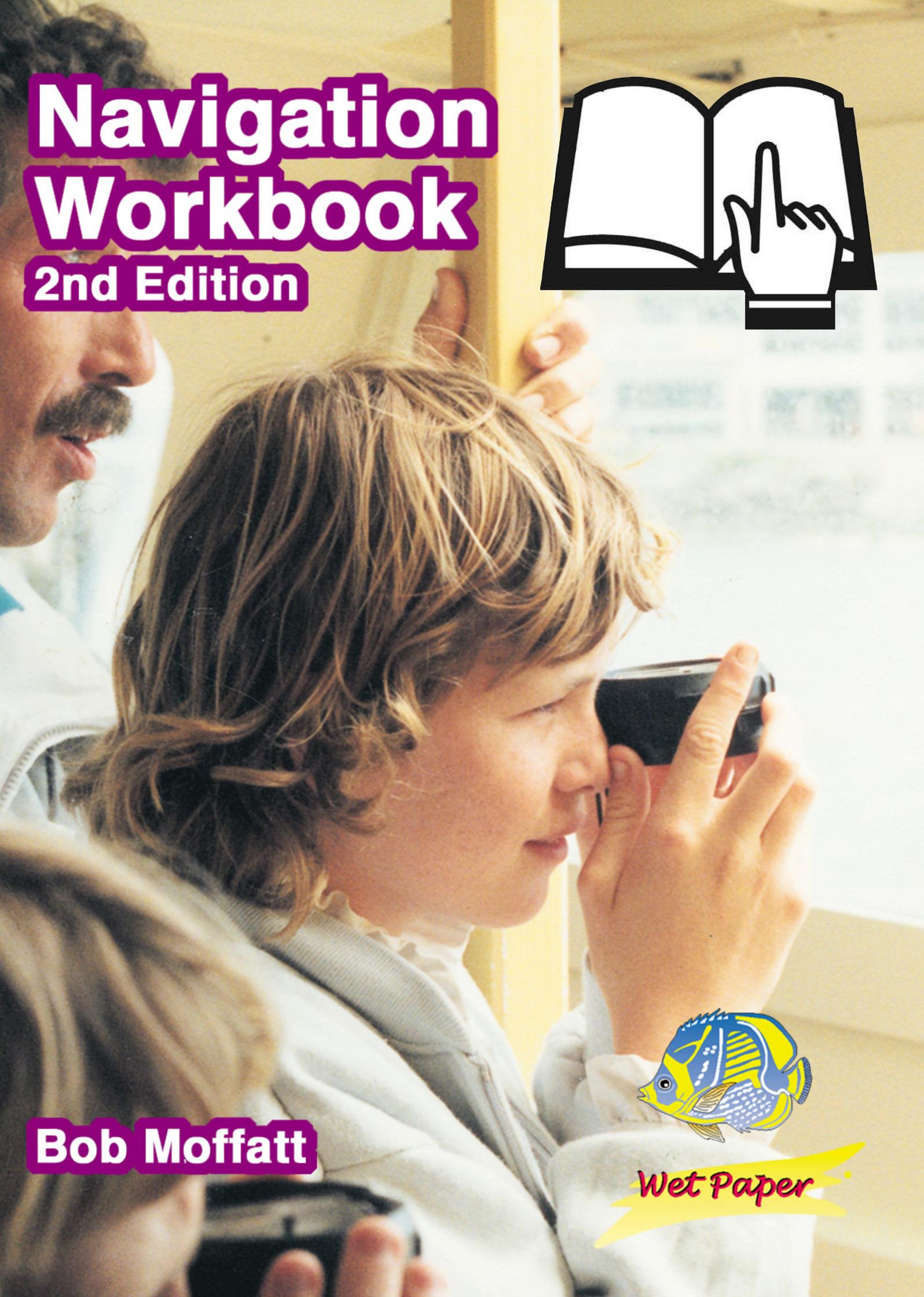


Navigation Workbook

2nd Edition



Bob Moffatt



Wet Paper

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ISBN

978-1-86283-143-8

Published by

Wet Paper Publishers and Consultants
A division of the Moffatt Group Australia Pty Ltd
ACN 086 521 084
PO Box 540 COOLANGATTA Q 4225
Telephone (07) 5525 6122
www.wetpaper.com.au



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Printed

1st Edition, February 1989
2nd Edition June 2001, Revised March 2004, Reprinted January 2006, Revised 2009
Reprinted February 2011
Flipbook 2014

Acknowledgements

The publisher would like to thank Tim Ryan, the Hydrographer of the Navy, 1982, Commonwealth of Australia for permission to publish sections of the Cape Hillsborough Channel training chart, John Wiley, Bob Critchley, Len Couzins, Sea World, John Armstrong, AUSAR, Bruce Chapman, GME Electrophone, TAFE NSW, Capt Dick Gandi, Australian Maritime College, students of Maryborough and Benowa High Schools for their assistance in this publication. Thanks also to Bruce Parmentier for his useful suggestions for this 2009 revision and the answer booklet.

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SECTION 1

INTRODUCTION

Navigation is the art of directing a vessel at sea.

It can be as simple as paddling a surf ski through shallow water or as complicated as steering an ocean liner across an ocean.

Knowledge and experience

The sea cannot be taken for granted no matter what size or type of vessel you take to sea because the shoreline is littered with the remains of vessels that could not find their way safely.

These wrecks lie as silent reminders of the need for good navigational skills. Even with all our modern navigational aids, over a hundred larger ships are lost at sea each year.

Most of these losses occur through human error, equipment failure, or being caught in natural disasters such as cyclones.

The sea can be a dangerous place, but with basic navigational knowledge it can be a rewarding experience.

It takes many years to train a mariner with many sea time hours logged under the direction of a ship's master to direct the movements of a vessel safely and efficiently from one point to another. Other aspects of navigation such as weather, tides and currents are discussed in other workbooks in this series.

However, having completed the workbook, you should have a basic insight into:

- Some local coastal features shown on a chart
- The use of navigational equipment
- Pilotage and buoyage systems
- Setting and plotting a course
- The importance of modern navigational aids



The word navigate is taken from the Latin “navagere” meaning navis (ship) and “agere” (move or to direct).



Figure 4.1 Navigation is the art of directing a vessel at sea.



Figure 4.2 The shoreline is littered with the remains of vessels that could not find their way safely.

Fundamentals of navigation



Many first time mariners believe that navigation is shrouded in mystery. How can you find your way at sea when there is no land in sight and everywhere you look is all the same? The novice is concerned that navigation involves complicated mathematics, star sighting, sextants and complex chart work — this is a myth.

It's not rocket science

Basic navigation is quite simple. We do it successfully daily on land when we use signs, road maps, and landmarks to get from point A to point B.

Navigation at sea is very similar and it requires minimal mathematics. You do need to be able to add and subtract, think rationally, process simple information and be practical.

The ability to navigate is extremely important to:

- Travel in strange waters
- Travel at night on water
- Travel in fog or when weather conditions do not allow the use of familiar features
- Find a safe path to your destination.

Most people can use a street directory to find their way around a town or city so if you don't feel confident with this topic, why not practise using a street directory before starting chart work.

History

Early mariners did not venture very far from the land and made sure that the coast was visible allowing them to identify the structures on the land and hence, know the position of their vessel. They usually travelled by day and went into protected coastal areas at night. They did not have charts but simply relied on basic lists of instructions and details of landmarks.

The art of navigation was born out of necessity. Once mariners had vessels that could travel beyond the sight of land, they needed to be able to find their way back to their starting point.

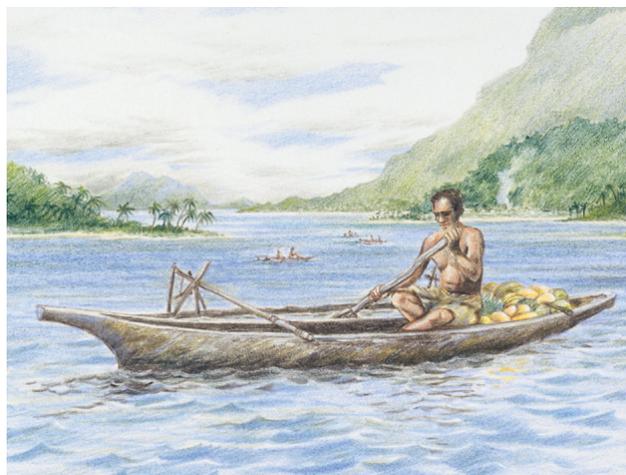
The only method these ancient mariners had to find their way back was to use observation of their ship's direction in relation to the sun, moon and stars or the direction of prevailing winds and currents in the area.

According to our best estimates sailors have been navigating the oceans for at least six thousand years – some say perhaps eight thousand years or more. Most impressive were the Polynesians, who traversed thousands of kilometres of open ocean in the Pacific on rafts made from reeds as early as 1500BC.

History records a number of great voyagers of varying significance to the development of today's knowledge of navigation.

As you progress through this course you may have a chance to go to sea to experience some of the difficulties in working there.

Hopefully you will admire some of the skills and determination of the seafarers who laid the foundations for modern navigation.



Queensland Museum

Figure 5.1 Polynesians, who traversed thousands of kilometres of open ocean in the Pacific on rafts made from reeds as early as 1500BC.

Challenge



- Write a postcard describing living conditions of a convict on board one of the ships of the First Fleet.
- What was a Scurvy Line?
- Some say there is an art to navigation while others suggest it is a science.
Debate this topic - navigation is an art and not a science.
- Web site for further information:
<http://www.education.qld.gov.au/tal/kla/compass>
- Tell a partner 10 facts you know about navigation at sea.
- Design a mind map to illustrate the to the class your prior knowledge of navigation.
- Suggest how migratory birds can follow the same migratory route each year.
- What is the angle of the North Star for Oslo in Norway, Berlin in Germany or Amsterdam in Holland?

The first navigational aids

Among the most important instruments developed to aid navigation of the sea are the compass, sextant, an accurate clock, almanacs and the telescope.

The compass

Date and origin of the magnetic compass are unknown. It is one of the oldest instruments and is thought to have originated in China with the discovery of the magnetic material, lodestone.

European mariners had known the magnetic properties of lodestone for centuries. This knowledge was used to develop the first magnetic compass, which was used by mariners in the twelfth century.

Figure 6.1 shows a photo of a modern magnetic compass that is mounted in a vessel at sea.



Figure 6.1 A magnetic compass

The sextant

Navigators in the northern hemisphere had used the North Star to navigate at night because they realized that it had a fixed position in the sky.

The North Star is almost directly above the North Pole. Not only does it show the position of North, but its angular height above the horizon is roughly equal to latitude.

For example the angle of the north star in London is 51° and the latitude is 51.5°N .

Early navigators believed that by finding the angle between themselves, the horizon and the star they might be able to relate this to a distance north on the Earth's surface. This was later refined by the use of tables and observations.

The angles were first measured by using a cross-staff. This instrument consisted of a long wooden staff upon which several cross pieces were mounted perpendicular at various lengths. In 1590 John Davis invented the back staff or sea quadrant, which called for the shadow of the instrument to be aligned with the horizon.

In 1730 the Englishmen Hadley developed the sextant as shown in Figure 6.3. The sextant remained practically unchanged since its invention over two hundred years ago.

Unfortunately there is no equivalent of the North Star in the Southern Hemisphere.

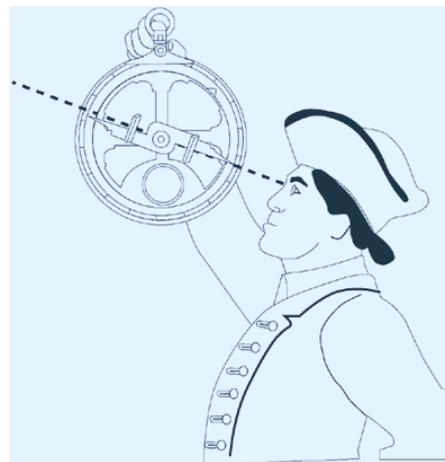


Figure 6.2 This astrolabe was used between the 13-16th century to measure the altitude of the sun and stars
Wet Paper

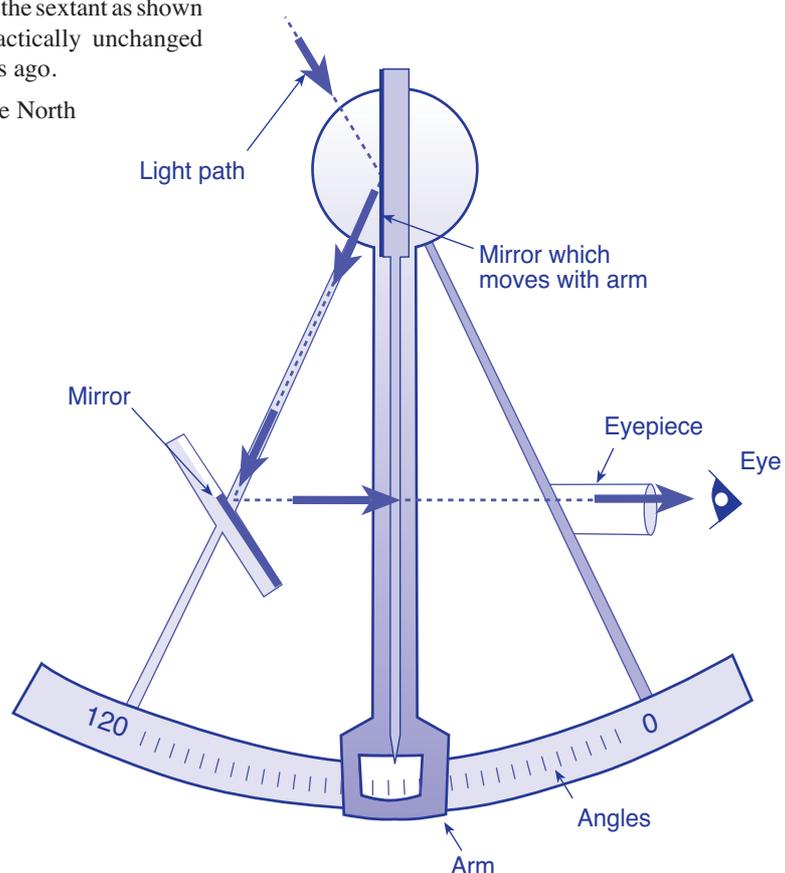


Figure 6.3 Sextant
Wet Paper

An accurate clock

Navigators also needed an accurate clock. The hourglass was the first clock that was used but this was very inaccurate. John Harrison, an English carpenter developed the first accurate clock the chronometer between 1730 and 1763. This clock used a type of pendulum that is still being used by clock makers today. Figure 7.1 shows Harrison's chronometer.

The almanacs

Almanacs were used by early astronomers and contained the recorded observations and tables of the angles and times to celestial bodies (sun, stars and moon).

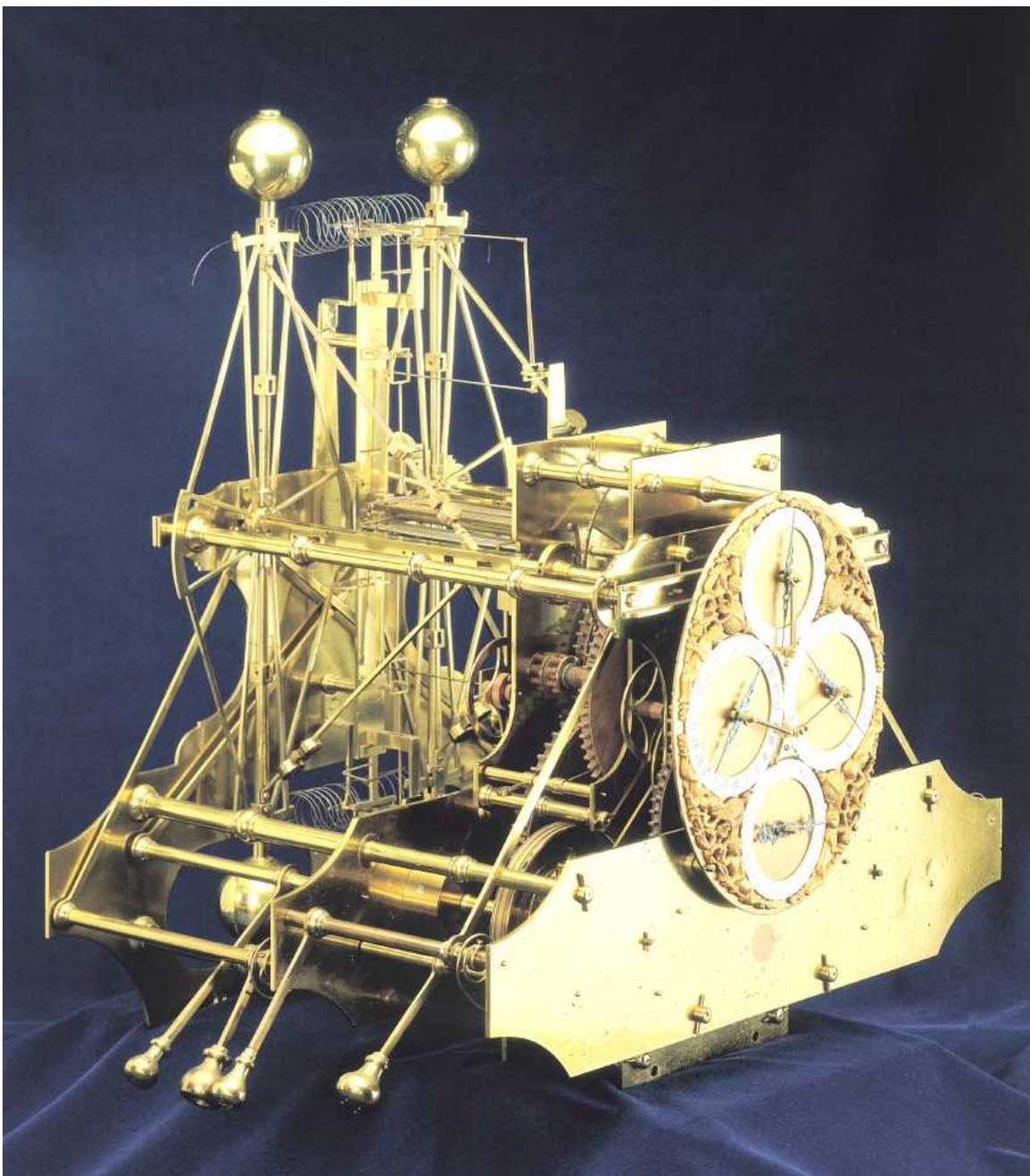
These were forerunners of the nautical almanacs, which are still used today to find one's position by using the sun, star and moons.

These nautical almanacs are produced each year by the Hydrographic Department.

The telescope

The telescope was of great importance to the early explorers as it was used as an early warning system to detect hazards such as reefs, shoals, and rocks early enough to allow the navigator to manoeuvre around the obstruction.

They were also used to identify landmarks, lighthouses and other ships at sea.



National Maritime Museum London

Figure 7.1 Harrison's chronometer

WORKSHEET 1 RESEARCH AND REVIEW

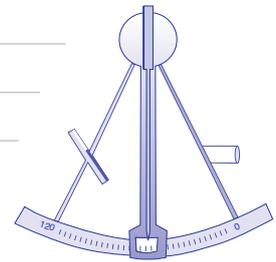
Questions

1. Who was the first person to sail around the world?

In what century did he complete this feat?

Why was it such a big deal in those days to accomplish this feat?

2. The figure opposite shows an early navigation aid. What is it, how was it used and show how it worked.



3. Make a list of modern navigation equipment that is available for inshore navigation.

4. Investigate a major maritime disaster that has occurred in the 20th century. From your investigations suggest the cause of this accident and how it might have been prevented.

5. Would you take up the challenge that Jessey Martin did — to sail alone around the world? Why?

SECTION 2 PILOTAGE

IALA buoyage system A

- The buoyage system helps skippers navigate into and out of a port or an anchorage. The system uses five markers, namely - *Lateral, cardinal, isolated danger, safe water and special marks*.
- These marks can be shaped as cans, cones, spheres, pillars or spars.

Lateral marks

- These indicate port and starboard hand sides of the channel and are positioned in well established channels.
 - The port mark is coloured red and has the basic top shape of a can.
 - At night the port buoy may show a red light and flashes to any of the sequences as shown in the figure below.
- The starboard mark is green and has the basic conical top shape.

At night the starboard buoy may show a green light and flashes to any of the sequences shown in the figure below.

Leaving port

- When departing a port the port hand buoy (red) should be passed on the vessel's starboard side as shown by boat A.

Heading into port

- Upon entering port, the port hand mark (red) should be passed on your vessel's port side as shown by boat B.

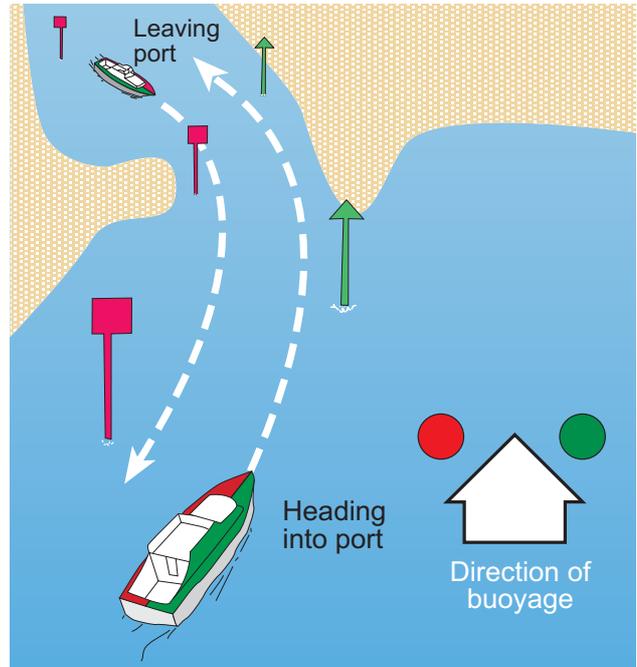


Figure 11.1 Direction of buoyage symbol and rules for entering and leaving port

Direction of buoyage

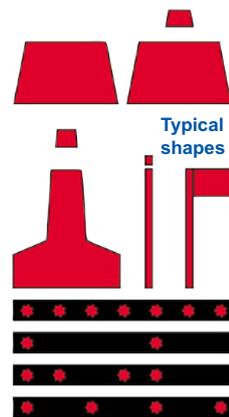
- Where there may be doubt, the direction of buoyage can be checked on charts as indicated by the symbol as shown in the figure above.



Port markers



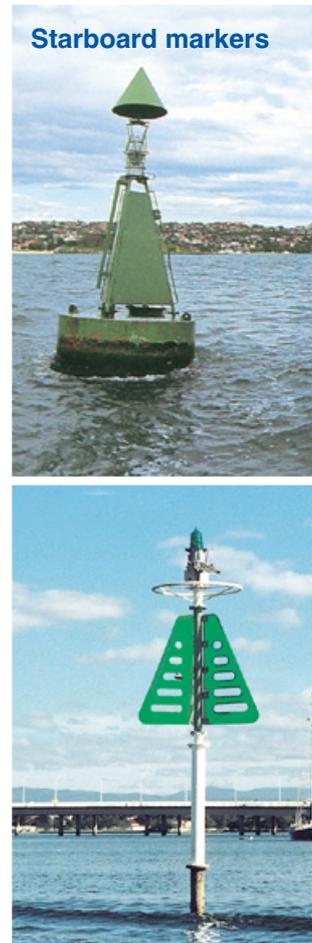
On a chart



Typical shapes



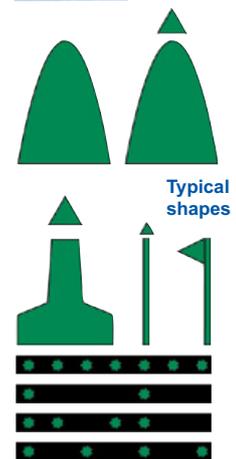
Night time sequences



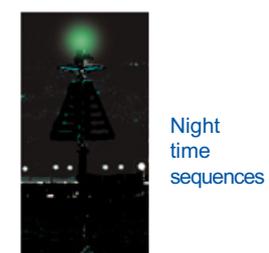
Starboard markers



On a chart



Typical shapes



Night time sequences

Figure 11.2 Lateral marks

Cardinal marks

A cardinal mark indicates where safest water may be found and is used in conjunction with the compass.

These marks are shown in Figures 12.1 and include the following features:

- Two black double cones are clearly separated.
- Black and yellow horizontal bands with the position of the black band (or bands) relative to the respective cardinal points.



Figure 12.1 Cardinal marks (Courtesy TAFE NSW)

Figure 12.2 shows how cardinal marks could be used to navigate around a reef if the skipper passes north of the north mark, east of the east mark, south of the south mark or west of the west mark.

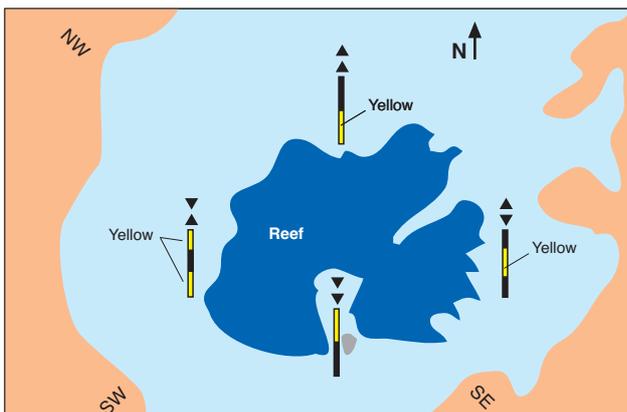


Figure 12.2 Cardinal marks protecting a reef (after TAFE NSW)

At night a white light flashes in a sequence that indicates the type of mark. The flashes are:

- North Uninterrupted continuous flash
- East 3 flashes in a group
- South 6 flashes in a group plus one long
- West 9 flashes in a group

To help you remember this associate the number of flashes of each group with that of a clock face.

Isolated danger marks

These designate an isolated danger of limited extent which has navigable water all around it. For example an isolated shoal, rock or wreck.

These marks are black with one or more horizontal red bands.

The top mark has two black spheres positioned vertically and clearly separated.

The light comprises a white flash showing groups of two flashes.

The best way to remember this is by associating the two flashes with the two spheres.

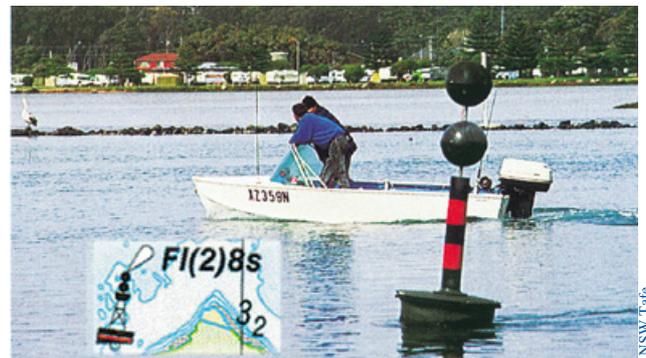
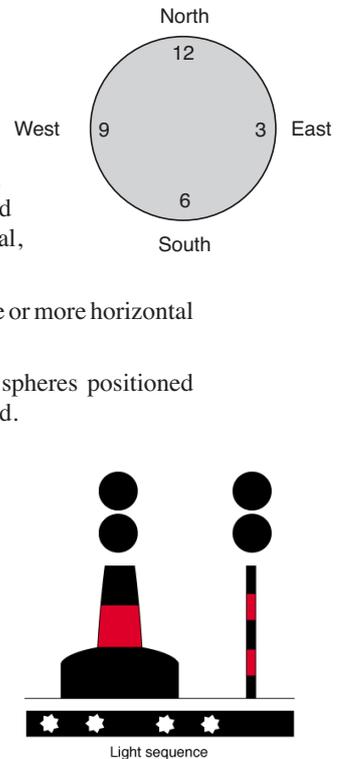


Figure 12.3 Isolated danger mark (Courtesy TAFE NSW)

Buoys, beacons and lighthouses

Buoys are used to delineate channels, indicate shoals, mark obstructions and warn the mariner of dangers. Buoys are floating aids that are anchored into position.

Safe water marks

These are painted with red and white vertical stripes and have one red ball on the top (see Figure 11.1).

They indicate that there is safe water beyond this point and are usually found at the end of a channel or when entering a port.

At night they flash with a white light followed by a period of darkness.



NSW Taife

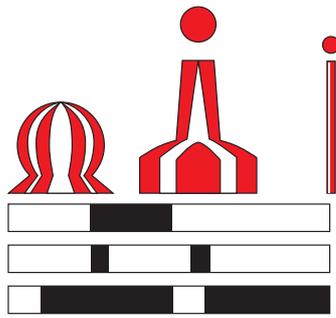


Figure 13.1 Safe water marks

Beacons

Beacons are fixed aids to navigation that are placed on the shore or in shallow water as shown in Figure 11.2.



Figure 13.2 A beacon

Lighthouses

Lighthouses have characteristic flashes which are clearly marked on a chart.

The lighthouse in Figure 13.3 has a light that flashes three times and each separate sector is white, red and green in 10 seconds. The height of the light is 145 metres and the visibility is 22 nautical miles out to sea.

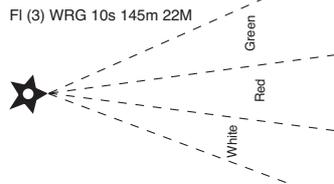


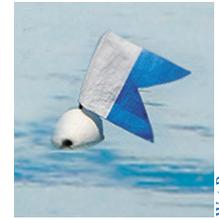
Figure 13.3 A lighthouse and its chart symbol

Special marks

These indicate a special feature such as a cable, outfall pipe, recreational diving area or ground marks. They also define a channel within a channel. For example a channel for deep draught boats in a wide estuary within the limits of the channel for normal navigation. Generally they are used where no other mark can be so the top of the mark carries a single yellow cross.

At night they show a yellow light with any light sequence (other than that used for the white lights or cardinal, isolated danger and safe water marks).

When you see a special mark – consult your chart.



A diver's flag



Figure 13.5 Special marks

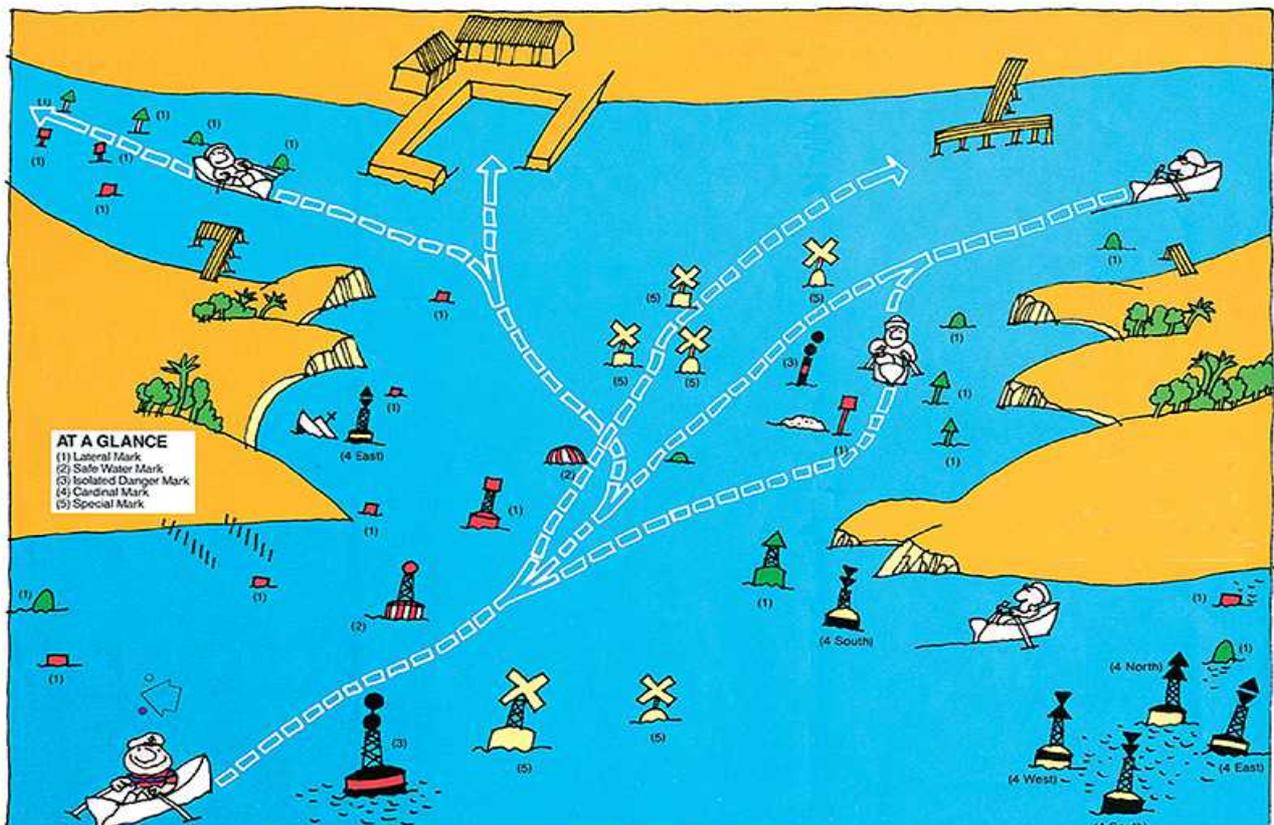


Figure 13.4 Summary of buoyage system (Courtesy Qld Transport)

WORKSHEET 3 NAVIGATION MARKERS

Name and colour in the following navigation symbols



(a) _____



(b) _____

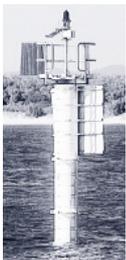


(c) _____



(d) _____

2. The following marks are observed.
Indicate the message each conveys.



(a) _____



(b) _____



(c) _____



(d) _____



(e) _____



(f) _____



(g) _____



(h) _____



(i) _____

Your school will supply you with a copy of this page

SECTION 3 NAVIGATION EQUIPMENT

See also pages 65 and 66 for GPS and Radar

The magnetic compass

If a small magnet is pivoted at a point or is free to turn, it will tend to align itself with the magnetic field of Earth and therefore show a direction.

Consequently, one of the most important navigational aids on a vessel is the compass.

There are two main types of compass:

- a. magnetic — which points to Magnetic North
- b. gyro — which points to True North

If a magnet were simply placed on a float in a bowl of water it would be of very little use in a vessel at sea in rough conditions. Thus the magnetic compass is constructed using a bowl commonly made of brass or non-magnetic metal with a glass top. The bowl is weighted at the bottom and is suspended in gimbals so that it remains fairly horizontal as the vessel is moved by the seas.

Since vessels are in constant motion when at sea, the magnetic needle (which is made of several magnets united parallel to each other) is located in a liquid that reduces or dampens the needle's movement. The liquid that is placed in the bowl is mostly water with some alcohol added to prevent freezing.

Since this compass has a magnetic needle it is important to choose the location of the compass carefully. The position should be-

- As far away from metal objects as possible
- Located well away from electrical wiring and instruments requiring electricity
- Have as stable a location as possible thus preventing vibration
- Be protected from the elements (rain, sun and sea spray)

The compass card

A compass card is a compass rose that is graduated in 360 degrees and is mounted in the bowl.

The compass card within a compass (the compass rose) is a circle marked off in a clockwise direction in 360 equal units (360 degrees). North is marked at 0°, east at 90°, south at 180° and west at 270°.

These are called the cardinal points of the compass. Mid-way between these cardinal points are the inter-cardinal points – north-east (45°), south-east (135°), south-west (225°) and north-west (315°). These can once again be subdivided giving another eight points e.g. north-north-east. The compass card normally has thirty-two points shown in a clockwise order and is known as 'boxing the compass'.



Figure 15.1 Binnacle mounted compass. Note — A binnacle is the pedestal in which a compass is mounted.

Wet Paper (Courtesy Sea World)

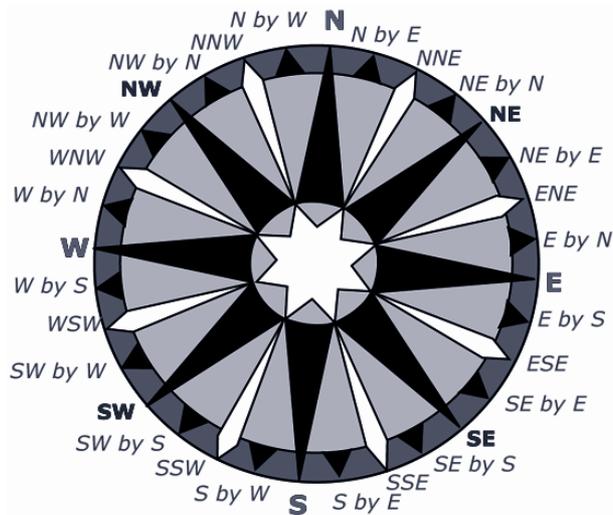


Figure 15.2 A compass card
Wet Paper

Statement

The marine magnetic compass was perfected in 1862 and was first used by the United States navy.

The steering compass

This compass is used “to steer” the boat and is usually mounted near the helm in a ‘free swinging’ or flush mounted position so it can easily be read when the ship rocks.

A ‘lubber line’ indicating which way the ship is heading is incorporated into the glass and a light illuminating the card makes the compass easy to read at night.

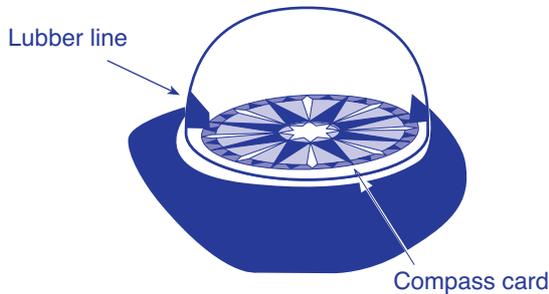


Figure 16.1 Lubber line

The steering compass can be mounted in a number of different ways to suit its location, bearing in mind the effect of outside magnetic fields which may induce errors into the reading. A steering compass is shown in Figure 16.3.

The hand bearing compass

Whereas the steering compass is usually a fixture near the helm, the hand bearing compass is free and can be carried to the most suitable spot on the boat for navigational observations as shown in Figure 16.2.

For this reason, the hand bearing compass is usually much smaller and lighter and incorporates some form of sighting device, the simplest and most common being the ‘V’ sight used on small rifles. Because it is relatively small, this type of compass usually has a magnifying glass to enlarge the figures on the card.

Others like the one shown in Figure 16.2 may have a built-in prism which reflects the bearing back to the eye.



Figure 16.2 Prism mounted handbearing compass

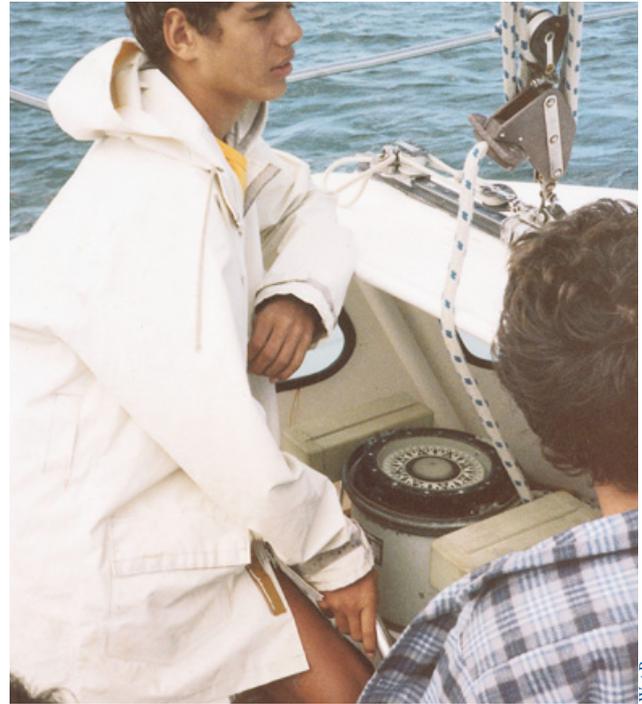


Figure 16.3 Steering compass

Fluxgate compass

The fluxgate compass does not use a magnetic needle to provide direction but consists of two coils carrying electric current. One coil is mounted horizontally and the other vertically. If the vessel changes its heading or position in the Earth’s magnetic field it alters the flow of current in one coil relative to the other.

Being electrical, the information can be displayed digitally. It can be fitted with microprocessors which can automatically compensate for both deviation and variation thus providing a true bearing.

The fluxgate compass does require power from a small battery for it to operate.

This compass must also be held fairly steady for accurate readings.

Two types of fluxgate compasses are shown in Figure 16.4.

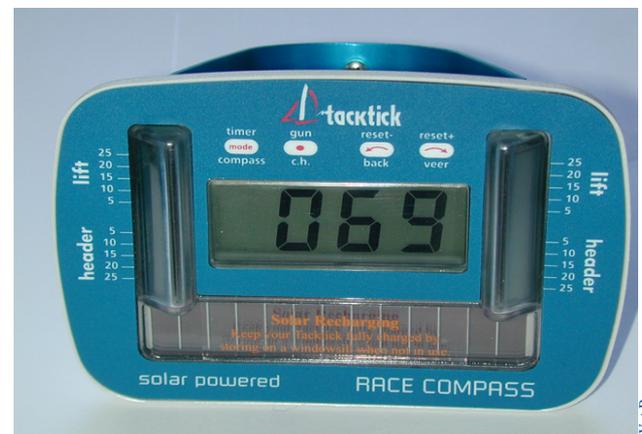


Figure 16.4 Two types of fluxgate compasses (compasses courtesy Bruce Chapman Marine)

Gyro compass

The age of the iron ship demanded a compass that could show True North and not be affected by the ship's hull. The magnetic compass was of little use in these steel vessels and a gyro compass was invented to take its place.

The gyro compass points to True North and does not rely on the Earth's magnetic field. It is a non-magnetic compass. It relies on the principle that a fast spinning wheel will maintain its direction. Once this is in motion, it will maintain its orientation and the direction a vessel is heading can be determined. It relies on electricity to spin the wheel.

Since a gyro compass is not affected by the magnetic field it is not subjected to the errors that are inherent in the magnetic compass such as deviation and variation. It can also have repeaters (slaves) in other positions on the vessel run from the main compass so that all vessel's workings are from the one compass.

Use of the sextant

The marine sextant is a hand held instrument used to determine the angle between your eye, the horizon and the distant object. It has been used for centuries to measure the altitude of celestial bodies such as the sun, moon and stars. The altitude of these celestial bodies changes as one moves in a northerly or southerly direction. This altitude can then be used to determine the latitude (position) on the Earth's surface.

The sextant can also be used to measure the difference in bearing between two geographical points on the coastline thus allowing the vessel to fix a position. The sextant is placed on its side to complete this measurement.



Courtesy John Armstrong

Figure 17.1 Using a sextant

Chart room

The chart room on a ship is where most of the navigation equipment is stored. The wheel house is where most of the measurements are taken and the ship is steered. Other navigation instruments and equipment discussed in this workbook include the clock, charts, echo sounders, parallel rules and rulers, radar and GPS. Figure 15.2 shows part of a chart room on a training ship operated by the Australian Maritime College in Tasmania.

Challenge

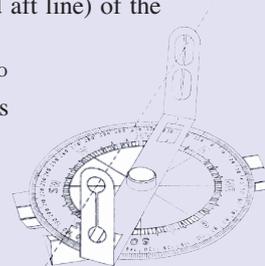


1. Construct a model to demonstrate how a sextant works
2. In winter - is the sun directly overhead at 12 midday at your school i.e. does it not cast a shadow?
Will the shadow fall to the north or to the south?
Will the shadow be greater or shorter in summer or in winter?
Explain your answers.
3. Why is it easier to maintain balance on a bicycle that is moving than one that is stationary?
4. Suggest some examples where the gyro or spinning effect is used to our advantage
5. Suggest why the gyro compass was not invented until the 20th century.

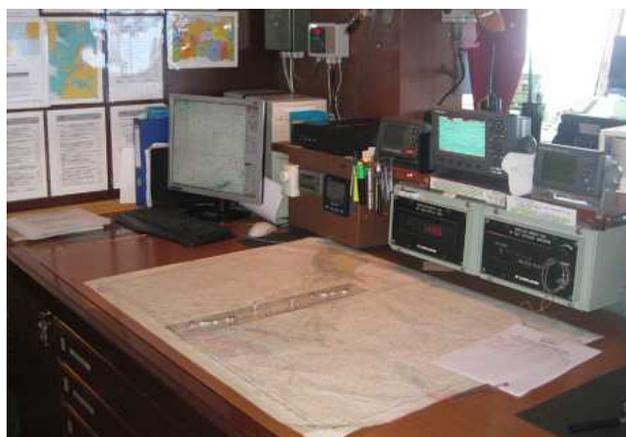
The pelorus

This is used to take bearings relative to the vessel's heading (the way it is pointing). This bearing can then be added to the vessel's heading to give the compass bearing. The pelorus consists of a set of sighting vanes mounted over a circular card showing 0° - 360° without a magnetic needle and it has no directional properties. It can be located anywhere on the vessel but it must line up on the Lubber Line (fore and aft line) of the vessel.

The pelorus must be set at 00° dead ahead. Relative bearings are then observed. You can read more about the pelorus and the gyro compass in Chapter 8 of *Australian Boating Manual* - Available from Sydney Maritime Group Tel: (02) 9907 6744



Pelorus illustration courtesy Capt Dick Gundi



Wet Paper

Figure 17.2 Navigation equipment in a chart room of a training ship.

Chronometer

An extremely accurate ship's clock is set at Greenwich Mean Time. This allows the navigator to find the time difference between Greenwich time 12 noon and the time the sun is directly overhead at your position (12 noon).

This allows you to calculate how far you are away from Greenwich. GMT (Greenwich Mean Time) is now called UTC (Universal Time Coordinated).

Calculating time by longitude

Your longitude can be calculated by the time difference between you and UTC.

The Earth rotates 360° in 24 hours, so:

1 hour = 15° of arc

4 mins = 1° of arc

1 min = $15'$ of arc

4 sec = $1'$ of arc

This means that if a vessel A is located at longitude 100° East and vessel B is located at longitude 160° East the time difference will be equal to $(60 / 15) = 4$ hours.

The sun will rise 4 hours earlier at position B.

Since the Earth rotates from West to East, places east of Greenwich will have times in advance of Greenwich Mean Time. (GMT)

If Perth and Sydney have 30° difference in longitude, what time difference should there be?

The international date line

The 180° meridian is very important as it is by international agreement, the date line.

A vessel sailing eastward will need to put back the calendar one day when it crosses the date line. A vessel will add a day when going in a westward direction. This is used to many people's advantage when they can celebrate New Year's Eve in two areas.

Note on UTC

UTC — Universal Time Coordinated, previously known as Greenwich Mean Time (GMT; 1928 - 1972). UTC was introduced in 1972 and replaces midnight GMT with 0000h (0 hours).



Figure 18.1 A ship's clock

Challenge



- Some ancient Viking mariners carried ravens with them on their voyages across the oceans. These birds were used for navigational purposes. Suggest a possible reason as to how they would assist in navigation.

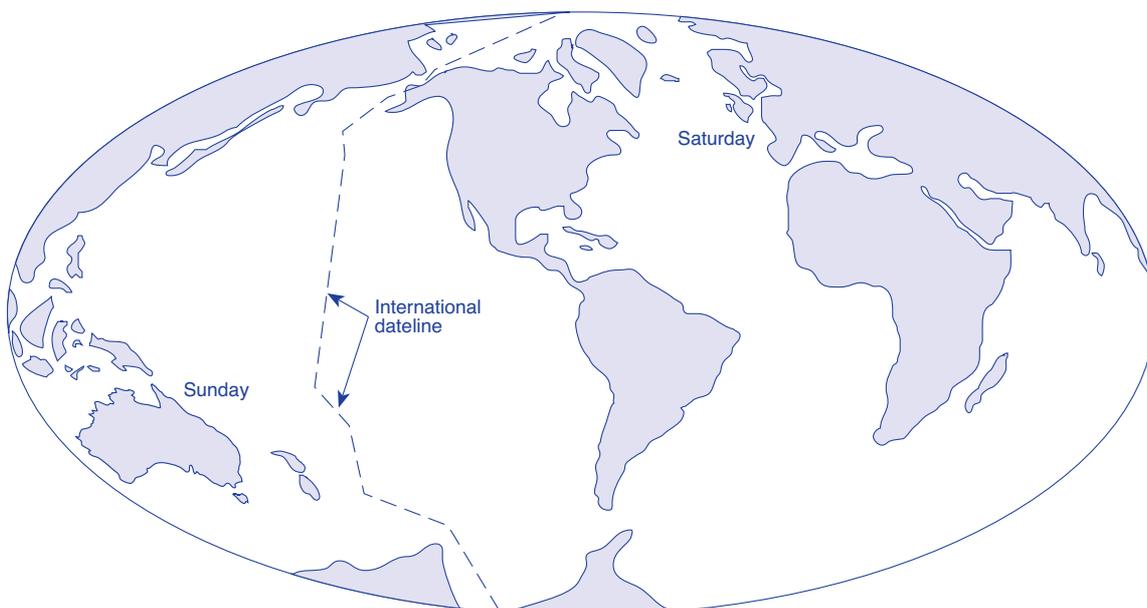


Figure 18.2 The International Dateline

Wet Paper



WORKSHEET 4 WHAT DAY IS IT?

Questions

1. GMT (Greenwich Mean Time) is now called UTC (Universal Time Coordinated). They are in effect the same time standard, but differ in that mid-night GMT is replaced by 0000 h. UTC time is 24 hour time.

If UTC is 1200 what will be the time at

a. East coast of Australia

b. Central Africa

c. Brazil

d. India

2. Two vessels are communicating on radio when the person on vessel A stated the sun is just rising at his position. Vessel B states the sun has been up for 2 hours at his position. If the vessels are at the same latitude, what is the difference in longitudinal position of each vessel?

3. Why do you believe the International Date Line does not follow the 180° meridian exactly?

Where does it deviate from the meridian?

4. Suggest why Australia has at least 3 time zones. What are they and what are the time differences?

5. A cricket fan in Australia wants to listen to a cricket match being played in England near Greenwich. The match is to start at the grounds at 11 am. The cricket fan knows his position is 20° 30S 150° 0' E. At what time will the game broadcast start at his home, if it is a direct telecast?

6. Locate the latitude and longitude of the following cities on an atlas and calculate the time at these cities if the Universal Time Coordinated (UTC) is 1200 hours.

London

New York

Beijing

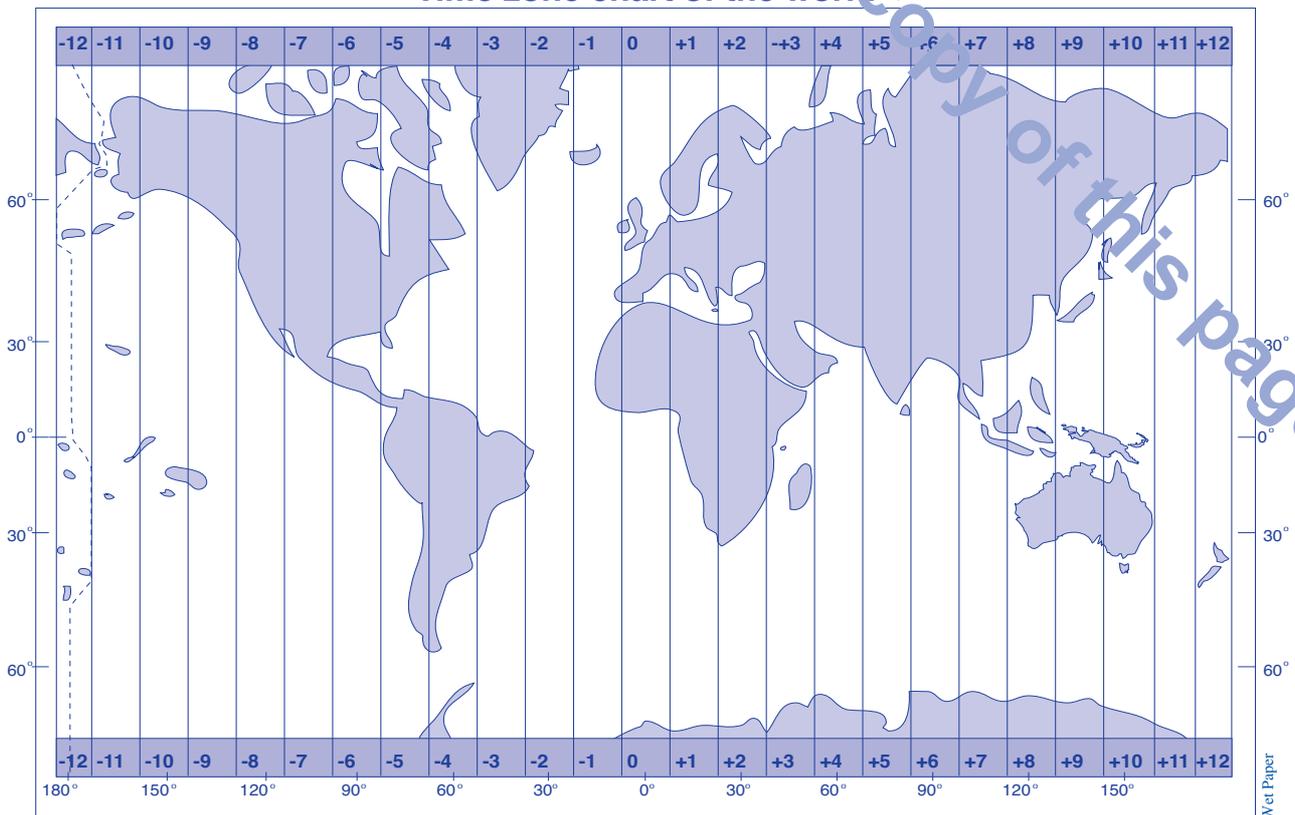
Paris

Los Angeles

Calcutta

Moscow

Time zone chart of the world



WORKSHEET 5 MAGNETIC FIELDS

Aim

To map a magnetic field.

Materials

- bar magnet
- iron filings
- a small compass
- acetate sheet (overhead transparency)

Method

A magnetic field is the area where the magnetic force acts.

1. Place a bar magnet on a desk and place a piece of A4 paper on top of the magnet. Keep the paper as level as possible by supporting the sides with books, etc.
2. Carefully sprinkle iron filings over the acetate paper so that the iron filings are spread evenly over the sheet. Place the acetate sheet with the iron filings on to the paper that is above the magnet.
3. Draw a sketch of the pattern made by the iron filings. You may need to sprinkle more iron filings to obtain a distinct pattern.
4. Remove the acetate sheet and place a small magnetic compass at a number of different positions on the paper. Record the direction in which the compass needle points at the different locations. Suggest which end of the magnet would be north and which end south.

Questions

1. What happens to the strength of the magnetic field as you move further from the magnet? What evidence do you have to support this conclusion?

2. Why do some of the iron filings stand up on the acetate? What does this tell you about the magnetic field in this area?

3. Do the compass needle directions and the shape the iron filings formed on the acetate have anything in common?

4. Where is the magnetic field the strongest? What evidence do you have to support your answer? Predict what would happen if you were to cut or break the magnet in half.

5. How might you make a simple compass? Endeavour to construct your own compass.

6. When you use a bar magnet to pick up small items such as pins, you use the end of the magnet. Suggest why you do this.

7. Suppose you were given a magnet and you were asked to label the north and south ends, how would you go about deciding which end was which?

Extension exercise

Aim

To discover which materials are magnetic.

Materials

- bar magnet
- iron
- copper
- steel (nails)
- stainless steel (bolt)
- aluminium (rivets)
- plastic
- glass
- silver
- gold (jewellery)
- lead
- brass

Results

Method

1. Design a table to display the results of this experiment showing which materials are magnetic and which are not.
2. Place a bar magnet on each of the substances and draw the magnet away. Record which materials are held by the magnet as it is drawn away.
3. Place a compass on the table. Place one material at a time near the compass needle and observe which substances have an effect on the needle. Record results.

Questions

1. Which of the materials tested need to be kept well away from the ship's magnetic compass?

2. Do you believe a magnetic compass could be used in a vessel made of steel?

3. Do you believe that a magnetic compass could be affected in any way on an operational aluminium vessel? Explain your answer.

4. Why do you believe modern steel vessels should carry a fluxgate compass?

5. Design an experiment to test if animals could detect magnetic current. What type of animal might you use?



WORKSHEET 6 USING A HAND BEARING COMPASS



Figure 22.1 Handbearing compass

Aim

To learn how to take a compass bearing

Materials

Hand bearing compass

Method

This exercise can be simulated in the classroom but later put into practice on a vessel at sea.

This is an important part to practise.

- Step 1 With some chalk mark a spot outside the classroom where there is a clear view of a number of features e.g. building, church steeples, trees, etc.
- Step 2 Make a list of six or more features your group must take a bearing to. _____
- Step 3 Record these bearings. _____
- Step 4 Compare the bearing students have taken. _____
- Step 5 Place a desk that has a metal frame on the spot. Repeat the exercise with the compass placed on the desk. _____
- Step 6 Record these results. _____
- Step 7 Go back to the classroom and mark the direction of Magnetic North. _____

Repeat the exercise marking South, East and West. Mark the positions with wall charts so students become familiar with the magnetic directions. _____

Results

1. What difficulties did you have in completing this exercise?

2. Compare your results with other students in the class. If there are differences in the bearing results, explain these differences.

3. What effect did the steel frame have on the bearing taken? Explain why this occurred.

4. Suggest a method to reverse the effect of the steel frame.

Extension

Design an experiment to show the effect of electric current on a compass.



WORKSHEET 7 MAKING

A COMPASS ROSE

Aim

To learn the points of the compass and take bearings in your classroom

Materials

- pencil, ruler and rubber
- orienteering compass
- A4 sheet of paper

Method

1. Use your pencil and ruler to make a map of your room on your A4 sheet of paper.
Draw in the desks and mark in conspicuous features such as the door, wall clock, blackboard and where you are sitting.
2. Using the circle in Figure 23.1 as a guide, mark in classroom North with a capital N and write 0° beside it.
3. Now mark in 10°, 20°, 30° to 360° around the circles as shown in Figure 23.1. You have now made a compass rose.
4. On the inside of the circle mark off the compass points: NE, E, SE, S, SW, W, NW to match numbers you have just marked.
5. Take the orienteering compass, place it in front of you away from the metal parts of the desk and find Magnetic North.
6. Now mark this on your compass rose as Magnetic North.

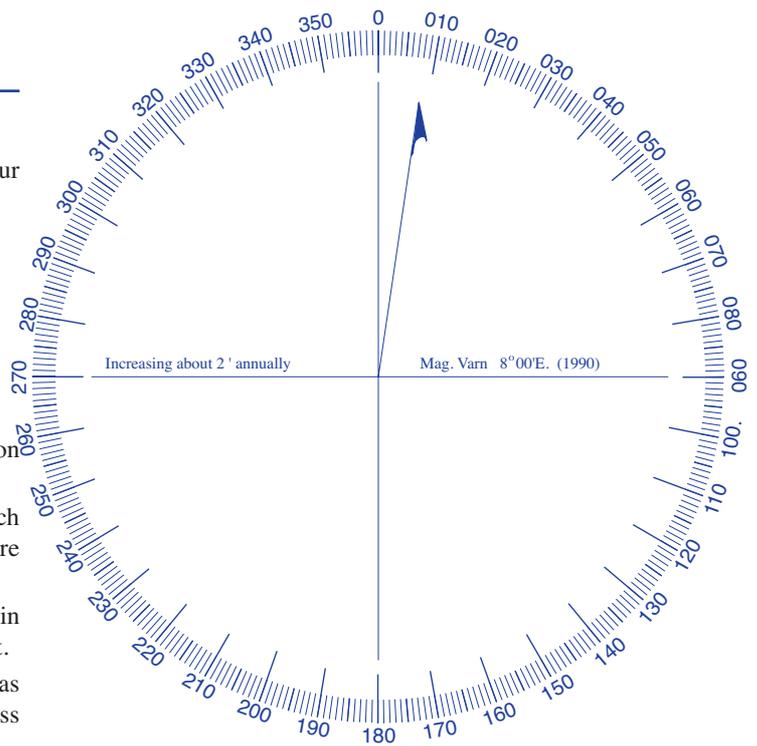


Figure 23.1 A compass rose

Questions

1. How many degrees difference is there between Classroom North and Magnetic North?
Give a reason for this difference.

2. From where you are sitting, what are the approximate compass point positions of the following conspicuous points in the classroom. Give your answer in compass points.

a. Right hand corner of room

b. Room entry door

c. Clock

d. Teacher's desk.

e. Nearest student's desk



SECTION 4 CHARTS

The Earth

In basic navigation, the Earth is, for all practical purposes, treated as a sphere.

The Earth in actual fact is similar to a sphere flattened at the poles and is termed an oblate spheroid. It rotates on an axis, which is inclined approximately 23.5 degrees to the vertical, and it rotates from West to East (Figure 24.1).

The problem then comes of how to represent this surface of the Earth on a flat chart. If the Earth was divided up with a network of lines running vertically and horizontally, it would form a grid. These imaginary lines would then intersect at right angles. Distances could then be measured and locations determined by means of angles calculated from these lines.

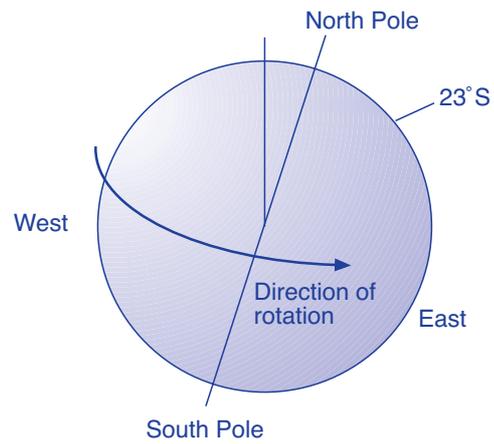


Figure 24.1 Earth's rotation
Wet Paper

A chart

A chart is a curved section of the Earth's surface reproduced on a flat piece of paper.

A map

A map is a representation of the Earth's surface on a plane surface.

Latitude (Parallels)

The line perpendicular to the Earth's axis that cuts the Earth into two equal hemispheres is known as the Equator and is mid-point between the poles. Lines drawn parallel to the Equator around the Earth are called lines of latitude. The line of latitude at the Equator is said to be 0° latitude (Figure 24.2).

The latitude of a position is given by the angle formed from its position at the surface to the centre of the Earth and to a position on the Equator.

The circles (lines of latitude) get smaller as you go to the poles.

This angle is measured in degrees, minutes and seconds for 0 – 90 degrees, North or South of the Equator.

1 degree (1°) = 60 mins (60)'

1 minute = 60 seconds

In the 13 century the Italians used a chart called a Portolano which showed an outline of the coast.

It was one of the earliest charts and also contained land features and safe anchorages.

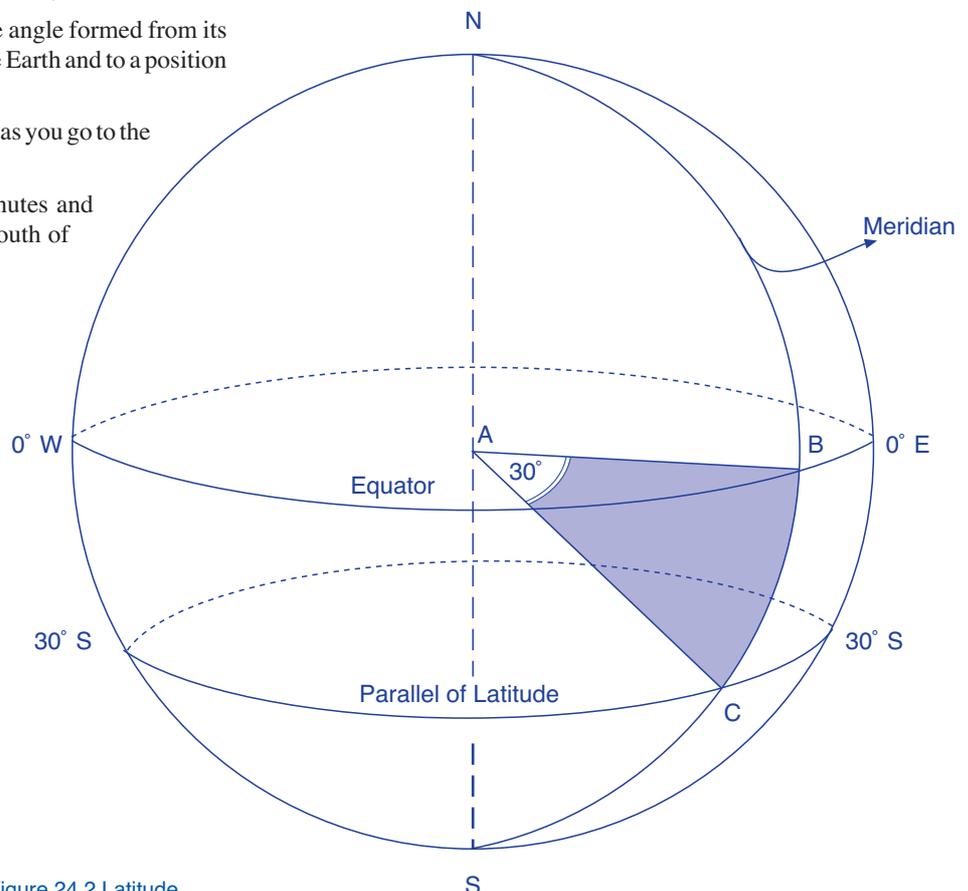


Figure 24.2 Latitude
Wet Paper

Challenge



- Do you believe the Earth is round?
Give three pieces of evidence to support your belief.

Longitude (Meridians)

Meridians are the imaginary great circles drawn on the surface of the Earth passing through both poles. These lines converge at the poles and are perpendicular to the Equator. The meridian or line passing through Greenwich (London) is called the Prime Meridian (Greenwich) and indicates zero degrees.

The longitude of a position is the angle (up to 180°) East or West of Greenwich that is formed when a triangle is drawn from one's position on the surface of the Earth to the centre of the Earth and back to Greenwich.

Lines of longitude are shown east or west of Greenwich and go up and down a chart (Figure 25.1).

If the Earth rotates 360 degrees in 24 hours it will therefore rotate 15 degrees in 1 hour.

Time	=	Arc
24 hours	=	360°
1 hour	=	15°
60 minutes	=	15°
4 minutes	=	1° = 60'
1 minute	=	15'
4 seconds	=	60"
1 second	=	15"

Message to "light" on the horizon

"This is the HMAS Enterprise to the light on the horizon, please alter course."

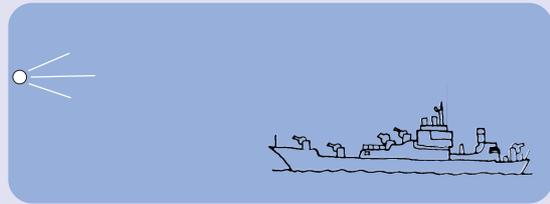
"This is the light on the horizon, please alter your course."

"This is the HMAS Enterprise, we are well armed and dangerous, I suggest you alter course."

"This is the light on the horizon, we don't care, please alter your course."

"This is the HMAS Enterprise, I you don't alter course we will RAM you, IDENTIFY YOURSELF."

"This is the lighthouse keeper of the light on the horizon, RAM at will."



Which is first

Latitude is usually followed by longitude

Eg: 24° 02.5' S, 162° 06.8' E

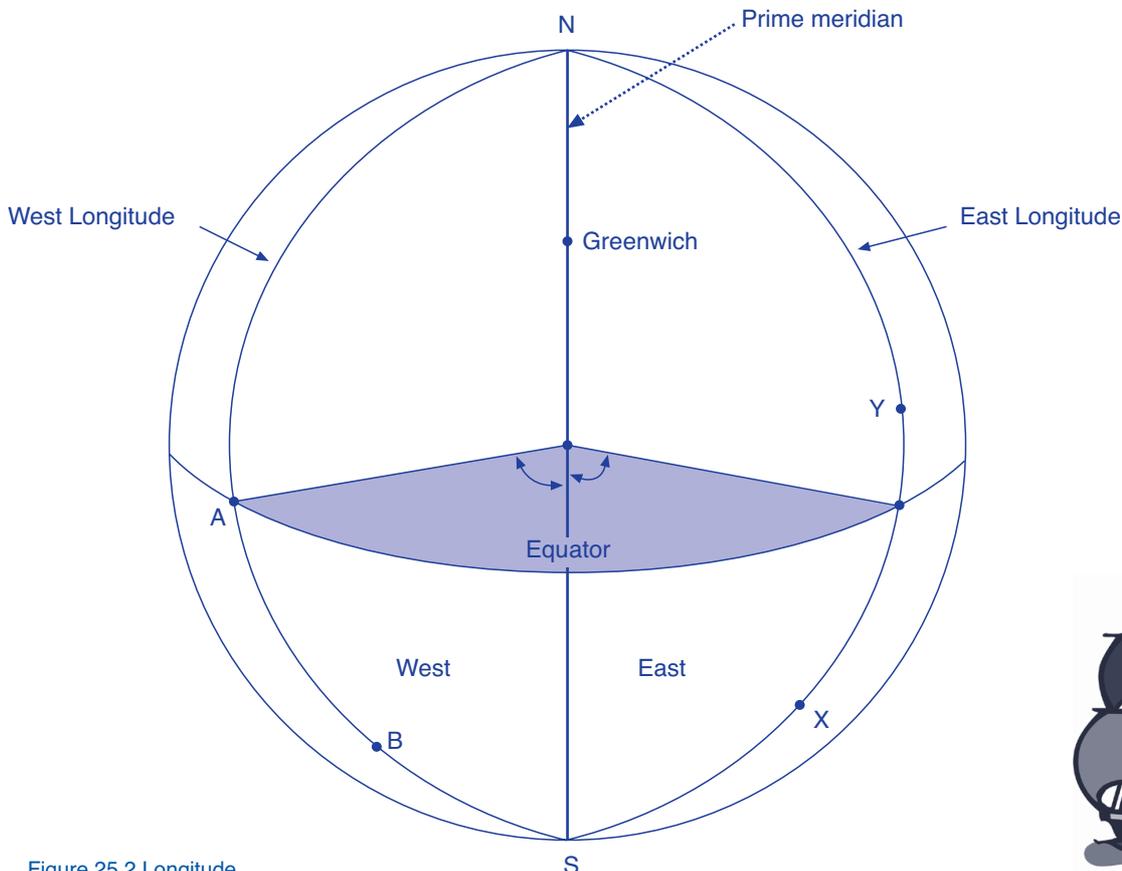


Figure 25.2 Longitude

Wet Paper

The mercator chart

Important features of charts based on the Mercator projection are:

1. Parallels of latitude are all straight lines although the distance between them increases as the latitude increases as shown in Figure 26.1
2. Rhumb lines are curved lines on the surface of the Earth that cut all meridians of longitude at the same angle. These are shown in Figure 26.2.

These are shown in Figure 26.2.

Challenge



- Two penguins are standing at the south pole.

One walks towards the north the other in the opposite direction. In which direction would the second penguin be walking? Explain your answer.

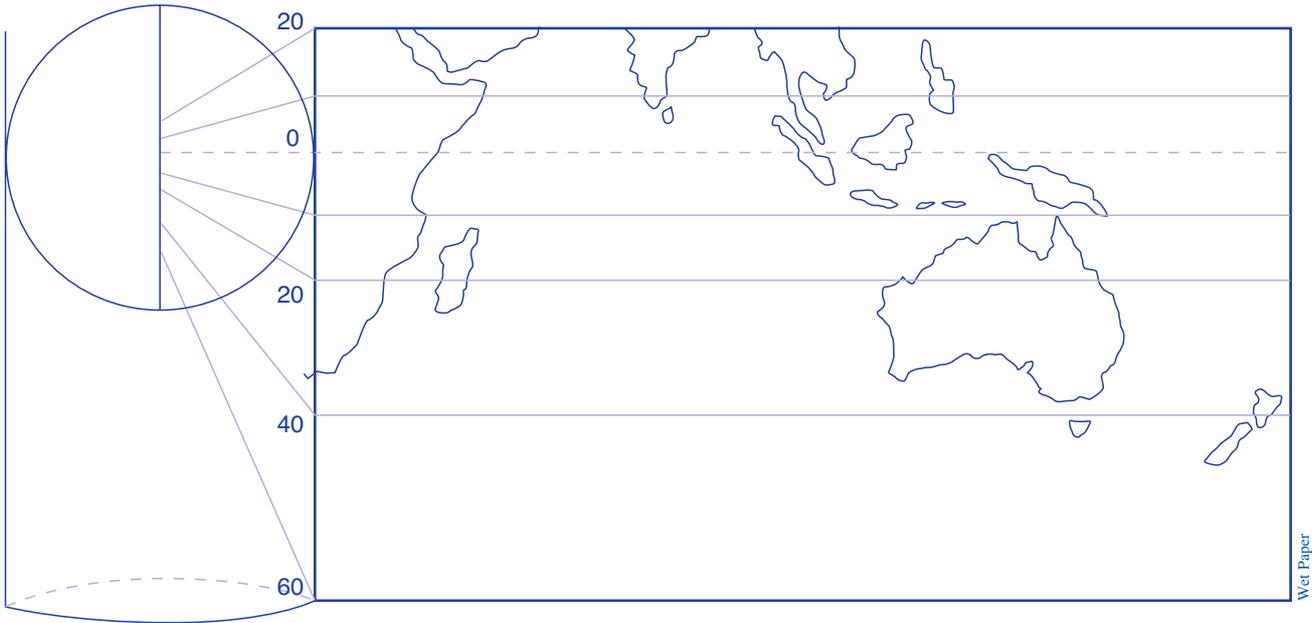


Figure 26.1 Parallels of latitude are all straight lines although the distance between them increases as the latitude increases.

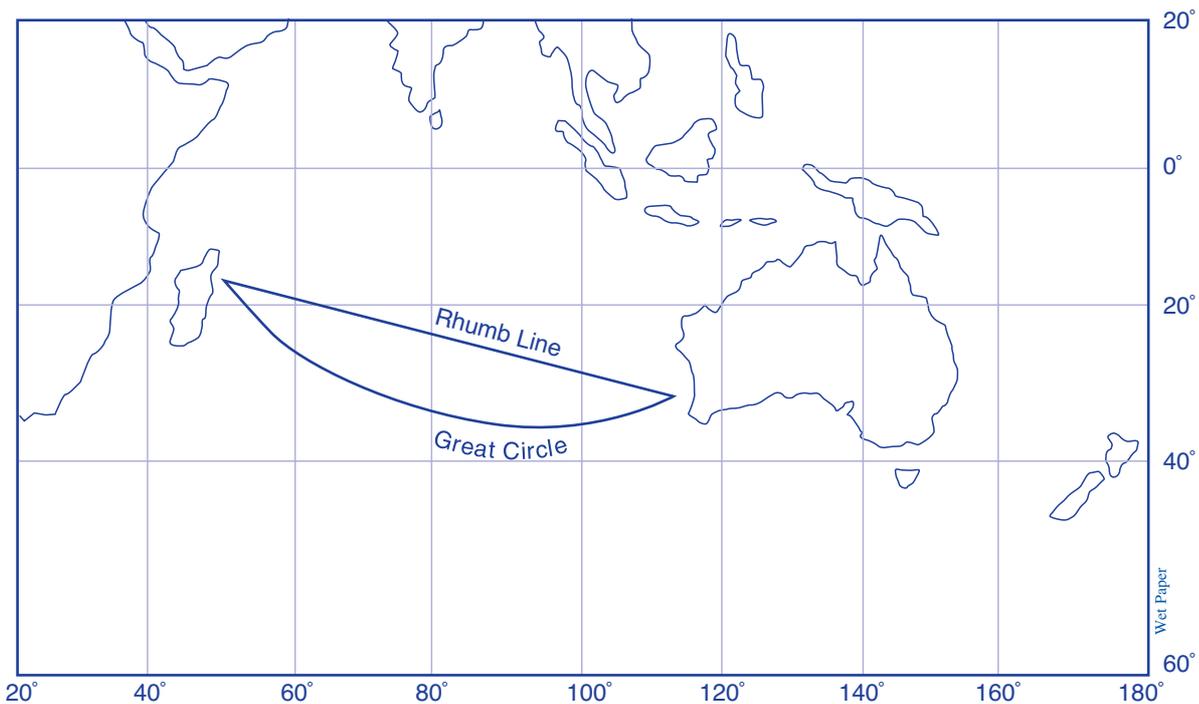


Figure 26.2 Rhumb lines or courses between two positions on the chart appear as straight lines.

- All the meridians appear as straight lines, which are perpendicular to the Equator. These meridians are equally spaced as shown in Figure 27.1.

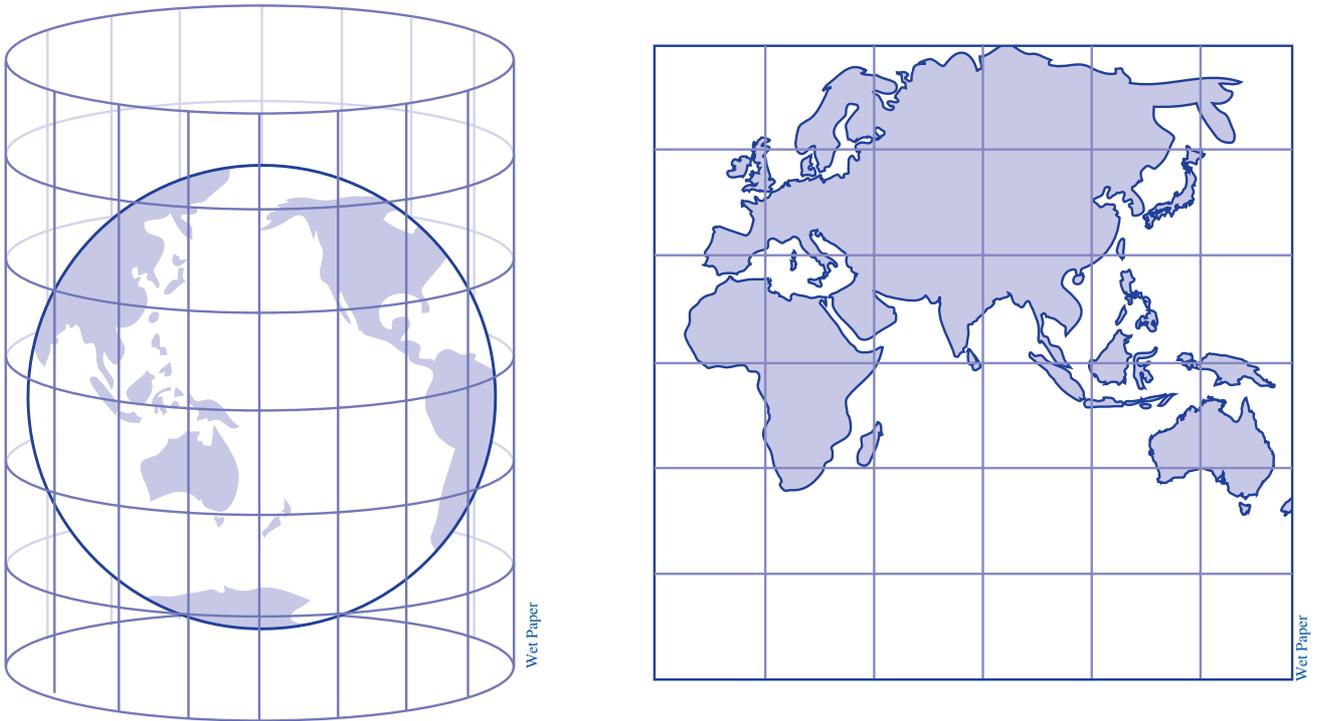


Figure 27.1 All the meridians appear as straight lines, which are perpendicular to the Equator.

Small scaled charts

In this map of Australia, we can see that there are a number of areas marked out. These are the small scaled charts which will show a large area. They are not much good for local conditions and should not be used for Worksheet one. Their main use is in large ocean voyages for calculations of positions.

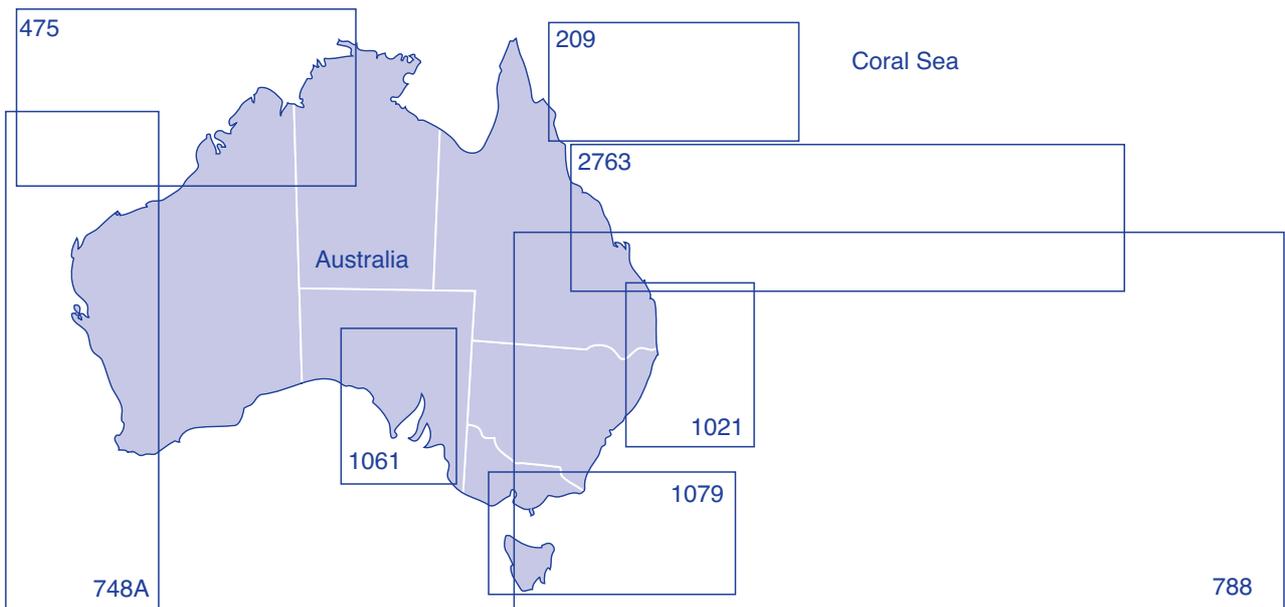


Figure 27.2 Small scaled charts are used for large areas of water

Wet Paper.

An important chart feature – depth

The depth printed on the charts are called soundings, which have been reduced to a common level known as the chart datum point. This datum point is the lowest astronomical tide (LAT) or the lowest low water spring tide in that area. These are therefore close to the minimum depth in the area and the height of the tides must be calculated to predict a real depth. (Tides are discussed in another workbook in this series.)

Most charts are now metric charts and a depth reading of 3₆ is 3.6 metres. If the chart is in fathoms (1 Fathom = 6 feet) a recording of 3₄ is 3 fathoms and 4 feet or 22 feet. 1 metre = 3.25 feet.

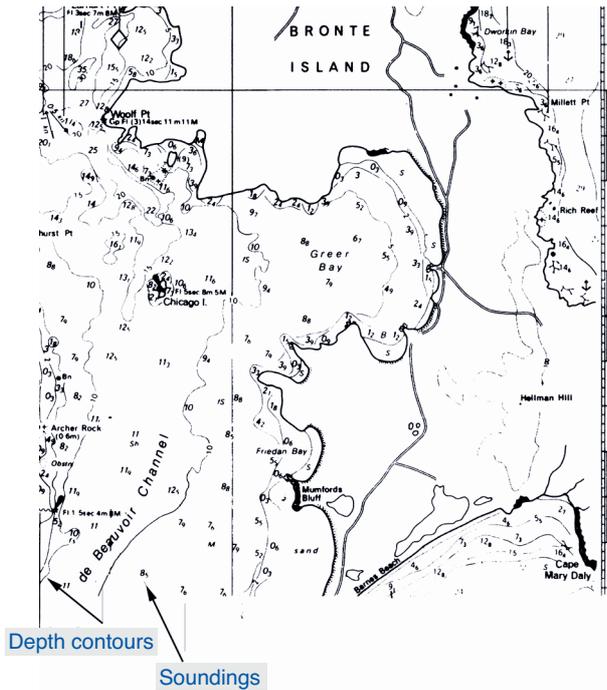


Figure 28.1 Depth sounder mounted in wheelhouse of small boat. (Photo Courtesy Dave Claridge)

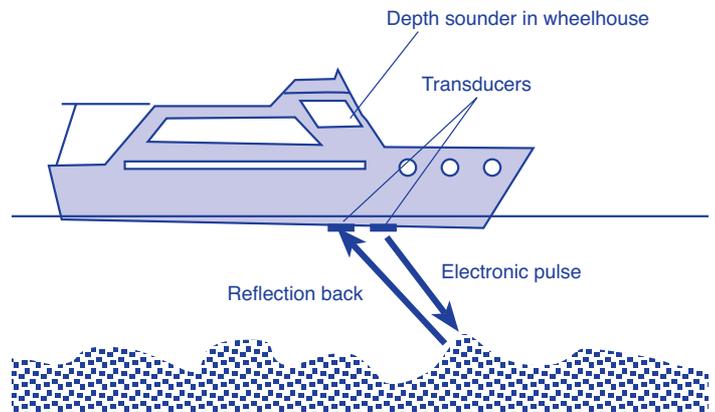


Figure 28.2 How a depth sounder works.
Wet Paper

Chart tidal datum

Chart datum is the level of water that charted depths on a nautical chart are measured from.

Figure 283 shows that the datum is derived from the lowest point of mean low water springs.

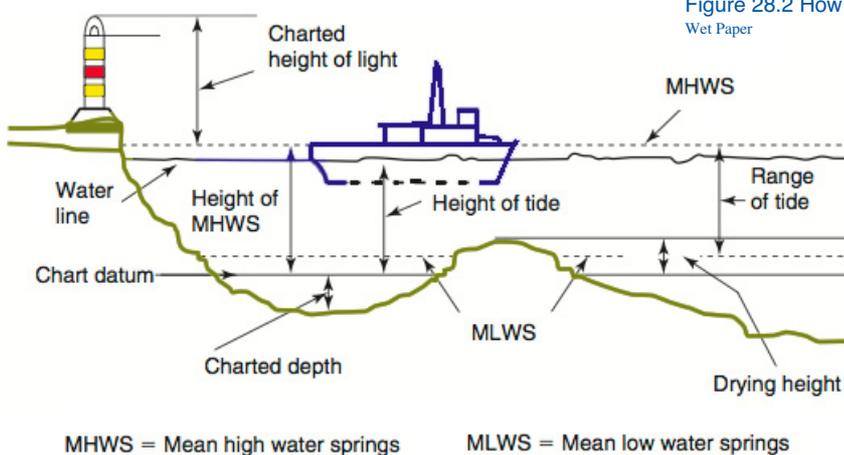


Figure 28.3 Tidal terms of reference

The rule of twelfths
This allows you to calculate the height of a tide below a boat and is discussed later.

WORKSHEET 8 YOUR LOCAL CHART

When you look at charts for the very first time they look quite complicated. This Worksheet seeks to introduce you to some chart features that don't occur on a map. Later activities will help you use the chart.

Materials

- chart of the local area
- map of the local area

Method

1. As a class, look carefully at the map and then at the chart and write a list of 10 differences between the chart and the map on the classroom blackboard, giving your reasons for the differences.
2. Now answer the questions below.

Questions

1. What is the deepest section of water on the chart?

2. What is the most northerly point on the chart?

3. Why does a chart need latitude and longitude?

4. What date was the chart prepared?

5. Is there a scale on the chart and if so what scale is used?

6. What are the main shipping lights nearest the local port?

7. What is the main degree of longitude and latitude?

8. Is the chart in fathoms or metres?

9. If you had to navigate a ship into port, why would you use a chart rather than a map?

10. Locate the photographs of the navigation marks in this workbook and tick off from the list below those you can identify.

- Starboard lateral mark []
- Port lateral mark []
- Port hand floating can []
- Starboard mark on pole []
- Port mark on pole []
- North cardinal mark []
- South cardinal mark []
- East cardinal mark []
- West cardinal mark []



Figure 29.1 A North cardinal mark

11. Select a venue for an overnight stay on your chart, noting:

- a. What time you should leave to arrive three hours before sunset?

- b. Will tides affect your trip? If so, how?

- c. How far are you going?

- d. What type of boat will you be in?

- e. What types of forecast will cancel your trip?

- f. How much fuel will you need?

- g. What will be your first compass course?

- h. How many course changes will you be making?

- i. What type of buoyage system (if any) is shown on your chart?



Figure 29.2 Offshore islands

WORKSHEET 9

HYPOTHETICAL BAY

Based on an original idea by Bob Moffatt

There are many things to learn about navigation. To navigate outside of the classroom requires skills and knowledge that come later in this set of notes. However for the present let us look at how to use a *chart*. The one we will use will be Hypothetical Bay

Questions

Use an atlas to find a map of Australia showing a Mercator projection.

1. What are the northern most and southern most latitudes?

2. What are the eastern most and western most longitudes?

3. Where is Greenwich? What line of longitude passes through it?

4. Name one place the Tropic of Capricorn passes through

5. What is the latitude of your school?

6. Look carefully at the latitudes and longitudes of Hypothetical Bay.

a. Is the bay in the Northern Hemisphere or Southern Hemisphere?

b. Off what continental shelf is the bay located?

c. How big is the bay approximately in kilometres?

Look carefully at Hypothetical Bay opposite and answer the questions below.

7. List any six chart features that are not found on a map.

8. Where are the deepest and the shallowest parts of the chart?

9. Use Worksheet 10 to make drawings of each of the following features:

• wreck _____ • direction of buoyage _____

• light _____ • water tower _____

• sectored light _____ • special mark _____

• hill _____ • rocky headland _____

• airport _____ • breaking waves _____

• coral reef _____ • stony beach _____

• sounding _____ • mangrove area _____

• sounding line _____ • starboard lateral unlit mark _____

• beacon _____ • sandy beach _____

10. What is the depth of water at the entrance to Jensen River?

11. What is the difference between pilotage and buoyage? Use your textbook index to write a definition of each.

12. What is the depth of water in Claridge Inlet?

13. Where is Thelma's Point?

14. What is found in Watson Swamp?

15. Describe the coastline features around the mouth of Lynch River?

16. Name any three hills over 500 m.

17. Name the two islands in the bay.

18. What is the speed of the ebb tide off Maclean Reef?

19. What is the sea floor made of in Perry Shoals?

20. What is the sea floor and surrounding coastline made of around Langley Reef?

WORKSHEET 10 YOUR OWN CHART

Project

Make up a hypothetical bay of your own using the symbols on this page.

Additional references

Chart and chart symbols and maritime buoyage system, published by the Hydrographer of the Navy, 1982, Commonwealth of Australia.

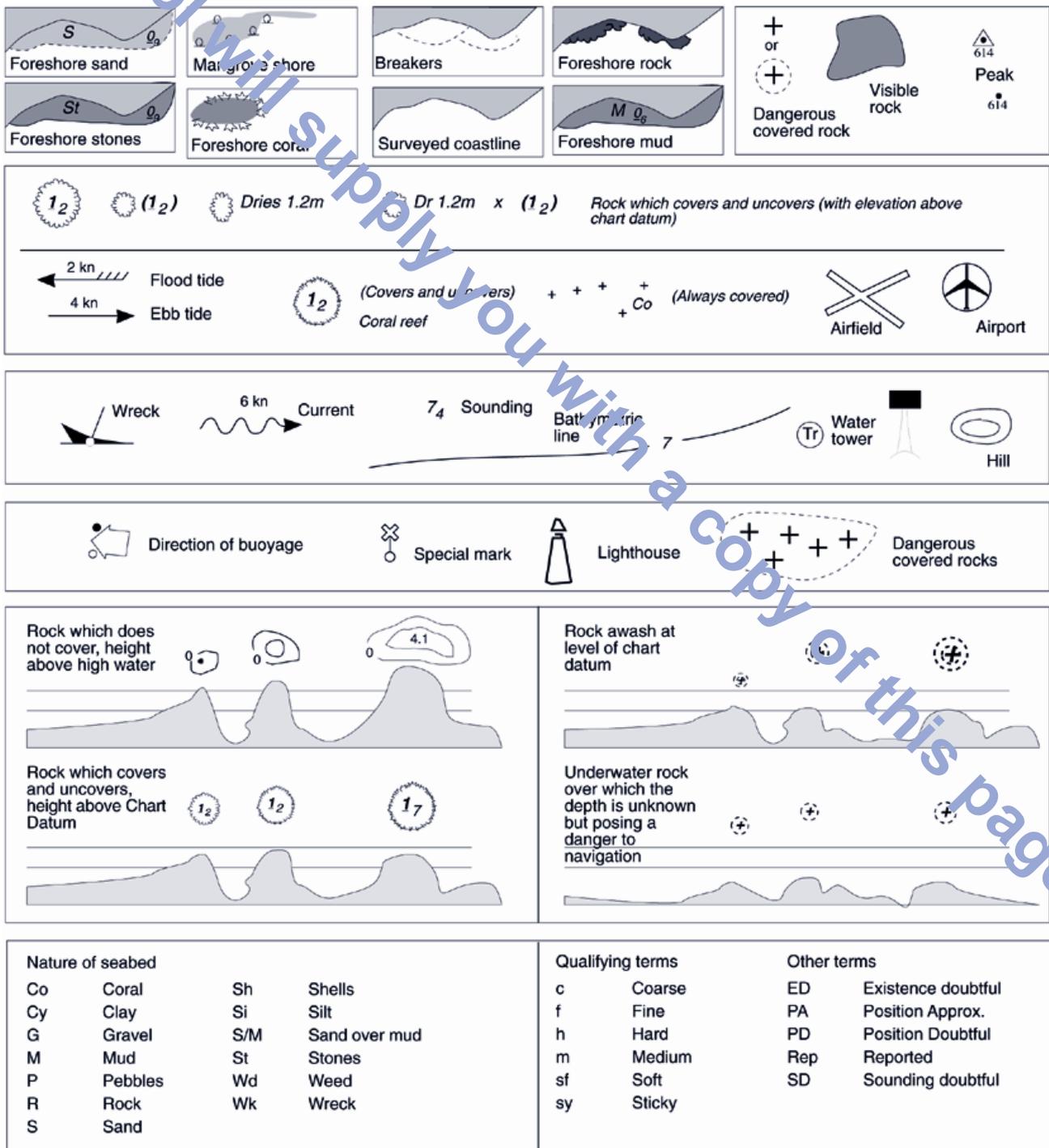


Fig 13.1 Common chart symbols

Wet Paper

WORKSHEET 11 CHART FEATURES



1. Lights

Suggest what you would observe at night if the chart features below were sighted:

F1 R2s

F1 (3) 10s

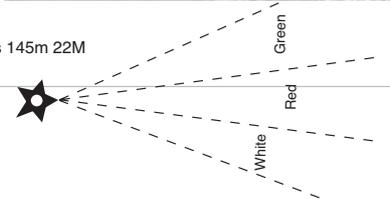
F1 (2) C 5s

F1 (2) 6s 52m 7M

F1 G 6s

F1 (2) WRG 10s

F1 (3) WRG 10s 145m 22M



2. Nature of Seabed

Describe the nature of the seabed in areas labelled

Cy

Cc

M

Si

Wk

S/M

Wd

St

3. Complete the sentences by drawing the following features:

a. Coral reef which is always covered

b. A flood tide of 3 knots

c. A submerged hazard

d. A rock which will be uncovered at low tide

e. A rock which will be 2 metres above at high side

f. An underwater rock which is considered dangerous

4. Make up a chart below using the correct symbols

Rocky area

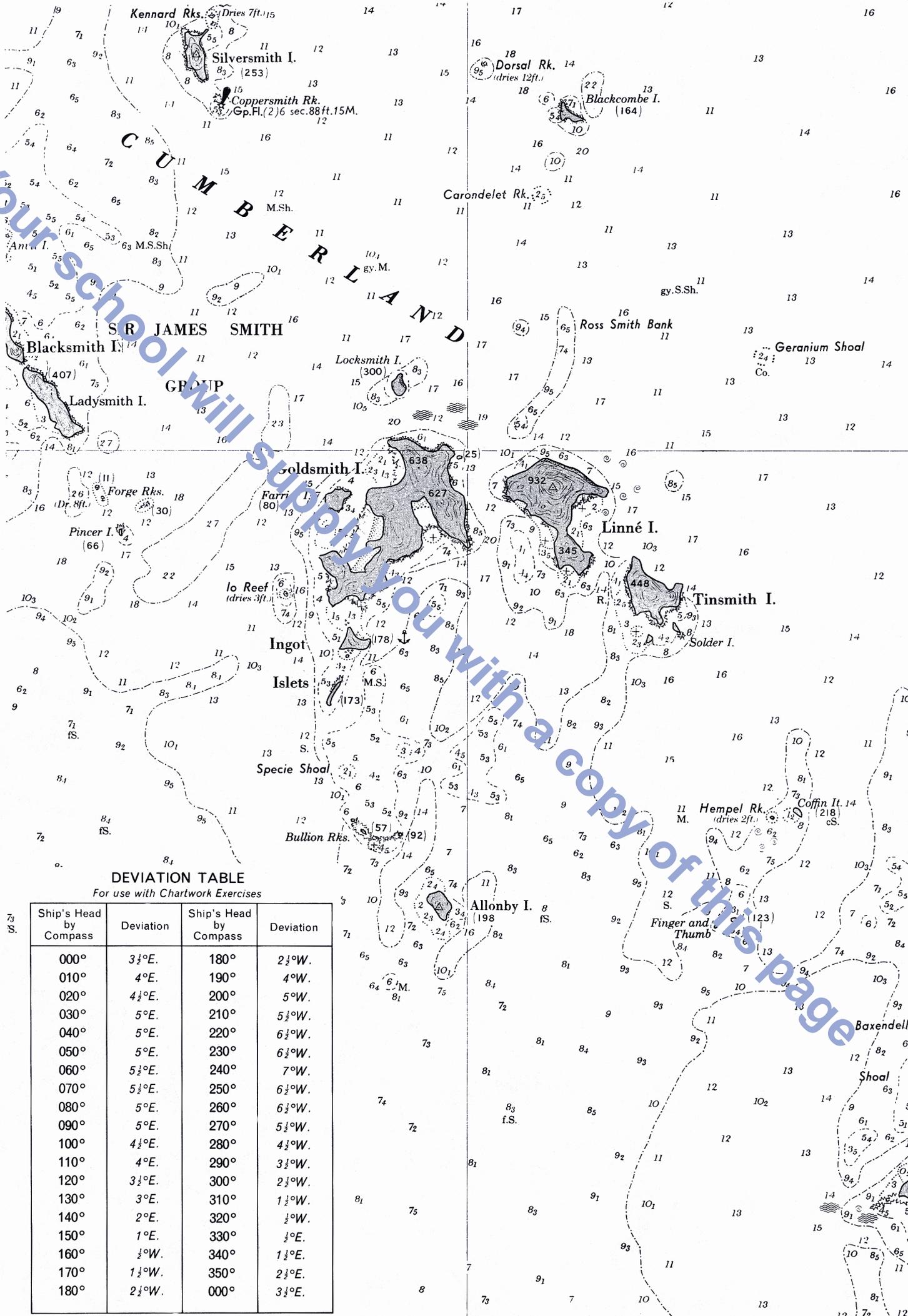
Coral reef

breakers

Submerged hazard

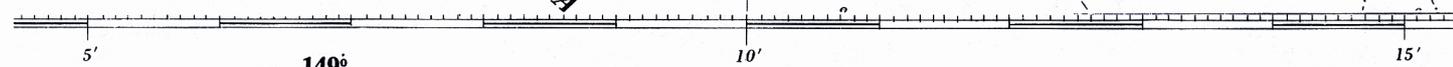
foreshore coral

Your school will supply you with a copy of this page



DEVIATION TABLE
For use with Chartwork Exercises

Ship's Head by Compass	Deviation	Ship's Head by Compass	Deviation
000°	3½°E.	180°	2½°W.
010°	4°E.	190°	4°W.
020°	4½°E.	200°	5°W.
030°	5°E.	210°	5½°W.
040°	5°E.	220°	6½°W.
050°	5°E.	230°	6½°W.
060°	5½°E.	240°	7°W.
070°	5½°E.	250°	6½°W.
080°	5°E.	260°	6½°W.
090°	5°E.	270°	5½°W.
100°	4½°E.	280°	4½°W.
110°	4°E.	290°	3½°W.
120°	3½°E.	300°	2½°W.
130°	3°E.	310°	1½°W.
140°	2°E.	320°	½°W.
150°	1°E.	330°	½°E.
160°	½°W.	340°	1½°E.
170°	1½°W.	350°	2½°E.
180°	2½°W.	000°	3½°E.



HILLSBOROUGH CHANNEL

FROM SURVEYS BY THE ROYAL AUSTRALIAN NAVY to 1960
with additions from Colonial-Admiralty Surveys to 1885

Skiddaw Peak Lat. $20^{\circ} 46' 10''$ S. Long. $149^{\circ} 17' 2''$ E

*Underlined figures express, in Feet, Drying Heights above Chart Datum.
All other Heights are expressed in Feet above Mean High Water Springs.
For abbreviations see Catalogue and Index of Australian Charts
and Admiralty Chart 5011.*

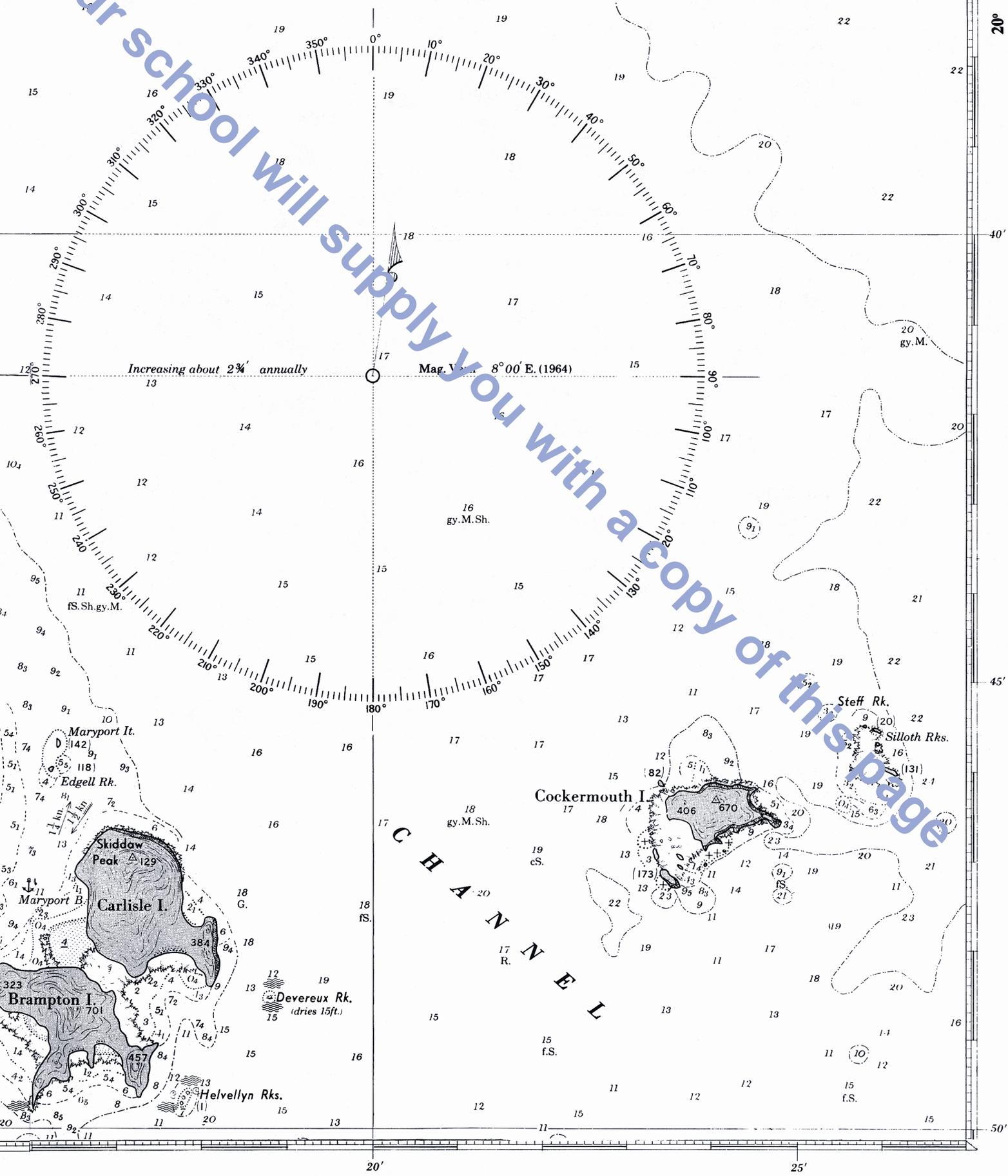
SOUNDINGS IN FATHOMS
(Under Eleven in Fathoms and Feet)

NATURAL SCALE 2:3

1 : 100,000 (at Lat. $20^{\circ} 30' S.$)

Projection Mercator

Chart tidal datum ¹⁹
Chart datum is the level of water
that charted depths on a nautical
chart are measured from.
¹⁸



Your school will supply you with a copy of this page

SECTION 5 CHART WORK

Chart work involves using a chart and other instruments to navigate a vessel. For example a vessel's position on a chart can be given by finding the latitude and longitude.

The latitude scale is marked on the side of the chart and the latitude increases as one moves further from the Equator. It increases as you go down the chart in the Southern Hemisphere. The longitude scale is marked across the top of the chart and increases eastward in Australia.

The nautical mile

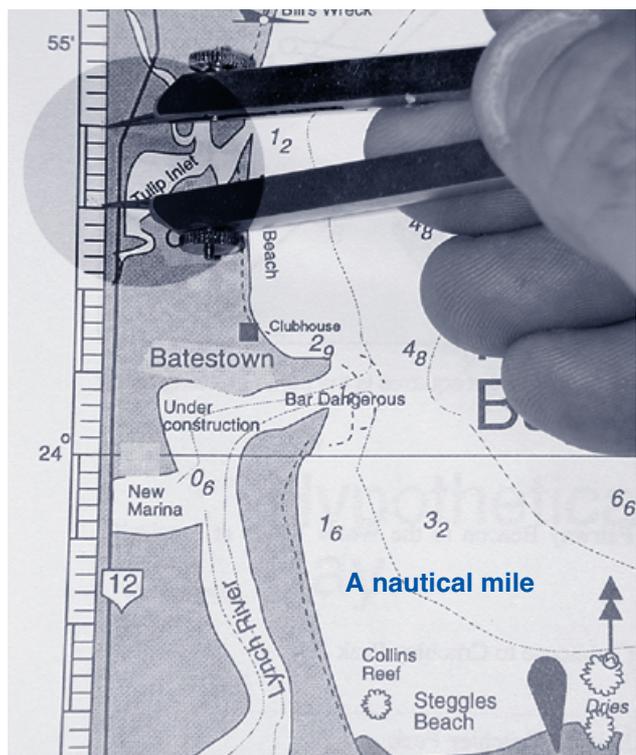
Because the Earth's surface is divided up in degrees and minutes, normal kilometres and metres are not used. The scale of measurement used is the nautical mile, which is represented by one minute of latitude.

1 Nautical Mile = 1 Minute of Latitude

Thus, few charts carry separate distance scales, the scale on the left or right side of the chart being used to measure nautical miles in any direction.

Distance is measured by dividers.

The spread of the divider's points are used to carry the measurement of the latitude scale, where it can be read off in minutes. Because of variations due to the chart's distortion, distance readings should be taken from the latitude scale at a point approximately level with the boat's position.



Speed and distance

These two factors are related by a formula that involves distance and time.

Think of the speed of a car. It is measured in kilometres per hour.

Speed is the total distance travelled, divided by the total time taken, and can be summarised in the magic triangle as shown in Figure 36.2

The speed of a vessel is measured by a speed log.

This computes the time it takes to travel a nautical mile.

Speed is measured in knots. The log on a boat shows distance and sometimes speed. Distance logs are more important because they can be combined with travelling time to compute a boat's speed.

The nautical mile is equal to a boat travelling at one knot for one hour or the distance travelled in one hour by a boat travelling at one knot.

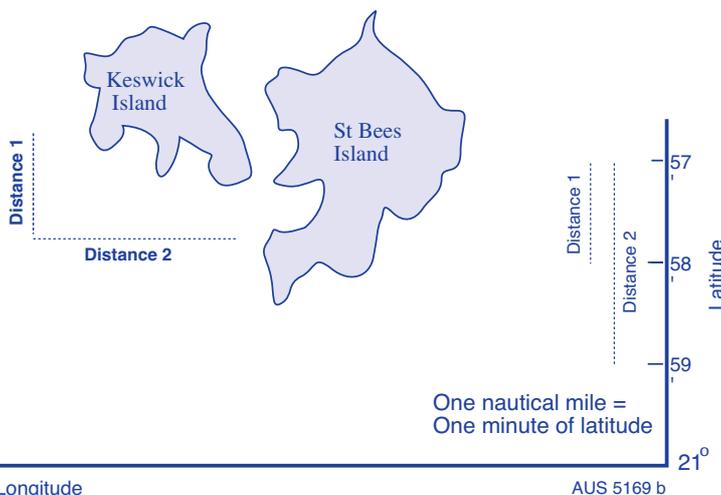
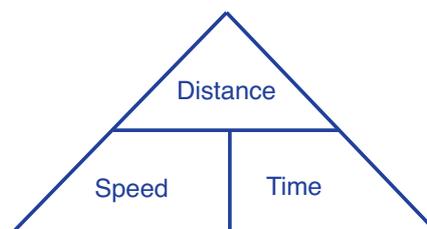


Figure 36.1 The nautical mile: Unit of distance equal to one minute of latitude. 1 n.mile = 1.852 km
Wet Paper



The magic triangle. Place finger on what you want to find to obtain formula

Figure 36.2 Formulas for distance, speed and time
Wet Paper

A navigator may be called upon to calculate three possible factors:

Boat speed = distance / time

Distance = speed x time

Time = distance / speed

Plotting a course

Plotting a course involves drawing lines on a chart to indicate where you want to go.

The main navigational instruments used for plotting, measuring speed or distance, depth, and direction are:

- dividers
- parallel rulers
- protractors
- plotters

A divider as shown in Figure 37.1, is an instrument that basically consists of two metal arms with pointed ends. These arms can be drawn apart to a fixed distance and it will hold this distance by friction at the hinge. Distances can be accurately transferred from a chart to a grid or ruler. If one of the arms has a pencil for drawing it is called a beam compass.

Parallel rulers basically transfer a line, parallel to the original line. It consists of two rulers hinged together and one ruler is held firm while the other arm is moved (walked) to a parallel position. It is mostly constructed of plastic and metal. A cheap substitute is the use of two triangles to produce a parallel line as shown in Figure 37.2.

A protractor is a device used in the measurement of angles on a chart. It is a graduated arc of usually 180 degrees and is made of plastic or metal.

A plotter is basically a protractor combined with a ruler. Some plotters have moveable parts.

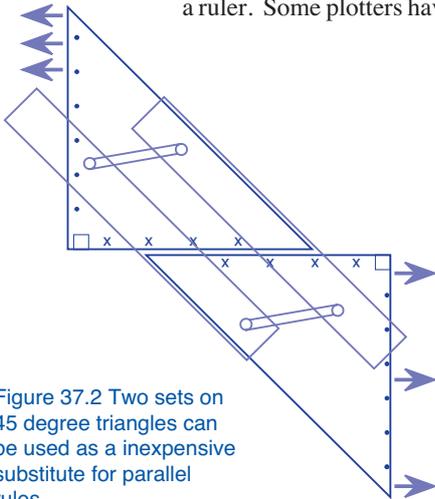


Figure 37.2 Two sets on 45 degree triangles can be used as an inexpensive substitute for parallel rules.

Wet Paper

Challenge



1. Wood fires maintained by Priests along the Mediterranean coast of Egypt were the first forms of lighthouses. Our coastline is dotted with old lighthouses. Why are the number of these lighthouses decreasing and not increasing?
2. Explain why the great exploration voyages of the 16 and 17 centuries were difficult to insure. Also few details of some of these expeditions were recorded. Suggest why.

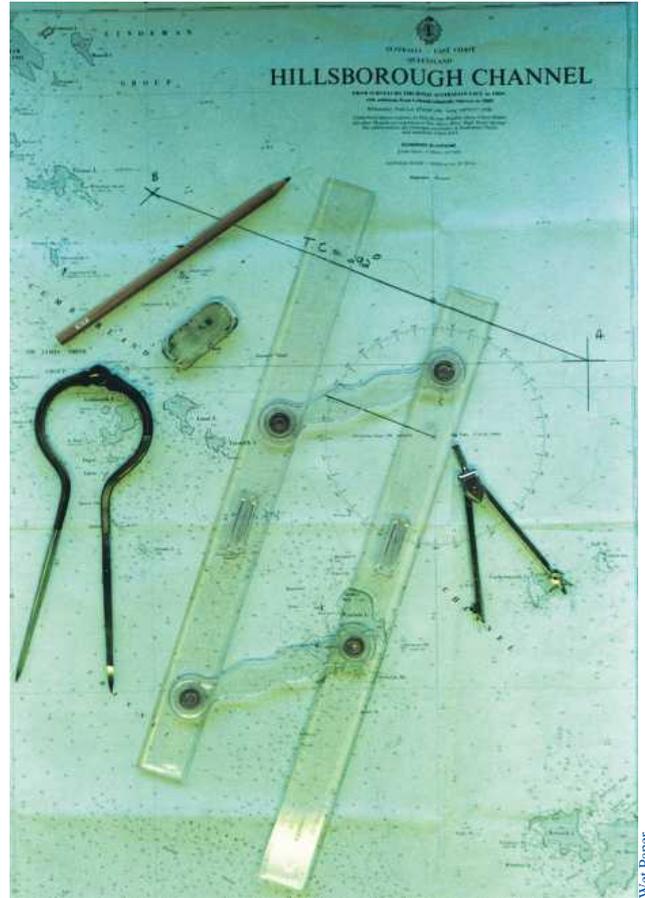


Figure 37.1 Some navigation instruments

Using parallel rules

Obtain two 90° set squares or parallel rules and complete the following tasks on the Hypothetical Bay chart.

1. 'Walk' the instruments from the top of the chart to the bottom, keeping the sides parallel. Now 'walk' the squares from one corner to the other, keeping the bases parallel.
2. Place one of the squares so that the hypotenuse lies over the Fairway Beacon and Paula's Light. Draw a light line between the two (remember that you will have to rub out all lines at the end of the exercise).
3. Now place the side of the other square opposite the side of the first square. Slide the second set square down the page until the hypotenuse of the second square is over the centre of the compass rose.
4. The bearing from Paula's Light to the Fairway Beacon can now be read from the number of degrees shown on the compass rose. What did you get? Discuss with your teacher the level of accuracy required in this exercise.



WORKSHEET 12

LATITUDE AND LONGITUDE

Notes: In these early exercises the compass rose has been left off the map of Hypothetical Bay. A nautical mile is one minute of latitude.

Questions

Use a ruler to find the latitude and longitude of the following places. Remember lines of latitude run down from the Equator and lines of longitude run east or west of Greenwich as shown in Figure 38.1 below.

1. Find the latitude and longitude of the following points:

- a. Gregory Light _____
- b. Paula's Light _____
- c. Pamela's Light _____
- d. Tony's Wreck _____
- e. Fishing Club on Claridge Inlet _____
- f. Airport at Lewisville _____
- g. Rickard Light _____
- h. Hamlyn Light _____
- i. the mouth of Kontos Creek _____
- j. Ryan Point _____
- k. the peak of Halpin Hill _____

2. Name the charted features at the following positions of latitude and longitude.

- a. $23^{\circ} 54' S$, $161^{\circ} 53' E$ _____
- b. $23^{\circ} 52' S$, $161^{\circ} 56' E$ _____
- c. $24^{\circ} 02' S$, $162^{\circ} 06' E$ _____
- d. $24^{\circ} 11' S$, $161^{\circ} 54' E$ _____

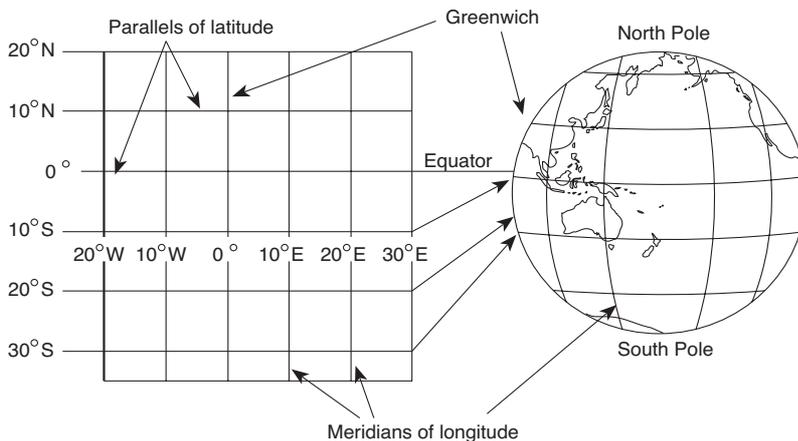


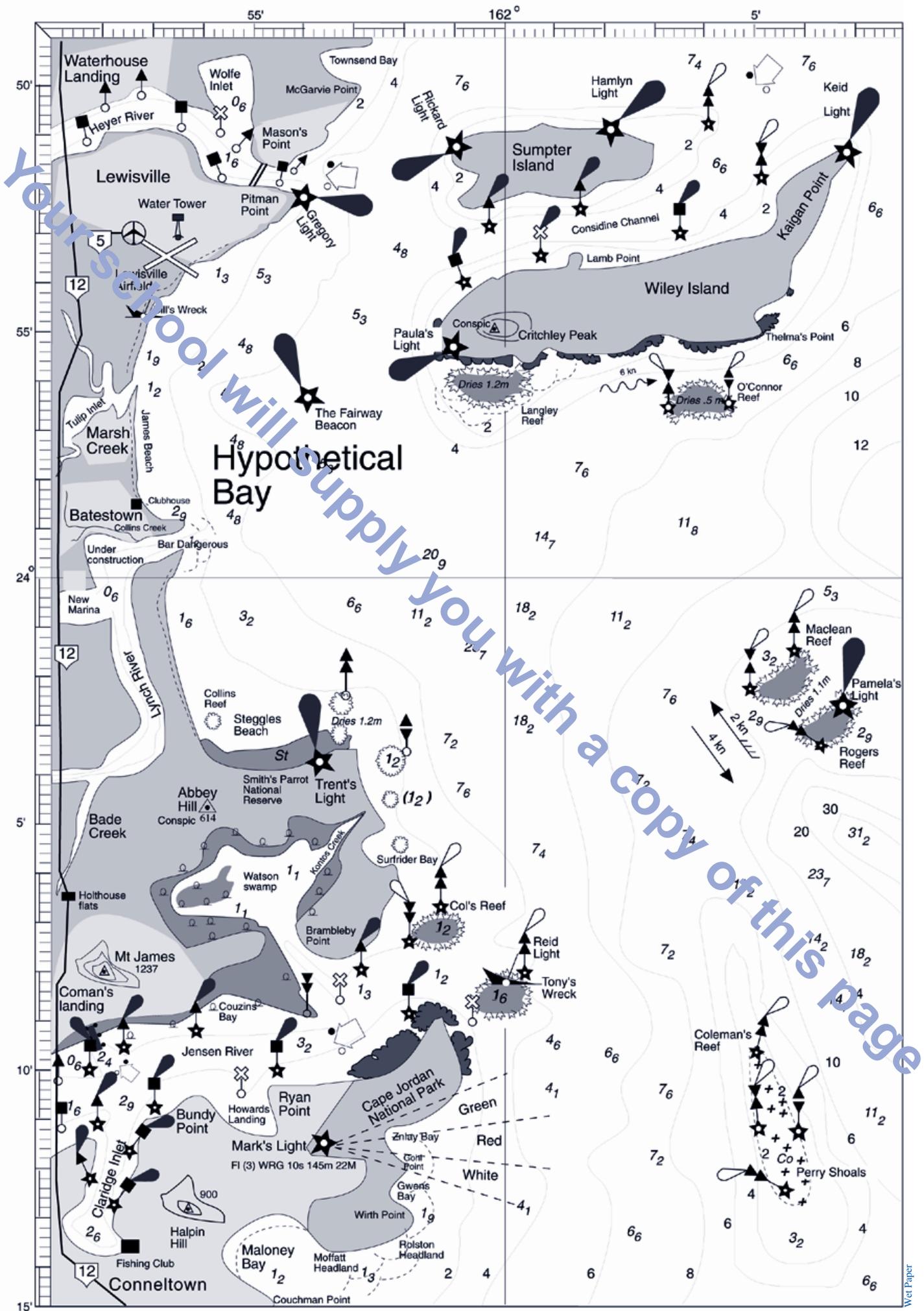
Figure 38.1 Wiley Island

- e. $24^{\circ} 02.5' S$, $162^{\circ} 06.8' E$ _____
 - f. $24^{\circ} 11.6' S$, $161^{\circ} 56.2' E$ _____
 - g. $24^{\circ} 6.6' S$, $161^{\circ} 51.2' E$ _____
3. Find two features at different latitudes but the same longitude.

4. Find two features at different longitudes but the same latitude.

5. What is the safest navigable distance between the following places for a deep draft vessel?
- a. Gregory Light and the Fairway Beacon _____
 - b. the Fairway Beacon and Trent's Light _____
 - c. Gregory Light and Keid Light _____
 - d. Keid Light and Maloney Bay _____
 - e. The north point on Maclean Reef and Bundy Point in Jensen River. _____
 - f. the Southern Mark on Ferry Shoals and Waterhouse Landing _____
6. Calculate the size of the following places:
- a. Watson Swamp _____
 - b. the new marina in Lynch River _____
 - c. Roger's Reef _____
 - d. Wiley Island _____

Figure 38.1 Latitude and longitude
Wet Paper



WORKSHEET 13

DISTANCE, SPEED AND TIME

Method

This exercise allows you to practise using the nautical mile to determine speed and time.

Remember one knot is equal to one nautical mile per hour.

Worked examples

- a. How fast am I travelling if I cover 100 Nm in 5 hours?

$$S = D/T = 100 \text{ Nm} / 5 \text{ hrs} = 20 \text{ Nm/hr or } 20 \text{ knots}$$

- b. How far can I travel in 2 hours and 30 minutes, if I am travelling at 10 knots?

$$D = S \times T = 10 \text{ knots} \times 2.5 \text{ hrs} = 25 \text{ Nm}$$

- c. How long is it going to take me to travel 75 Nm if my boat travels at a constant speed of 10 knots?

$$T = D/S = 75 \text{ Nm} / 10 \text{ Nm per hr} = 7.5 \text{ hrs} = 7 \text{ hrs and } 30 \text{ minutes}$$



Questions

- How far can I travel in 10 hours if I am travelling at 9 knots?
- How far can I travel in 6 hours at a constant speed of 4 knots?
- For 2 hours I travel at 10 knots, and for the next 3 hours my boat can only make 5 knots. How far have I travelled?
- My boat travels 10 Nm in two hours. How fast did she go?
- I left harbour at 7 a.m. and travelled 5 Nm by 10 a.m. How well did my speed boat perform?
- If I set out in my sailing boat at 10.30 a.m. and reached my destination at 2 p.m. after travelling 35 Nm, what was my average speed for the trip?
- How long did it take a mariner to travel 20 Nm at an average speed of 5 knots?
- Your sailing boat is travelling at 4 knots and your navigator predicts 32 Nm to go. How many hours will it take to reach your destination?
- How far is it from the fishing club in Connelton to the 4 m line off Col's reef? My boat can do 6 knots and draws 2.9 m. When can I leave the fishing club on the morning of 4 January and how long will it take to get to Col's reef? Use the tide tables in Figure 40.1 to help you.
- How far is it from the port mark at the mouth of Heyer River to Lamb Point on Wiley Island?



Figure 40.1 Jensen River

- Wet Paper* I leaves the new marina on Lynch River at 0800 hrs and travels to $24^{\circ} 01'S, 161^{\circ} 59'E$. She can do 25 knots, but a 15 knot S/E is blowing and she can only make 12.

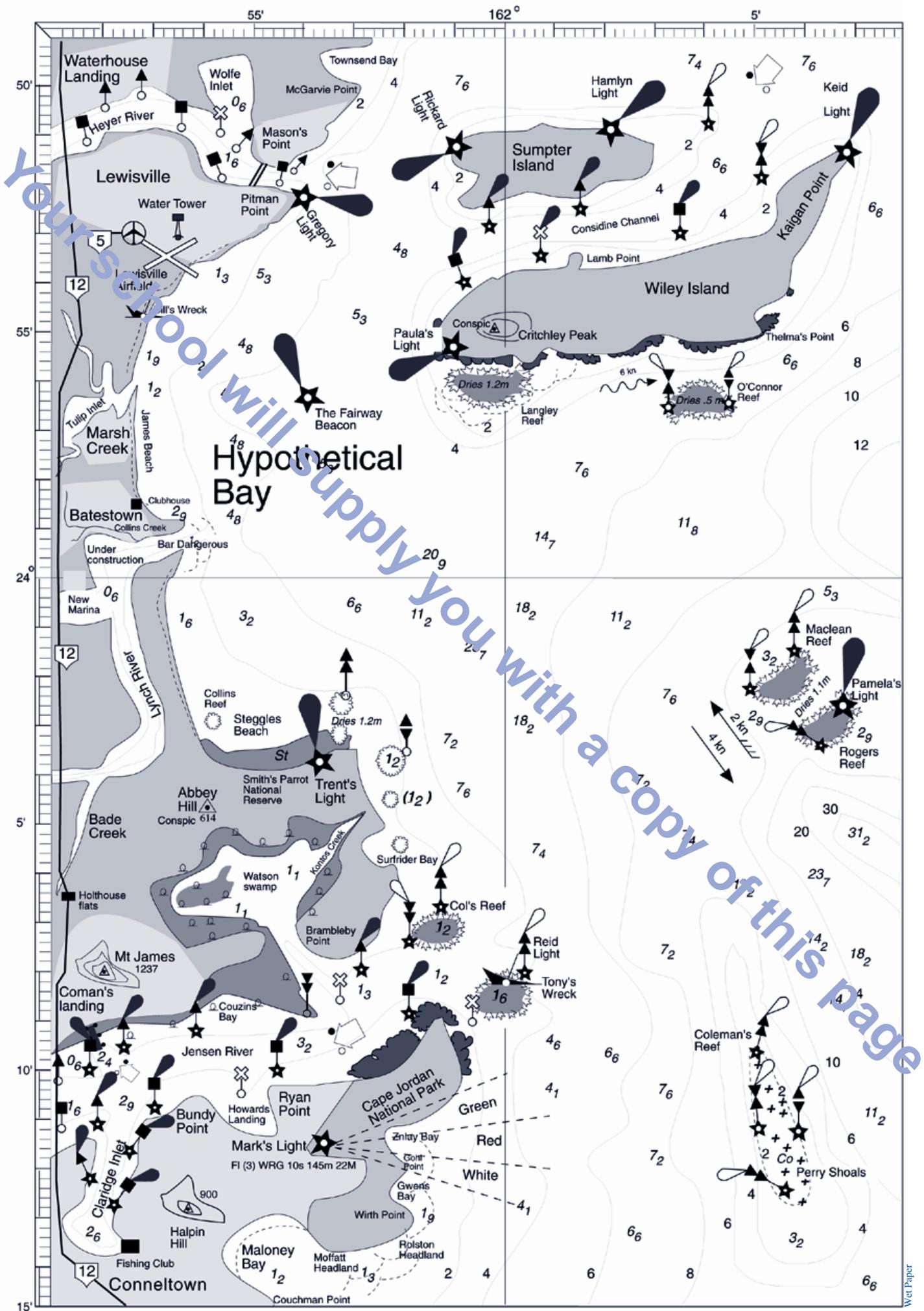
 - How long will she take to get there?
- Whales have been spotted off Thelma's Point. Can *Wet Paper I* make it in time for lunch? Show all working.
- Another vessel, *Whyamber*, can make 5 knots and travels from the same marina. How long will she take?
- If you were running a coach company and wanted to tap into the growing market of whale watching tourists from Hypothetical Bay, and your cousin has a restaurant at Marsh Creek, what bus schedule would you draw up for your operation? Lewisville airport can take direct flights from Tokyo and Sigatoka.

Tide tables for Jensen River

Date	Time	m	Date	Time	m
Jan 1	0221	0.99	Jan 4	0409	1.20
	0815	2.32		0930	1.93
	1424	0.51		1559	0.54
	2101	2.55		2252	2.66
Jan 2	0252	1.06	Jan 5	0502	1.99
	0835	2.22		1007	3.32
	1452	0.49		1642	0.71
	2133	2.58		2301	3.55
Jan 3	0321	1.16			
	0900	2.06			
	1524	0.51			
	2201	2.55			



Figure 40.1 Tides for Jensen River



SECTION 6 MAGNETIC EFFECTS

All navigators need to understand how a compass guides the ship as well as the errors caused by the Earth's magnetism and the steel in the ship. Figure 42.1 shows the Earth's magnetic field and explains why charts are corrected for east or west variations. The two most significant errors are variation and deviation.

Variation

This is the error caused by the magnetic and true poles being in different places.

Error is defined as the angle between True and Magnetic North caused by the Magnetic North pole moving. It manifests itself in every compass by deflecting the needle away from the true north until it is pointing at Magnetic North.

There may be a difference of up to thirty degrees or more between these poles and this is obviously a factor which must be taken into consideration when steering a course or taking bearings.

The deflection may be to the east or the west of True North, and varies as the boat progresses across the surface of the Earth. However, it is well plotted, and is listed on every chart so that the navigator can be immediately aware of its value.

Once found, the error is constant for that area, and changes only slowly as the boat progresses.

Deviation

This error is due to the effect of each ship's individual magnetic field.

It is found by creating a deviation card as shown in Figure 41.1 by swinging the compass around a known mark as shown in Figure 42.3.

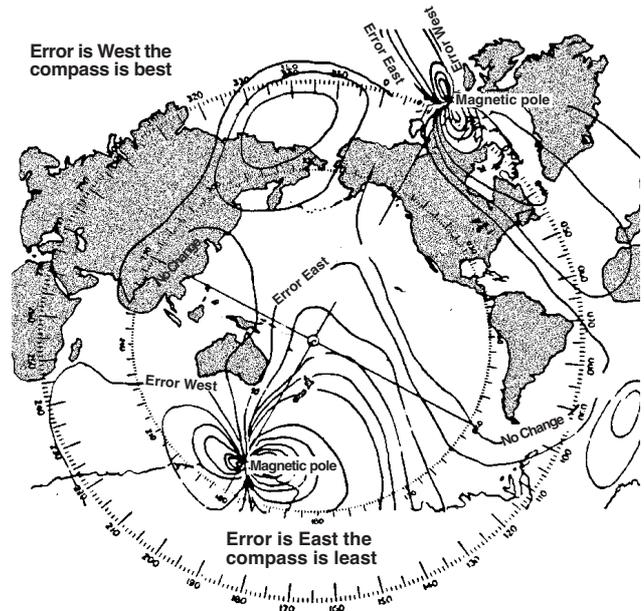


Figure 42.1 Magnetic North is now in Hudson Bay Canada.
Wet Paper

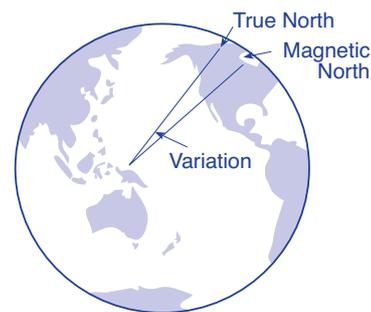


Figure 42.2 Variation
Wet Paper



Figure 42.3
A fixed mark is used to swing a compass on a small vessel.



Wet Paper

Swinging the compass

To find whether or not a deviation exists on your vessel's compass you will have to 'swing the compass'. If the vessel is a large commercial vessel intended for serious coastal and offshore work, the compass should have its deviations chart made up professionally, as well as having the compass adjusted. Fitting a compass binnacle and/or magnets inside the binnacle may reduce the deviation. A deviation chart will be set up for use with that compass.

The deviation of a compass in a smaller vessel may be evaluated by lining up a fixed mark and/or a charted mark with a distant conspicuous mark as shown in Figures 40.3 and 43.1.

Use the chart to find the true bearing and the variation to calculate the magnetic bearing. Compare the magnetic bearing with the compass bearing on the line as shown in **A** 2° East (Figure 43.1).

The vessel is then moved through each of the four compass bearings along the transit line and a note is taken between the compass bearing and the known chart bearing and a graph drawn. Note that for more accurate work eight bearings are used making a curved graph as shown in Figure 43.1.

Total error

Variation and deviation together give the compass error (sometimes called the Total Error or just Error).

Magnetic polarity reversals

One of the most remarkable characteristics of the Earth's magnetic field is that studies of the magnetic rocks in the Earth's surface reveal that the magnetic poles have been reversed in the past. It is believed these changes have occurred a number of times with the north pole changing to south and vice-versa. The last reversal occurred 730,000 years ago and the next is predicted for 1,300 years time.

Terms

Variation

is the angle between True and Magnetic North.

Deviation

is the angle between Magnetic and Compass North

Error

is the sum of Variation and Deviation

True North

True North (geographic north) is the basis of the lines of latitude and longitude.

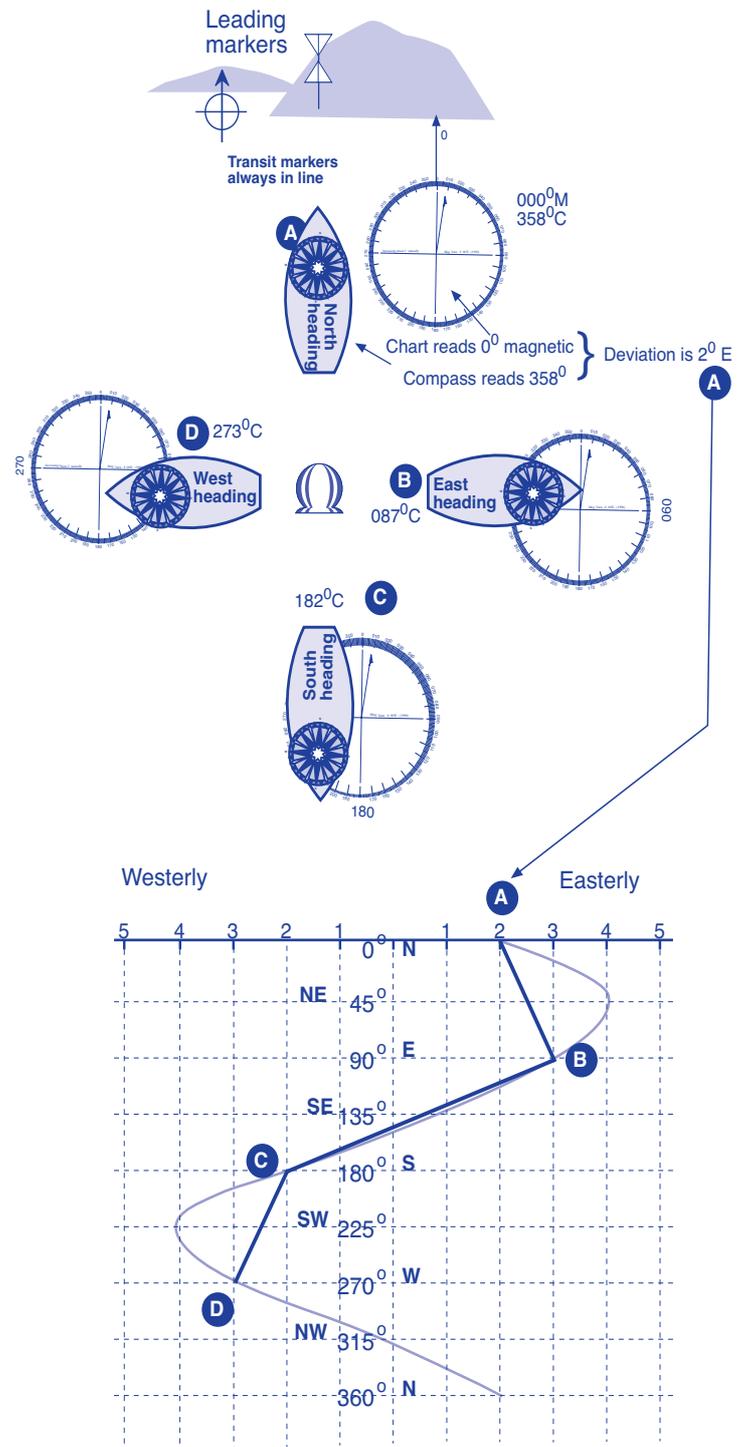


Figure 43.1 Swinging a compass

Wet Paper

Challenge



- Imagine you are a newspaper reporter interviewing a young person who has just sailed around the world alone. Why type of things might you ask this person? Give an account of the interview.

Compass conversions

In any location, the Earth's magnetic field is at an angle to the meridians of longitude, and so your compass (either steering or hand-bearing) does not point to the True North of the longitude lines on the chart.

Because of this we end up with three types of angular bearings which need to be interpreted for navigation.

True bearings

These are relative to True North and are taken off the compass rose on the chart or measured with a protractor against the grid lines of the chart.

- These are usually written with a T after the angle, eg 32°T means an angle of 32° to the True North of the chart.

Compass bearings

Compass bearings are relative to the Earth's magnetic field lines in the area, and are read off the hand bearing compass or the steering compass.

- Usually written with a C after the angle, eg 165°C means an angle of 165° to the Earth's magnetic field in that area.
- The bearing (or direction) from one position to another on a chart is found by drawing a line through the compass rose that is parallel to the line joining the position.

Variation

This is the local *variation* (for the particular year). It is taken off the compass rose information on your chart, and is always given in the direction of east or west to indicate which way the magnetic field lines are pointing as well as how far. Figure 43.1 shows the variation.

- Variation in 2002 for the compass rose shown in Figure 43.1 is as follows:

The variation was measured in 1964 as 8° 00'E

The number of years between 2002 - 1964 = 38 years

Therefore variation 2002 = 8° 00'E + (38 x 2.75)

$$= 8° 00'E + 104.5'$$

$$= 8° 00'E + 1° 44'$$

$$= 9° 44'E$$

Conversion rules

Rule 1

To convert between true and compass bearings we use the rule:

Error East - Compass Least

Error West - Compass Best (best means the bigger number)

The table below shows some examples.

Example	a.	b.	c.	d.	e.
True bearing	40°T	85°T	243°T	5°T	356°T
Variation (error)	8°E	5°W	10°E	10°E	12°W
Compass bearing	32°C	90°C	233°C	355°C	8°C

In example d. think of 5°T as 365°T before you subtract the 10°.

In example e. 356° + 12° = 368°, which becomes 8°C.

Rule 2

To find out which course to steer a boat.

This rule indicates the steps to be taken in changing from Compass to True (left column) and True to Compass (right column).

The rule can be remembered by writing the letters CDMVT in either the forward or reverse direction as shown below.

The end result is the ship's head or direction in which the ship is steered. Figures 44.1 and 43.2 summarise this process.

Conversions from compass to true		Conversions from true to compass	
C an	Compass	T ele	True
D ead	Deviation	V ision	Variation
M en	Magnetic	M akes	Magnetic
V ote	Variation	D ull	Deviation
T wice	True	C ompany	Compass

Worked example

Which direction do you steer a boat if you want to go 50° True North out of Sydney heads if the deviation is 8°E?

Because you are working from True to Compass, Rule 2 — CDMVT is written backwards. Total error is 18°E and because it is east, Rule 1 says to take it away.

So you steer your boat 32° by compass.

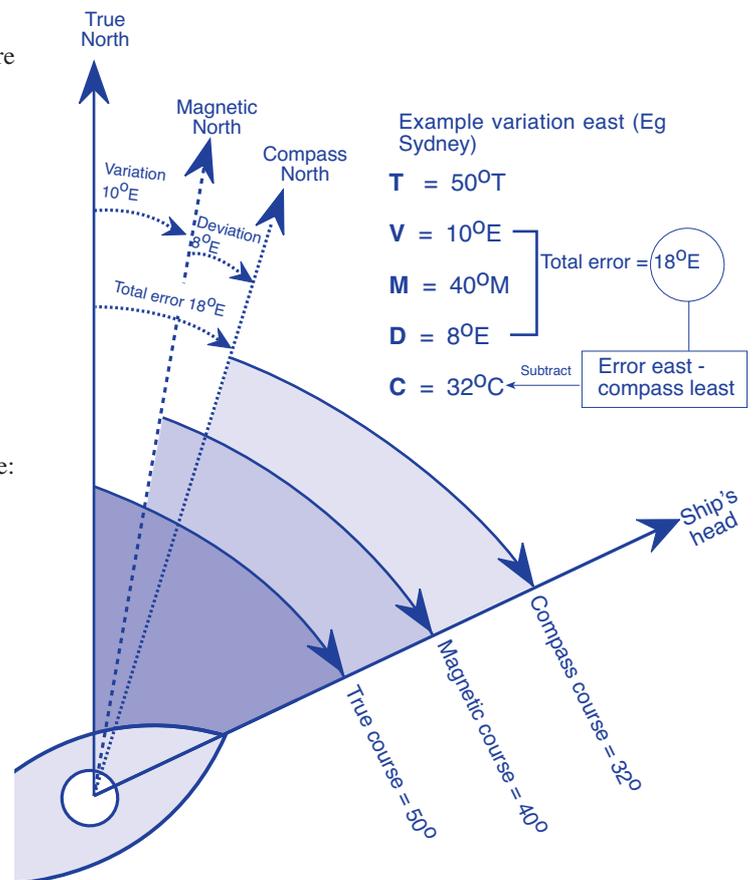


Figure 44.1 Variation east

The compass rose

The compass rose is printed on charts to indicate direction and is aligned with the True or Geographic North.

A small half arrow head is printed inside the rose indicating the direction of the Magnetic North Pole and the angle between True and Magnetic is printed across the centre of the rose with the date of the last determination of the rate of change.

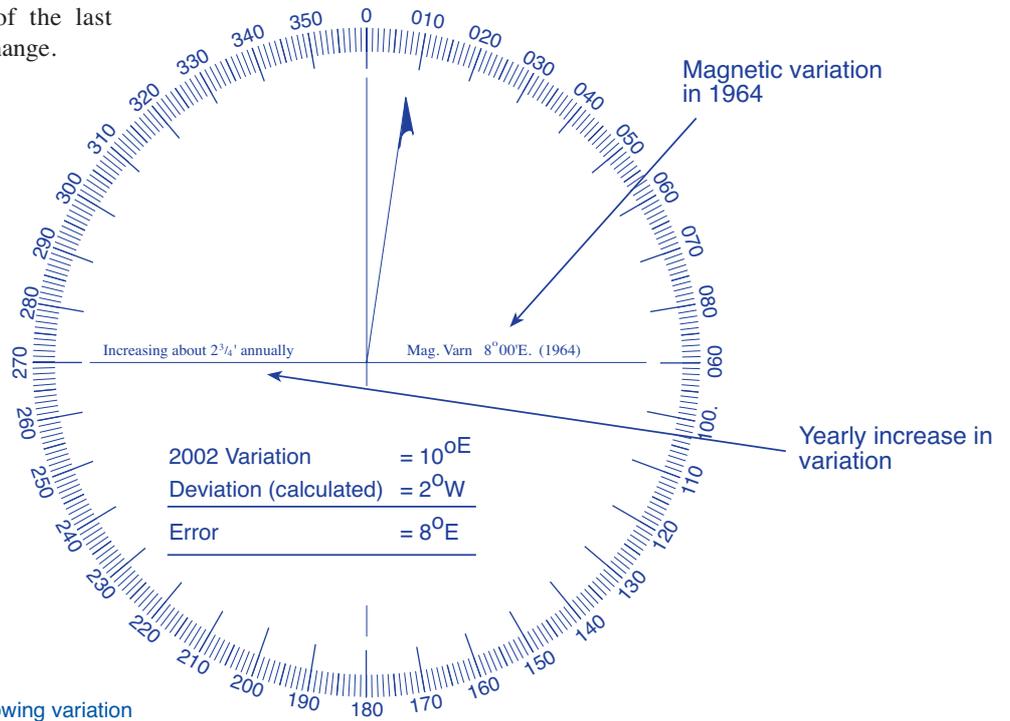


Figure 45.1 A compass rose showing variation
Wet Paper

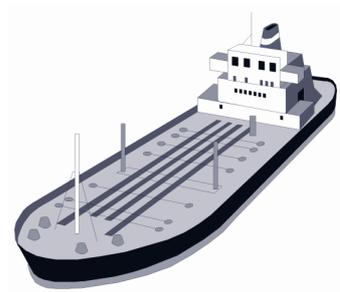
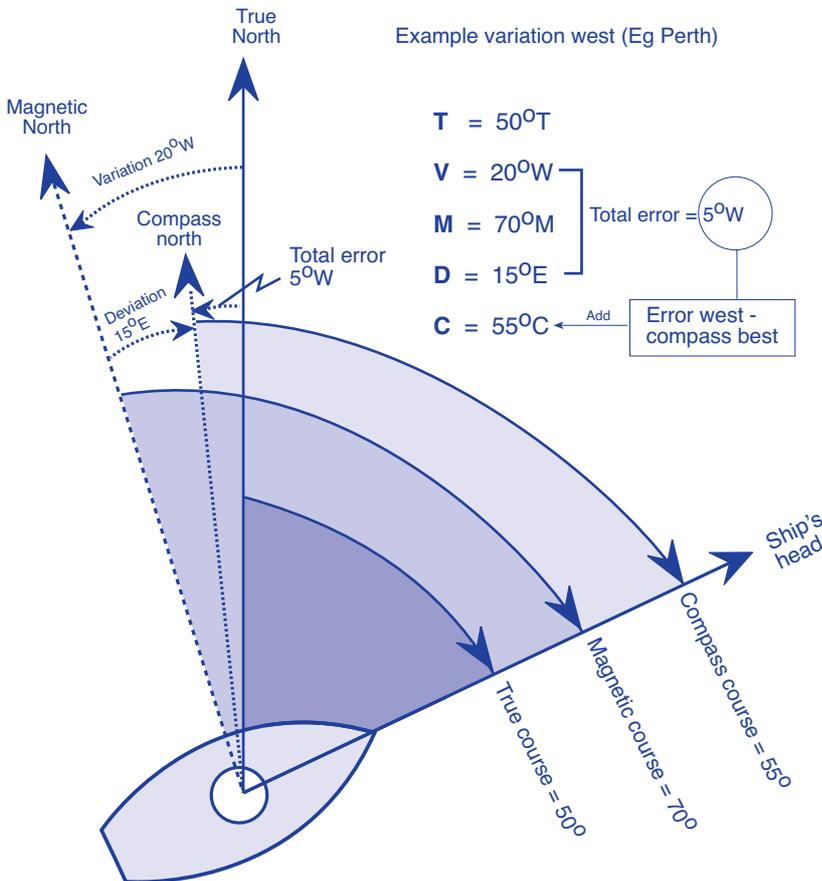


Figure 45.2 Compass error west
— for West Australians

Wet Paper

WORKSHEET 14 COMPASS CONVERSIONS

1. Complete the following exercises, using the deviation table in Figure 46.1.

T	300°	T	201°	T	95°
V	10°E	V	10°E	V	
M		M		M	85°
D		D		D	
C		C		C	



Wet Paper

2. On the compass rose the variation is shown as:
In 1970 the variation was 9° 25' E increasing at 2' annually.
What will be the variation on 20.04.2005?

3. On the compass rose the variation is shown as:
In 1972 the variation was 7° 45' E increasing at 4' annually.
What will be the variation today?

4. On the compass rose the variation is shown as:
In 1984 the variation was 9° 55' E increasing at 3' annually.
What will be the variation on the 21.11.2010?

5. The true course from Point A to Point B is 230°T. Using a variation of 11°E and a deviation from the table on the bottom of the page, calculate the compass course from A to B.

6. Use the deviation chart in Figure 46.1, to find the course to steer by compass if the true course is 75° and the variation is 10°E.

7. Brainstorm criteria for a great navigator or make a wall chart for uses for magnets.

8. Apply the following compass errors to complete the following statement:

a. 132° (C), 16° W = _____ ° T

b. 357° (T), 7° W = _____ ° C

c. 004° (C), 11° E = _____ ° T

d. 097° (C), 5° E = _____ ° T

e. 116° (T), 7° E = _____ ° C

f. 274° (T), 8° W = _____ ° C

g. 324° (C), 7° W = _____ ° T

h. 339° (T), 6° W = _____ ° C

i. 157° (C), 8° E = _____ ° T

Ships head True	Dev	Ships head True	Dev	Ships head True	Dev	Ships head True	Dev
000	2° E	105	2° E	195	3° W	285	8° W
015	3° E	120	1° E	210	5° W	300	5° W
030	4° E	135	1° E	225	7° W	315	2° W
045	5° E	150	Nil	240	9° W	330	1° W
060	4° E	165	1° W	255	12° W	345	Nil
075	3° E	180	2° W	270	9° W	360	2° E
090	3° E						

Figure 46.1 Deviation chart

9. Given the magnetic variation = 5° E, find the compass error and deviation from the following sets of transit bearings. [TRUE , COMPASS]

- a. 042° T , 036° C E _____ D _____
- b. 358° T , 010° C E _____ D _____
- c. 176° T , 192° C E _____ D _____
- d. 246° T , 245° C E _____ D _____
- e. 263° T , 291° C E _____ D _____
- f. 148° T , 140° C E _____ D _____
- g. 083° T , 077° C E _____ D _____
- h. 039° T , 048° C E _____ D _____
- i. 306° T , 291° C E _____ D _____

10. Given variation and deviation, find total error

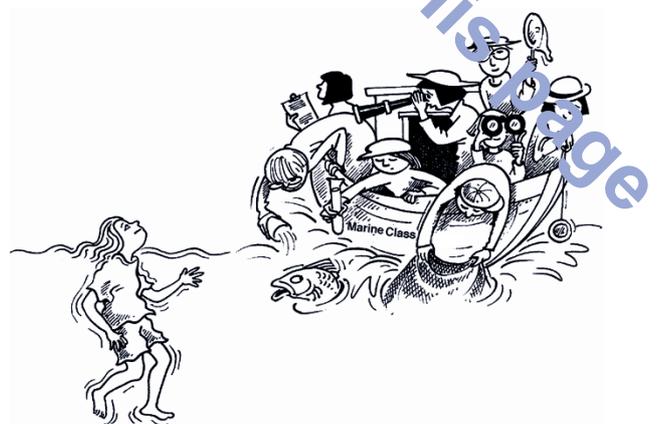
- a. 8.5° E, 3° E _____
- b. 9° E, 4.5° E _____
- c. 10.5° E, 1° E _____
- d. 11° E, 5.5° E _____
- e. 9° E, 1° E _____
- f. 8.5° E, 2.5° E _____
- g. 11° E, 3° E _____
- h. 10.5° E, 6.5° E _____
- i. 11° E, 7° W _____
- j. 8.5° E, 1.5° W _____
- k. 10.5° E, 3° W _____
- l. 9° E, 6° W _____
- m. 8.5° E, 8.5° W _____
- n. 11° E, 4° W _____
- o. 9° E, 1° W _____
- p. 10.5° E, 2.5° W _____

11. Given Variation and Total Error — find deviation

- a. 11° E, 17.5° E _____
- b. 8.5° E, 1.5° E _____
- c. 10.5° E, 13° E _____
- d. 9° E, 15.5° E _____
- e. 8.5° E, 8.5° E _____
- f. 11° E, 9° E _____
- g. 10.5° E, 16° E _____
- h. 9° E, 5.5° E _____

12. Deviation, Total Error - find Variation

- a. 3° E, 12.5° E _____
- b. 6.5° W, 2° E _____
- c. 4° E, 14.5° E _____
- d. 5.5° E, 13.5° E _____
- e. 1.5° W, 9° E _____
- f. 2° W, 8° E _____
- g. 0.5° E, 10.5° E _____
- h. 2.5° W, 6° E _____



Gee I'm glad to see you people... which way to the coast?

Sharon Madder

SECTION 7 CHARTING

YOUR COURSE

When you make an observation with a hand bearing compass to an object such as a hill or a lighthouse, this information can be placed on a chart.

The compass bearing must first be changed into a true bearing as all the chart bearings are set to True North. A line can then be drawn on the chart from the lighthouse or hill at the bearing observed.

This line on the chart is called a line of position or LOP.

Lines of position — LOP's

Conversions of compass bearings to true bearings

When you make an observation with a hand-bearing compass, and transfer it to a chart as an LOP (line of position), you have to convert a compass bearing to a true bearing to be able to plot it off the compass rose on the chart.

Example

Note: The deviation for the vessel has been calculated at zero

1. Suppose you are out on Hypothetical Bay somewhere to the north of Trent's Light and east of Batestown. You are looking through your hand-bearing compass at Critchley Peak.
2. The hand-bearing compass is reading 30°C. Because of the 8°E variation, you need to add 8° to get 38°T before you may plot your line of position on the chart. (Error east, compass 30° is less than 38°T). See Figure 48.1.

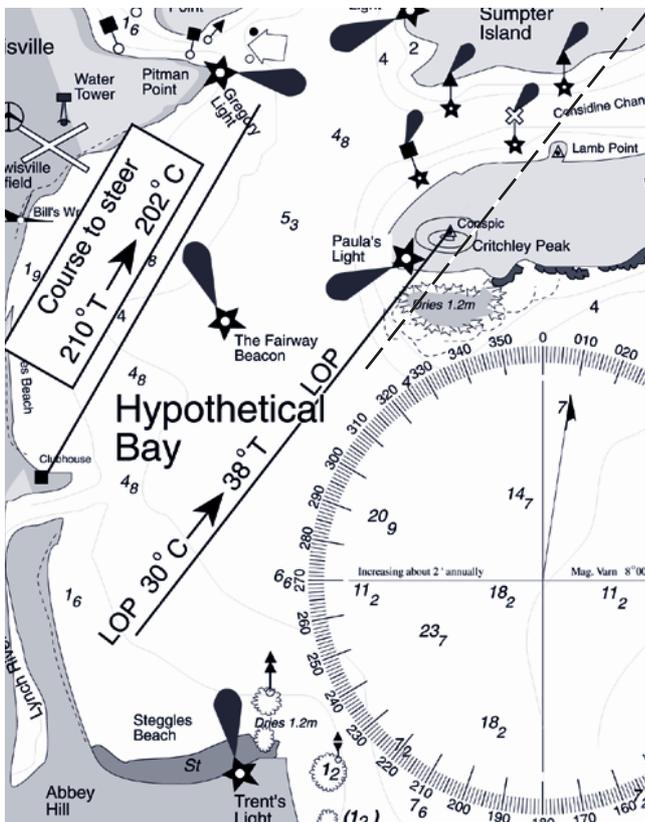


Figure 48.1

Wet Paper

Conversions of true bearings to compass bearings

Note: The deviation for the vessel has been calculated at zero

When you draw a line on a chart to indicate where you want your boat to go (that is a course to steer), you read off the chart the true bearing of the course to steer.

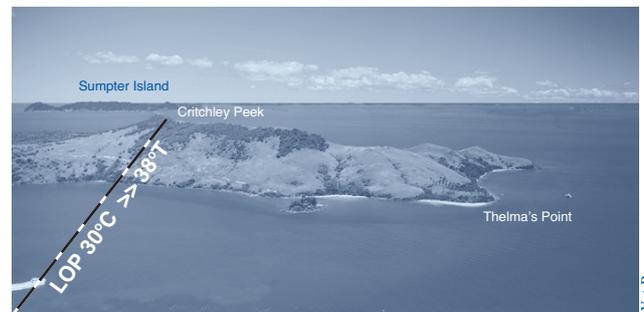
Before the skipper can start moving the boat, this must be converted to a compass course to steer, so you know what numbers to be reading on the steering compass.

Example

1. You have just come out of Heyer River, and want to go straight to the clubhouse at Batestown. The deviation is 0.
2. On the chart you have drawn the course (see Figure below) and with your parallel rule have found from the compass rose that the course is 210°T.

Now you must subtract the 8°E to get the compass course to steer of 202°C.

Error east, compass of 202° is least/less than 210°. (You yell to the helmsperson to steer 202° by the compass).



Compass bearing is 30° to Critchley Peak

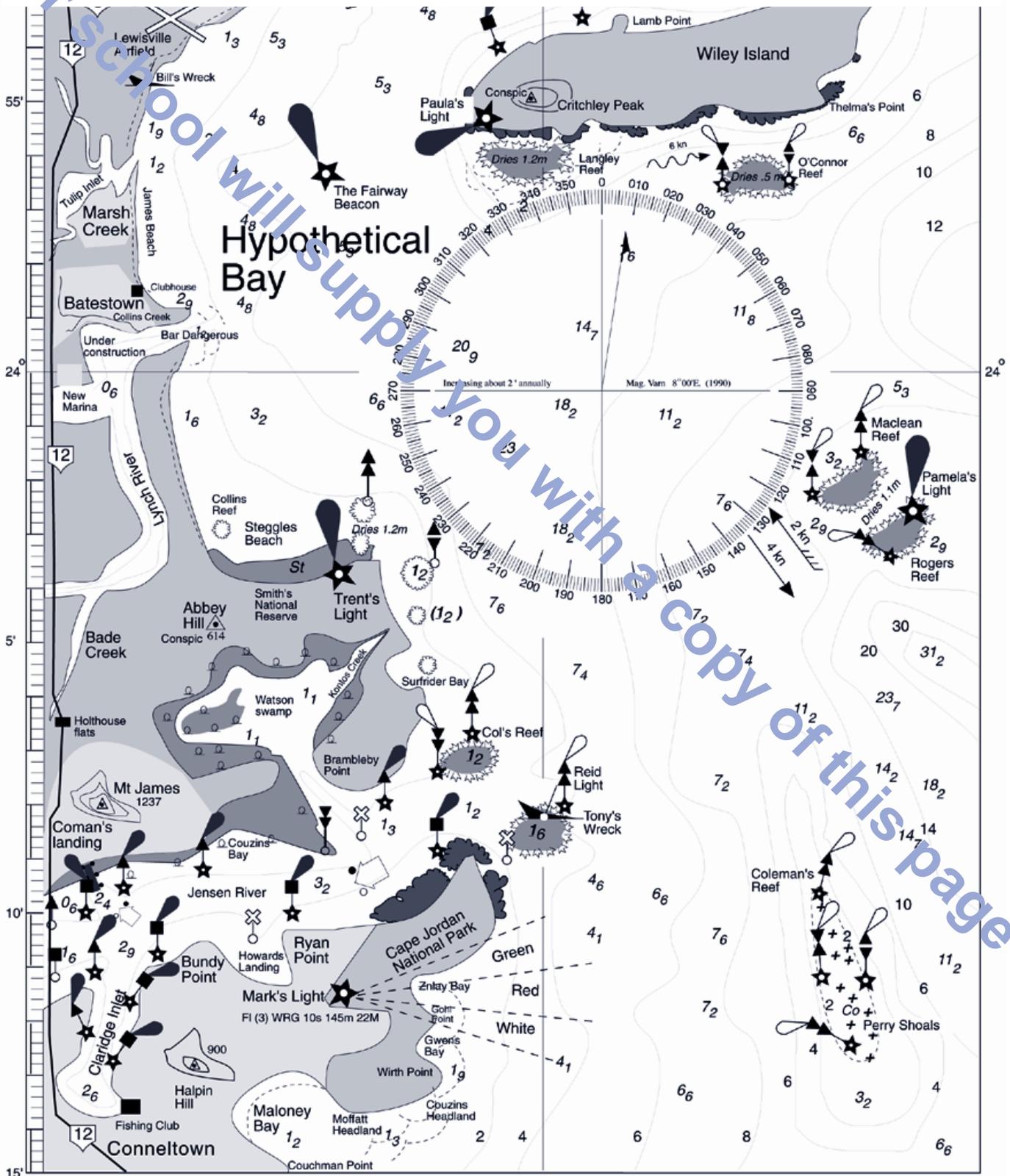


WORKSHEET 15 LOP's

Draw in LOP's for the following hand bearing-compass observations

Each set of three gives a cocked hat position fix.

1. Mark's Light 258°C, Trent's Light 294°C, Pamela's Light 346°C
2. Trent's Light 216°C, Paula's Light 325°C, Pamela's Light 110°C
3. Critchley Peak 279°C, Keid Light 13°C, Pamela's Light 155°C



WORKSHEET 16

COMPASS COURSES

In a perfect world Geographical North and Magnetic North would be the same.

When you draw a line on your chart to indicate where you want your boat to go - that is the course to steer, you read off the chart the true bearing of the course to steer.

The course the skipper needs to steer is slightly different because the compass points to Magnetic North and not True North.

Worked example

Calculate the compass course to steer between the Fairway beacon to Paula's light.

Answer

By using parallel or roller rulers, draw a line from the Fairway beacon to Paula's light. Now walk the ruler so that a parallel line passes through the centre of the compass rose and its outside circle.

The true direction is $70^{\circ}T$. The deviation is zero.

Since the variation is $8.00 E$ in 1990 and increasing $2'$ annually, the variation in 2001 - 11 years later will be $11 \times 2' = 22'$

The variation in 2001 = $8^{\circ}22'$ (For most navigation exercise this is rounded down to Variation of 8° .)

Therefore the compass course is: $70^{\circ} - 8^{\circ} = 62^{\circ}$ (Error East Compass Least)

Questions

The deviation is zero for Questions 1 - 3.

1. Calculate the true course to steer between

- a. Gregory Light and Paula's light

- b. Trent's Light and Roger's Reef Light

- c. Trent's Light and The Fairway Beacon

- d. Batestown Clubhouse and Richard Light

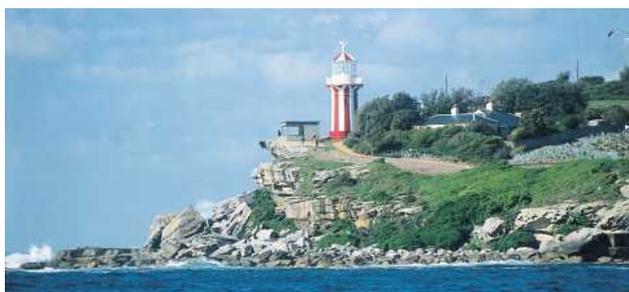


Figure 50.2 The Fairway Beacon

2. Draw lines of position for the following hand bearing compass observations:

- | | |
|-------------------------|---------------|
| a. Marks Light | 260° |
| b. Trent's Light | 290° |
| c. Fairway Beacon | 280° |
| d. Pamela's Light | 180° |
| e. Mouth of Lynch River | 270° |
| f. Paula's Light | 160° |

3. Calculate the compass course to steer to go between the following places:

- a. Fairway Beacon to Gregory Light

- b. Gregory Light to Keidard Light

- c. Batestown Clubhouse to northern tip of Maclean Reef

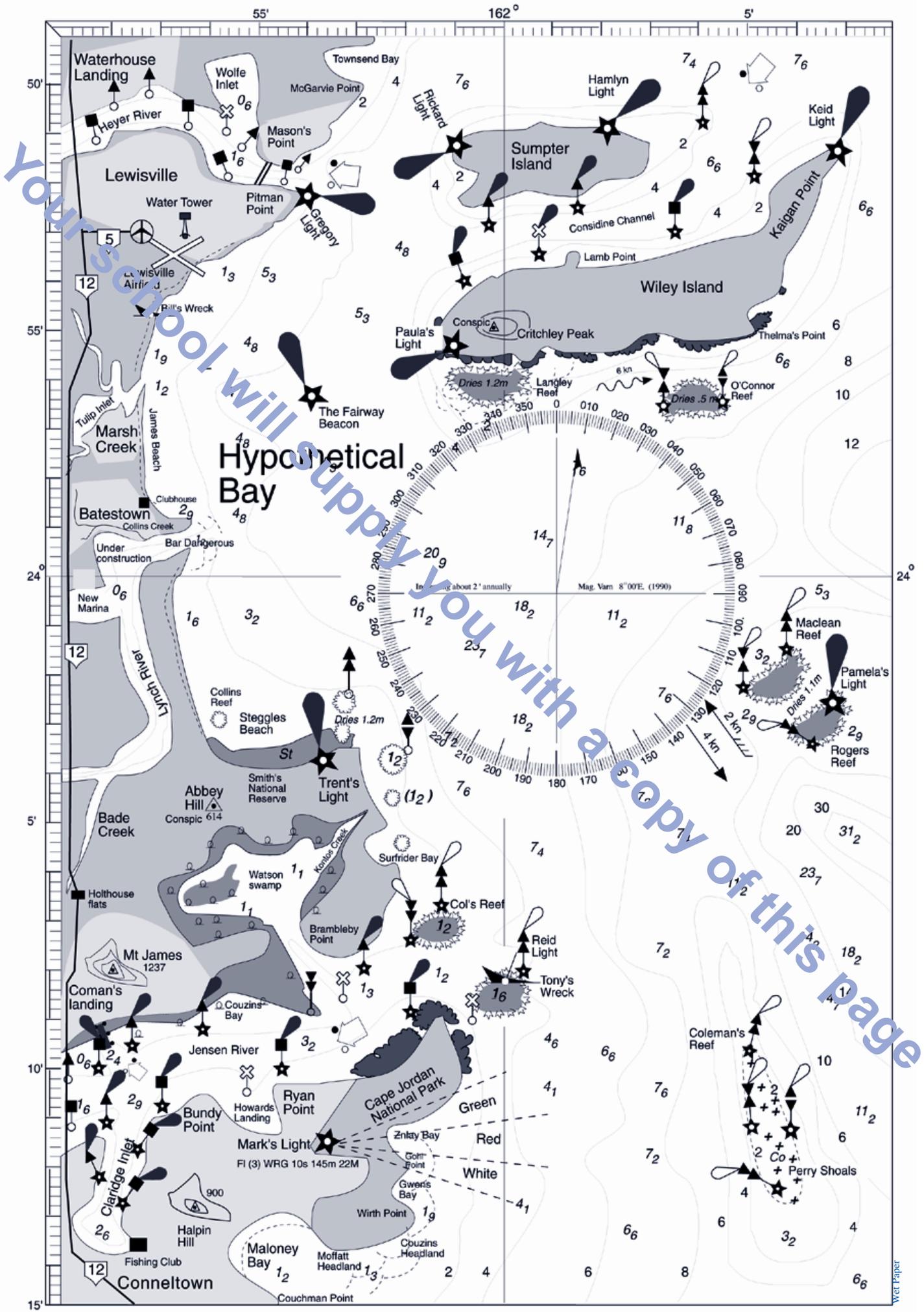
- d. Pamela's Light to Keid Light

- e. Keid Light to Hamlyn Light



Figure 50.1 Paula's Light

Wet Paper



SECTION 8 POSITION FIXING

When travelling at sea, it is very important to know where you are. It is essential to the safety of the vessel for the navigator to frequently or as continuously as possible, get positional information. This is essential in areas where there are navigational hazards such as rocks and reef where a small error could cause loss of the vessel. It is therefore very important to know the position of the vessel at all times. The navigator may use a number of methods to find or fix position. Some of these methods are discussed below.

Single bearing fix

A single bearing fix can be used to approximate a vessel's position. For example if the bearing on the water tower in Figure 52.1 is 40 degrees, a line of position drawn on a chart will indicate that the boat is somewhere on that line.

The position line found is known as a line of bearing. It is important that the chart feature, for example a water tower, has been correctly identified and the compass work is accurate.

When drawing the line on the chart the line extends outward from the landmark along the reciprocal of the observed bearing.

Therefore, if the bearing taken to the lighthouse is 40 degrees the line extending from the water tower will equal $180 \text{ degrees} + 40 \text{ degrees} = 210 \text{ degrees}$.

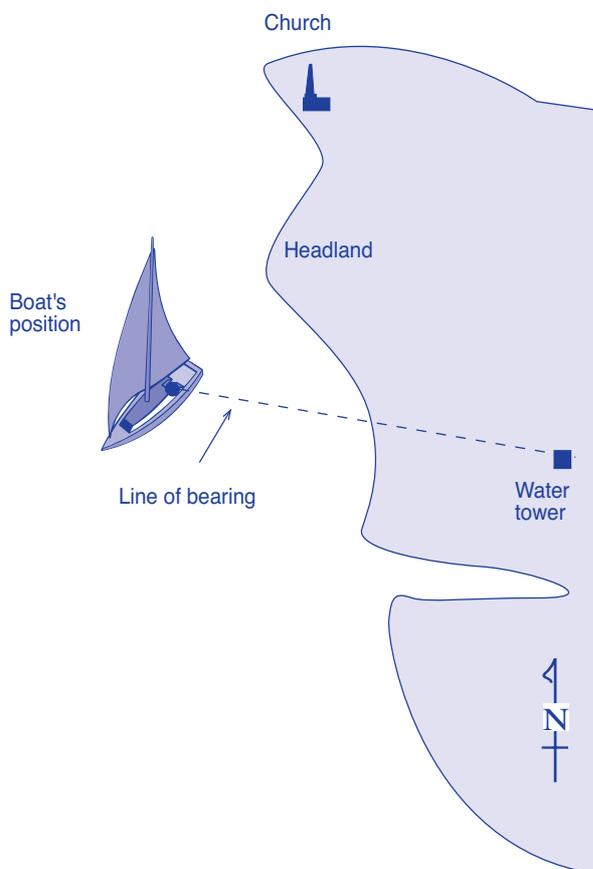


Figure 52.1 The line of bearing
Wet Paper

A transit

If two objects are lined up they are said to be in transit. The vessel must be on the same line extended away from this line. These transits may be used to check compass error or act as leads to steer a course or maintain a heading.

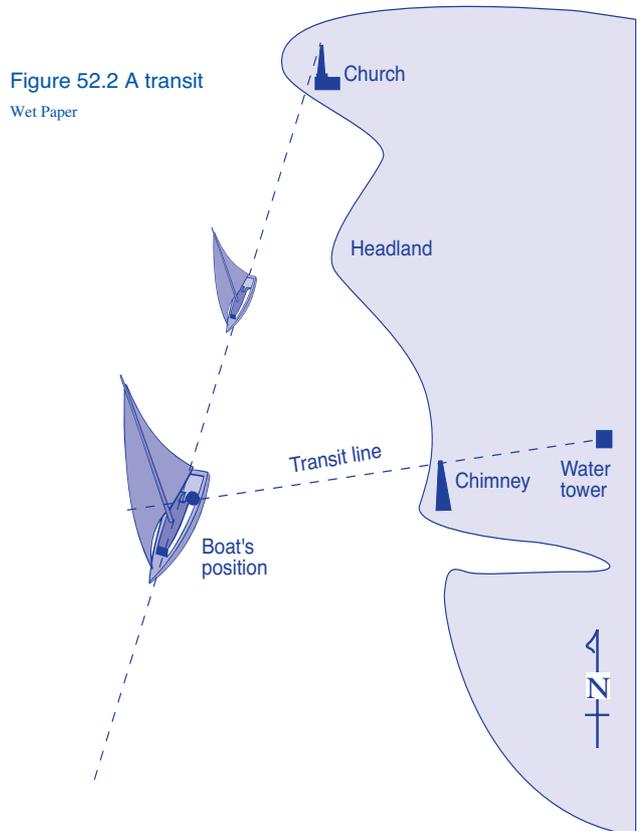


Figure 52.2 A transit
Wet Paper

True bearing fix

When lines of bearing are obtained from two different landmarks at the same time (Figure 52.3), the vessel must be located at the intersection of these lines. This point is one method of position fixing. If you are trying to fix your position the angle formed between the two lines should be more than 30° to give an accurate fix.

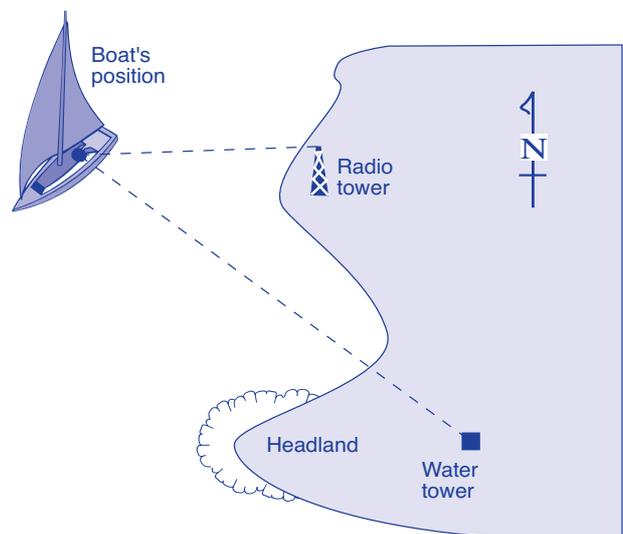


Figure 52.3
Wet Paper

True bearing fix or cocked hat

Most navigators will take a third line of bearing to confirm a position. It is rare to have the three lines meet at one point and then mostly they form a triangular or cocked hat. The vessel's position can be expected to be in the centre of the triangle.

The accuracy of the fix is indicated by the size of the cocked hat. If you are in an area where there is a shipping hazard, your position should be taken as the corner of the triangle nearest the hazard.

The size of the 'cocked hat' depends on:

- The identification of the mark
- Error in the plotting of the lines
- The time taken to obtain the bearing and the speed of the vessel
- Compass error or deviation of the compass not included



Worked example

Find the position of a vessel from three bearings taken off Carlisle Island in Hillsborough Channel. Assume that there are no other errors than variation.

A: 232°M (Finger and Thumb)

B: 297°M (Soldier I.)

C: 151°M (Skiddow Peak, Carlisle I.)

Step 1 The variation from the compass rose is calculated as $8 + 2'$ annually since 1964 = 9° .

Step 2 Convert the compass bearing A to its true bearing on the chart.

Can	=	Compass	=	232°C
Dead	=	Deviation	=	0°
Men	=	Magnetic	=	232°
Vote	=	Variation	=	9°
Twice	=	True bearing	=	232°C + 9° = 241°T

Step 3 Draw the line using your parallel rules

Step 4 Repeat for the other two bearings and your position is where the lines intersect

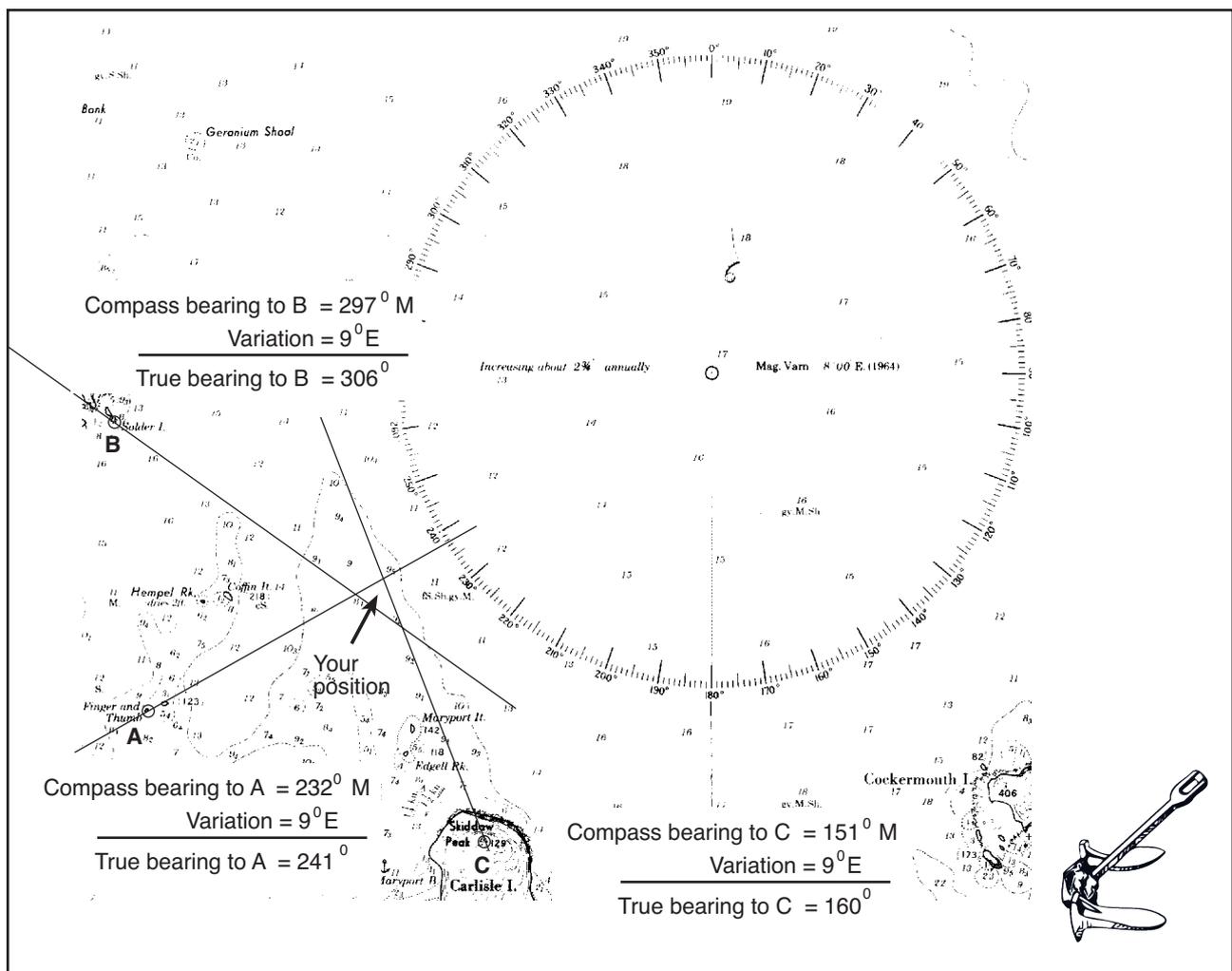


Figure 53.1 The cocked hat - locating your position by three bearings

Other methods of fixing position

Radar and bearings

The position of a vessel may also be found by using information gained from different instruments, eg, a bearing from a compass could be used with the distance calculated from radar.

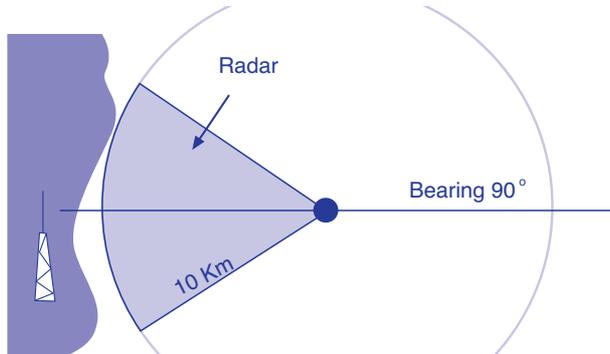


Figure 54.1 Radar

Wet Paper

Depth soundings

An approximate position may also be obtained by using a bearing from a compass and the depth recording from a depth sounder.

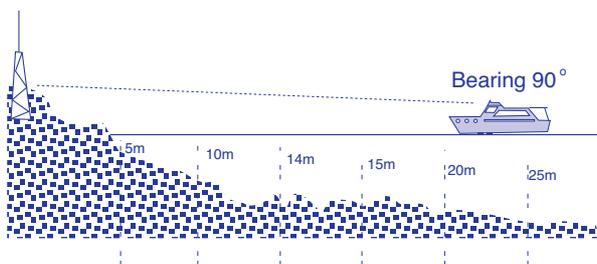


Figure 54.2 Depth soundings

Wet Paper

Distance between two marks

The position may also be found by calculating the distance from two landmarks, by use of radar or sextants and using the depth sounder to confirm the position.

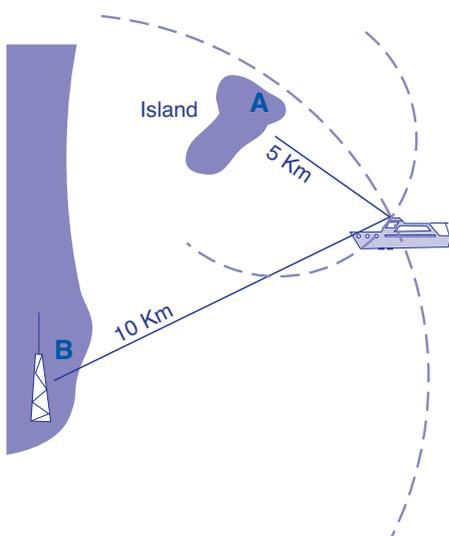


Figure 54.3 A vessel 5 nautical miles from A (an island) and 10 nautical miles from B (a lighthouse)

Wet Paper

The running fix

This fix is taken while the vessel is moving and the bearings are taken to landmarks at different times. It may also be a bearing taken to the same object at different times. The vessel's speed is used in this calculation and this must be known accurately for a definite fix.

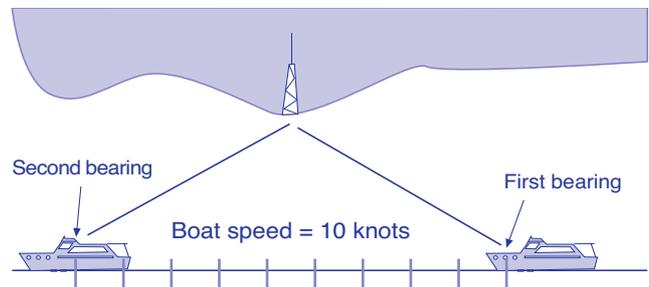


Figure 54.4 Running fix

Wet Paper

Vertical sextant angle

The vertical sextant angle is used to calculate the distance a vessel is from an object located high on the shore.

$$\tan \theta = \frac{h}{d} \quad d = \frac{h}{\tan \theta}$$

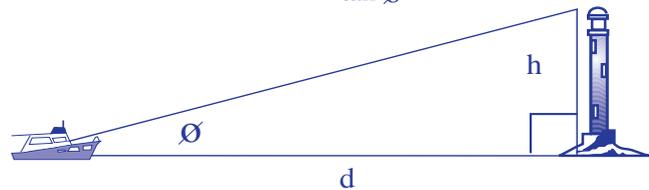


Figure 54.5 Vertical sextant angle

Wet Paper

θ	$\frac{1}{\tan \theta}$	h
1°	57.30	
2°	28.64	
3°	19.08	
4°	14.30	
5°	11.43	
10°	5.67	
20°	2.75	

Wet Paper

Example

Distance from a lighthouse of 90m seen at 2° equals

$$\begin{aligned} d &= \frac{h}{\tan \theta} \\ &= 90 \text{ m} \times 28.64 \\ &= 2577 \text{ m} \\ &= \underline{2.6 \text{ km}} \quad \text{Ans} \end{aligned}$$

WORKSHEET 17 CHARTWORK

Method

Cape Hillsborough Channel courtesy Hydrography Service for the Navy, exercises prepared by Bob Critchely, Bowen SHS. Reproduced with permission. Notes: Variation for 2001. No Deviation. Work in soft lead pencil. Leave all your working on the chart.

Written answers to be done on a separate sheet and attached to chart. All distance to within 0.1 mile, and all angles to 0.5°. Your teacher may have prepared a chart and overlays with all the solutions so you can check your progressive working. The numbers at the bottom of the page are page numbers and are not lines of longitude. The longitude is 149°E. 1 fathom = 1.83 metres.

Questions

This exercise uses the A3 Version 5169 B and variation 2001 - nearest degree.

1. What are the latitude and longitude of the following points?

a. Hempel Rock

b. Coppersmith Rock Lighthouse

c. Hill 670 Cockermouth Island.

2. You are at the anchorage at Maryport Bay, Brampton Island, in position 20°48' S 149°16' E. Mark this on your chart as position A and answer the following questions. Variation for 2001. No deviation.

a. What is your magnetic variation to the nearest whole degree?

b. You want to go to Coffin Island. What compass course will you steer?

c. How far is it from position A to Coffin Island?

d. How long will it take to arrive at Coffin Island if you travel at 6 knots?

e. After you have been travelling for half an hour, what will be your DR position? Mark this on the chart as position B.

f. You are worried about what you can see and decide to fix your position. You take the following bearings:

Allonby Island Hill 198 273°

Brampton Island Hill 323 131°

Tinsmith Hill 448 340°

Plot this position and mark it on the chart as position C.

g. What are the rocks you can see in front of you?

h. How do you account for the change in position from point B to point C?

3. a. You are anchored near Geranium Shoal. Locksmith - S (southern tips of Locksmith Island) is in transit with Ladysmith - S.

You also have Allonby Island Hill 198 in transit with Tinsmith Island - SE. Mark this position as position D.

b. What is the latitude and longitude of point D?

c. How far are you from Geranium Shoal?

d. What course would you steer to arrive at the shoal?

e. How long will it take you to get there at 6 knots?

f. It is now a 3 m tide. What will your Metric Depth sounder read as you find the shoal?

WORKSHEET 18

POSITION FIXING

It's nice to know where you are and this exercise lets us use our chart to find out where we are.

Worked example

Having travelled out for 45 minutes from the marina in Lynch River, the skipper of *Wet Paper I* wants her first mate to plot their position. She takes three bearings, as follows, using a hand-bearing compass.

Bearing 1 to Pamela's Light CB = 88°C

Bearing 2 to Trent's Light CB = 163°C

Bearing 3 to Mt James CB = 202°C

These convert using error east compass least rule.

Step 1 Do conversion for bearing 1

To Pamela's Light CB = 88°C TB = 96°T

Step 2 Place rule or square on compass rose from the centre to Pamela's light. (See figure 56.1)

Step 3 Walk rule or square to Pamela's Light and draw a line back towards the mainland.

Step 4 Do conversions for bearings 2 and 3 respectively and repeat as described in steps 2 and 3.

Step 5 Shade in your cocked hat as described in your textbook.

Questions

Find the latitude and longitude of the following positions and mark them on your chart. Check your answer with the suggested answer given. Note all bearings have been made with a hand-bearing compass.

1. Position A.

Bearing to Pamela's Light 20°

Bearing to Mark's Light 257°

Bearing to Trent's Light 314°

(Suggested answer 24°11' S, 162°02'E)

- Position B.
Bearing to Pamela's Light 20°
Bearing to Paula's Light 327°
Bearing to Reid Light 244°

(Suggested answer 24°07' S, 162°04.5'E)

- Position C.
Bearing to Halpin Hill 178°
Bearing to Mt James 306°
Bearing to Trent's Light 013°

(Suggested answer 24°10' S, 161°54'E)

- Position D.
Bearing to Trent's Light 222°
Bearing to Pamela's Light 175°
Bearing to Critchley Hill 263°

(Suggested answer 23°55' S, 162°07'E)

- Position E.
Bearing to Pamela's Light 357°
Bearing to Trent's Light 281°
Bearing to Paula's Light 320°

(Suggested answer 24°07' S, 162°06'E - you are on the beach)

- Position F.
Bearing to Halpin Hill 302°
Bearing to South Cardinal Mark Perry Shoals 74°
Bearing to Mark's Light 20°

(Suggested answer 24°14' S, 161°55'E)

- Position G.
Bearing to Trent's Light 242°
Bearing to Fairway Beacon 310°
Bearing to Clubhouse at Batestown 285°

(Suggested answer 24°02' S, 162°01'E)

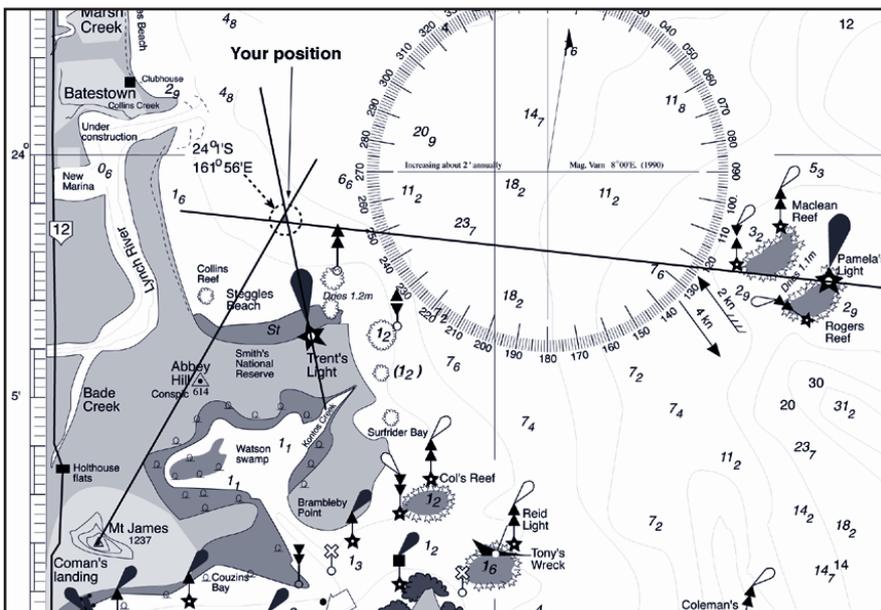
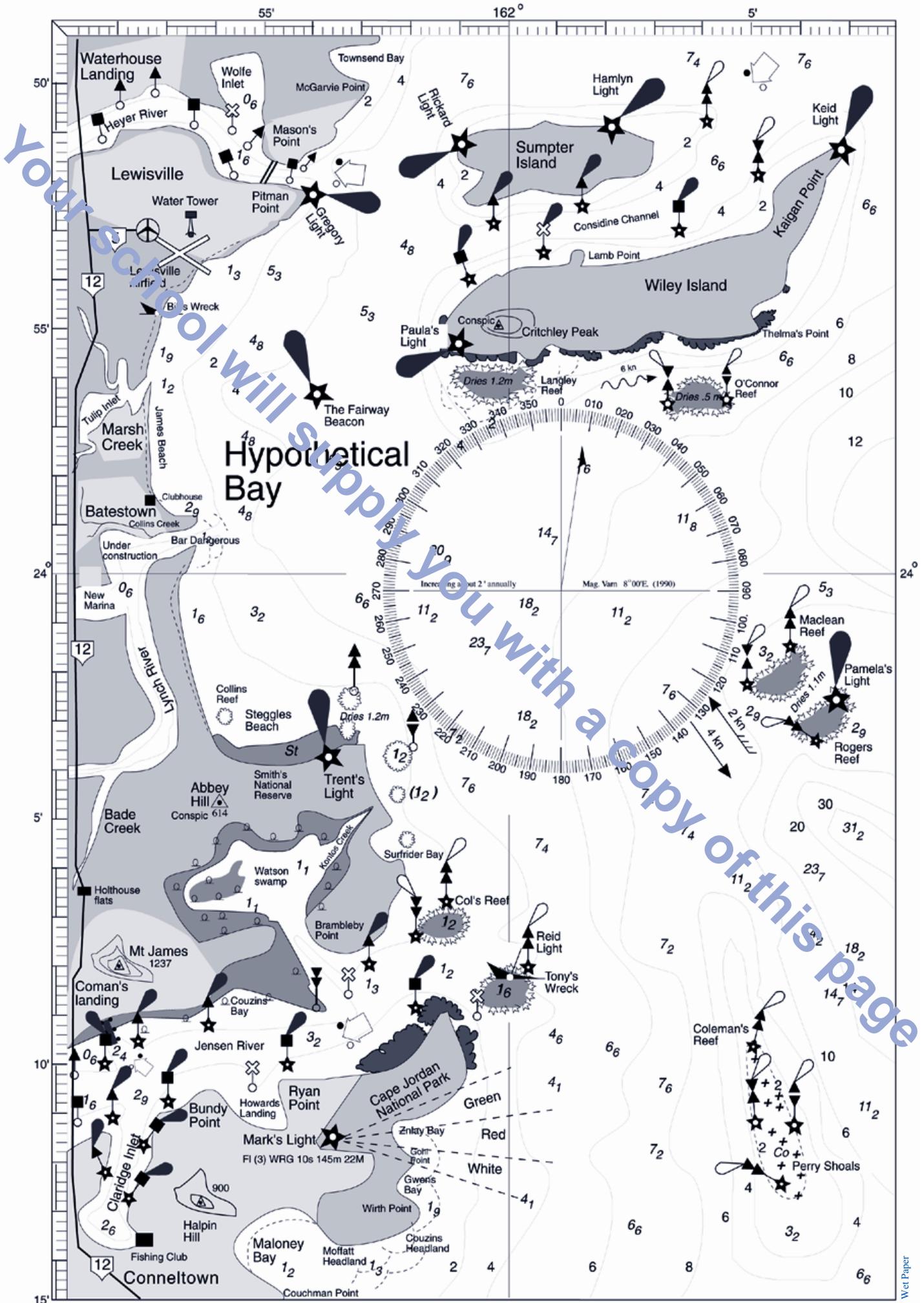


Figure 56.1 Worked example



Note: It is not good practice taking two bearings along the same line



WORKSHEET 19

LAYING OFF AND PLOTTING



Which course do you steer, how long will it take to get there and are you on course? This exercise lets you practise the skills in laying off and plotting a course.

Worked example

A day's outing and whale watching is planned off Thelma's Point. You live at Waterhouse Landing and are planning the trip.

From Gregory Light, you decide to go around Paula's Light and Wiley Island Reef as shown in the chart of Hypothetical Bay opposite.

- You decide to avoid all water below 4 metres and draw four lines with changes in direction at A, B, C and D (as shown).
- You calculate your distances in nautical miles for each course and the total distance. You figure you can make at least 10 knots and so decide that this is safe for the day.
- Using your parallel rule and compass rose, you find the true course from Gregory Light to point A is $153^{\circ}T$. This converts to $145^{\circ}C$ (Error east, compass least).
- You will need to know when you are at point A. From the chart you find that it is 6 miles from Gregory Light. At 10 knots, this will take 0.6 hours, or 36 minutes, give or take a bit depending on currents, etc. and instrument error. (Your speedo might be slightly out).
- From the chart you can see that Critchley Peak should be on your port beam quarter when you are at A, if you stayed on your intended track.

It is far more reliable to use a hand-bearing compass reading, so on the chart you find that the bearing of Critchley Peak should be $25^{\circ}T$, which is $17^{\circ}C$ when you are at point A.

On the day

- The day has come and you have your chart ready with the planned course marked in. You pass Gregory Light at 9 a.m. and so immediately mark it on the chart.
- At 9.30 you are not sure of what you are looking at on your port beam, so calculate your DR position on the chart. Since your boat is travelling at 10 knots and it is 30 minutes since you passed Gregory Light, you should be 5 miles along your track. You mark this in as your 9.30 DR position, which gives you a better idea of what you should be able to see.

Entry	Date	Time	Position		Var	Course		Speed
			Lat	Long		True	Mag	

Figure 58.1 A voyage record log

- As you should have only about a mile to go to point A, you get your hand-bearing compass ready, and take a bearing on Critchley Peak. The reading is $22^{\circ}C$, so you are not yet up to point A.
 - Over the next few minutes, the compass bearing of Critchley Peak will decrease, and when it gets to $17^{\circ}C$, you know you are at point A and can alter course to point B.

Questions

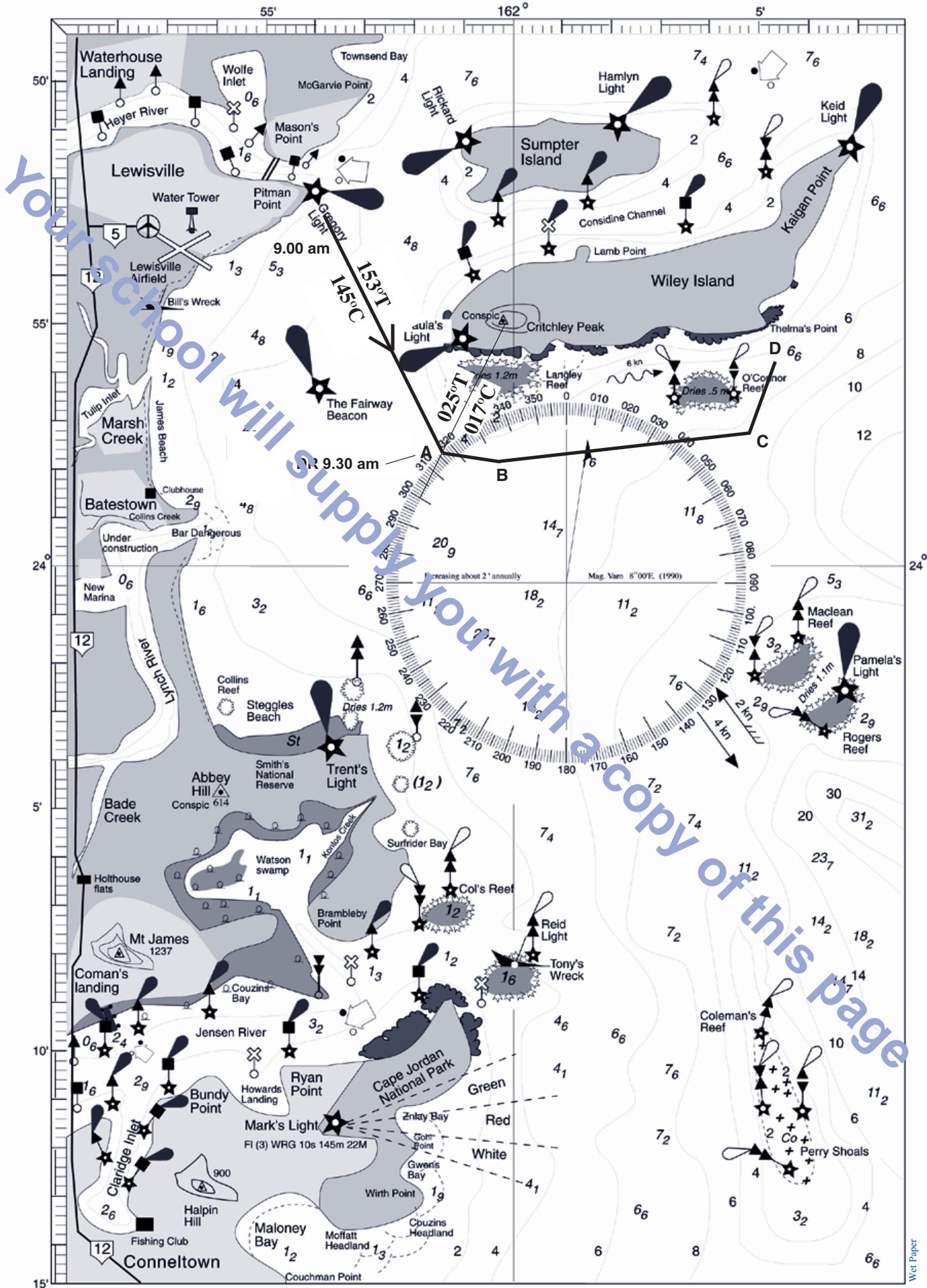
- Lay off a course from position A to position D as outlined in the figure opposite.
 - How far is it from A to B, B to C and C to D?
 - What are the true bearings from B to Critchley Peak and Paula's Light?
 - When you are supposed to be at position C, what compass bearings should you get on Critchley Peak and Keid Light?
 - What compass course should you steer from A to B? You propose to make 10 knots, what is your ETA at position B?
 - What is your compass course from B to C?
 - What is your compass course from C to D?

- A fishing trip is planned to Rogers Reef from the Fishing Club at Conneltown. Lay off a compass course from midway between the two reefs at the entrance to Jensen River to Rogers Reef. You plan to leave at 0800 hrs.
 - You can make 12 knots. Estimate your ETA at Rogers Reef.

- The fishing is lousy and you stay for only one hour. Avoiding all water below 4 m, plot the shortest course to the marina in Lynch River.
- When you pass Maclean Reef Light, what compass course do you steer?

- You make 6 knots, what is your ETA at the marina?

- You left the fishing club in the morning. How far have you travelled during the day?



WORKSHEET 20 SET

AND DRIFT

To allow for currents such as ebb or flood tides (Figure 60.1), the navigator must allow for set and drift.

The ship's navigator has to set a course either to port or starboard of the course line. If the set is known (by checking charts) then the navigator can successfully navigate for these currents.

Worked example

Your boat is positioned at Point A (Figure 60.2), North West of Edgell Rock and you wish to plot a course to Solder Island making allowance for currents in this area.

The boat's speed is say 4 knots.

The direction the current is flowing (the set) is 180° .

The current speed (the rate) is 1.25 knots.

1. Place the direction of the current on the boat's course line. This may be at any point. (See Figure 60.2).
2. Using dividers, measure off the distance the current (drift) will run in 1 hr from A and mark it on the current line. Call this X.
3. Space the dividers to the distance the boat will travel in 1 hr and place one point of the dividers at Point X (on the current line) and sweep round until it touches the boat's course line. Mark this and call it point Y.
4. XY is the course to steer so with parallel rulers work out the T.C. and convert it to C.C. by subtracting the $9^\circ E$ error.
5. Steer the boat for one hour at 4 knots on C.C. 293° and re-check your position. Make the necessary corrections after this time.

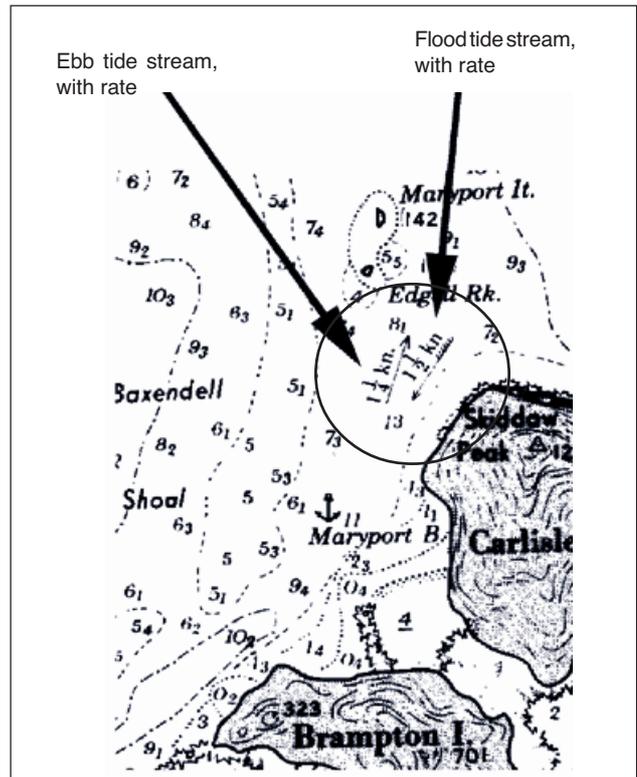


Figure 60.1 Ebb and flood currents

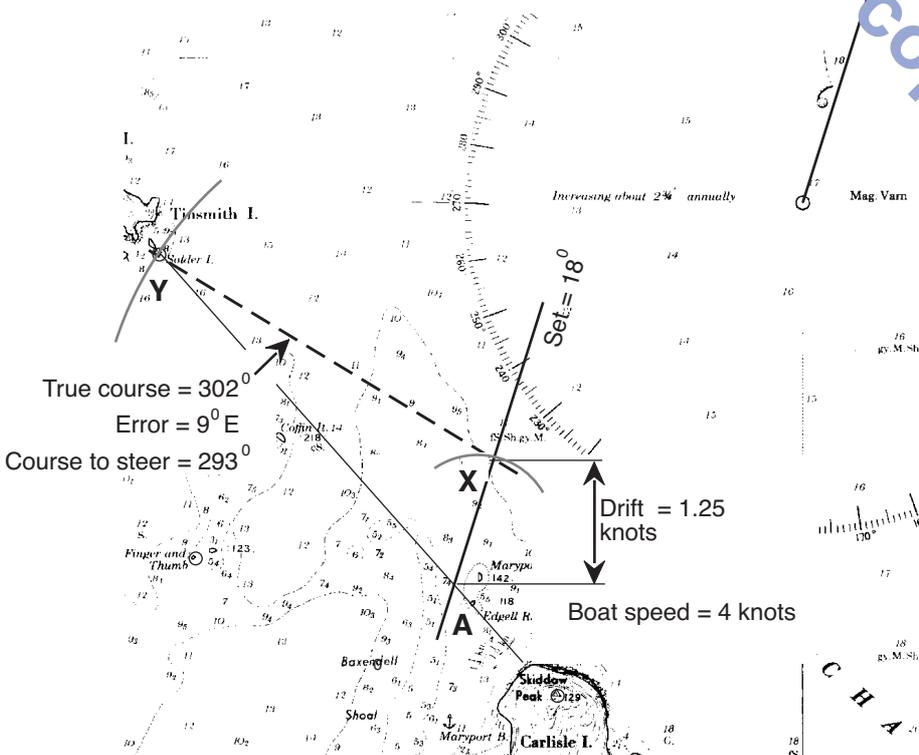


Figure 60.2 Calculation of set and drift

Wet Paper

Some set and drift terms

Leeway

This is the amount which a vessel drifts or makes to leeward of her course by compass when she is steaming with the wind on her side.

The set

This is the direction in which a current or tidal stream is flowing.

The drift

This is the rate at which a vessel deviates from its course due to wind, current or tidal influences.

Tidal streams

These are marked on charts by arrows pointing in the direction of the set with the rate of the set marked on the shaft. A current is marked with an arrow pointing in the direction of the set. The arrow has a wriggle on the shaft with no arrows. The rate of the set is marked on the shaft.

Set and drift questions

1. At 0615 you depart the anchorage west of Carlisle Island, steering a compass course of 261° (C) at 5 knots. At 0703, Allonby Island bears 334.5° (C) and Skiddaw Peak (129) bears 069.5° (C).

a. What is your fixed position at 0703?

b. What set and drift have you experienced since departing the anchorage?

2. From a position 1.5 nautical miles north of the centre of Cockermouth Island, you steer a compass course of 315° (C) at 6 knots for 1 hour.

At this time you fix your position as follows:

Carlisle Is (E)	184°
Tinsmith Is (N)	260°
Cockermouth Is (E)	134°

a. What is your fixed position at this time?

b. What set and drift have you experienced?

3. You wish to sail from one nautical mile South of Allonby Island to Anchorage at Maryport B near Carlisle Island. You will experience a set and drift of 1.25 Nautical miles at 20° T. Your speed is 4 knots.

What is the compass course you will need to steer and how long will it take you to reach your destination?

Dead reckoning

Dead reckoning is the determination of a position by projecting a known position to courses and direction. It is also called an estimated position.

It is believed to have developed from when the speed of the ship was determined by throwing a floating object into the water (dead object) and estimating the vessel's speed relative to that object.

This vessel speed together with the course being steered was used to estimate its position at a future time (dead reckoning).



WORKSHEET 21

CHOOSING AN OBJECTIVE

Before leaving you should study the chart along the path you would like to go. As you study the chart you should take particular notice of any dangers involving depth, currents and tides and shipping channels.

When you have decided your course you should then mark the course. Any dangers should be avoided and at least (if possible) one mile (to 5 miles) should be marked around the danger.

If it is a lee shore then a greater margin of safety should be marked. To mark this danger a circle is best used around the danger and your course is to go around it.

Worked example

We have camped overnight at Fairyport Bay on Carlisle Island and want to go to the anchorage at Goldsmith Island for the next night. We have heard that there is some good fishing at the 10 fathom line off Allonby Island and around Specie Shoal.

Set a course for these places.

- Step 1 First decide on where you are and mark it on the chart. We call this Position 'A' (20 degrees 47.5' south, 149 degrees 16.7' east). You will need to use your parallel rulers for this job.
- Step 2 Next mark the next position you wish to go to on the chart. We call this Position 'B' (20 degrees 45.4' south, 149 degrees 9' east). Finally make a line between the two.
- Step 3 Now use the parallel rulers to find the direction. Remember to use your compass rose! Plot the following courses.
- Step 4 When you plot the course write the course next to the line in the following manner. TC = 286°

Now complete the following exercises



1. Plot the following courses. For each of the legs maintain speed at 6 knots.
 - a. From position B to the 13 fathom mark at Specie Shoal (Position C)
 - b. From Position C to the windward anchorage at Goldsmith Island .4 Nm from Ingot Island (Position D)
 - c. From Position D to 1 Nm east of Soldier Island (Position E)
 - d. From position E to Geranium Shoal (Position F)
 - e. From Position F to A (Allow for a ebb tide)
2. While steering a compass course of 300°C and a speed of 5 knots, Hill 448 Tinsmith Island was 260° at 0700. At 0800 the same hill had a compass bearing of 205°C. What was your latitude and longitude at 0800?

3. The light on Coppersmith Rock has a height of 88ft. It can be seen at a distance just above the horizon. It is estimated (using a sextant) to have an angle of 1°: How far are you from the rock?

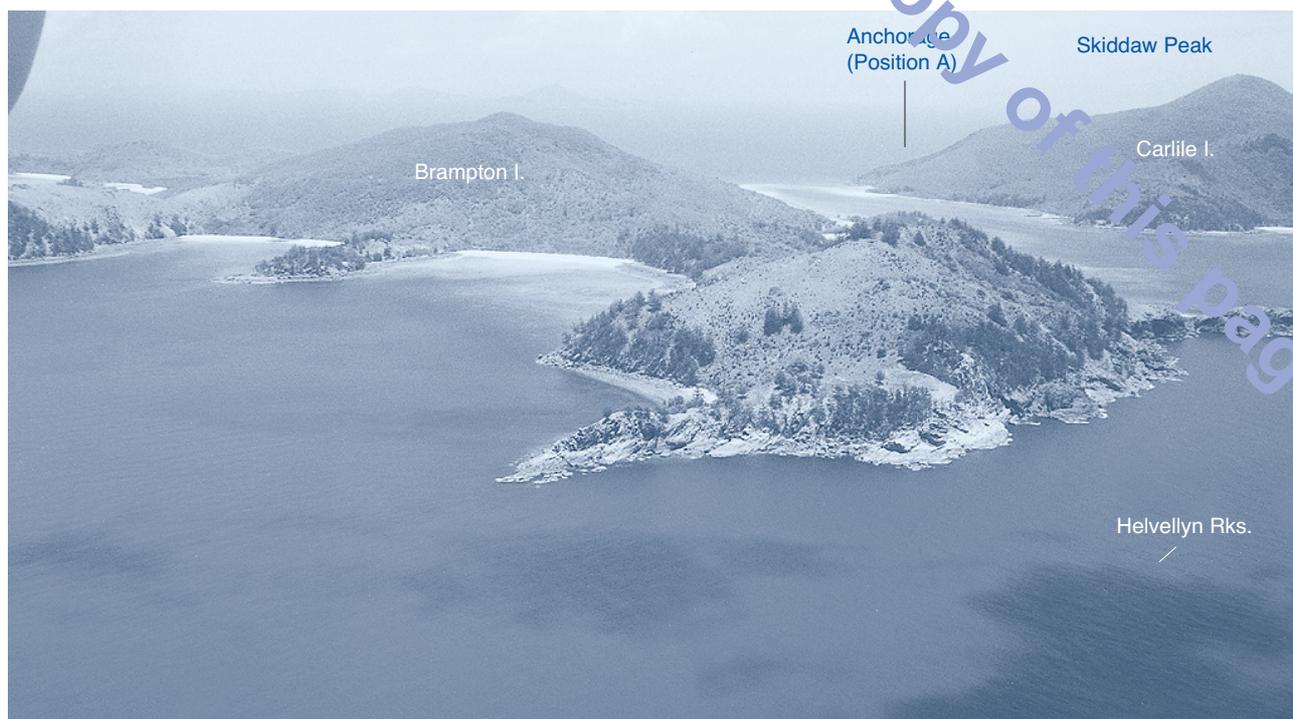


Figure 62.1 Flying into Brampton Island from the South

WORKSHEET 23

RULE OF TWELFTHS

Worked example

This rule is used as a guide to determine tidal height. Because the wave that the Earth spins through is not symmetrical, the rise and fall of the tide is not equal. A simple rule has to be found to work out how much water is under a boat at a certain time in the tide.

This rule is called the **rule of twelfths** because it divides the time and height by 12.

The formula works on the height of water that changes between the tides – called the tidal range. The calculations are as follows:

- In the **first and sixth hour** of the tide the height will drop by $1/12$
- For the **second and fifth hour** of the tide the height will drop $2/12$
- During the **third and fourth hours** it will drop $3/12$

If the tidal range is 6 m and you want to find out how much the tide has fallen 3.5 hours after HW, an approximate answer is as follows:

In the first hour

$$\text{The tide falls } 1/12 \times 6 = 0.5 \text{ m}$$

In the second hour

$$\text{The tide falls } 2/12 \times 6 = 1.0 \text{ m}$$

In the third hour

$$\text{The tide falls } 3/12 \times 6 = 1.5 \text{ m}$$

$$\text{The tide falls } 1/2 \times 3/12 \times 6 = 0.75 \text{ m}$$

$$\text{Total fall} = 3.75 \text{ m}$$

Hours	1	2	3	4	5	6
Fraction of tide rising or falling	$1/12$	$2/12$	$3/12$	$3/12$	$2/12$	$1/12$

Questions additional information

Q2.LAT is 2.25, therefore at HT depth should be 6.25m

Q4.LT 1400 hrs is 0.5m

Questions * See additional information notes below

Read the worked example and answer the questions below. Assume all areas have two high and two low tides each day and the tide heights are similar.

Q1.If the tidal range at Gladstone was 4 m and the time of high tide was 1 p.m., predict the height of the tide at 3 p.m. on the same day. Depth of water at low tide is 2m.

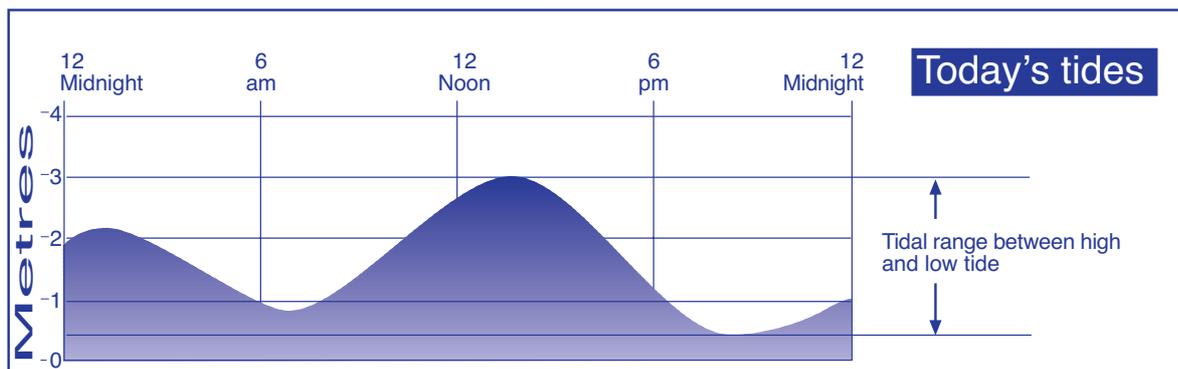
Q2.An amateur fisherman is fishing in a depth of water of 6 m. It is 9 a.m. and the tide for that day is high tide of 4 m at 8 a.m. Calculate the depth of water at 12 midday.

Q3.Bar crossing at a river mouth area is a problem when the tidal flow is great as this increases wave height. The tides for a day when ocean conditions were suitable for safe boating were as follows:

Time	Height (m)
0140	3.10
0744	0.74
1411	3.84
2044	1.00

Predict possible safe crossing times.

Q4.Your vessel has a draft of 2.4 m and you wish to enter a channel that is shown on the chart as having a depth of 1.5m. A check of the tide book reveals on that day a high tide of 3 m occurs at 8 a.m. You wish to have at least 0.5 m clearance for safety. Calculate the period of time (giving the times) when entry into the channel would be safe.



SECTION 9 RADAR AND GPS

Many vessels now rely on electronic navigation. This term is used to describe navigation involving electronics in any way. This type of navigation is important for offshore-navigation where the mariner can only see the sea.

Radar

(Stands for **R**adio **D**etecting and **R**anging.)

Radar is, perhaps, the best coastal navigation instrument since it eliminates so many of the problems of visual navigation. It is however subject to incorrect readings in strong rain squalls.

It can 'see' in the dark, penetrate fog and mist and combine all the usual coastal navigation plotting systems into one. This enables the navigator to check a boat's progress at regular intervals without leaving the wheelhouse.

Radar works on a similar principle to the depth sounder. An electronic pulse is transmitted from the scanner which 'bounces' back off shore or other objects close by. The 'echo' is picked up by the receiver. As the scanner on top of the wheelhouse rotates through 360 degrees, these echoes are converted into a map-like picture on a cathode tube with the boat as the centre of the picture, and the local scene spread out around a 360 degree horizon.

The set incorporates a method of measuring bearings and distances enabling the navigator to carry out position plotting. Because of a number of limitations, radar must be used with caution. One of its biggest problems is the tendency of the pulse to 'echo' only off certain objects.

A cliffy coastline, for example, will usually present an excellent picture on the radar screen, whereas a low sandy shoreline may show up only faintly, perhaps not at all. Navigation marks such as buoys or channel indicators may not show up too well on the screen unless they are fitted with radar reflectors. These reflectors increase the strength of the radar echo and create a much stronger 'blip' on the screen.



Figure 65.1 Modern navigation instruments contain computer chips for radar, sonar, GPS and many more.

Navman

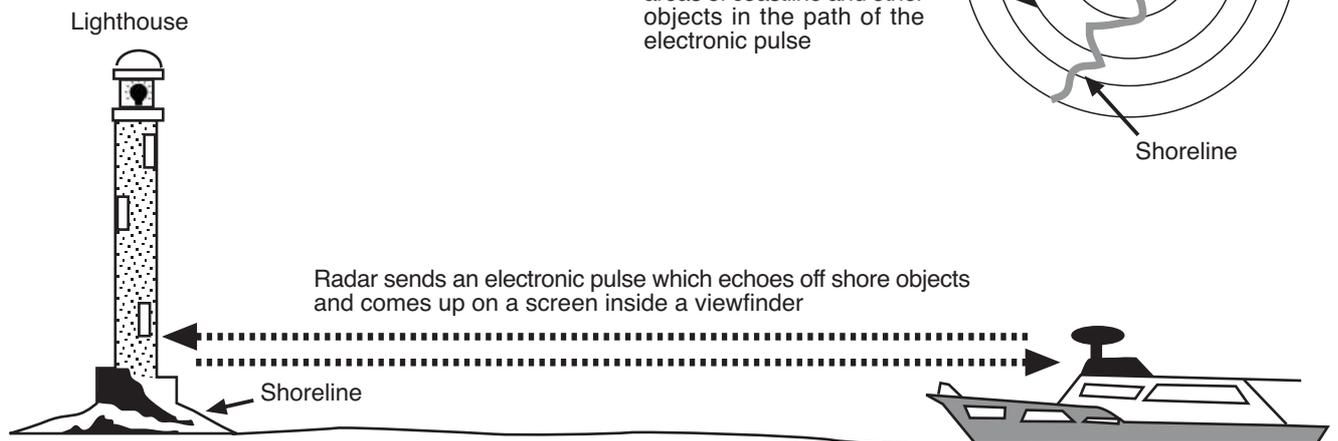
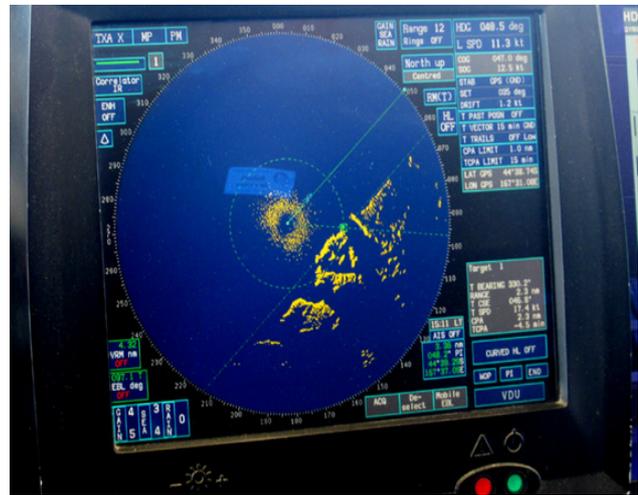


Figure 65.2 How radar works
Wet Paper

The Global Positioning System GPS

The Global Positioning System or GPS, determines the position and speed of a vessel at sea very precisely from a number of satellites 10,900 miles above the Earth.

Each satellite sends out signals which are interpreted by the GPS navigator on board the vessel (Figure 66.3).

Position determination usually requires that the GPS navigator is receiving signals from four satellites. It then calculates the latitude, longitude, altitude and time. Each satellite transmits signals allowing the user to find its position and time of transmission.

The transmission delay (Δt) is found by comparing the time of transmission to the arrival time.

The transmission delay (Δt multiplied by the speed of light (c) equals the range (R) to the satellite.

A GPS relies on a power supply and has to be replaced by traditional navigation position fixing methods when this supply fails.



Figure 66.1 A GPS and chart plotter mounted at the helm

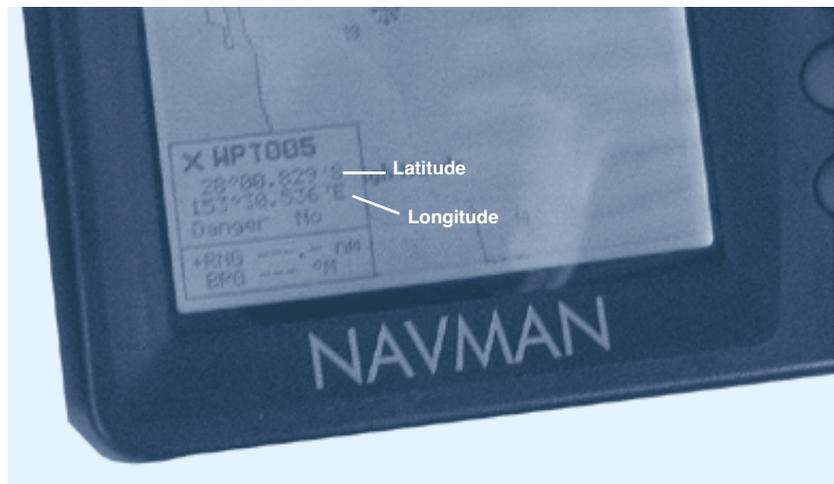


Figure 66.2 Display

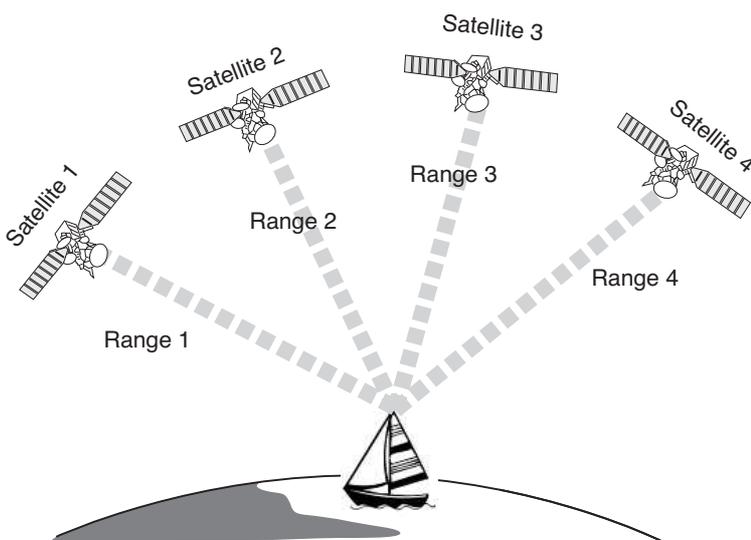


Figure 66.3 The receiver position is determined by the intersection of the spheres centred around each satellite with a radius equal to the respective range.

Datum checking

- It is advisable to switch the unit on and select the correct chart datum before departing. Many boat ramps have signs showing datum points.

GPS units require time to initialize, and the skipper needs time to assess the accuracy of the position information prior to starting the voyage.

- The accuracy of GPS units can be compromised by power failures or poor electrical connections.
- Always ensure your electrical charts are updated with supplier upgrades. When going to a waypoint in a straight line, check what is in between your boat's initial location and the waypoint.
- The figure below shows a GPS image of a track around a headland from A-B. One chart uses a datum called WGS 84 and the other AGD 66 (an out of date datum).
- Use the wrong datum and you end up on the rocks.

Waypoint navigation

Many vessel owners who have a GPS receiver program a number of latitude and longitude positions into their receiver to help compute courses.

These positions are called waypoints and can be used to show a safe path to a particular place — usually a favourite fishing or dive location.

When these waypoints are called up, the GPS receiver will show the course to steer and the distance that the vessel has to travel from one waypoint to another.

As the vessel arrives at the waypoints, a signal beeps and the next waypoint is automatically displayed on the receiver.

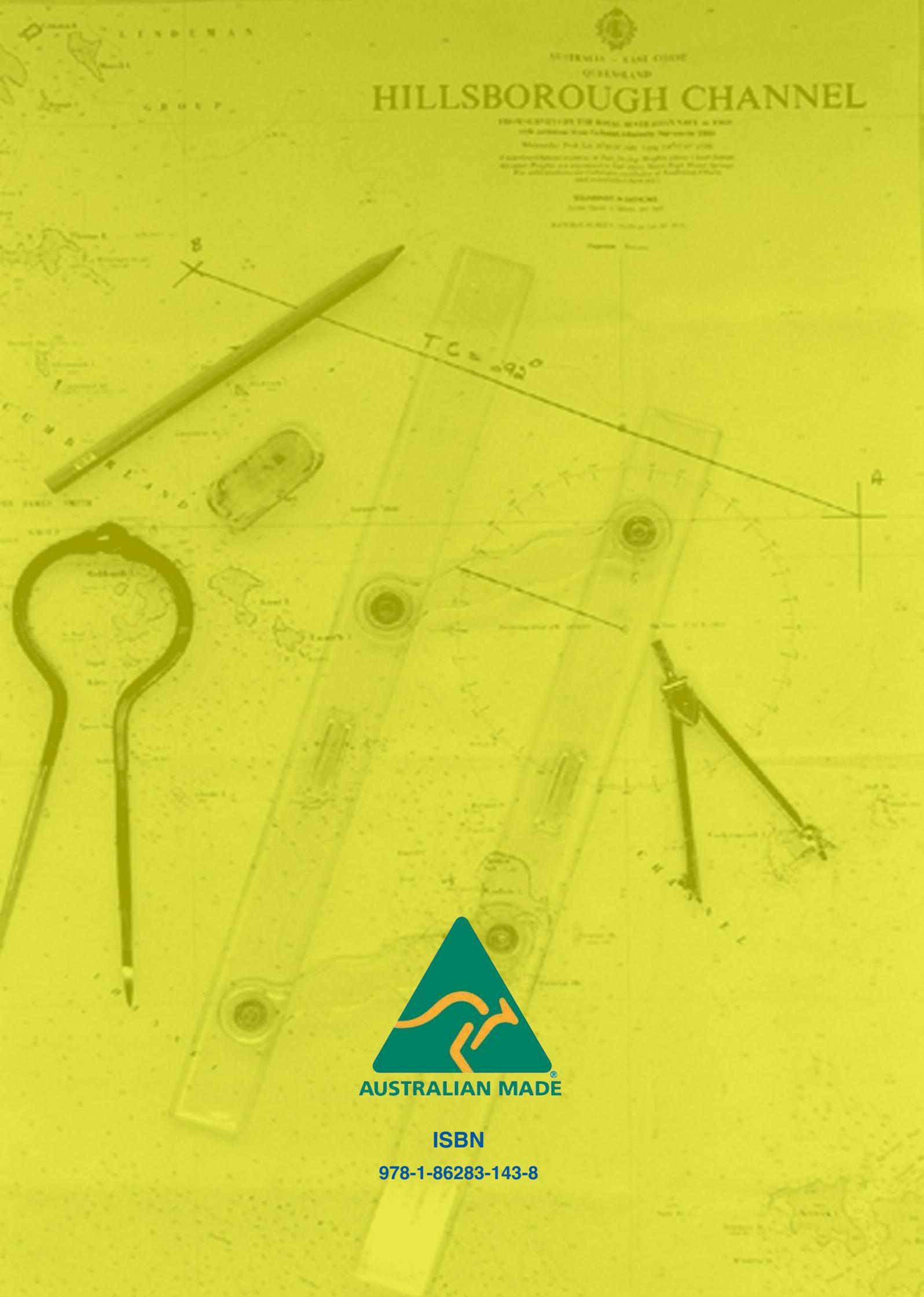
A GPS receiver can also be attached to an autopilot, which will track the data and steer the ship through a number of course changes.



Figure 67.1 GPS check sign



Figure 67.2 Screen of a ship's chart plotter



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ISBN

978-1-86283-143-8