using sieves.
5. If the sediments are coarse, measure their axes (widest part) using vernier calipers. Record your findings in the recording sheet.
6. Refer to Figure 1.21 and match the size of the sediments with the sediment type.

C. Analysing data

1. Using the data collected, plot a scatter graph in your recording sheet. Draw the line of best fit, where an equal number of variables are above and below the line. Suggest and explain the relationship.
2. Note any anomalies and suggest reasons for them. Consider whether there were any conditions that could have affected your results.
3. Observe if your findings agree with what you have learnt about sediment size and beach gradient. Suggest reasons for the differences, if any.

D. Presenting data

Besides presenting your scatter graph, provide enough information for your audience to understand your findings. This can be done by including the following:

- Map of the area showing where data was collected; and
- Photographs showing features of the cliff and the methods of data collection.

E. Forming a conclusion

1. State whether the hypothesis 'the bigger the sediment size, the gentler the beach slope' has been proven or disproven. If proven, accept the hypothesis. Otherwise, reject it.
2. Reflect on the reliability of data collected by taking into account conditions which may have resulted in inaccuracies of the data. Think of ways to minimise or prevent these inaccuracies.
3. Evaluate the data collection methods used by assessing if they were the most appropriate. If they were not, suggest ways to improve the methods.

INVESTIGATE THIS 8

Study Figure 1.32. Suggest a hypothesis about the size and distribution of the materials along the beach and propose a method to test the hypothesis.

Figure 1.32 A beach at Charmouth Beach, United Kingdom.

Spits and tombolos

A **spit** is a long, narrow ridge of sediments with one end attached to the land. A spit is formed by longshore drift. Where there is an abrupt bend in the coastline, longshore drift may continue to transport materials in the original direction for some distance. The materials are deposited in the sea after the bend where they accumulate over time along the original direction of the coastline. This forms a ridge of sediments from the point where the coastline changes direction. A hook or curve may develop at one end of the spit, most likely due to wave refraction concentrating at that point.

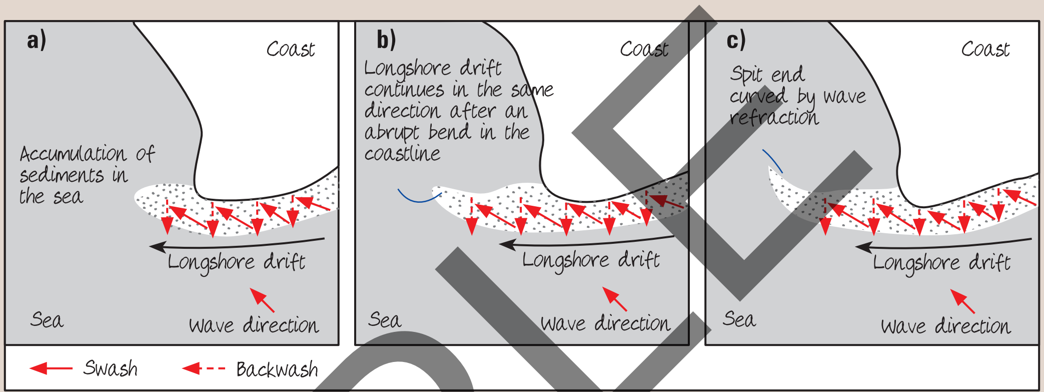


Figure 1.33a) A spit in Cape Pakarang, southern Thailand. **Figure 1.33b)** Formation of a spit.

A spit has one end connected to a mainland and has another end projecting out into the sea. If an offshore island lies near the mainland where the spit is forming, the spit may continue to extend until it connects the offshore island to the mainland. This new landform is called a **tombolo**. A tombolo may also join two existing islands.

Figure 1.34 A tombolo in Bintan island, Indonesia.

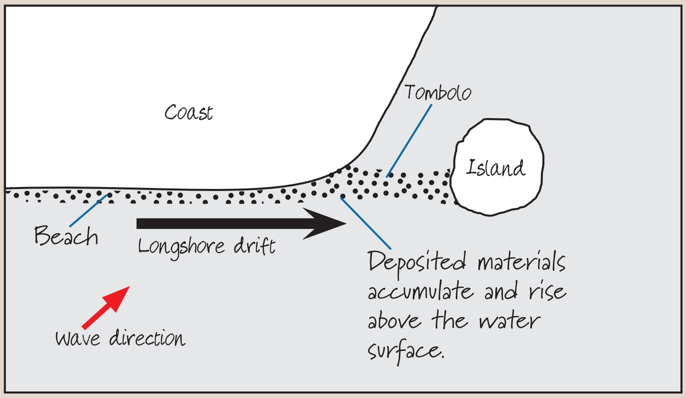


Figure 1.35a) Formation of a tombolo when the spit extends to a nearby island.

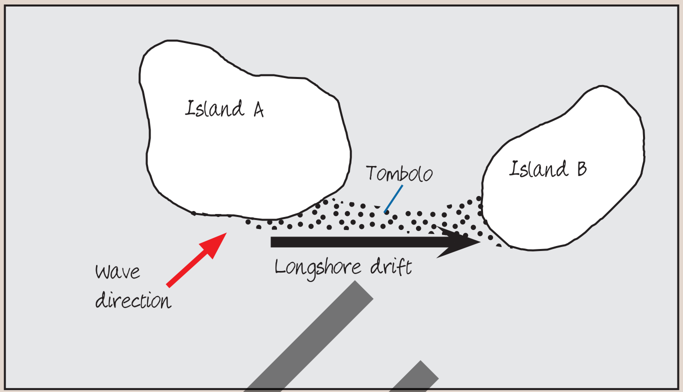


Figure 1.35b) Formation of a tombolo between two existing islands.

PITSTOP 5

1. Explain how caves such as the one shown in Figure 1.28 are formed by wave action.
2. With the aid of diagrams, suggest how the beach shown in Figure 1.31 may have developed.
3. How will materials eroded from headlands, cliffs and stacks further affect erosion in the same area in the future?
4. Changi Beach is a wide spit measuring about 600 metres on the east-northeast coast of Singapore as seen in Figure 1.36. This spit is a very popular place among beachgoers and park visitors.
   a) With reference to what you have learnt about coastal processes, explain how an extension of the spit might occur.
   b) If the changes occur, in what direction will the spit extend? Use a pencil and draw on the map.
   c) Give evidence to show that human activities are taking place on Changi Spit.
   d) Suggest two reasons why Changi Spit is important to Singapore.
   e) Explain how the possible extension of the spit will affect human activity.

Figure 1.36 Map extract of a spit along Changi Beach in Singapore. *Adapted from: Streetdirectory.com.*

CHECK-POINT

Use the following questions to check your understanding and apply what you have learnt.

1. Name the coastal erosion processes which occur on a cliffed coast.
2. a) Name three coastal landforms that are the result of deposition.
   b) With the aid of well-labelled diagrams, explain the formation of a tombolo.
3. What is the difference between constructive waves and destructive waves?
4. Explain how waves can both erode and build up a beach at different times.
5. Refer to Figure 1.23. Explain how the cliff and shore platform are formed by wave action.
6. Explain with the aid of a well-labelled diagram how headlands and bays are formed.
7. With reference to Figure 1.37, draw an annotated sketch to show the processes responsible for the formation of the coastal landform in the foreground.
8. Refer to Figure 1.38.
   a) What is the grid reference of the bridge where Hermin Grenier Road crosses over the river?
   b) In which direction does the Public Beach near Le Gris Gris lie from the Government Vocational Centre (983644)?
   c) What is the average gradient of Main A Road between grid references 993645 and 010655?
   d) Describe the coast between eastings 99 and 01.
   e) Suggest how the angle of slope at the Public Beach near Le Gris Gris at grid reference 9864 can be determined.
   f) Suggest the type of waves operating on this coast and describe their characteristics.
   g) Explain why swimming near grid reference 987641 is risky and not recommended.

Figure 1.37 A coastal landform.

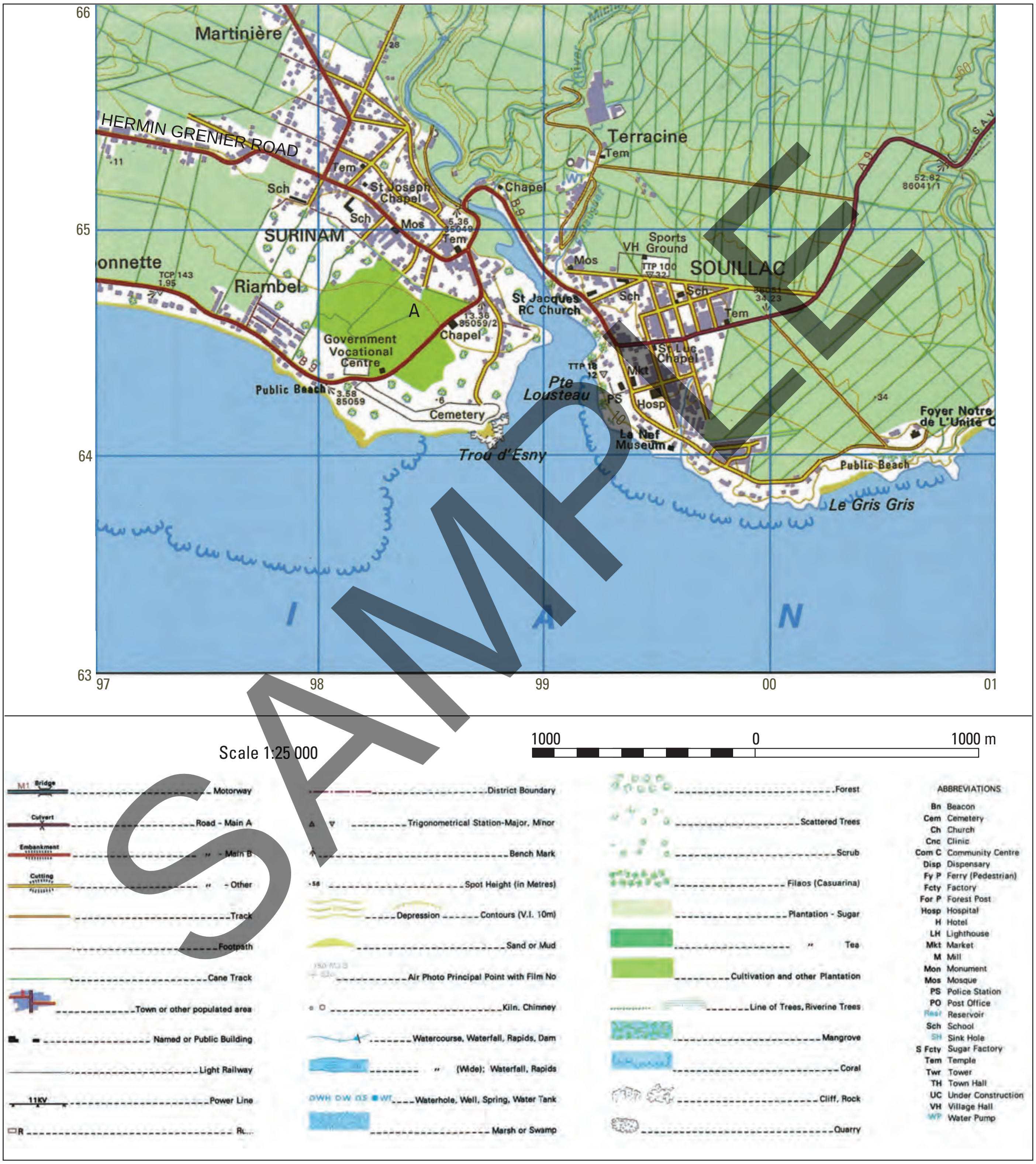


Figure 1.38 Topographical map extract of Souillac, Mauritius.

9. Study the feature in grid reference 982641 in Figure 1.38.
   a) Suggest a possible resultant landform that may emerge over time due to coastal processes.
   b) Draw a well-labelled diagram to show the formation of the resultant landform.
10. Refer to Figure 1.39.
   a) What appears to be the main factors causing some of California's beaches to disappear?
   b) In what way could these beaches 'replenish themselves' naturally?

Southern California beach erosion is worst in a decade

In southern California, powerful winter storms have swept away a spectacular amount of sand.

The vanishing beaches have forced city crews in Dana Point to remove fire rings, picnic tables and shower pads so lifeguards have room to patrol the remaining sand.

"This year it was just plain rock pile," said Ken Frank, city manager of Laguna Beach. "Forget the beach."

"The amount of sand taken away from Doheny is going to take many, many years to replenish, if it does replenish at all."

The storms' scouring of the southern California shoreline, which is remarkable at some beaches and barely noticeable at others, has caused the worst damage and most significant beach erosion in at least a decade, according to parks and beach officials.

In January and February, powerful swells, high tides and strong winds swept away tons of sand from the coastline, stealing as much as 30 to 40 feet (10 to 13 metres) of beachfront at some locations.

Figure 1.39 An article on beach erosion in southern California, United States of America. *Adapted from: Los Angeles Times (2 April 2010).*